A Multi-Attribute Value Assessment Method for the Early Product Development Phase With Application to the Business Airplane Industry

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ABSTRACT

The early phase of product development, sometimes referred to as the fuzzy front-end, is critical to the success of enterprises and plays a dominant role in the formation and execution of corporate strategy. In addition, it has been argued that the concept of consumer value is central to effective product development. In this research, a new product value assessment method is established for the fuzzy front-end of business airplane development. Existing value assessment techniques used in the business aviation industry are found to poorly balance the theoretical rigor of the method with the ease of use and accuracy required by practitioners in early product development. A recently-developed multi-attribute value method, based on Taguchi's loss function approach to quality assessment, is modified and extended in this study and applied for the first time to the domain of business aviation. A comprehensive 40-year historical product database is developed for use in testing and evaluating the method, referred to as the Relative Value Index (RVI), enabling the scope of value method appraisal to be expanded to an industry-wide examination over a significant time span. A top-down approach is developed for calibrating value models to empirical market data via attribute weighting factors. Sensitivity analyses and Monte Carlo simulations are developed to test the RVI method's robustness and the reliability of the results, enabling a rigorous definition of the determinants of product competition in this industry. This methodology is a useful advance in the methods to extract objective findings from historical industry market activities. The RVI approach is used to develop evidence in support of a ratio theory of product price and value differentiation in the business airplane market. The method is also used to extract quantitative evidence indicating the existence of enterprise-related attributes for consumer value in products. Marking the first independent review of the loss function-based value method, this study finds that the Relative Value Index is superior to existing value methods at retaining simplicity of implementation and minimal data requirements while maintaining a firm grounding in economics and consumer choice theory. The method is shown to be useful for estimation, though robustness of the results is not certain when used in this manner, and may also be extended to the analysis of large-scale engineering systems and their value to society.

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The capacity to learn is a gift;
The ability to learn is a skill;
The willingness to learn is a choice.

Brian Herbert & Kevin J. Anderson
Dune: House Harkonnen

EXECUTIVE SUMMARY

New product development plays a dominant role in the formation of corporate strategy, determining the customer base that a company can serve, the technological capabilities a company must nurture, and the competitive environment the company may expect to encounter. Well-developed product portfolios, and the capability to identify and develop strong new products, are hallmarks of well-managed companies. It is also a commonly cited belief that the majority of product characteristics, including consumer appeal, costs and technical performance, are locked in based on decisions made in the early conceptual design phase. This early, "fuzzy front-end" of product development, characterized by product specification and design tradespace exploration, is of paramount importance to the future success of enterprises.

Product value assessment has its origins in the marketing literature addressing important industry questions regarding ways to improve product appeal to consumers. It has been argued that the concept of consumer value has become central to effective new product development, and value assessment methods have the potential to play an increasingly important role in the fuzzy front-end of product development.

The current business aviation industry lacks effective value assessment methods for use in the early product development phase. In this study, a broad evaluation is conducted of existing value assessment techniques used in the industry, including marketing science methods and figures of merit. Models for market share estimation, product diffusion, and project screening are found to typically focus on factors exogenous to the product under study, such as advertising budgets, substitution effects of competing products, and management support of development projects. Conjoint analysis studies and random utility models focus on attributes inherent in the product itself, but tend toward complex mathematical structures not accessible to non-specialists. Conjoint studies are found to be further limited in the number of attributes and attribute levels that may be studied due to issues of respondent fatigue. Aerospace industry figures of merit tend toward oversimplification of important issues, are found to lack a firm foundation in economics and consumer decision theory, and are not well vetted with empirical data. Product assessment in the business airplane fuzzy front-end design phase merits a quantification of value that is more rigorous and detailed than any existing published study.

A little-known multi-attribute value method, developed by Harry Cook and his colleagues at the University of Illinois, is extended in this study to application in the domain of business aviation. Product-related attributes of importance to customers are identified based on an extensive literature review and interviews with industry experts and observers. A relatively mutually uncorrelated set of business airplane attributes that are quantifiable and previously measured are incorporated into the multi-attribute value method, referred to here for clarity as the Relative Value Index (RVI).

A comprehensive 40-year historical product database is developed for use in testing and evaluating the new method, and enables the scope of value method appraisal to be extended to an industry-wide examination of product value over a significant time span. The database includes both product technical performance characteristics as well as market factors such as list prices and unit shipment data.

In utilizing the historical database, a technique is presented for estimating parameters in the RVI method based on empirical market data. Previously-developed demand/price relationships are used to estimate the consumer revealed value for a range of competing products. This revealed value is in turn matched to product value estimates originating from the multi-attribute RVI method through optimization of the RVI attribute weighting factors.

Two evaluation techniques are developed as approaches to assessing value methods. Fitting of the RVI parameters to empirical data necessarily results in optimization errors, the sensitivity of which to changes in the model attribute weighting factors is useful for determining the reliability of the resultant weighting factors. A byproduct of the analysis is an objective assessment of determinants of product competition in the industry. As an example, the cruise speed attribute, while not serving as a differentiating factor in current markets, is found to have played an important role in the early executive transport market. Specific periods in time when other attributes acted as determinants of competition are also identifiable. Evaluating the impact of input parameter uncertainties on the RVI results also serves as an indicator of the robustness of the attribute weighting factor results. This Monte Carlo analysis is similarly found to be useful in extracting the determinants of product competition. These two methods present objective means of extracting findings of historic market activities that are not subject to personal opinion or memory.

The utility of the RVI method for engineering-type design optimization, also known as marginal analysis, is demonstrated in this study. A hypothetical new midsize jet entrant is examined via tradeoffs between two attributes and the associated changes in RVI for the aircraft. The analysis indicates how engineers may better optimize the technical performance of products while working in cooperation with marketing specialists and mangers to balance the overall aircraft value to consumers.

The RVI approach is used to develop evidence in support of a ratio theory of product price and value differentiation in the business airplane market. The belief that consumers perceive differences between products based on percent increases in prices or other product attributes, rather than absolute increases, has long been advanced in the consumer behavior literature. Despite this, little quantitative evidence has been published in support of the supposition. This study provides evidence not only of the existence of price ratios, but also of value ratios in the business aviation industry, though the data indicates that the ratio theory may break down at very high prices and values.

The method is also used to extract quantitative evidence indicating the existence of enterprise-related attributes for consumer value in products. Errors in the revealed value and multi-attribute estimated values for products indicate systematic biases among the major business airplane manufacturers. It is proposed that the systematic errors are the result of attributes missing in the RVI approach that reflect enterprise-related value. Such attributes might include after-sales customer support and the ever elusive value of a product "brand."

As the first independent review of Cook's value method, this study finds that the method retains simplicity of implementation and minimal data requirements while maintaining a firm grounding in economics and consumer choice theory. The approach is flexible enough to be easily adapted to the products and customer base of the business aviation industry. Useful advances in the application of value methods to product design and to extracting market activities from empirical data are presented in this study. Furthermore, the study indicates that the RVI approach to value assessment has potential for extension into enterprise-related value such as profit estimation, and to the analysis of large-scale engineering systems and their value to society.

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I don't subscribe to the tradition that one should acknowledge the most important people last. My wife, Cathy, is the singular person that fills my thoughts and without whom life would be that must less meaningful. There is no other person with which I would wish to share this incredible adventure called life. I call upon her and lean on her and she has always been there for me. There is no compensation sufficient for the sacrifices she has made and the burdens she has carried as a result of my decision to pursue this degree. In return, I can only say "thank you" and "I love you."

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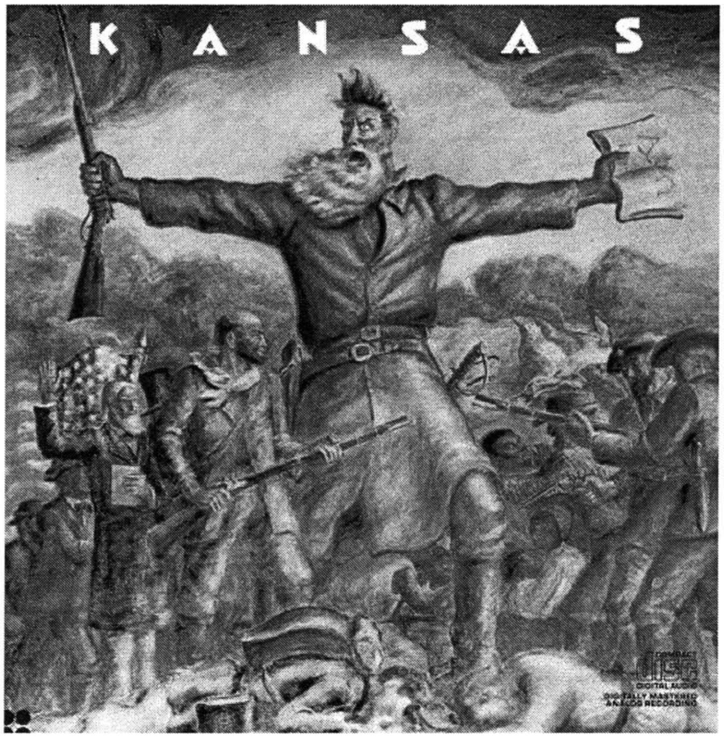
And finally, a very special group of my peers at MIT; you were stalwarts through all the ups and downs (and downs and downs) of this process. Someday we will look back and laugh (I think). To everyone in our small, special group: if I can do anything for you, don't hesitate to call. I'll be there to return the favor.

“Troy Downen, you’ve just completed your Ph.D. at MIT! What’re you going to do next?”

“I’m going to… *KANSAS*!”



Kansas: Kansas (1974)

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NOMENCLATURE

AC	alternating current
AIA	Aerospace Industries Association
AOG	aircraft on ground
B/CA	*Business & Commercial Aviation* magazine
BOW	basic operating weight (lbs)
CPI	Consumer Price Index
DARPA	Defense Advanced Research Projects Administration
dB	decibel
DC	direct current
D	annual demand for a product in a competitive market with available capacity
DOE	design of experiments; based on Taguchi methods
D_{avg}	average annual demand for N competing products
D_0	annual demand for the baseline product used in determining absolute value
D_T	total annual demand for products in the segment with the baseline product used in determining absolute value
E_p	price elasticity for product i when only product i changes price
FAA	Federal Aviation Administration (United States)
g	level, or numerical value, of a product attribute in the RVI model
g_0	baseline level of a product attribute in the RVI model; average level at which the product is currently available to consumers
g_C	critical level of a product attribute in the RVI model; level at which further degradation in the attribute renders the product as a whole worthless to the consumer
g_I	ideal level of product attribute in RVI model; level at which further improvement in the attribute is of no additional value to the consumer
GAMA	General Aviation Manufacturers Association
GARA	General Aviation Revitalization Act
ISA	International Standard Atmosphere
K	negative slope of the demand-with-price curve; $-\partial D/\partial P$

ktas	knots true airspeed (nm/hr)
J	sum-squared error cost function for RV and VI best fit optimization
LIB	larger-is-better
$L(g)$	Taguchi loss of quality at attribute level g
MP	marginal price
MRS	marginal rate of substitution
MSRP	manufacturers suggested retail price
MTOW	maximum takeoff weight (lbs)
MV	marginal value
$\mathrm{M_{MO}}$	maximum operating Mach number
NACA	National Advisory Committee on Aeronautics
NASA	National Aeronautics and Space Administration
NBAA	National Business Aviation Association
N_k	effective number of competitors for the k^{th} segment in determining absolute value
N_T	effective number of competitors for all segments
NIB	nominal-is-better
nm	nautical miles (1 nm = 1.15 statute miles)
OEI	Gulfstream Ownership Experience Index
P	price at which a product is sold
PD	product development
pax	passenger(s)
P_{avg}	average price for N competing products
P_0	price of the baseline product used in determining absolute value
QSP	Quiet Supersonic Platform research program
Q_I	Taguchi ideal quality level
$Q(g)$	Taguchi total quality at attribute level g
r	correlation coefficient for two variables
R^2	multiple coefficient of determination
RP	revealed preference
RUM	random utility model(s)

RV	Revealed Value (dimensional)
RVI	Relative Value Index (dimensionless)
SIB	smaller-is-better
SNR	signal-to-noise ratio
SP	stated preference
SSBJ	supersonic business jet
SUV	sport utility vehicle
TVI	Traditional Value Index
TOFL	runway takeoff field length (feet)
UCX	Utility Cargo/Transport Experimental
UTX	Utility Trainer Experimental
V	Volts
VI	Value Index (dimensional)
V_I	ideal value level
V_0	absolute value of a baseline product; used to convert relative value to absolute value
$v(g)$	part-worth relative value contribution of attribute g

Greek Characters

α	given a portfolio of products arranged in ascending order for an attribute, fractional increase of that attribute over the attribute level of the previous product in the portfolio
β	constant coefficient for attributes in random utility models
ε	error term for consumer utility equation in random utility models
π	product market share; percentage
σ	standard deviation for the distribution of a random variable
μ	mean value for the distribution of a random variable
γ	weighting factor for attribute in RVI model; reflects the relative importance to the overall product value of the attribute under consideration

Subscripts

i	index for products; the i^{th} product
j	index for attributes; the j^{th} attribute
k	index for segments; the k^{th} segment
m	total number of options for a product
n	total number of products; $j = 1, 2, 3, \ldots n$ products

1 INTRODUCTION

New product development plays a dominant role in the formation and execution of corporate strategy. The specification and design of new products determines the customer base that a company will serve, the technological capabilities a company must nurture, and the competitive environment the company may expect to encounter. Well-developed product portfolios, and the capability to identify and develop strong new products, are hallmarks of well-managed companies.

It is widely recognized that new products are critical to the success and survival of enterprises. Anecdotal evidence, as well as academic research, shows that new products and product improvements can stimulate market growth, both in the size of the total market and in market share for the enterprise, through a combination of increased usage and more users [Shocker and Srinivasan (May 1979)]. Yet a landmark study by Booz, Allen & Hamilton (1982), with follow-up studies by others [among them, Urban and Hauser (1993)], have found that new product failures are both common and expensive. It is also a commonly cited belief that the majority of product characteristics, including costs and technical performance, are locked in based on decisions made in the early conceptual design phase.[*] This "fuzzy front end" of product development is of paramount importance to the future success of enterprises.

In today's aviation industry, new aircraft development is characterized by large investments and long lead times where several, or perhaps even dozens, of companies join together as risk-sharing partners. Business aircraft development is a high-risk venture even for the largest of corporations. A new airframe development program for a single turbine-powered aircraft can cost from $500 million to $1 billion or more, and require up to a decade from program launch to first product delivery.[†] These magnitudes are particularly large considering that the total revenue for all companies is of the order of $10 billlion [GAMA *General Aviation Airplane Shipment Report* (2003)]. Parallel development of new avionics or propulsion systems increases the investment and risk. The viability, financial and otherwise, of many enterprise

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[*] This widely cited belief is treated as fact in both academic and industrial circles, though this author has not seen published data to confirm or deny the perception.

[†] Two proposed supersonic business jet designs were announced in October, 2004, each expected to cost more than $1.5 billion to bring to certification and take a minimum of seven years to develop [*Aviation International News Online*, October 14, 2004].

participants is highly contingent on getting the right product to market at the right time and on budget.

The general aviation industry in 2003 claimed nearly $10 billion in billings and traces its roots to interwar flying enthusiasts and entrepreneurs such as Clyde Cessna, Walter Beech, Bill Lear and Geoffrey de Havilland. Each of these engineers/businessmen spawned companies that today compose the heart of the general and business aviation industry: Cessna Aircraft, Raytheon Aircraft (nee Beechcraft combined with elements of the former de Havilland Aircraft), and Bombardier (composed of Lear Jet Corporation and Canadair, also a direct result of Bill Lear's entrepreneurship). Despite the passing of most of the original founders by the 1960s, the industry has remained rooted in many of their philosophies, including their approach to product development and their engineering-centric focus.

In today's business and general aviation industry, the choice of new airplane product attributes by airframe manufacturers is difficult to link to an overall product/technology portfolio or company strategy. Specifications can naturally be driven by available technologies or capabilities, be based upon product platforms that already exist and can be conveniently modified, result from pressures to align with competitor product portfolios, or be the result of perceived niches in loosely representative market segmentations. At this level of ambiguity, the desires of one or more dominant personalities within the company or an important customer can be excessively important. Thus, the plans may not reflect the true needs of the overall market, manufacturer or suppliers, and are perhaps poorly aligned with the enterprise's capabilities.

This thesis presents an analytical approach to aid in new product assessment, specification and conceptual design through development of a quantitative, multi-attribute, interdisciplinary product value assessment model. While alone it cannot completely alleviate the difficulties, the intent is to contribute to a solution.

The choice of an interdisciplinary approach to product development is a pragmatic one. Interfaces exist between engineering, marketing, customer support, manufacturing, management and other disciplines. Questions and decisions regarding product development are not arranged to fit neatly the artificial boundaries of specific disciplines. Factors that a company must consider in new product development are not compartmentalized and isolated such that a single person or single discipline can address every issue. Product development must take place in an environment that transcends traditional boundaries of engineering, marketing and management.

1.1 Research Objectives

In the development of new products, there exist a number of steps common across product types for bringing the new concept to market. These steps include:*

- New product search, to locate potentially profitable additions to a firm's product portfolio. This may include market studies, research and development activities, and acquisition studies.
- Preliminary financial and technical evaluation, eliminating weak proposals.
- Detailed financial and technical evaluation, resulting in go/no-go decisions for projects.
- Product development, testing and evaluation.
- Product commercialization and entry into service.

The chief objective of this research is to to identify and/or develop a method to aid in quantitatively exploring the first two steps: new product search and preliminary evaluation. There are indications, discussed later in this document, that the method may also be helpful in the later phases of sales and marketing of the product.

After identifying a basis, and developing a generalizable method, for quantitative new product search and preliminary design, a second objective of the research is to test and evaluate the method using empirical data with a sizeable historical database to broaden the evaluation. This broad testing of the method has a second aligned purpose which is to apply the method to develop objective explanations and insights about the history of product competition in the business aviation industry.The business aviation industry was chosen for a number of reasons, including the availability of a 40 year historical product characteristics database, the previously cited need in the industry for more quantitative methods, and the author's personal experience working in the industry.

A third objective of the research is to develop new methods for evaluating the utility of product assessment models, such as the one developed in this research. Sensitivity analyses, including Monte Carlo simulations, are leveraged to help identify strengths and weaknesses of the new assessment methods. These analyses are also used as secondary product assessment methods, as it is shown in this research that the analyses do quite well at objectively explaining

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* Adapted, in part, from Pessemier (1966).

historical events in the business aviation industry (see Chapter 6). By accomplishing this we also believe it greatly strengthens the tools available for *objective* longitudinal industry analysis.

A final objective of the research is to explore, through the modeling and product assessment literature as well as through use of the newly developed assessment methods, some of the practical and philosophical considerations involved in creating models. The philosopher Karl Popper (2002) and marketing scientist John Little (1970), especially, prove to be valuable references in exploring considerations of what it means to develop "good" models.

As overarching objectives of the research, the author is also interested in formulating methods that are *descriptive*, in the sense that they help us understand how consumers make decisions, *generalizable*, in the sense that they can be formulated in terms not specific to particular circumstances, and *operational*, in the sense that they are based on parameters that may be measured and that results may be obtained from the methods and analyzed.

1.2 Motivation for the Research

Companies make their business decisions on a fairly subjective basis, making use of the experience and entrepreneurial skills of their managers. To a large extent this will remain so for most businesses in the future; the individual skills, experience and deep knowledge of managers are, and always will be, an essential ingredient in the success of a company. An extensive body of operations research, known as "OR," was developed after World War II and has served to move business decision-making toward more quantitative, analytic approaches. These advances in theory, combined with the advent of the digital computer, and particularly the personal computer, have provided managers access to larger amounts of better organized data, often implemented in analytic models to aid managers in their decision-making process. This research, by attempting to quantify some aspects of value, contributes to this initiaitive.

One of the early driving forces advancing OR and the development of analytic models was the Cold War era defense industry. Much of this research benefited the aerospace industry, resulting in sophisticated program management techniques such as PERT and CPM, and technical design tools such as computational fluid dynamics (CFD) and NASTRAN structural analysis computer codes. Immediate beneficiaries included those aerospace companies directly involved in military development programs, but lessons and tools soon transferred to commercial programs within those same companies (e.g., Boeing). Smaller aerospace companies not associated with, or only indirectly involved in military development projects often lacked access, as well as the resources, to invest in new processes and tools for their civil programs. A series of acquisitions and mergers in the 1980s and 1990s* first enabled many of these companies to significantly leverage new program management methods, digital computers and advanced technical design tools, particularly the now ubiquitous computer aided design/computer aided manufacturing (CAD/CAM), CFD and NASTRAN.

Despite the advances in technical design and program management, many of the smaller general aviation companies may find it difficult to break from the philosophies of their founders regarding the early product development process. This front-end process, involving stakeholder needs assessment, product specification and conceptual design, would then be still largely driven by pressures to align with competitor product portfolios, an engineering-centric focus on technical performance, and could be governed by dominant personalities within the company's senior management team. This possibility applies to the smallest general aviation companies, such as Piper and Mooney, as well as to the larger business aviation companies, such as Cessna and Raytheon.

As March and Simon (1958) point out, some sort of model is always used in decision making, namely, the decision maker's definition of the situation. Normative approaches to decision making emphasize the importance of making formal models, and the use of such models has become a hallmark of systems analysis and operations research [Morris (1967)]. The motivation for this study is not a desire to wholly replace the experience and skills of decision-makers with formal models, but instead to provide a data-based environment for more informed decision-making.

With the costs and risks associated with airplane product development higher now than ever before, the business aviation industry is currently experiencing a transition from the founders' philosophies to data-driven, formal approaches to product design. Structured stage-gate processes and integrated product teams have, within the last decade, found a place in the business aviation industry. Certifications such as ISO 9001, indicative of formal and structured processes, are now considered essential for manufacturers and suppliers alike. Despite this, the early fuzzy-front end of product development remains less quantitative, which motivates the

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* For example, Cessna by General Dynamics (1985) and later Textron (1992), Beechcraft by Raytheon (1980), Learjet by Bombardier (1990). See Pattillo (1998).

major thrust of this research in focusing on data-driven methods for new product search and preliminary evaluation.

1.3 Overview of Approaches

With the motivations and objectives of the research now expounded, it is appropriate to briefly consider the philosophical approach taken in this research. A number of approaches are combined, as is usually necessary when creating a workable method to apply in a novel way. Each approach uniquely contributes to the effort of developing a useful, practical method for product development solidly grounded in theory and vetted through empirical data.

A positivist approach is taken in that cause and effect relationships are sought for business aviation market developments through the 40 year history of the industry. Given the astonishing success of the first generation of turbojet business aircraft over their turboprop competitors, quantitative methods are sought that allow such an event to be explained. As shown in Chapter 3, existing industry methods do not allow the story to be told with the data at hand. At the same time, an empiricist view of the industry database and literature provides an objective approach where the data offers the only reality upon which to base the study. The sensitivity analyses of Chapter 6 provide an objective reality for the evolution of the industry that is not dependent on opinions or memory. The empiricist approach allows, in this study, for theory to be vetted through application.

The Relative Value Index approach pursued in this study is itself descriptive, in that we seek an understanding of empirical consumer behavior. A 40-year database of empirical market data has been compiled for use in the study to allow contextual interpretations of the value model behavior and to test the descriptive ability of the method. But the approach is also normative in that the RVI method may be used prescriptively to study alternative courses of action. It is shown in the course of this study that the RVI method is useful for evaluating future and near-term proposed products. Though the final disposition of such products will not be known for some time to come, the RVI method demonstrates greater potential for such evaluations than current industry methods. The distinction between descriptive and prescriptive approaches is not unlike that between basic (pure) and applied research.

As Wilkie and Pessemier (November 1973) have observed, preference models may draw upon either a compositional or decompositional approach. In the first approach the part-worths or utilities of each attribute are assessed separately and then combined into a multi-attribute utility function [Bettman, Capon, and Lutz (March 1975), Shocker and Srinivasan (May 1979), Roberts and Urban (February 1988)]. In the second approach the objective is to decompose a set of overall responses to "total" product profile descriptions so that the utility of each product attribute can be inferred from the respondent's overall evaluation of the products [Green and Rao (August 1971), Green and Wind (1973), McFadden (1974)]. As shown in Chapters 4 and 5, the preference model developed in this study uses a combination of both approaches to calibrate the method with empirical data.

1.4 Overview of the Document

In Chapter 2 an overview of the business aviation industry is presented which will serve in a number of test cases in exercising and evaluating the Relative Value Index approach to product assessment. A brief history of the industry, including its origins and development over the past 40 years, is presented along with an overview of the industry structure that serves to introduce the industry's products, its market segmentation, and its relationship to other parts of the aviation industry. The chapter concludes with a detailed examination of the industry product database that was assembled for this research, including a critical evaluation of the data reliability and accuracy, and commentary on additional data that is currently difficult to obtain but that would likely prove insightful if available.

A brief review of pertinent literature in the area of consumer behavior and preference modeling opens Chapter 3 on product value and value assessment methods. The review is followed by a discussion of the term "value," its operational definition within the context of the economics literature, and potential uses of value in product planning and decision making. Some of the primary existing value assessment methods are also reviewed in Chapter 3, including commonly used marketing science methods such as conjoint analysis, the major value assessment models that are currently used in the aerospace industry, and a relatively new technique based on Cook's extension (to economics and value) of Taguchi's loss function approach to quality assessment.

The Relative Value Index (RVI) approach, as applied in this thesis, is developed in detail in Chapter 4. The foundation of the RVI mathematics and theory is documented in the first section on the loss function approach to product quality and value. Concepts such as product attribute bounds and multicollinearity are first addressed in this chapter. In the second section the multi-attribute RVI method is developed in full, and issues such as value options and absolute value are introduced. In the final section of the chapter a new method for estimating attribute weighting factors is developed based on consumer revealed preference data. In the process, a product demand model is developed and quantitative methods for forecasting market share are established.

The theoretical development of Chapter 4 is put to use to develop a business aviation relative value index method in Chapter 5. The philosophy and structure of the approach is first addressed, including the choice of business aviation as a subject for the study. Attributes are identified and bounded, then the attribute weighting factors are determined using the Revealed Value approach introduced in Chapter 4. Concerns and uncertainties with the business aviation database are addressed, and results for the current market are presented, along with an analysis of sensitivities to changes in the model parameters.

In Chapter 6, the RVI method is evaluated through a number of analyses that measure the sensitivity of the approach to uncertainties in input data and to changes in the model parameters. Some of the sensitivity analyses show great potential for use as additional methods for objectively interpreting historical market events. Thus, the methodology expands the objective tools available for historical industry analysis. The RVI method is also subjected to a number of exercises through which its utility is demonstrated for replicating historical market events, product differentiation, demand forecasting, and design tradespace exploration.

The RVI value approach is compared in Chapter 7 to the alternative methods first introduced in Chapter 3. The emphasis of the chapter is to demonstrate the greater utility and ease of use of the RVI method – particularly for the business airplane case. Generalization of the method is demonstrated through development of two additional RVI models; one for the automotive SUV industry, and one for aircraft product support service. Finally, a number of practical and philosophical issues are discussed regarding the limitations and common misuses of models, and how one may judge a model to be "good." Hallmarks of "good" empirical models are also presented, as advocated by Karl Popper and John Little.

A number of future directions for the research are discussed in Chapter 8, including the potential for linking the RVI method to enterprise profits, and extending the utility of using the model to examine product flexibility and product families.

An extensive list of references is included in the final chapter of the document, and the appendices list business aircraft data used as input in the RVI analyses, as well as data for the generalized RVI models.

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2 BACKGROUND ON THE BUSINESS AVIATION INDUSTRY

In this chapter a brief background is provided on the business aviation industry. This information is not intended to be exhaustive, but instead to provide a level of familiarity that enables a better understanding of the analyses in Chapters 5 and 6 involving the business aviation industry. Throughout this study, the terms "business aviation industry" and "business airplane industry" are frequently used. Though "business airplane" more precisely limits the topic to fixed-wing aircraft and excludes rotorcraft, the two terms will be used interchangeably. The reader should be aware that fixed-wing aircraft are the intended focus of the terms. Similarly, the terms "business aircraft" and "corporate aircraft" may be used interchangeably.

General aviation is defined by the National Business Aviation Association (NBAA) as consisting of "all aircraft not flown by the airlines or the military" [NBAA (2004)]. Business aviation, a subset of the general aviation industry, includes "companies and individuals using aircraft as tools in the conduct of their business." NBAA reports that in 2003 there were 10,661 companies operating 15,879 business aircraft in the United States, and that more than 72 percent of business aircraft worldwide were located in North America [NBAA (2004)]. In 2003, according to data compiled by the General Aviation Manufacturers Association (GAMA), the general aviation industry claimed nearly $10 billion in billings.*

In the first section of this chapter, a brief history of the industry is recounted, with particular emphasis on events surrounding the present-day business airplane manufacturers. In §2.2 the structure of the business aviation industry will be discussed, both in terms of the industry's products and market segments, and in how the business aircraft industry relates to other parts of the larger aerospace industry. Finally, in the last section of this chapter the product database compiled for use in this research will be discussed and critically assessed in preparation for its use in the analysis of Chapters 5 and 6.

2.1 A Brief History of the Industry

Two of the most comprehensive texts focusing specifically on the general aviation and business aviation industries are Pattillo's *A History in the Making* (1998) and Phillips, et al.'s *Biz Jets* (1994). Minor but interesting contributions regarding the industry are made in numerous

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* New aircraft shipments only. Does not include parts, support, etc.

other publications such as Murman, et al.'s *Lean Enterprise Value* (2002) and Patillo's *Pushing the Envelope* (2000). Well researched histories focusing on specific industry segments or manufacturers include Rodengen's *The Legend of Cessna*, Phillip's *Beechcraft: Pursuit of Perfection*, and Price's *Wichita's Legacy of Flight.* The concise history presented here, focusing on the general and business aviation industry, follows from information found in all of these sources.

> "In the early years of powered flight, as aircraft first began to be produced in series, almost all aviation activity was encompassed within what would later be defined as general aviation. There were no well-defined military roles for aircraft and no scheduled commercial services. Thus the market for aircraft was largely limited to sport flying and training by and for a wealthy few." [Pattillo (1998)]

The aviation manufacturing industry grew explosively after World War I as flying gained legitimacy as something more than simply a hobbyist's venture. A number of important advances had also been made in flight technology during the war, helping to make aviation safer. Production techniques, stronger materials, better structural design methods, and even rudimentary cockpit instruments were all outgrowths of military spending in the war years, and enabled general aviation to gain a toehold in the transportation industry. Even the United States government began to take an official interest in civil aviation. William P. MacCracken, head of the MIT aeronautical engineering program, was named first chief of the new United States Aeronautics Branch (later the Civil Aeronautics Authority, and later yet the Federal Aviation Administration), and was issued federal pilots license No. 1 on April 6, 1927.

In the 1920s the aviation industry enjoyed popularity akin to that of the dot-com industry in the 1990s. Venture capital flowed from established industries, such as railroads and oil, into startup airplane manufacturing firms. It was at this time that Clyde Cessna and Walter Beech made their historic decisions to move to Wichita, Kansas and go into business together under the banner of Travel Air Airplane Manufacturing Co.[*], [†] After the stock market crash of 1929 and the

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[*] Lloyd Stearman, the eventual founder of Stearman Company, also joined forces with Cessna and Beech at Travel Air. Stearman was bought out by Seattle's William Boeing in the 1930s and thus created a Boeing Company presence in Wichita that continues to this day.

[†] Mac Short, an MIT engineering graduate and native Kansan, also joined the Travel Air team and played an important engineering role in this early company. He would later follow Lloyd Stearman and become Vice President of Stearman Company.

accompanying aviation industry bust, Cessna and Beech went their separate ways to found in the 1930s what would become two of business aviation's most famous brands: Cessna Aircraft and Beechcraft. Of interest is the fact that Al Mooney also formed his own firm in Wichita in 1929. Several incarnations later, Mooney Aircraft Company finds itself located in Kerrville, Texas, where it today remains one of the most important small aircraft manufacturers in the world.

In 1931 wealthy oilman William T. Piper entered the aviation industry by purchasing the assets of bankrupt New York firm Taylor Aircraft Corporation. Piper's early products, though not designed especially for the business traveler, were enormous successes, winning the "Piper Cub" a place in aviation history. Piper today, itself reorganized through bankruptcy a few times, has relocated to Florida and continues to be a primary player in general aviation.

Perhaps the first "superstar" product of the fledgling business aviation industry was Walter Beech's 1932 Model 17 Staggerwing (Figure 1).* Designed especially for the business traveler, the Model 17 was large, powerful, and faster than even the military pursuit planes of its day. Versions of the Staggerwing served in the military throughout World War II and continued in production for a brief time after the war. A total of 781 were delivered between 1932 and 1948.

source: www.chicagocentennialofflight.org

Figure 1: Beechcraft Model 17 Staggerwing

World War II placed the entire civil aviation industry on hold as it converted to military production. However, some visionary designers obviously didn't wait for the war to be over before they started thinking about the next generation of executive travel. Beech again beat the

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* Several general aviation products had also "hit it big" by this time, including the Piper Cub and the Laird Swallow. The Staggerwing was the first product designed especially for the business traveler.

executive transport industry to the punch by introducing his all-metal, single-engine Model 35 Bonanza to the post-war business airplane market (Figure 2). This 1947 model proved so popular with business travelers (1,229 were delivered in 1947 alone), and the design was so far ahead of its time, that it is still in production today, making it the longest continuous production aircraft in the world.*

source: www.airwaysmuseum.com

Figure 2: Classic Beechcraft V-Tail Bonanza

It was in the 1950s that the business aviation industry finally came into its own, with Beech, Cessna and Piper forming the "Big Three" of general aviation. Each company introduced a number of highly successful single and twin reciprocating engine models that kept the companies at the top of the market. President Eisenhower's highly publicized use of an Aero Commander twin piston, produced by a small firm called Aero Design that later would be acquired by Rockwell-Standard, helped alleviate safety concerns and boosted the use of general aviation aircraft for executive transport. Economic conditions favored a market upswing in the early 1950s that would continue for the next 15 years (Figure 3).

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* Beech's 1937 Model 18 "Twin Beech" was the longest continuous production aircraft until it ceased production in 1970, after which the Beech Bonanza soon took top honors.

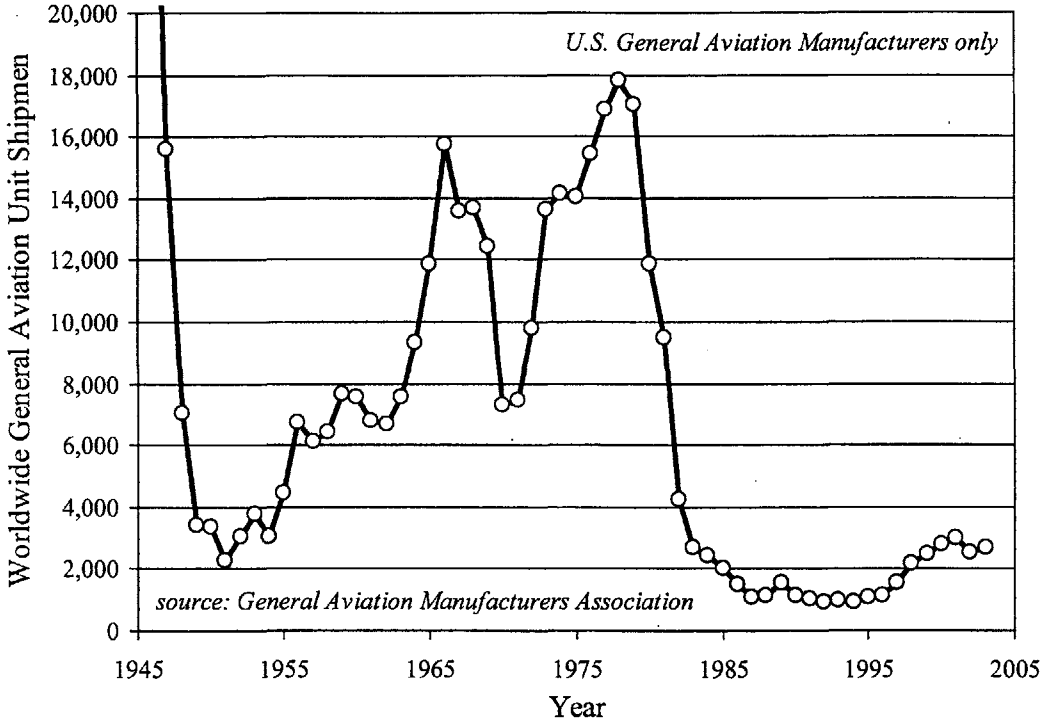

Figure 3: Annual Shipments of New U.S. Manufactured General Aviation Airplanes

In the 1950s a fundamental change began occurring in aviation with the introduction of turbine power. First developed for the military, turbine-driven propellers, and then pure turbine jet powered aircraft, began to appear in the airline fleets. In contrast to reciprocating engines, turbines offered greater speed (more torque for propellers and, in jet form, no limiting cruise speeds due to the propellers), more comfort because of reduced vibration, less down-time for maintenance, higher resale values, and the ability to operate economically at higher altitudes, thus enabling the airlines to fly over bad weather rather than through it.* Business aviation initially adopted converted heavy turboprop airliners such as the Dart Herald and Fairchild F-27 due to the lack of anything comparable coming from the general aviation manufacturers (Figure 4). Many initially questioned the market's ability to absorb more than a handful of these $800,000+ turboprop aircraft in the late 1950s (equivalent to approximately $5 million in 2004). It was Grumman American Aviation Corporation, traditionally a military contractor, that first ventured directly into the business turbine field with their 1959, $860,000, 12-seat turboprop G-159 Gulfstream (later known as the Gulfstream I) (Figure 5).

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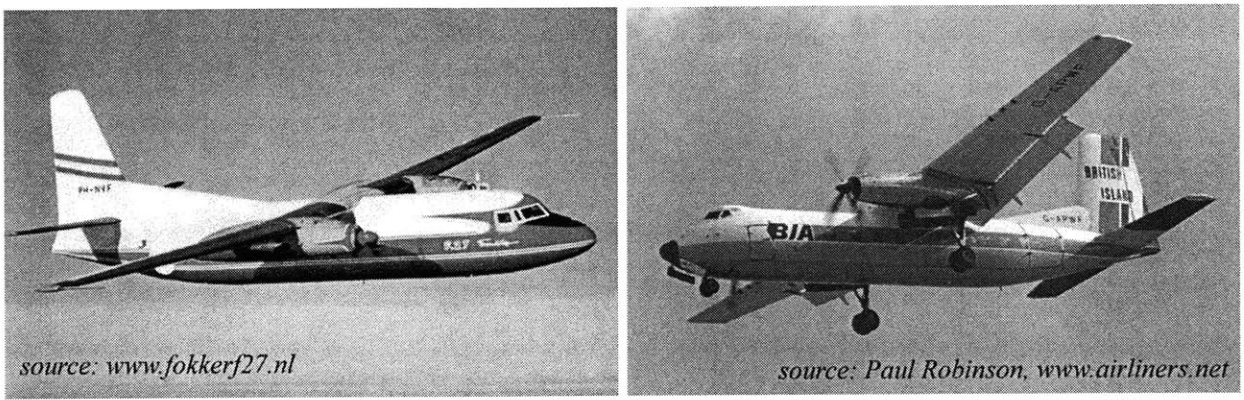
* Well summarized in the contemporary Nozick (January 1961).



source: www.fokkerf27.nl

source: Paul Robinson, www.airliners.net

(a) Fokker Fairchild F-27 Friendship (b) Handley Page Dart Herald

Figure 4: Heavy Turboprop Airliners Pressed into the Executive Transport Role

source: Erik-Jan Noomen, www.airliners.net

Figure 5: Grumman G-159 Gulfstream

Beech soon followed with the smaller, but soon-to-be world-famous, 1964 turboprop King Air, Rockwell Aero Commander with the 1965 Turbo Commander, and overseas player Mitsubishi with the 1966 turboprop MU-2.*

The face of business aviation changed forever when, in 1956, the U.S. Air Force released specifications for the Utility Trainer Experimental (UTX) and Utility Cargo/Transport Experimental (UCX) competitions. The goal was to spur development of small jet passenger aircraft for military training and utility transport, but the potential for business use was obvious. Initially, the largest general aviation firms, Beech and Cessna, held back, fearing the overwhelming capabilities of the large military manufacturers. Lockheed, North American, and

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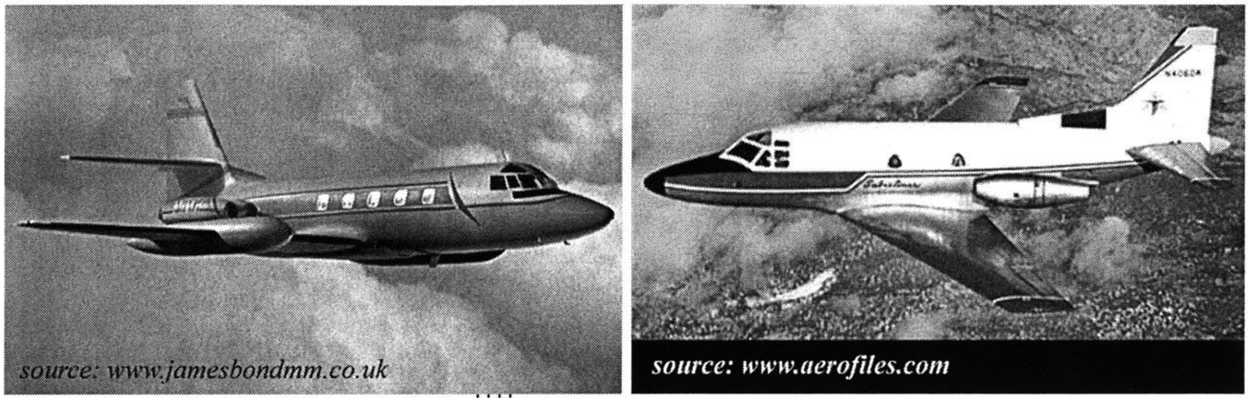
* The Mitsubishi MU-2 and jet-powered MU-3 series aircraft were acquired in the 1980s by Raytheon Aircraft.

McDonnell did indeed jump into the competitions with their winning designs for the Lockheed JetStar (UTX) and North American Sabreliner (UCX) (Figure 6).[§§§, ****]



source: www.jamesbondmm.co.uk

source: www.aerofiles.com

(a) Lockheed 1359 JetStar 6[††††] (b) North American Sabreliner 40

Figure 6: First Generation Business Jet Airplanes

Hawker Siddeley soon entered the fray with the 1964 DH-125 (later Hawker 400), joined by Dassault with the 1965 Falcon 20 (initially marketed in North American by Pan American), and Rockwell Aero Commander with the 1965 Jet Commander.[‡‡‡‡]

Entrepreneur and avionics producer Bill Lear believed that the business jet market lacked a light and relatively inexpensive jet, all of the above weighing in at over 16,000 lbs and costing up to $1.5 million. From his Wichita, Kansas facility he introduced his 1964 LearJet 23 at $500,000 and 12,500 lbs, and single-handedly invented the light jet market segment (Figure 7).

Cessna, unsuccessfully competing with Beech in the business turboprop market, introduced their version of the light jet in 1970. This Citation 500, now known as the Citation I, spawned the hugely successful Citation family of aircraft. Eighteen major Citation models have been produced at one time or another, and the current Citation X is marketed as the fastest business jet in the world, cruising at a maximum speed of Mach 0.92. Meanwhile, Grumman

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[§§§] The McDonnell 119 entry into the UCX competition lost against the North American entry.

[****] Ironically, the large military manufacaturers were so heavily invested in their government contracts that few resources could be spared on a regular basis for design upgrades on the JetStar and Sabreliner. The relentless pursuit of better business airplane performance by the later entrants (Cessna, Hawker, etc.) eventually drove Lockheed and North American from the executive transport market. Only Dassault continues in 2004 as a major military and business airplane manufacturer.

[††††] This is the JetStar used in the James Bond film *Goldfinger*

[‡‡‡‡] Hawker Siddeley was acquired in the 1980s by Raytheon Aircraft, which now markets the latest incarnation of the Hawker business jets. The Jet Commander design went to Israeli Aircraft Industry in 1967 and eventually led to the Astra and Galaxy designs, now owned by Gulfstream Aerospace.

expanded at the other end of the market by introducing the 1966 turbojet Gulfstream G-II as a replacement for the turboprop G-159.

source: www.centennialofflight.gov

Figure 7: The Light Jet Market Opens with the LearJet 23

Contrary to what one might expect, the growth in new business jet models came amid a general depression in the aviation market in the late 1960s (Figure 3). Uncertainty over the Vietnam War and its economic impacts, continued inflation, and the United States' balance of payments deficit all conspired to dampen corporate profits and hamper new aircraft sales [*Aviation Week & Space Technology* (March 18, 1968)]. Surprisingly, the 1973 Arab oil embargo appears to have had no immediate adverse affect on new aircraft sales. It wasn't until the early 1980s that high fuel prices, rampant inflation, and poor exchange ratios for the U.S. dollar finally hit the general aviation industry as reflected in the dramatic decline in unit shipments (Figure 3). Despite the decline in quantity, the steady rise in high-profit turbine shipments as a percentage of total unit shipments meant that business aviation manufacturers remained relatively healthy.

Another factor playing an important role in the shipments depression was the increasing burden of defending against liability suits. Manufacturers found themselves held legally responsible for the condition of every aircraft they built for its full lifetime. The long-lived companies such as Beech, Cessna, and Piper found themselves exposed to potentially devastating lawsuits for tens of thousands of aircraft, some reaching 30 years or more in age. Although the tort laws were reformed by the General Aviation Revitalization Act (GARA) of 1997, manufacturers have chosen to largely continue focusing on building smaller quantities of high-margin business jets.[§§§§]

As new business jet models proliferated, military contractors Lockheed and North American found it difficult to divert resources from their government Air Force projects to keep their business jets competitive. The Lockheed JetStar was discontinued in 1973, with a brief reintroduction from 1977-1980. The North American Sabreliner held on a bit longer thanks to the company's acquisition by Rockwell, but eventually succumbed in 1983 due to poor sales.

Meanwhile, the major business airplane families that would dominate the market took form: Lear's light LearJets (later acquired by Bombardier), Cessna's light to midsize Citation jets, British Aerospace's midsize Hawker jets (later Raytheon), Dassault's light to large Falcon jet series, Grumman's Gulfstream family of large and long-range jets, Mitsubishi's MU-2 turboprop family (later Raytheon), Piper's Cheyenne turboprop series, and Beech's King Air turboprop series. It would be the mid 1980s before Beech finally entered into business jet production by purchasing Mitsubishi's new MU-3 Diamond, renamed the Beechjet 400.[*****] Canada's homegrown aerospace manufacturer Canadair would enter the large business jet market by purchasing Bill Lear's LearStar design in the early 1980s and rename it the Challenger 600 (Lear had since sold LearJet to Gates tire company). Canada-based Bombardier would later acquire Canadair along with Wichita's LearJet.

In the year 2005 there exist five major business aviation manufacturers of turbine powered aircraft:

- Bombardier Aerospace, the current corporate entity for legacy manufacturers Learjet and Canadair
- Cessna Aircraft Company, a Textron company (which, incidentally, also owns Bell Helicopter, a major manufacturer of business rotorcraft)
- Dassault Aviation, which also operates defense and space manufacturing groups
- Gulfstream Aerospace Corporation, a General Dynamics company
- Raytheon Aircraft Company, a Raytheon company and the current corporate entity for the legacy manufacturers Beechcraft and Hawker Business Jets

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[§§§§] Cessna is the only exception. On the same day the liability reform laws were enacted, Cessna announced plans to reopen production of their most popular single-engine piston models. Today the company annually ships nearly 1,000 of these smaller aircraft.

[*****] For a short time in the 1960s Beech marketed the Hawker series of business jets in North America.

In addition, Boeing and Airbus each market purpose-built business jets based on derivatives of their 737 and A319 series airliners, respectively.


source: www.Boeing.com

Figure 8: Boeing Business Jet

2.2 Structure of the Industry

A brief background on the structure of the business aviation industry is presented in this section. The summary here is not intended to be complete or exhaustive, but is for familiarization to aid in better understanding the industry analyses presented later in Chapters 5 and 6.

As noted before, the terms "business aviation industry" and "business airplane industry" are used here interchangeably, but in both cases only fixed-wing business aircraft are under consideration. A rotorcraft (helicopter) aviation industry exists, but is mainly confined to specialty markets such as the offshore oil rig business, emergency medical transport, and heavy lift utility industry. With a few exceptions, rotorcraft have not made the same significant inroads into the executive transport market that fixed-wing aircraft have made.

The majority of the business aviation industry is located in North America – both manufacturers and customers. A leading industry expert explains the concentration as being a byproduct of the business airplane's role in increasing corporate productivity:

> "This emphasis on productivity as the paramount factor in business is a largely North American trait, which explains the success of US technology companies. This fact also explains why the business jet market remains focused on North American demand. Excluding public demand (governments, militaries, etc.), over 80% of the world's private business jets are based in North America" [Aboulafia (May 2004)].

Three principal business associations represent the industry for promoting its political and public relations goals. The Aerospace Industries Association (AIA) "represents the nation's major manufacturers of commercial, military and business aircraft, helicopters, aircraft engines, missiles, spacecraft, materials, and related components and equipment."[†††††] The General Aviation Manufacturers Association (GAMA) represents and reports on the United States' manufacturers of non-military and non-airline usage aircraft.[‡‡‡‡‡] The National Business Aviation Association (NBAA) is specifically "dedicated to the success of the business aviation community" and publishes a number of position papers and statistics on the international business aviation industry each year.[§§§§§]

2.2.1 Industry Products and Segmentation

The business aviation industry is a sub-segment of the larger general aviation industry. General aviation is typically defined as all aviation other than military and commercial airlines. Business aviation consists of companies and individuals using aircraft as tools in the conduct of their business.

Those industry products studied in this research are selected from annual lists of new, fixed-wing business aircraft for sale in the *Business & Commercial Aviation* (B/CA) "Purchase Planning Handbook" of various years. The handbook started publication in 1960 in the April issue of B/CA, and later moved to the annual May edition of the magazine. Even considering the 100 year history of *Jane's All the World's Aircraft*, since 1960 *Business & Commercial Aviation* has become the de facto standard for providing detailed technical intelligence on business aircraft (both fixed-wing and rotorcraft). Each year, manufacturers work closely with the publication to update technical performance information on their aircraft products, and manufacturers use the publication as one of their key sources of information on competing aircraft.

The airplane products in this industry are powered by both turbine engines and reciprocating (piston) engines, though turbine powered aircraft constitute 83% of the aircraft operated by NBAA members [NBAA (2004)]. Interviews with industry marketing specialists indicate that piston powered business aircraft are typically owned and operated by a customer

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[†††††] Mission statement available on the AIA web site: http://www.aia-aerospace.org/

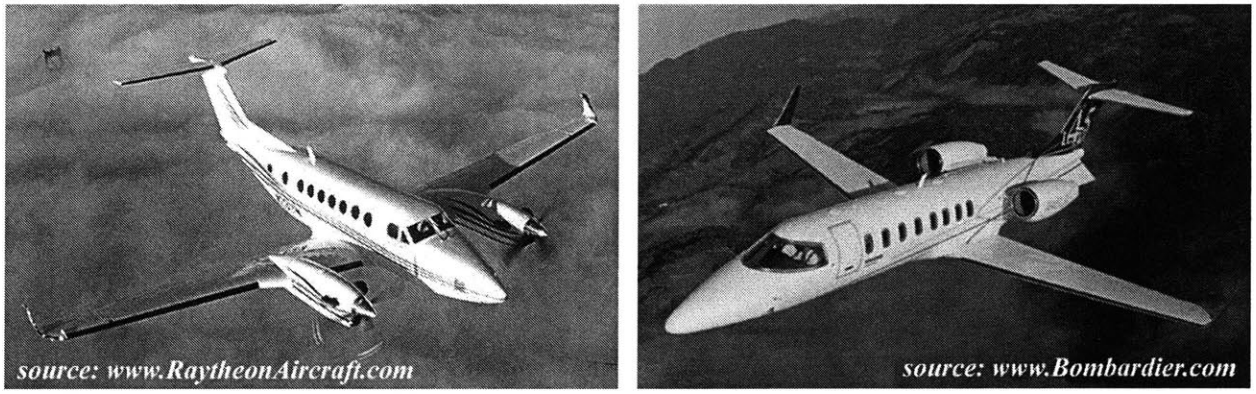
[‡‡‡‡‡] Further information on GAMA is available on their web site: http://www.GAMA.aero/

[§§§§§] The goals of the association are available on the NBAA web site: http://www.nbaa.org/

segment viewed as wholly separate and distinguishable from turbine aircraft customers. In an effort to narrow the number of customer segments and product attributes considered in this study, reciprocating engine business aircraft have not been considered. This will also allow the study to focus on so-called "organizational buyers" rather than individuals. See Chapter 5 for more details on the philosophy of choosing organizational buyers.

The turbine fleet may be divided into two types, propeller-driven turboprop airplanes and jet-driven turbofan airplanes (Figure 9). Of the United States turbine fixed-wing fleet in 2003, 40.5% are turboprops according to information published by NBAA (Figure 10).

Segmentation is regarded as "the process of partitioning a heterogeneous market into segments" for purposes of better tailoring products and marketing efforts to particular consumer needs [Loudon and Della Bitta (1993)]. There are many different ways to segment a market, including subdividing the market by customer, by product or by situation. Though the theory of segmentation will be further discussed in Chapter 4, the business aviation market is in various circumstances segmented along any one of these lines: by customer into owner/operators and professionally managed aircraft (organizational buyers); by product into light, medium, large and long-range aircraft; and by situation into executive transport, utility, recreation and other uses. As previously mentioned, organizational buyers will be the focus of this study (see Chapter 5).



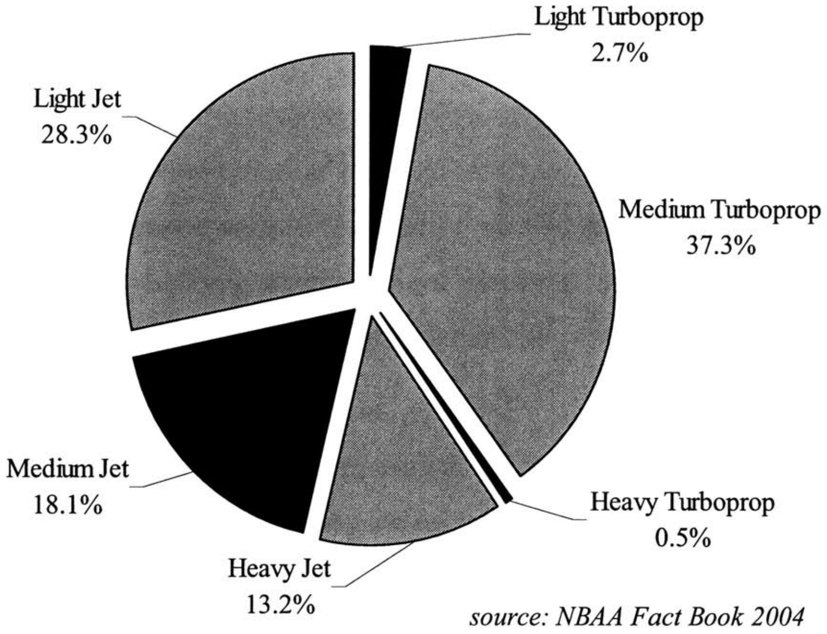
source: www.RaytheonAircraft.com

source: www.Bombardier.com

(a) Raytheon Beechcraft King Air 350

(b) Bombardier Lear 45

Figure 9: Typical (a) Turboprop and (b) Turbofan Business Airplanes



source: NBAA Fact Book 2004

Figure 10: United States Fixed-Wing Business Turbine Fleet by Type, 2003

Products in the industry are often segmented inconsistently, with primary segmentation attributes consisting of maximum takeoff weight, price, passenger accommodation, flight range, or some combination of one or more of these or other attributes. The exact division of aircraft into segments often varies depending on the organization doing the categorization, and even the segment names can vary. No single standard has yet been established for segmenting the business aviation industry, though similarities do exist among the various methods. The development in this research of a composite figure of merit, based on a number of primary attributes, may be of use in clarifying the industry segmentation. Based on reports in a number of different sources and interviews, the data in Table 1 may be used as a rough guide to segmenting the current market of business aircraft. One should consider these segments as being flexible since, for example, the categorizations in Table 1 do not even have a one-to-one mapping to those in Figure 10. The reader should also note that segments change over time, with new segments emerging at the lower and upper ends of the market and with the fragmentation of intermediate segments.

In Table 1 the "bizliner" segment includes a relatively new class of commercial airliner designs marketed specifically to business aviation customers and purpose-built for executive transport. Boeing currently offers two such aircraft: the Boeing Business Jet 1 (BBJ1), which is a

737-700 with modifications for increased gross weight, and the BBJ2, which is a 737-800. Airbus also offers one bizliner: the Airbus Corporate Jet (ACJ), which is a derivative of the A319 airliner.

Note that some aircraft may easily fit into two or more segments, depending on which figure of merit is being considered. To add further confusion to the issue, aircraft from some segments may directly compete with aircraft from another segment. For example, the Cessna CJ1 from the "very light jet" segment is considered a direct competitor for many medium turboprop aircraft.

Table 1: Typical Figures of Merit for Segmentation of the Business Airplane Market

		Traditional Figures of Merit			
	Business Airplane Segment	**Maximum Takeoff Weight (lbs)**	**Maximum Cruise Range (nm)**	**Executive Cabin Accommodation (passengers)**	**2004 Price (US$, millions)**
Turbo-prop	Light	< 6,000	-	4	-
	Medium	6,000 – 12,500	-	4-8	-
	Heavy	> 12,500	-	8-12	-
Turbofan	Ultra Light ("Micro jet")	≤ 10,000	~ 1,500	4	≤2.5
	Very Light ("Entry Level")	10,001 – 12,500	< 1,500	4-6	2.5 – 5.5
	Light	12,501 – 20,000	1,500 – 3,000	4-8	5.5 – 10
	Midsize	20,001 – 35,000	1,500 – 3,000	6-8	10 – 15
	Super Midsize	35,001 – 40,000	3,000 – 4,000	8-10	15 – 20
	Large	40,001 – 85,000	3,000 – 5,000	8-14	20 – 35
	Long Range	> 85,000	> 5,000	≥ 14	> 35
	Bizliner	> 100,000	> 5,000	> 20	> 45

Those attributes marked "-" typically are not distinguishing figures of merit for the segment.

For the purposes of this study, the business aircraft used in the various analyses were categorized into consistent market segments throughout the 40 year history of the business aviation industry. For example, if *Airplane A* was categorized as a "light jet" in the year 1975 it was not re-categorized as a "midsize jet" in a later year. As an example, according to *Business & Commercial Aviation*, there were 25 models of business turbine airplanes in production and being offered for sale in the 1999-2001 market.****** These airplanes were categorized into the seven competitive segments shown in Table 2 based on a combination of the attributes in Table 1, actual history of how the aircraft have competed in the market, and also based on the value assessments performed in Chapters 5 and 6.

Table 2: Current Market Competitive Segments, Prices, Shipments and Attribute Data

		Price[a]	Max. Takeoff Weight	Max. Cruise Range	Executive Cabin Seating
Segment	Airplanes	(US$ millions)	(lbs)	(nautical miles)	(passengers)
Medium Turboprops & Very Light Jets	Socata TBM 700	2.36	6,579	1,467	5
	Cessna Caravan I	1.44	8,000	866	4
	Pilatus PC-12	2.83	9,920	1,833	6
	Raytheon King Air C90B	2.82	10,100	1,176	4
	Cessna CJ1	3.74	10,600	1,248	4
Heavy Turboprops & Light Jets	Piaggio P-180	4.64	11,550	1,575	7
	Raytheon King Air B200	4.29	12,500	1,653	6
	Raytheon King Air 350	5.28	15,000	1,524	8
	Cessna CJ2	4.71	12,375	1,550	6
	Cessna Bravo	5.20	14,800	1,614	7
Light Jets	Bombardier Lear 31A	6.41	16,500	1,290	7
	Cessna Encore	7.13	16,630	1,668	7
	Raytheon 400A	6.39	16,300	1,428	7
Midsize Jets	Bombardier Lear 45	8.87	20,500	1,885	8
	Bombardier Lear 60	11.65	23,500	2,289	6
	Cessna Excel	9.02	20,000	1,704	8
	Raytheon 800XP	11.85	28,000	2,407	8
Super Midsize Jets	Cessna Citation X	17.50	36,100	3,070	8
	Dassault Falcon 50EX	18.27	39,700	3,191	9
	Bombardier Chall. 604	22.51	48,200	3,973	9
	Dassault Falcon 2000	20.63	35,800	3,038	10
Large Jets	Dassault Falcon 900EX	31.17	48,300	4,404	12
	Gulfstream G-IV-SP	30.69	75,000	4,033	14
Long-Range Jets	Bombardier Global Express	40.13	95,000	6,390	15
	Gulfstream G-V	40.48	85,100	5,748	15

[a] based on a 3-year average, 1999-2001

****** Markets are averaged over 3-year increments to help smooth noise in the data. See Chapter 5 for details. The turbine aircraft models considered in this research do not include executive cabin refits of regional aircraft or commercial aircraft. Such refits are higly variable in the number of passengers they can accommodate and do not therefore have "standard" configurations enabling comparison with other business aircraft.

It is important to note that the segments listed in Table 2 have not necessarily existed for every year over the 40 year course of the business aviation market, nor have the categories remained static. Categories have moved up-market, creating the large and long-range segments within the last 20 years; categories have moved-down market, recently creating the very light jet segment; and categories have fragmented, resulting in the super midsize niche seated between the midsize and large jet segments. A similar pattern has been evident in the automotive industry for decades. The SUV market alone has recently split into the small utility (Toyota RAV4) and large utility (GMC Yukon) categories.

2.2.2 Relationship to Other Parts of the Aviation Industry

The heart of business and general aviation manufacturing is located in Wichita, Kansas, also known as the "Air Capital of the World." Of the five major manufacturers of fixed-wing business turbines, three have facilities in Wichita (see the locations noted in Figure 11). Both Cessna and Raytheon have their manufacturing facilities wholly located in Kansas, while Bombardier manufactures its Lear series of business jets and flight tests all of its business aircraft in Wichita. Additionally, Boeing Commercial Airplane Group also has a major manufacturing facility in Wichita where 737 (including the BBJ1 and BBJ2) forward fuselage sections are built before being shipped to Seattle for final assembly. (Airbus has recently located a design facility in Wichita, but currently has no manufacturing facility outside of Europe.)

The remaining business airplane manufacturers are located in Canada (Bombardier's Challenger and Global Express production); Georgia, USA (Gulfstream); and France (Dassault). Two principal general aviation manufacturers, New Piper Aircraft and Mooney Aircraft, are located in Florida and Texas, respectively. These companies are well-known for their single- and multi-engine piston-powered aircraft. One of the only other major civil aerospace airframe manufacturers not located in North America is the regional jet producer Embraer from Brazil.

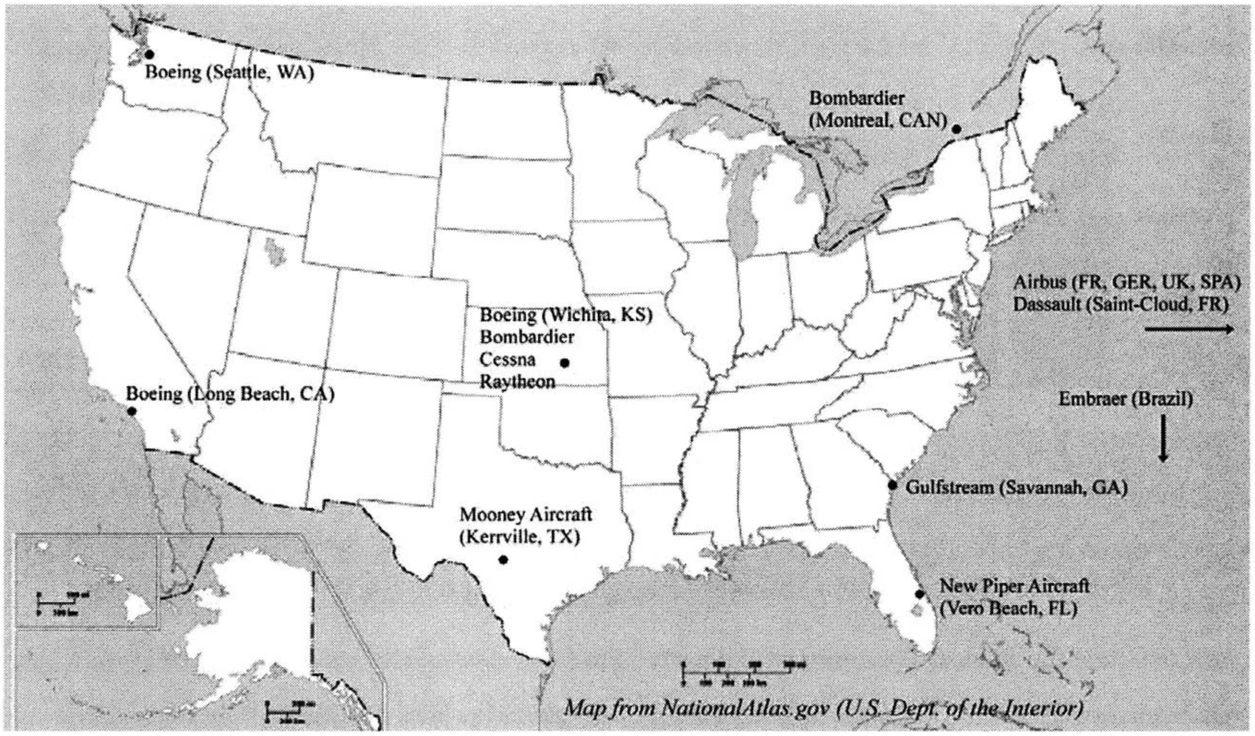
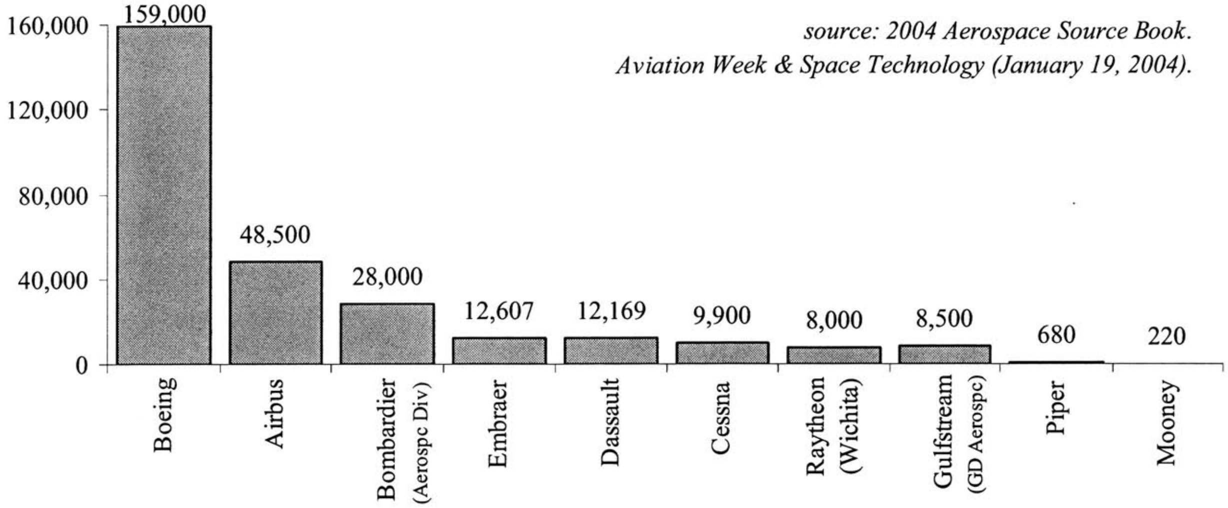


Figure 11: Locations of Selected Civil Aviation Industry Manufacturers

Employment levels among the major civil aerospace manufacturers vary greatly, as shown in Figure 12 (the figure includes engineering, manufacturing and support staff). Boeing clearly dominates the field by an order of magnitude, though the data in the figure reflects Boeing's worldwide employment, including many non-commercial activities. The business airplane companies tend to fall between the "heavies" of Boeing and Airbus and the general aviation companies Piper and Mooney.

It is interesting to compare the employment levels of Figure 12 to the unit shipments of Figure 14. Although some might speculate as to the efficiency of each company's workforce, the differences seem to relate more to the level of support and product development (and price) that each company achieves as it is not possible to determine the portion of the employees in Figure 12 actually dedicated to manufacturing-related activities.

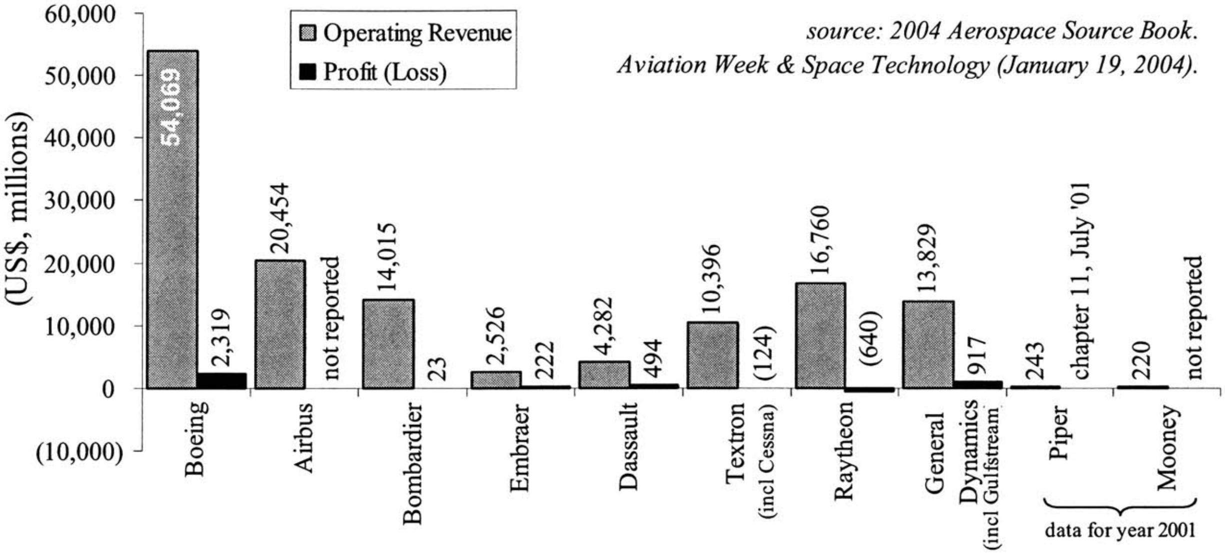


source: 2004 Aerospace Source Book. Aviation Week & Space Technology (January 19, 2004).

Figure 12: 2003 Aviation Industry Employment Levels for Selected Companies

Since the market downturn in the early 2000s the civil aerospace manufacturing industry has been suffering hard times. The year 2002 revenues and profits for each of the companies studied here are shown in Figure 13. Employment clearly does not predetermine operating revenue, nor does unit shipments if one is to examine Figure 14. Higher profit margins are typically to be found in the larger turbine aircraft (particularly Boeing and Airbus' commercial aircraft), whereas many of Cessna's annual shipments are of low-margin piston-powered aircraft.

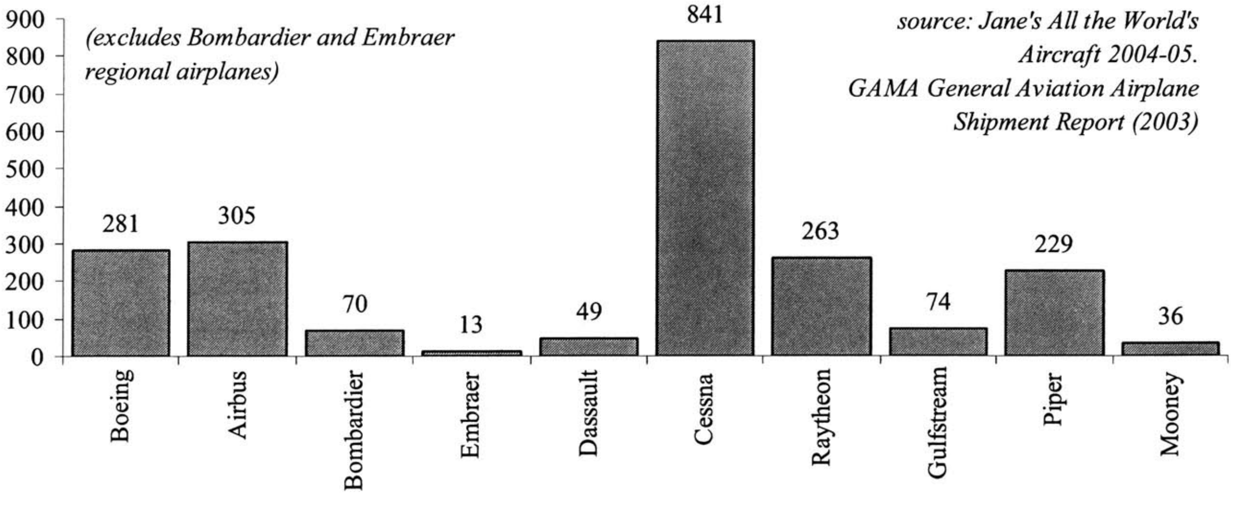
A sobering reminder of the current financial state of the industry is the fact that one company has been in chapter 11 bankruptcy for three years (Piper is just now emerging) and a number of other companies are losing hundreds of millions of dollars or are just breaking even. Although data is not yet available for 2003, financial analysts are expecting the market to steadily improve through the end of the decade. Still, as the old joke says, "The best way to make a small fortune in the aviation industry is to start with a large fortune."



source: 2004 Aerospace Source Book. Aviation Week & Space Technology (January 19, 2004).

Figure 13: 2002 Aviation Industry Revenues and Profits for Selected Companies

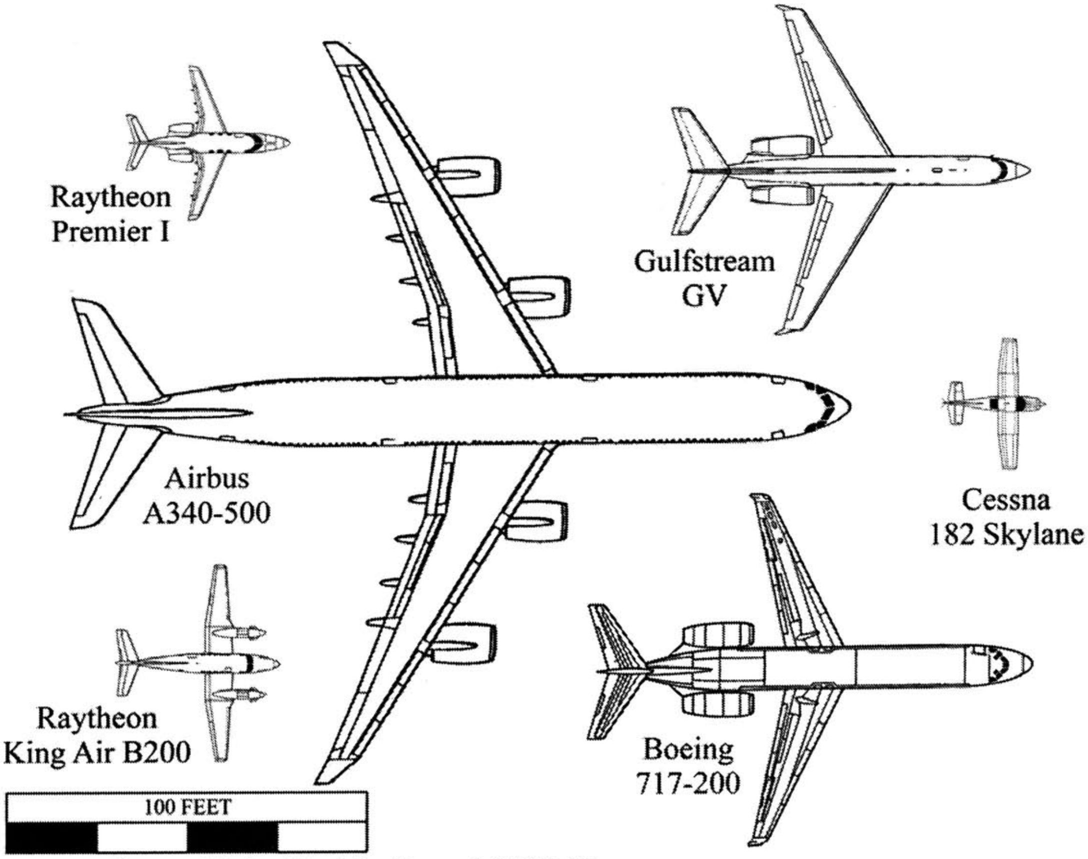
Aircraft unit shipments vary widely within the aerospace industry, with Cessna the clear leader due to its mass production of small, single-engine piston aircraft in its Independence, Kansas facility (Figure 14). Embraer manufactures regional jet aircraft for the airlines (its ERJ series not reflected in Figure 14) plus a very few executive transport conversions of its ERJ, known as the Legacy Executive aircraft. Perhaps a fact not well known is that Boeing, Airbus, Raytheon and Piper each deliver on the order of the same number of aircraft annually.



source: Jane's All the World's Aircraft 2004-05. GAMA General Aviation Airplane Shipment Report (2003)

Figure 14: 2003 Aviation Industry Unit Shipments for Selected Companies

The physical dimensions of the aviation industry's products also vary greatly, with business aircraft fitting squarely between the large commercial airliners of Boeing and Airbus, and the small general aviation products of Cessna, Piper and others (Figure 15). The scale comparison of Figure 15 shows to good effect the fact that the larger business airplanes, such as the Gulfstream GV, approach the size of the smaller commercial airliners, such as the Boeing 717. As mentioned previously, Embraer and Bombardier both offer executive conversions of their smaller regional airliners for those businesses requiring larger business aircraft, and Boeing and Airbus started offering purpose-built executive transport variants of their smaller 737 and A319 airliner designs in the early 1990s. On the smaller end of the scale, entry-level (or "very light") jets such as the Raytheon Premier I and Cessna CJ1 are approaching the size of some larger general aviation aircraft. A new class of "micro jets" proposed by Cessna, Eclipse Aviation, and others hold the potential to at last bring turbine power to individual owner/operators which heretofore has been the sole province of corporate owners/professional operators.

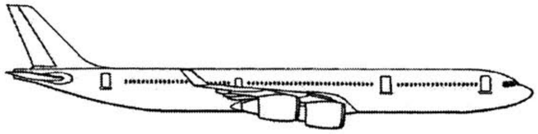
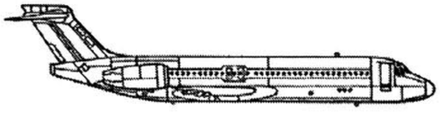
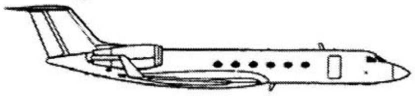
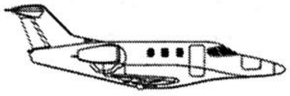
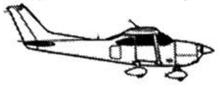


source: Janes All the World's Aircraft 2004-05

Figure 15: Scale Comparison of Selected Aviation Industry Products

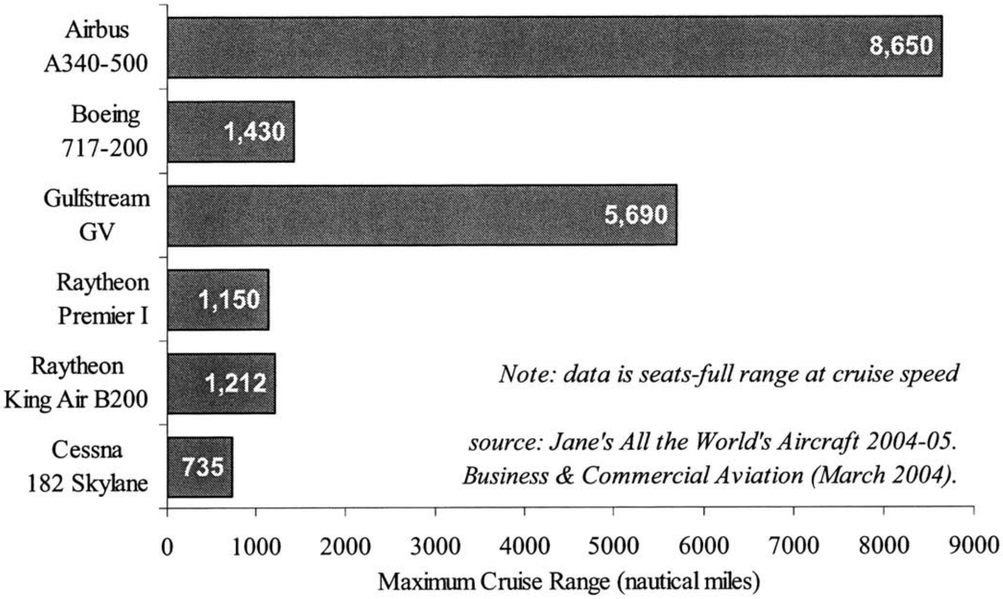
Along with size, the prices and passenger accommodations of the aviation industry's products range from the astonishing ($177.8 million and 300+ passengers) to nearly affordable ($300,000 and 4 passengers) (Table 3). Purchase prices for larger aircraft (Gulfstream GV and above, in the table) can be misleading, however, as they typically reflect aircraft delivered "green," or without interiors. Airlines and owners of larger business aircraft specify their level of interior décor, which may cost only an additional few million dollars for a bare bones GV, or as much as an additional $20 million for brass fixtures, state-of-the art-electronic communications and entertainment systems, and the like. Third-party companies specialize in designing and installing business aircraft interiors to the tastes of their clients, and the sky is literally the limit in what may be spent outfitting one of these aircraft.

Table 3: Passenger Capacity and List Prices for Selected Aviation Industry Products

Aircraft [a]	Typical Passenger Capacity	2004 List Price (US$ millions)
 Airbus A340-500	313 (3 classes) (+ crew)	177.8 (for year 2002)
 Boeing 717-200	106 (2 classes) (+ crew)	35.0 (for year 2001)
 Gulfstream GV	15 (+ crew)	38.0
 Raytheon Premier I	6 (+ crew)	5.67
 Raytheon King Air B200	8 (+ crew)	4.99
 Cessna 182 Skylane	4 (incl. pilot)	0.30

[a] aircraft side views not to scale
Source of data for A340, 717: *Jane's All the World's Aircraft 2004-05.*
Source of data for all others: *Business & Commercial Aviation* (March 2004).

One might be surprised to note that the Gulfstream GV can cruise nearly four times as far as the Boeing 717 airliner, as indicated by Figure 16. However, for two aircraft that approach the same size, the Gulfstream is designed to cruise with, at most, 15 passengers whereas the 717 carries up to 106 fare-paying passengers. Very recent additions by Gulfstream to the turbine fleet have extended the maximum business jet range to just over 6,000 nautical miles. Much like airliners, business aircraft are designed to perform certain missions, such as transcontinental flight, transatlantic, etc. and thus there are aircraft models to accommodate nearly every customer need.



Note: data is seats-full range at cruise speed

source: Jane's All the World's Aircraft 2004-05. Business & Commercial Aviation (March 2004).

Figure 16: Flight Ranges for Selected Aviation Industry Products

Within technological and physical constraints, the aviation industry as a whole has converged on a limited number of cruise speeds (Figure 17). The old adage "time is money" is a mantra for business aviation customers, thus their aircraft need to fly as fast as technology will allow within financial reason.* The data in Figure 17 indicates that approximately 450-490 knots (true airspeed, ktas) is the current technological limit for turbofan driven aircraft, regardless of whether they are large commercial airliners or a small, light business jet. Turboprop aircraft such as the Raytheon King Air series cruise somewhat slower due to the physical limitations of a

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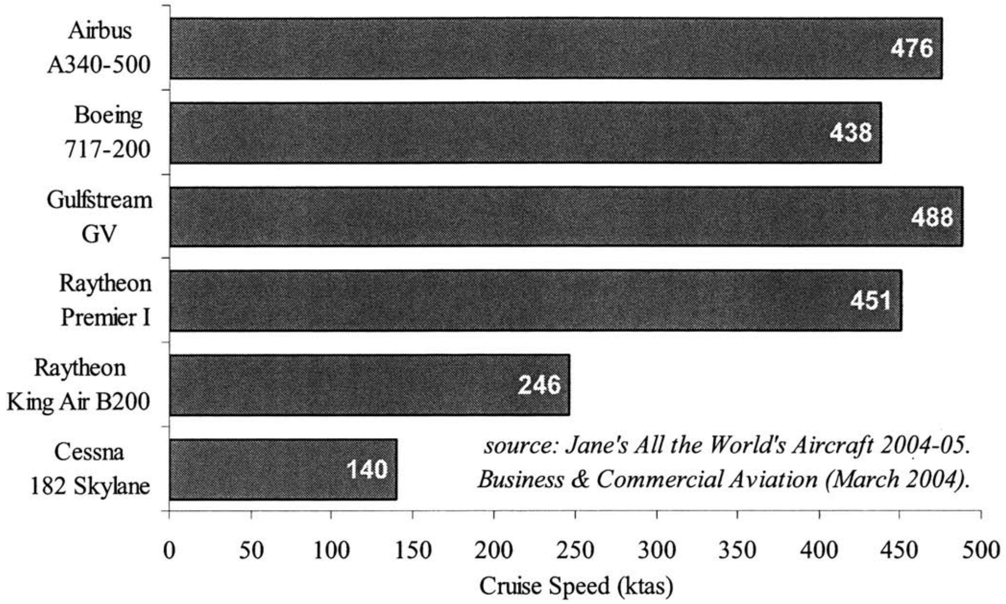
* "Within financial reason" is a partial explanation for why there are currently no supersonic business jets on the market. Once certain technological and political barriers have been overcome, supersonic business aircraft may become common. See the discussion in Chapter 6 on the current state of supersonic business jet development.

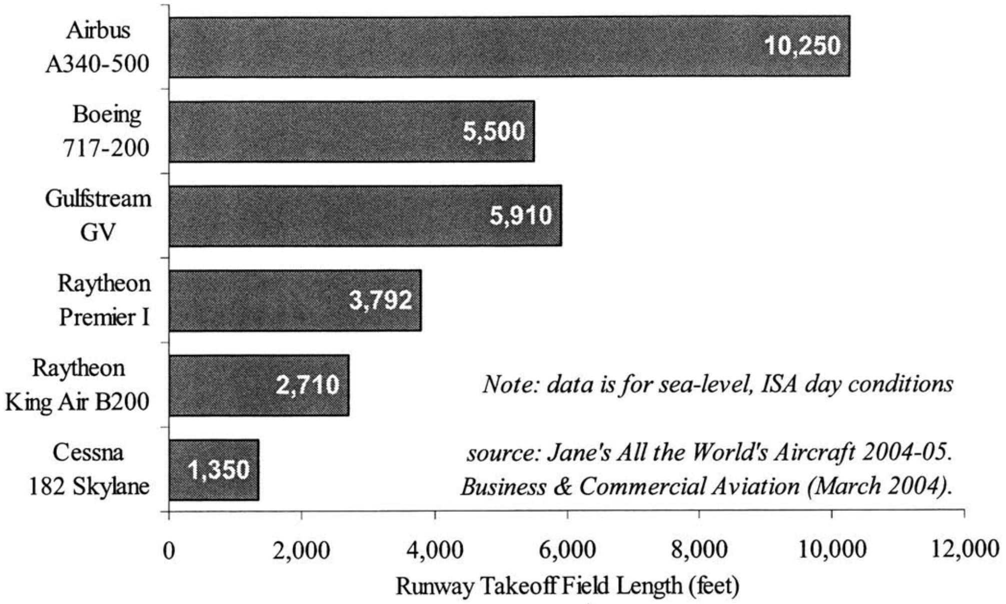
limitations of a propeller-driven system. Reciprocating engine aircraft such as the Cessna Skylane, lacking the horsepower of a turbine engine like that of the King Air, "putter" around the sky at a "mere" 140 knots (approximately 160 mph).



source: Jane's All the World's Aircraft 2004-05. Business & Commercial Aviation (March 2004).

Figure 17: Cruise Speeds for Selected Aviation Industry Products

One important factor that distinguishes business aircraft from some of their commercial airliner brethren is the length of runway required to land and take off. Figure 18 shows the extraordinary lengths of runway required for the heaviest of airliners (nearly two miles!). Business aircraft are, again, designed to meet certain mission goals that include landing at particular airports throughout the world. Manufacturers are aware of which airports their corporate customers frequent, so their aircraft are designed to be able to land within certain runway lengths. While the Cessna Skylane can land on practically any paved runway in the world, the Premier I and Gulfstream GV were designed for particular locations "of interest" to certain market segments of the business aviation customer base.

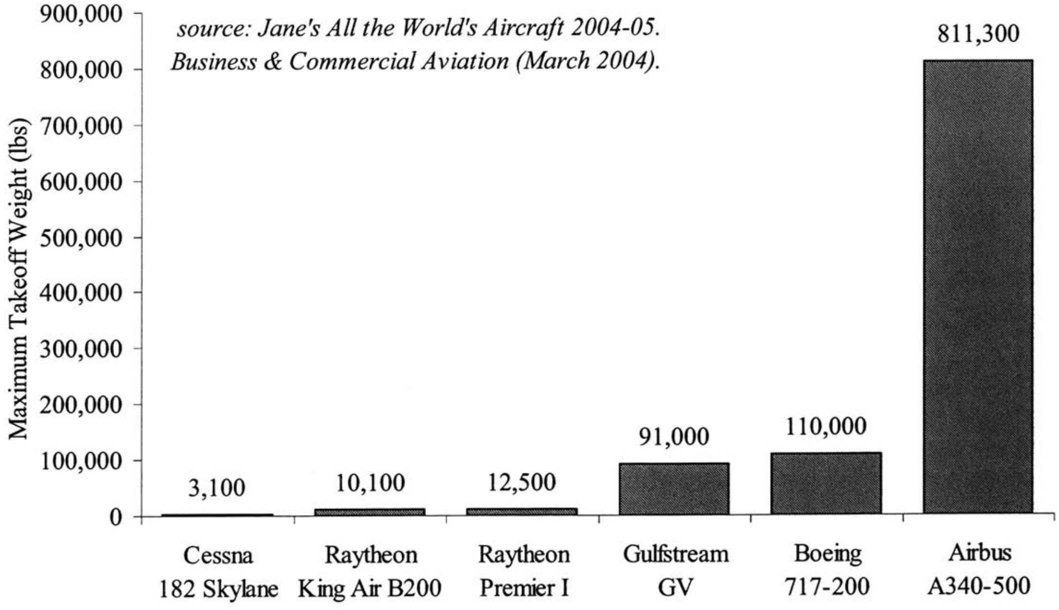


Note: data is for sea-level, ISA day conditions

source: Jane's All the World's Aircraft 2004-05. Business & Commercial Aviation (March 2004).

Figure 18: Takeoff Field Lengths for Selected Aviation Industry Products

Continuing the theme of "some are big, and some are *really* big," the data in Figure 19 shows how very different aircraft can be. It is interesting to note again that the Gulfstream GV and Boeing 717 are not altogether dissimilar in size, yet each fulfills very different missions and meets very different performance goals.



source: Jane's All the World's Aircraft 2004-05. Business & Commercial Aviation (March 2004).

Figure 19: Maximum Takeoff Weights for Selected Aviation Industry Products

Without a doubt there are a wide variety of aircraft currently in production throughout the civil aviation industry. The boundaries are vague for just what kind of aircraft typifies the business aviation industry, and the periphery continues to shift with larger BBJ-style airliners entering the market, as well as the smaller "micro jets" looming on the horizon. Nevertheless, The data shown in this section emphasizes the need for a valuation methodology that allows product comparisons based on multiple attributes in various combinations. Data from this industry will prove useful in critically assessing the usability and external validation of Cook's Relative Value Index method.

2.3 Building and Critically Assessing a Business Aviation Product Database

> "A mathematical model, when constructed, is little more valuable than a map with a road network but no printed data. Therefore, data must be acquired to qualify the relationships that have been described in the model." [Kidera and Hoff (1977)]

Chapter 4 of this document will describe in detail the development of the Relative Value Index (RVI) model for product development and evaluation. As Kidera and Hoff note, such a model would be of little use or importance without data by which to exercise and evaluate the model. For this purpose, a self-consistent database of over 40 years of historical information on business airplane prices, performance, physical characteristics and annual market demand was assembled specifically for use with the RVI model. As will be discussed in Chapter 5, the business aviation industry was chosen in part for its base of organizational buyers, in part for the relatively complete and extensive data available, and in part due to the author's familiarity with the industry.

Fortunately, a great deal of the industry information required was available from only a handful of sources which served to improve the consistency of the raw data. Still, it was necessary to resolve a number of errors and inconsistencies in the collected raw data and also to fill certain gaps in what data was available. The database of business airplane characteristics used in this research is documented in its entirety in Appendices A (physical and performance characteristics), B (shipments data), and C (price data).

This database represents over 40 years of product evolution in the business airplane industry, and includes every turbine-powered business aircraft that entered full-scale production for which information could be found. The record in this document represents the first time, to this author's knowledge, that such a comprehensive and self-consistent database of business airplane information has been published in one location. Development of the database, corrections to the raw data, and sources of error are discussed in detail in this section.

All technical and pricing data is from *Business & Commercial Aviation* of various years. Annual unit shipments are taken from the *Weekly of Business Aviation* and GAMA's annual "General Aviation Airplane Shipment Report." Technical parameters vary from year to year based on what the equipment manufacturers report to the publisher, but efforts have been made to preserve consistency in the parameters and to verify any that are in question with alternate sources. When comparing historical airplanes with current airplanes, one needs to be aware that measurement and reporting methods have changed over the years even though *Business & Commercial Aviation* has been the consistent source of data publication. Some modification in parameter values will be necessary for a valid comparison using historical business airplane data.

2.3.1 Selection of Product Models and Years for Study

Those industry products studied in this research are selected from annual lists of currently marketed, fixed-wing business aircraft in the *Business & Commercial Aviation* (B/CA) "Purchase Planning Handbook" of various years. The handbook started publication in 1960 in the April issue of B/CA, and later moved to the annual May edition of the magazine. Even considering the 100 year history of *Jane's All the World's Aircraft*, since 1960 *Business & Commercial Aviation* has become the de facto standard for providing detailed technical intelligence on business aircraft (both fixed-wing and rotorcraft). Each year, manufacturers work closely with the publication to update technical performance information on their aircraft products, and manufacturers use the publication as one of their key sources of information on competing aircraft.

As previously mentioned, only turbine powered aircraft are considered in this study because their customer base is composed primarily of organizational buyers. These buyers are more likely to base their decisions on objective criteria and well-researched attributes, thus facilitating the use of a quantitative model in this research. See Chapter 5 for more information on organizational buyers.

Partly because the assumption was made of organizational buyers, the corollary was assumed that any potential business aviation customer would be aware of all in-production airplane models listed in *Business & Commercial Aviation.* Market decision heuristics theory typically first separates products (or brands) into categories of those known to the customer and those for which the customer is unaware [Roberts (1989)], but all mass production aircraft are assumed to be known to the customer in this research. Even without organizational buyers or their typical thorough research, the business aviation community is rather small and with only a limited number of products in production at any one time. Therefore, there are no "obscure" or "little-known" business airplanes listed in B/CA but excluded from the research database.

On occasion, B/CA lists some regional aircraft as executive transport conversions, one example including the Embraer Legacy corporate shuttle. Similarly, the Boeing Business Jet (1 and 2) and the Airbus Corporate Jet are also listed in recent years of the publication. These models have been omitted from the database because there is no "standard" executive seating configuration for them, and thus a "typical" version is difficult to identify for use in the analyses. The market for such aircraft has proven limited to date, so the variability in passenger accommodation and its attendant influence on model results has not yet been addressed.*

Commuter aircraft such as the Raytheon Model 1900 are also not included in the database. Neither are highly-specialized, limited production derivatives of major models included, such as the Raytheon King Air 350SE (special edition derivative of the King Air 350). Shipments of such derivatives, if reported separately, are included in the shipment totals of the major models.

All aircraft models are categorized in the database according to their 2005 corporate owner. For example, the Beechcraft Bonanza is listed as the Raytheon Bonanza, the Learjet 23 is listed under Bombardier, etcetera.

As mentioned before, B/CA started publishing its annual handbook of data on business aviation industry products in April of 1960. It is convenient that the first business turbines were introduced not long before, in 1959. The first jets were certified in 1961 (Lockheed JetStar) and 1962 (North American Sabreliner). Although the early shipments, prices and technical characteristics have been carefully pieced together from a number of sources, it is a recent development that precludes maintaining a complete set of current-day data. In 2002 Gulfstream Aerospace stopped reporting shipments data for its aircraft except as grand totals for the

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* For RVI model users who wish to study the converted regional jet and bizliner market segments, this issue would necessarily need to be addressed.

company as a whole. It is no longer possible to assemble model-by-model shipments data for any Gulfstream aircraft except by rough estimates based past performance and shipments for similar competing aircraft. This development has concerned a number in the industry, including the major reporting organizations such as GAMA, and advocacy groups such as NBAA who monitor industry performance. As a result, the database assembled for this research is not complete for shipments data after the year 2001. All analyses in this research requiring shipments data will be for the year 2001 or before.

2.3.2 Pricing Data

Appendix C contains a complete listing of all pricing data used in the analyses for this research. All pricing data is derived from *Business & Commercial Aviation*, with only a few exceptions as noted in the appendix. Prices are "list" from 1960 through 1973 and reflect information provided to B/CA by the manufacturers. For this 13 year period the prices reflect varying levels of installed options and equipment onboard the airplanes, depending on how the manufacturer chose to advertise its products. Direct price comparison between products in this period should be performed with care, and it would be best to consult original period publications for any information on how aircraft were equipped. No single method of converting the "list" prices from this time period is possible, but the prices in the database are believed to be useful for direct comparison between contemporary aircraft.

In 1974 B/CA addressed this inconsistency by listing an "equipped" price in its annual Purchase Planning Handbook. The equipped price, according to B/CA, reflects the "computed retail price with at least the level of equipment specified in the B/CA Required Equipment List." The B/CA Required Equipment List is available in every Purchase Planning Handbook and represents that level of equipment, from avionics to air conditioning and ice protection, necessary to safely conduct flight operations typical for most business aviation missions. The list varies depending on the aircraft type, from single-engine turboprops to jets weighing over 20,000 lbs.

The equipped prices better enable a direct comparison between aircraft, but likely do not reflect the true sales price of the aircraft. Much as the Manufacturers Suggested Retail Price (MSRP) on automobiles can only be used as a guide to car prices, the B/CA equipped price is only an estimate of actual prices. Industry experts have indicated that some poor-selling models may be discounted as much as 10-20%, and discounts are typically offered to customers that purchase large numbers of aircraft.* As in the automobile industry, actual sales price data is closely held by both the manufacturers and customers and is unavailable for this analysis.

In some parts of this study it is necessary to directly compare groups of historical aircraft that were not in production at the same time. In these cases it is necessary for some aircraft prices to be adjusted to a common year using the Consumer Price Index (CPI). Appendix D lists the CPI data for 1960-2004 and explains how the index may be used to adjust historical prices.

2.3.3 Unit Shipments Data

Appendix B contains a complete list of the worldwide business airplane shipments data used for analysis in this research. According to GAMA, "A shipment occurs when a general aviation airplane is shipped from its production facility to a customer located anywhere in the world." Business airplane annual unit shipments data is taken from three primary sources, depending on the level of detail available and the years the source was published: *Aviation Week & Space Technology* "Forecast & Inventory" issues (March of 1959-1965), *Weekly of Business Aviation* (various issues, 1966-2000), and GAMA's *General Aviation Airplane Shipment Report* (2001 onwards). There is some overlap in the years each of these sources was published, so shipments data was corroborated among sources and made to be consistent to the greatest extent possible. All shipments, unless noted in the appendix, are for customers in the civilian market.

Although worldwide unit shipments were employed in this model as equivalent to consumer demand, in reality annual unit shipments are set by a number of factors such as manufacturer capacity and order backlogs. Ideally one would use orders booked rather than unit shipments, but such data is proprietary.

As previously noted, in 2002 Gulfstream Aerospace stopped reporting detailed shipments data for its aircraft, instead choosing to report only grand totals for the company as a whole. It is no longer possible to assemble model-by-model shipments data for any Gulfstream aircraft after 2001. As a result, all analyses in this research requiring shipments data will be for the year 2001 or before. Though this adversely impacts our ability to examine the industry using the most up-

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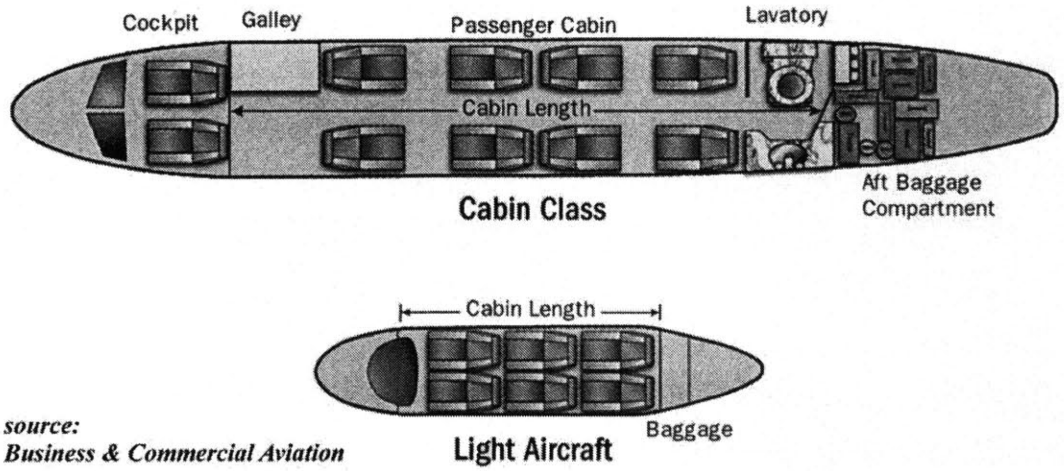
* Orders in quantities above a handful of aircraft at one time are a relatively new phenomenon since the inception of fractional ownership programs. In 1999 fractional provider NetJets placed a record order for 100 Raytheon Aircraft Hawker Horizons, valued at over $2 billion [*Wichita Business Journal* (June 15, 1999)].

to-date market information, the RVI method is useful in indicating historic market trends, enabling an extrapoloation of market activities to the current market (see Chapter 6).

2.3.4 Physical Dimensions and Weights

Appendix A contains a complete list of all aircraft dimensions, accommodations, and weights data used for this study.

Internal dimensions are in terms of length, width and height, measured in feet, for the aircraft cabin. Based on information in B/CA, these dimensions "are based on a completed interior, including insulation, upholstery, carpet, carpet padding and fixtures." As shown in Figure 20, the cabin length is measured from the aft side of the forward cabin divider to the aft-most bulkhead in cabin class aircraft. For light aircraft, the measurement is made from the forward bulkhead ahead of the rudder pedals to the back of the rear-most passenger seat. Where a distinction is made, the "net length" measurement is used from B/CA. The B/CA "maximum width" measurement is also used.



source:
Business & Commercial Aviation

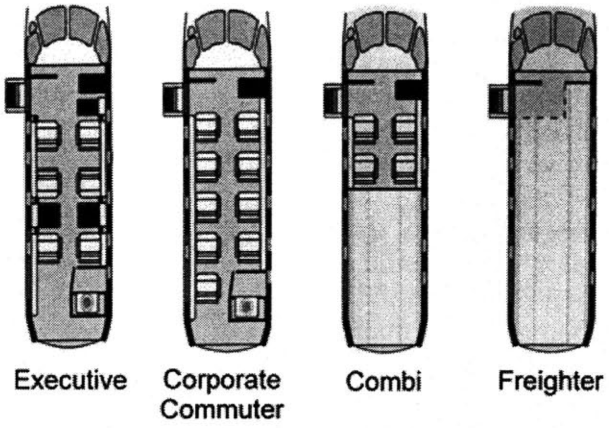
Figure 20: Cabin Length Measurement for Business Airplanes

When a cabin volume measurement is required for an analysis in this research, the following simple approximation is made:

$$\text{Cabin Volume} \cong \text{Length} \cdot \text{Width} \cdot \text{Height} \qquad \textbf{(2-1)}$$

Though a typical pressurized aircraft cabin cross section more closely resembles a circle than a rectangle, the approximation was applied consistently across the database when necessary and should equally favor or penalize all aircraft.

Passenger accommodations are those listed for a typical executive configuration in B/CA. In practice, business airplane interiors can vary widely in quality of appointments and number of seats, even for the same model of aircraft. As shown in Figure 21, the Pilatus PC-12 can be configured as an executive transport, corporate shuttle, combination passenger/cargo freighter, or pure freighter. It is typical for manufacturers to offer "standard" executive configurations for their aircraft, upon which the accommodations in the database are founded.



source: Pilatus Aircraft

Figure 21: Pilatus PC-12 Cabin Configurations

The maximum takeoff weight (MTOW) reported in the database is determined by structural limits and is a well-known engineering term defined by federal regulations. The basic operating weight (BOW) is that reported by B/CA and consists of the aircraft empty weight (airframe, trapped fuel and oil, and options) plus the weight of the required flight crew. The aircraft useful load is the MTOW minus the BOW. The maximum fuel weight is that reported by B/CA.

2.3.5 Aircraft Performance

A complete list of all aircraft performance data used for this study is contained in Appendix A. All performance data is from B/CA of appropriate years. Performance parameters assembled for the database include the following:

- High speed cruise speed (ktas): short-range, high speed cruise with four passengers and one-half fuel load. Sometimes listed in early B/CA issues as "max recommended."
- Long range cruise speed (ktas): cruise speed for maximum range with four passengers and one-half fuel load.

- Maximum operating Mach number (M_{MO}): M_{MO} is an engineering term defined in the federal regulations
- Takeoff field length (TOFL): approved flight manual takeoff runway distance for sea-level, International Standard Atmosphere (ISA) standard day.
- Certified ceiling (feet): maximum allowable operating altitude as determined during aircraft certification.
- Seats-full range (nautical miles): based on typical executive configuration with all seats filled by 170 lb occupants, maximum available fuel less 45 minute IFR fuel reserve. Note that for multi-engine turbines this figure is not directly available from B/CA and was therefore estimated given the available data.
- Tanks full range (nautical miles): based on BOW, plus full fuel and the maximum available payload up to maximum ramp weight.
- High speed cruise speed fuel flow (lbs/hour): fuel flow for high speed cruise.
- Long range cruise speed fuel flow (lbs/hour): fuel flow for long range cruise.

Performance parameters for the same aircraft can vary from year-to-year based on what the manufacturer provides to B/CA. Aircraft models are often first listed in B/CA while they are still in development, in which case the performance parameters are those estimated by the manufacturer and may not reflect in-service performance. In most cases, the performance data collected for this study is based on the B/CA information published one year after first delivery of the aircraft model. At that time, it is reasoned, the manufacturer should be providing fairly accurate data to the publication.

There are a few cases, particularly in the early issues of B/CA, where performance data for a particular model significantly changed several years after the aircraft entered production. It appears that such changes typically corrected oversights or misprints that had been overlooked for some time in the publication. Every effort has been made to note the source of each piece of data in Appendix A.

Early issues of B/CA listed fuel flows in gallons per hour and speeds in miles per hour. This information has been converted in the database to the more standard pounds per hour and nautical miles per hour (knots).

2.3.6 Operating Costs

As will be noted in Chapter 5, some quantification of aircraft operating costs is desirable for use in the RVI model. In 1998 *Business & Commercial Aviation* started annual publication of an "Operations Planning Guide" in their August issue. This guide provides information on operating costs for currently in-production business aircraft, but unfortunately does not provide an historical set of operating cost data for the industry. In 1998 the Federal Aviation Administration published the report *Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Decisions* [Hoffer, et al (June 1998)]. In this report is listed "economic values for use in the conduct of benefit-cost and other evaluations of investments" as they apply to commercial, business and general aviation aircraft. An abbreviated set of aircraft operating costs are also estimated in the report, including some out-of-production business airplanes. The list is, unfortunately, not complete enough to enable one to compile a set of historical operating costs sufficient for use in the analyses of this study.

As noted in the pervious section, however, fuel consumption data for the complete historical set of aircraft is available through the B/CA publication. It was determined that operating costs could be approximated by the fuel consumption data to a degree sufficient to be useful in this study.

Operating costs consist of two contributions: fixed and variable costs. Fixed costs include insurance, crew training, hangar fees and other costs that do not vary based on the amount of flying that is done. According to data available in the B/CA "Operations Planning Guide," fixed costs are directly proportional to the business aircraft purchase price, though that proportionality does differ slightly for turboprop versus turbofan aircraft. For the purposes of this research, it is assumed that fixed costs vary directly with purchase price, and thus a separate variable is not developed for this cost element.

The variable cost typically consists of fuel & oil and maintenance costs (labor charges for the crew are sometimes included as well, but are often charged separately under professionally managed flight departments). Fuel & oil and maintenance costs for a number of different category aircraft are shown in Figure 22 as they are estimated in the FAA report [Hoffer, et al (June 1998)]. In the chart, the costs are normalized to a baseline cost of 1.0 representing the costs for the Piston 1-3 seats category. For example, the variable costs for operating a twin-engine turbojet weighing more than 20,000 lbs are approximately 35 times higher than for a piston-engined aircraft with 1-3 seats.

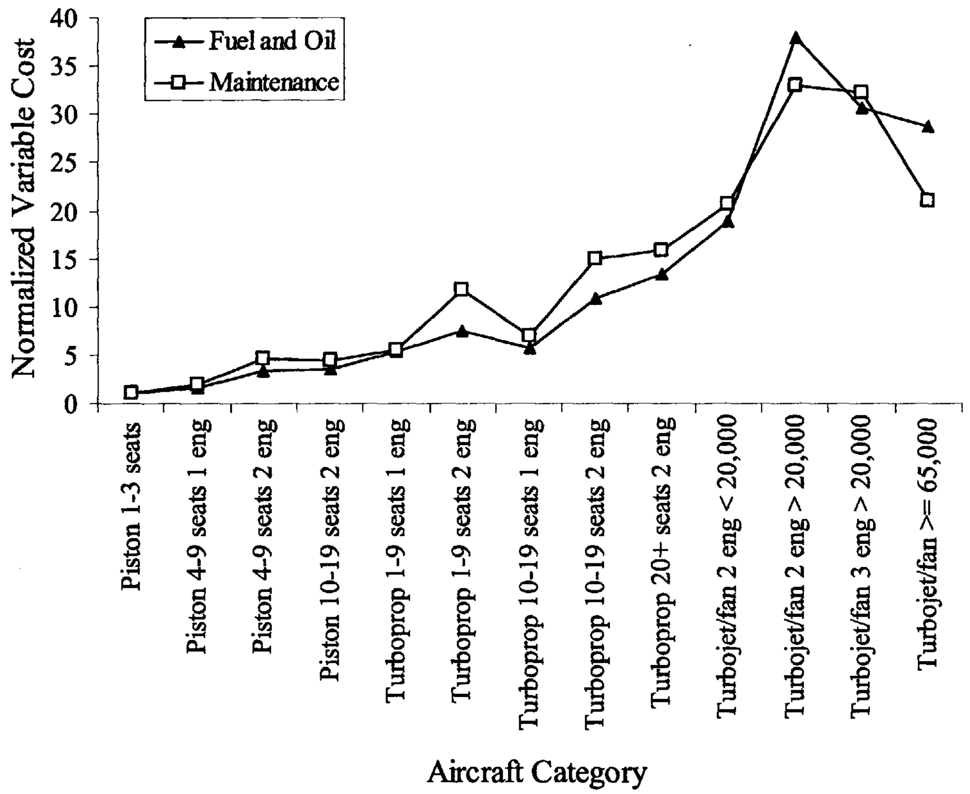


Figure 22: Variable Operating Costs for Several Aircraft Categories

The chart indicates that maintenance costs vary in proportion to fuel and oil costs, and therefore a separate maintenance parameter would be redundant. Furthermore, oil costs are small compared to fuel costs according to data in the FAA report. This indicates that if fuel costs are approximately tracked, then those proportions should be indicative of total variable costs for these aircraft. Fuel costs are directly related to fuel consumption for a particular aircraft, so use of the fuel flow variable (lbs/hr) should be an adequate proxy for the operating costs of business airplanes.

2.3.7 The Need for Additional Data

Although a thorough historical set of operating cost data is not available, adequate information is published nowadays for current in-production aircraft. There is, however, a lack of publicly available data on several parameters thought to be of importance to the types of analysis conducted in this study.

Business aviation industry marketing and product managers have indicated their belief that mission dispatch reliability and after-sales customer support, in particular, are quite important to the customer purchase decision. Unfortunately reliability statistics have not, until very recently, been formally collected in the business airplane industry and are currently not publicly available. Quantification of customer support levels is also difficult as they can vary widely from product to product even within the same manufacturer's product line. Two industry publications, *Aviation International News* and *Professional Pilot*, currently issue annual customer support surveys based on reader feedback. Unfortunately the surveys are variable in the number of participants, from as few as ten survey responses to as many as several hundred for any given airplane model. As a result the data is not statistically reliable enough for meaningful analysis in academic research.

It is unlikely that reliability and customer support data will ever be available for an historical set of business aircraft, but the need exists to collect information on these attributes to further enhance analyses such as those conducted for this research.

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3 PRODUCT VALUE AND VALUE ASSESSMENT METHODS

The central theme in product value assessment is how consumers make choices among competing products, each with multiple attributes of importance to the decision maker. In this chapter the issue of consumer choice will be first addressed through a brief review of the relevant literature in both the consumer behavior and product marketing areas. Following the literature review, a discussion of what the term "value" means and how it may be used, particularly as it applies to this current research. Finally, a description and evaluation of current value assessment methods is presented in §3.3 for later comparison to the value method utilized in this research.

3.1 Consumer Choice

The average person makes hundreds of choices each day, ranging from selecting foods for meals, clothes to wear, and people to talk to. Substantial attention has been focused in the marketing and behavioral psychology literature to how consumers make choices in their purchase decisions. Of particular interest are decisions with numerous choices, each involving multiple attributes.

The research literature indicates that an individual is unlikely to evaluate all choice alternatives on a buying occasion, but will instead simplify their decision making by eliminating many alternatives from consideration. For example, among the more than 300 distinct auto models available to consumers Urban, Hauser and Roberts (1990) have shown that U.S. consumers consider on average only 8.1 of the alternatives available. A framework for such "phased decision heuristics" was originally proposed by Howard (1963), further expanded by Howard and Sheth (1969), and is borne out by experimental research such as that reported by Payne, Bettman, and Johnson (1988).

The first phase of a phased decision heuristics strategy involves using simple heuristics to narrow a field of numerous complex products, each consisting of multiple attributes, to an "evoked set" as Howard and Sheth refer to the smaller subset of products. These are the brands on which the consumer gathers information in the second phase of the decision process. This more detailed analysis of the competing products may be conducted based on price, brand, performance and other attributes of importance to the consumer. Urban, Hulland and Weinberg (April 1993) propose a market forecasting model for the automobile categorization process based on the amount of information (via advertising and dealer visits) available to the consumer in considering the evoked set (also Urban, Hauser and Roberts (1990) propose such a model and test it).

Considerable research has focused on the size of the evoked set [Roberts (1989), Hauser and Wernerfelt (March 1990)], with Hauser, Urban, and Roberts' 8.1 automobiles the largest reported evoked set found through experimental measurement. Although attempts at quantitatively modeling how the evoked set is selected have been made [Roberts (1989), Roberts and Lattin (November 1991)], the business aviation industry value model proposed in this research will consider all products in the market as being under consideration. The reason for this is twofold; first, it is desired that a model be developed from which direct comparisons across the entire business aviation market may be made, and second, interviews with industry marketing experts reveal that typical business airplane customers are extremely knowledgeable and methodical in making their purchase decision. Some will spend months comparing numerous attributes of a variety of products before making a final decision.

In contrast to the more detailed decision models considered in §3.3, Gigerenzer and Todd (1999) advance the concept of human minds dealing with decisions in a complex world as that of "a bounded mind reaching into an adaptive toolbox filled with fast and frugal heuristics." Humans, the authors assert, base decisions on only a limited set of data using decision criteria that appear to allow the decision maker, with limited time, to arrive at a "good" if not "best" decision in the majority of cases, when the quality of the decision outcome may be judged. As an example, Gigerenzer and Todd cite the decision tree heuristic that emergency room doctors use for classifying incoming heart attack victims as either high-risk or low-risk. The heuristic allows doctors to classify patients in only a brief time using at most three data points; minimum systolic blood pressure, patient age, and the presence of sinus tachycardia.

It is assumed for this research that the decision-maker has the luxury of considering choices over extended periods of time, and thus does not need to employ the "fast and frugal heuristics" of Gigerenzer and Todd. The authors do, however, make an important point in addressing an aspect of decision modeling related to Occam's Razor; that no more entities should be presumed to exist than are absolutely necessary. In other words, prefer the simplest model that explains the data and do not add complexity in the decision criteria or decision variables beyond what is necessary. This theory builds on Simon's vision of bounded rationality [Simon (1982)];

that the human mind is limited in its capacity for analyzing knowledge and thus our models of human judgment and decision making should reflect such limitations. It must be recognized that there are a finite number of attributes that can be weighed by the human mind at any one time, and that not all attributes of importance to the business aviation customer are quantifiable or available publicly for inclusion in this model. More will be discussed on this issue when the business aviation model is developed in Chapter 5.

The Relative Value Index work presented in this document is referred to by Monroe (1990) as *value engineering*; "an organized effort to analyze the ability of products or services to perform desired functions, satisfy needs, or provide pleasure or satisfaction in the most profitable manner" [Kaufman and Becker (1981)]. This is in contrast to *value analysis* which "focuses on the process that customers use to determine the relative value to them of alternative product or service options. The focus of value analysis is on the customer and how customers determine the value of the product or service to them" [Monroe (1990)]. The model of customer phased decision heuristics recently developed by Urban, Hulland and Weinberg (April 1993) is an example of value analysis.

3.2 Defining the Term "Value"

There exist many vague definitions of "value" as consisting of exchanges of worth and as being the level of importance of an object to stakeholders. Among the seemingly more quantitative definitions, Johansson, et al. (1993) propose that value be quantified in terms of product quality, Q, service, S, sale price, SP, and lead time, LT:

$$\text{Value} = \frac{Q \cdot S}{SP \cdot LT} \tag{3-1}$$

Park (1998) proposes that value be based on the product's functionality and cost:

$$\text{Value} = \frac{\text{Function}}{\text{Cost}} \tag{3-2}$$

Weinstein and Johnson (1999) define value as the benefits to cost ratio for a product as perceived by consumers:

$$\text{Value} = \frac{\text{Perceived Benefits}}{\text{Perceived Price}} \tag{3-3}$$

Slack (July 1999) defines product value for military applications as

$$\text{Value} = \frac{N \cdot A \cdot f(t)}{C} \qquad \textbf{(3-4)}$$

where N is the need for the product, A is the ability of the product to satisfy the customer need, $f(t)$ is the dependency for the timing of the product or service, and C is the cost of ownership.

Despite the seemingly quantitative nature of these value definitions, all of them involve qualitative parameters such as "quality," "function," "benefit," "need," and levels of satisfaction. A more operational definition is the aim of this work when considering the value of a portfolio of products relative to one another.

In biology, the quality of an organism is measured using a metric called "fitness." In economics, the concept analogous to fitness is "value." In the economics literature the term *value* refers to the level of satisfaction the consumer receives from the product. Economists refer to this as *use value* or, often, *utility* [Nagle and Holden (1995)]. The terms *utility* and *value* are nearly always used interchangeably,* but for the purposes of this research *value* will be used to more closely relate the term to its economic roots.

Operationalizing the concept of consumer value requires an examination of consumer demand theory, which will be discussed in greater detail in Chapter 4. It will be shown that annual demand for a product, D, may be expressed as a linear function of the difference between the product's price, P, and its value, V:

$$D = K(V - P) \qquad \textbf{(3-5)}$$

In the equation, K represents a constant that may be determined from the price elasticities of the competing products.

Economists have developed the concept of *consumer surplus* to aid in determining the gains or losses that individuals experience as a result of price changes. In his 1890 *Principles of Economics*, Alfred Marshall first proposed the concept in which the price at which consumers are willing to forego consumption of a product is treated as a measure of the value of the product to the individual. Products that are priced below this value yield a surplus of benefits to the

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* One exception is de Neufville (1990) who defines value as being a rank order of preferences and utility as existing on a cardinal scale with units that have meaning relative to each other.

consumer. The resulting linear demand model, and the value, *V*, associated with a product, is sketched in Figure 23.

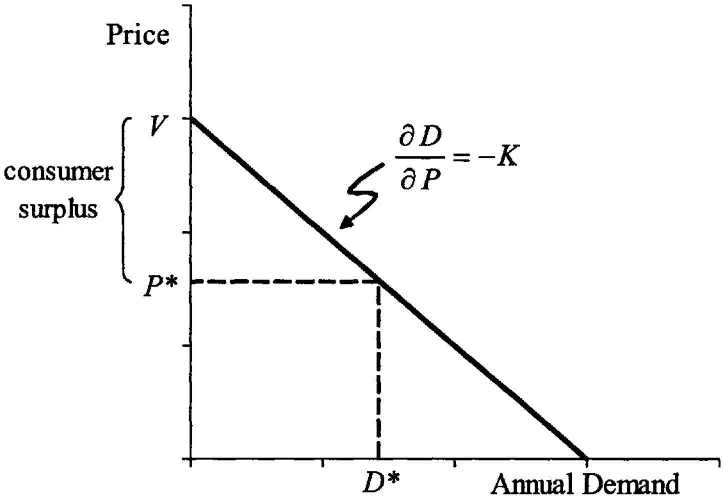
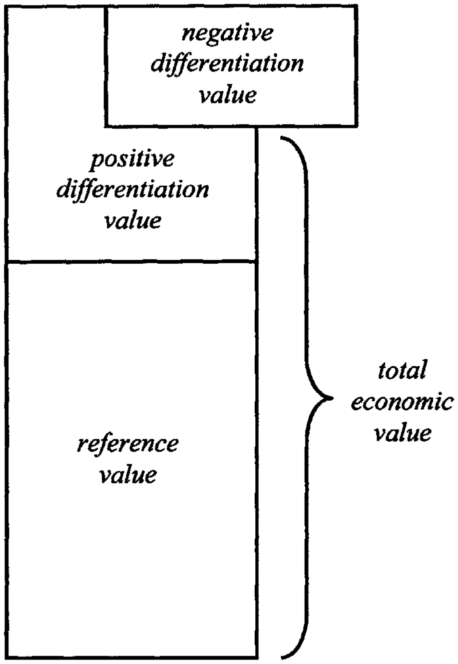


Figure 23: Demand as a Function of Price (linear approximation)

Note that in this model product value is not equivalent to product price. Rockefeller (Spring 1986) contends that "value (in contrast to price) conveys a more stable sense of worth within a broader temporal and conceptual context than price alone." Though prices may fluctuate in the short term, the value of a product to the consumer remains unchanged until the nature of the product itself is altered.

Product price is, in fact, often set by the *total economic value* of the product [Nagle and Holden (1995)]. This is composed of the product's *reference value*, which is the price of the customer's best alternative, and the product's *differentiation value*, which is the value of whatever differentiates the product from the best alternative (both positive and negative). The concept of *total economic value* is illustrated in Figure 24. The *total economic value* is the maximum price that a fully informed consumer who rationally analyzes all purchase decisions would pay for any product. As will be shown in this research, the relative value model developed can be useful in pricing strategy when defining the *total economic value* of a product.



Adapted from Nagel & Holden, 1995.

Figure 24: Total Economic Value

It is worth noting that, once the value of the product is set (via multiple attributes judged to be of importance to the consumer), then the price the market will accept for that product is known based on the total economic value for the product. According to Equation (3-5), this serves to set the forecast demand for the product. Based on a set production rate, the costs associated with producing a product should be known, and a profit margin may then be determined given the price and demand estimates. This approach, a result of the value approach followed in this research, is in contrast to cost-plus pricing where costs are often assumed with little knowledge of potential demand, and prices are set at a margin above cost. Nagle and Holden (1995) explain:

> "Cost-based pricing is product driven. Engineering and manufacturing departments design and make what they consider a 'good' product. In the process, they make investments and incur costs to add features and related services. Finance then totals these costs to determine a 'target' price. Only at this stage does marketing enter the process, charged with the task of demonstrating enough value in the product to justify the price to customers."

If the price proves unjustifiable then discounting and other flexibilities in the markups must be allowed. The value research in this document allows, in part, for this process to be reversed to Nagle and Holden's so-called "value pricing." "For value pricing, the target price is based on an estimate of value, not costs. The target price then drives decisions about what costs to incur, rather than the other way around."

3.3 Existing Value Assessment Methods

In problems of decision-making it is the value (or utility) function that is most often used to describe or predict the preference judgment. In situations where multiple attributes are judged to be of importance, the decision maker is often faced with a problem of trading off the level of one attribute against another (e.g., aircraft speed against range) for the purpose of achieving some objective (e.g., meet a transportation requirement at minimal cost). One way of expressing the formal decision rule utilized in such situations is to combine the various attributes into a scalar index of preferability (or value, or utility) and choose the alternative with the greatest ranking on this index, subject to constraints such as cost.

Numerous multi-attribute preference models have been proposed in the marketing and engineering literature to address various aspects of the decision-making process Eliashberg (January 1980) and Girifalco (1991) review some of the mathematical forms these models assume and the theory underlying the model structures.

In this section three primary categories of value assessment methods found in the marketing and engineering literature are reviewed: marketing science methods, engineering figures of merit (specific to the aerospace industry), and Cook's S-Model permutation of Taguchi's loss function approach to quality assessment. Each method is evaluated as to its strengths and weaknesses, and its potential for extension to the business aircraft industry for product assessment in the multi-disciplinary environment of the fuzzy front-end of product devleopment.

3.3.1 Marketing Science Methods

The marketing science methods discussed here have their origins in the need to solve important industry questions regarding anticipated market share for a new product, how to choose among proposed new products when making funding decisions, ways to improve product appeal to consumers, and the rate at which a manufacturer may expect new products to find acceptance within the market, particularly as a function of advertising. This section is meant only as an overview of the most common types of assessment methods for the purpose of comparing and contrasting them to the value methods developed in this research. An expository discussion of the current state of conjoint analysis and related marketing science methods for use in product development may be found in Hauser and Rao (2004). For more extensive reviews of other product preference models in the marketing literature see: Wilkie and Pessemier (November 1973), Green and Srinivasan (September 1978), Cattin and Wittink (Summer 1982), and Wittink and Cattin (July 1989).

3.3.1.1 Market Share and Product Diffusion

A number of quantitative models exist for assessing the potential market share and rate of diffusion of new products. Massy (1968) offers an early market share model that includes the effects of uncertainty in market parameters and product appeal. In another early model, Urban (February 1969) proposed a market share model as the mathematical product of price, *P*, advertising, *A*, and distribution level, *D*, factors for competing products.

$$X_j = aP_j^{EP} A_j^{EA} D_j^{ED} \tag{3-6}$$

where *X* is the industry sales of product *j* and *a* is a scale constant. Each of the three product attributes is associated with an exponential weighting factor reflecting the elasticity of the attribute, *EP*, *EA* and *ED*. Roberts and Urban (February 1988) expanded on Urban's model by estimating market share also as a function of the product utility to the consumer. Additionally, a logit form of the market share model was developed that also considered uncertainty, on the part of the consumer, of the product's true features.

Product diffusion, or the rate at which a product enters the market, was addressed in part by Roberts (1989) in his model of how likely a product is to enter into a consumer's consideration choice set (evoked set) for full evaluation in the purchase consideration. Fisher and Pry (1971) developed one of the most widespread models for growth that appears to fit a great many cases of product and technological substitution:

$$f = \frac{1}{2}[1 + \tanh a(t - t_0)] \tag{3-7}$$

where *f* is the fraction of market share, t_0 is the time for 50% substitution, and *a* is a shape coefficient for the growth curve. Blackman [(1972) and (1974)] proposes the following substitution model for the rate at which a market develops for a product or technology:

$$\ln\left[\frac{m}{L-m}\right]=-\ln\left(\frac{L}{N_0}-1\right)+\varphi(t-t_1) \qquad \textbf{(3-8)}$$

where *m* is the market share captured at time *t*, *L* is the upper limit of the market share captured in the long run, N_0 is the market share captured when $t = t_1$, and φ is a constant governing the substitution rate. Considerable attention has also been devoted to mathematically modeling product and technology diffusion through the use of Lotka-Volterra equations, first proposed for predator-prey type models. Pistorius and Utterback [(1995), (1996) and (1997)] propose using a system of nonlinear differential equations that describe symbiotic interactions between two technologies or products:

$$\begin{aligned}\frac{dN}{dt}&=a_nN-b_nN^2+c_{nm}NM\\ \frac{dM}{dt}&=a_mM-b_mM^2+c_{mn}NM\end{aligned} \qquad \textbf{(3-9)}$$

where *N*(*t*) and *M*(*t*) represent the "populations" of two competing technologies or products. The *a*, *b* and *c* coefficients govern the rates of growth and interactions for the two competing products. Bhargava (1989) presents a more generalized Lotka-Volterra model for competition. Girifalco (1991), Blackman (1974) and Martino (1983) present several data-based historical examples of product and technology diffusion along with additional proposals for modeling rates of diffusion.

Despite considerable research in the area of product market share and diffusion, little work has been done to model characteristics of the product itself. In other words, the existing models do not directly relate market share or diffusion to attributes inherently possessed by the product. To date, much of the work has focused on exogenous factors such as product advertising budget and price and has not covered the influence of engineering-controlled attributes on value – the focus of this thesis.

3.3.1.2 Product Screening for Product Development

Considerable attention has been focused in the marketing science literature on methods for screening portfolios of proposed new products (or development projects) for funding and development decisions. These methods are commonly referred to as "product screening" or "portfolio management" techniques. The common practical application is to select for further research or development, among numerous proposals, the few projects with the greatest chances of eventual success, with "success" defined in a variety of ways. Financial potential of proposed products is the most common measure for success found in the management literature. Synergy with corporate strategy, competencies, or existing product portfolios is also used as a criterion in evaluating the potential success of new products. Secondary criteria include the differential advantage a product may offer over competitors, and also the potential product lifespan as it may affect the company separate from profit considerations (maintenance, liability, etc.).

For early, management-focused qualitative methods of screening new products, see O'Meara (January-February 1961) and Freimer and Simon (February 1967). An early quantitative screening method is the SPRINTER model of Urban (Spring 1967). The Specification of PRofits with INteraction under Trial and Error Response model was developed by Urban to address the problem of deciding how new products would interact with existing product lines and whether such new products should be developed and introduced. The model combines demand, cost, investment, profit, and uncertainty information regarding the new product to determine, under differing price, advertising and distribution levels, the profits to be anticipated from introduction of the new product. Based on the results, SPRINTER makes a recommendation of product development "go", "no-go" or further research on the product in question. Despite the apparent promise of the method, no further research appears to have been published on the model since Urban's initial studies.

Screening models that evaluate proposed projects based on risk, financial returns, and resource requirements are proposed by Albala (November 1975), Graves, Ringuest, and Case (May-June 2000), and Ghasemzadeh, and Archer (2000). Pessemier (1966) presents an early, and intriguing, documentation of a new product search and evaluation method, including a manual method for conducting Monte Carlo simulations of potential project financial returns. These models range from complex and detailed evaluative criteria in Albala, to a relatively simple financial returns assessment in Graves, et al. All of these models focus on financial aspects of product development and *do not examine the attributes of the particular product.* For overviews of numerous other screening models, Souder and Mandakovic (1986) and Weber, Werners, and Zimmermann (1990) offer reviews and comparisons.

One of the most published screening methods is the NEWPROD model developed by Robert Cooper and his associates.* The genesis of the model is found in Cooper's observation that his research "results suggest that many managers may oversimplify the screening decision by reducing it to a handful of evaluative criteria" [Cooper and de Brentani (1984)]. In contrast, Cooper's NEWPROD is a scoring model that requires input on dozens of evaluative criteria for the purpose of assessing the probability of success of proposed development projects (Table 4). Cooper, et al. claim a better than 80% success rate in forecasting development project failures and successes using the NEWPROD model [Cooper, Edgett, Kleinschmidt, and Elko (2001)]. NEWPROD focuses on the development project and associated attributes such as management support and the technical complexity of the development program, and is not directly linked to attributes of the product. Though perhaps a useful tool for managing large portfolios of R&D projects, NEWPROD is of little use to product designers or marketers in assessing the performance or market appeal of new products.

The common thread among all the product screening methods noted so far is that they focus on attributes exogenous to the product itself, such as management support and investment requirements, to assess the eventual profitability or chance of reaching the market. Green and Krieger (Winter 1985) do make an interesting contribution to product line selection in developing a mathematical model based on product utility functions (as measured by consumers), and using the model to optimize a portfolio of products in terms of composition and size. The research specifically focuses on the promotional benefits of product line composition; for example, the benefits of offering an "optimal" selection of breakfast cereals to meet consumer tastes given limitations on store shelf space. Though the problem formulation and optimization methods behind the model are "black box" the approach does offer intriguing possibilities for product line optimization using the Relative Value Index methodology described in this thesis.

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* The documentation is extensive. See Cooper [1979, August 1981, February 1983, 1985, 1999]; Cooper and de Brentani (1984); Cooper, Edgett, and Kleinschmidt [July-August 1998, 1999]; Cooper and Kleinschmidt [1987, 1988, 1995, July-August 1996]; and Cooper, Edgett, Kleinschmidt, and Elko (2001).

Table 4: Key Factors and Weights for the NEWPROD Screening Model

Factor	Regression Coefficient (weight of factor)	Variables Loading on Factor	Variable Loading
1. Product superiority, quality, and uniqueness	1.744	Highly innovative product, new to market	0.422
		Product had unique features	0.772
		Superior to competing products	0.845
		Product let customer reduce his costs	0.431
		Product did unique task for customer	0.538
		Product higher quality than competitors'	0.745
2. Overall project/company resource compatibility	1.138	Had adequate financial resources for project	0.563
		Had compatible R&D resources	0.405
		Had compatible engineering skills	0.427
		Had necessary marketing research skills	0.790
		Had needed managerial skills	0.798
		Had compatible production resources	0.402
		Had compatible sales force/distribution resources	0.785
		Had adequate advertising/promotional skills	0.698
3. Market need, growth, and size	0.801	Customers had great need for product type	0.521
		Market size (dollar volume) was large	0.673
		High growth market	0.704
4. Economic advantage of product to end user	0.722	Product reduces customers' costs	0.436
		Product is priced lower than competing products	-0.613
5. Newness to the firm (negative)	-0.354	New customers to the firm	0.696
		New product class to firm	0.759
		New types of customer needs	0.742
		Product process new to firm	0.398
		Product technology new to firm	0.413
		New distribution/sales force to firm	0.745
		New type of advertising/promotion to firm	0.732
		New competitors for the firm	0.664
6. Technological resource compatibility	0.342	Had compatible R&D resources for project	0.755
		Had compatible engineering skills	0.712
7. Market competitiveness (negative)	-0.301	Highly competitive market	0.780
		Intense price competition in market	0.793
		Many competitors in market	0.754
		Many new product introductions	0.475
		Changing user needs in market	0.400
8. Product scope	0.225	Market-derived new product idea	0.251
		Not a custom product, i.e., more mass appeal	0.432
		A mass market for product (as opposed to one or a few customers)	-0.627
constant (for model)	0.328		

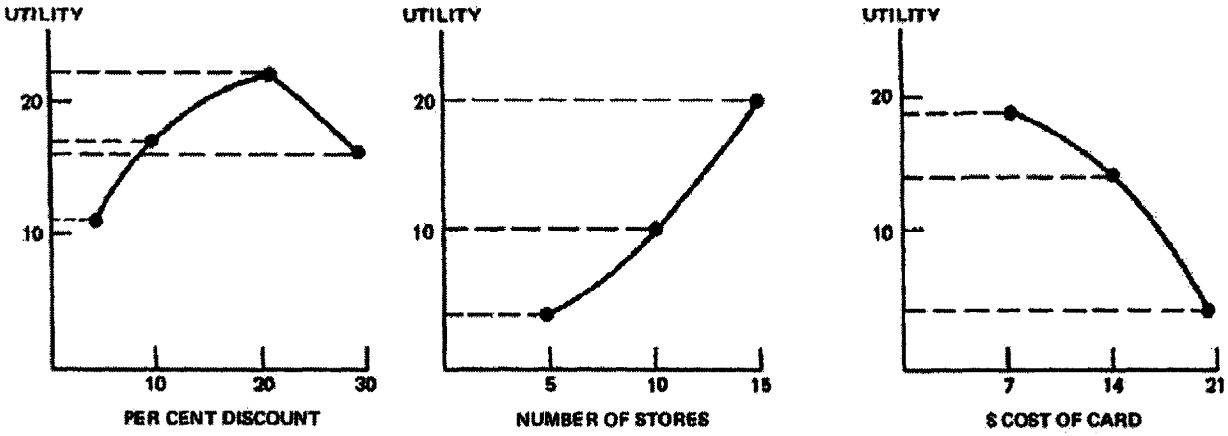
Adapted from Cooper (August 1981) and Cooper (1985)

3.3.1.3 Conjoint Analysis

Conjoint analysis, also known as conjoint measurement, has its earliest development in the theory of multidimensional scaling, in which consumer multidimensional preferences are represented relative to an existing set of products. Early work in psychometrics by Luce and

Tukey (1964) and Krantz, et al. (1971) explored methods by which consumer judgments could be decomposed along a number of different dimensions. In a ground-breaking paper Green and Rao (August 1971) extended this work to the product development problem of identifying and rank ordering the importance of various product attributes to consumers. Since that time a flood of research has explored conjoint methods, addressed some of the shortcomings of the method, and attempted to validate the theory with industry observations.

At its heart, conjoint analysis provides a means to decompose consumer preferences into the part-worth contributions of individual product features. Products are represented as sets of product features, and respondents are asked to rank their preferences, which requires that they make tradeoffs simultaneously across multiple features. Green and Srinivasan (1978) discuss the steps necessary in a conjoint analysis study, including model selection, data collection and data analysis. Green and Rao (August 1971) first applied the method to grocery store discount cards to find the "component utilities (or part-worths) that housewives attribute to various characteristics of discount cards." Attributes studied included the percent discount of the card, the number of participating stores at which the card could be used, and the initial cost of the card. Figure 25 shows the utility curves resulting from this landmark study.



source: Green and Rao, 1971

Figure 25: Conjoint Analysis Utility Curves for Store Discount Cards

A variant of the conjoint analysis stated choice survey is the Direct Value survey method [Donndelinger and Cook 1997, Cook 1997, McConville and Cook 1997]. The Direct Value method differs primarily in providing cardinal, customer values of options and features relative to a baseline, and closely linking those results to price and profit.

Most conjoint analysis studies have focused on physical features of products, such as a carpet cleaner study by Green and Wind (July-August 1975) in which package design, brand name, seal (Good Housekeeping, etc.), guarantee and price features were studied. Some analyses have been published in which more qualitative features were studied, such as a healthcare study by Hauser and Urban (July-August 1977) featuring "personalness," convenience, and quality of care. *CA is most suitable for established products where consumers hold well defined cognitive structures* based on the benefits they experience in using the product [Hauser and Rao (2004)].

Respondent fatigue has long been one of the major weaknesses of conjoint analysis methods and limits the number of product attributes that can be studied, the number of levels at which each attribute may be tested (e.g., the number of stores in the discount card example) as well as the ability to study interdependences among those attributes [Carmone, Green, and Jain (May 1978), Louviere, Hensher and Swait (2000)]. A number of sophisticated methods have been developed to address this shortcoming, including choice-based conjoint analysis in which the task is simplified for the respondent such that they need only choose one "best" profile from a set of many product attribute profiles. Hybrid conjoint analysis, Hierarchical Bayes, and adaptive choice-based conjoint analysis are but a few of numerous additional methods by which researchers may, in theory, obtain more accurate estimates from respondents with fewer questions.* New methods that show promise for assessing the importance of product attributes without fatiguing the customer include "listening in" with virtual advisors and virtual customer techniques [Urban and Hauser (January 2003), Dahan and Hauser (September 2001)]. These new leading-edge studies are currently being assessed in the automotive industry and may find wider application in the near future.

The area of respondent fatigue remains under active research and, based on discussions with marketing managers of major airframe manufacturers and managers of marketing research groups, the methods appear to have had only limited penetration beyond the halls of academe into industry application. The major issues with conjoint analysis in general, and the more sophisticated methods such as choice-based and hybrid conjoint analysis, include the complexity of the data analysis and the resource-intensiveness of the methods, both in terms of time and budget. The requirement in all cases for substantial and detailed preference data at the individual

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* A discussion of such methods is beyond the scope of this paper, but see for example Green (May 1984) and Lenk, DeSarbo, Green, and Young (1996).

consumer level necessitates large survey population bases and investments of time that are relatively significant for the fuzzy front-end product development phase, and almost not applicable to the business aircraft industry with limited corporate customers. Data analysis for the more sophisticated conjoint analysis methods often relies on complex "black box" programming codes that are opaque to all but a few specialists.

Another concern with these methods is the reliability of the results. There are two types of validation for conjoint methods: internal and external. Considerable internal validation has been performed in conjoint studies, meaning that the methods have been tested to see if consumer responses to the surveys are consistent. Indeed, the internal validity of the conjoint analysis methods appears to be quite good [Louviere, Hensher and Swait (2000), Loudon and Della Bitta (1993)]. However, little in the way of external validity has been published to indicate the correlation between consumer stated preferences and revealed preferences. Most sources tend to treat the issue axiomatically; that if good conjoint analysis is performed then the external validity will be good assuming that survey respondents are, in aggregate, truthful. More will be said on revealed preferences versus stated preferences in §3.3.1.5.

3.3.1.4 Random Utility Models

Random utility models (RUM) relate preference data to choice probability models, and have seen extensive use in travel demand forecasting. In the models, the consumer's utility for a product, y, is represented as a combination of part-worths of $x_1, x_2, \ldots, x_n$ product features plus an error term, ε.

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \qquad \textbf{(3-10)}$$

Based on the assumed form of the error term, the model used may be of the probit or logit form. If the error terms are considered multivariate normal random variables then the probit form of consumer choice is used, as shown in Equation (3-11) for binary choice.

$$P_n(i) = \Phi\left(\frac{V_{in} - V_{jn}}{\sigma}\right) \qquad \textbf{(3-11)}$$

In Equation (3-11) $P_n(i)$ is the probability of choosing alternative i over alternative j, V_{in} and V_{jn} represent vectors of the deterministic components in Equation (3-10), σ is the assumed standard deviation of the errors, and Φ(·) denotes the standardized cumulative normal distribution. Unfortuntaely, the probit form has no closed-form solution. If the error terms are considered independent Gumbel extreme value random variables then the more convenient logit form of Equation (3-12) may be used, where μ is a scale parameter often assumed to be unity.

$$P_n(i) = \frac{e^{\mu V_{in}}}{e^{\mu V_{in}} + e^{\mu V_{jn}}} \qquad \textbf{(3-12)}$$

McFadden (1974) first provided the RUM interpretation and estimated utility based on existing product features and the demonstrated choices made by consumers for that product in the market. Such models are also known as "revealed preference" models. Ben-Akiva and Lerman (1985) pioneered the use of the logit form of RUM in concert with revealed preference data in the travel demand industry. In recent years RUM methods have been combined with conjoint analysis methods where study participants choose proposed products that span the feature set space of interest; in other words these models may now be used as "stated preference" models [Louviere, Hensher and Swait (2000)].

RUM methods would appear to present an attractive prospect for use in developing a product value model for the business aviation industry since they employ a compositional approach (a multi-attribute utility function) and can be combined with revealed preference data. Despite recent progress in RUM applications in academia, interviews with industry marketing researchers reveal that RUM methods are not yet seeing widespread use for practical applications. Part of the reason is the complex mathematical forms and theory underlying the probit and logit forms, taking methods out of reach of many non-specialists. When combined with conjoint analysis survey data, RUM analysis also does not compensate for the limitations in attributes and attribute levels that may be studied.

Perhaps the greatest detraction of the RUM method is its lack of inherent connection to economic factors such as product price. If price (or cost) is to be assumed to enter the consumer decision calculus, it must be included in the utility vector V_{in}. Price and utility cannot be considered separately in the RUM choice of Equation (3-12), though choice theory contends that consumers weigh value for cost in making decisions. In other words, consumers maximize utility given constraints on budget, a feature of choice theory stated by Ben-Akiva and Lerman (1985) themselves. RUM methods thus limit the ability to study price and value tradeoffs for products; a feature desireable in a business aviation value method.

3.3.1.5 Preference Data: Revealed versus Stated

The use of revealed or stated preference data in consumer choice modeling each come with advantages as well as disadvantages. Ben-Akiva and Lerman (1985) pioneered the modern use of revealed preference, RP, data as indicating the true state of consumer decision making. Louviere, Hensher and Swait (2000) properly point out, however, that situations may require estimating demand for products with novel attributes or features for which only stated preference, SP, data can be used. The qualitative sketch in Figure 26 shows how RP data can describe only those alternatives that exist; that is, it can only be of aid in determining the shape of the frontier of existing alternatives. When designing products with features that diverge from the frontier of existing alternatives, SP data becomes more useful in estimating the value of the new attributes. On the other hand, the marketing literature commonly cautions that stated preferences may not reflect the true purchasing behavior of consumers when put into practice.*

Relying on RP data can make the modeler vulnerable to explanatory variables that are highly collinear and that also present a set of parameters that may have little variability in the marketplace due to competitive pressures to create “me too” products with similar attributes and features. In the development of the business aviation model in Chapter 5 it will be seen that certain performance parameters, such as fuel consumption per passenger seat mile, show little variation from product to product in the current market place and therefore are difficult to leverage in building a product value model. Louviere, Hensher and Swait (2000) explain why such “clumping” of attribute values occurs:

> “This happens because competition tends to result in similar products with similar marketing activities. Even if some product differentiation exists, a similar tendency to homogenization typically exists in each subclass of products and/or competitors tend to copy successful attribute/features. This state of affairs makes it difficult to estimate the impact of a firm’s marketing activities on its own product and/or on its competitors’ products because each competitor’s independent attributes tend to track to the others’.”

Although a strong debate continues over the merits of each approach, using a combination of both types of data in preference modeling would appear to provide the modeler

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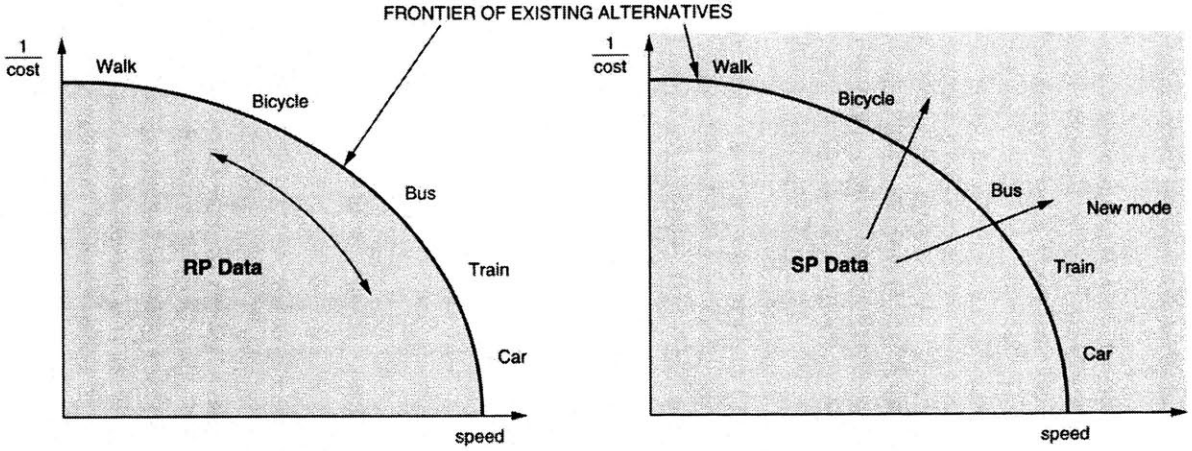
* One prominent marketing researcher commented to this author “Everyone says they want less sugar in their (breakfast) cereal, but what do they buy? They keep buying cereals loaded with sugar.”

with the strongest foundation for building a choice model. Such pooling or combining RP and SP data is commonly referred to as "data enrichment."



source: Louviere, Hensher and Swait (2000)

Figure 26: Roles of Revealed and Stated Preference Data

3.3.2 Aviation Industry Figures of Merit

Design engineers use preliminary techniques such as those in Raymer (1999), Roskam (1990), and Stinton (1998) to assess in detail the technical performance of proposed airplane designs. In the early fuzzy front-end phase of PD both engineers and managers require a simplified yet meaningful metric for more rapidly evaluating designs that are not yet well enough detailed in their definition for more advanced analysis methods. This has resulted in a number of less resource intensive and simplified productivity or value metrics being developed throughout the aviation industry. Several figures of merit used in the aviation industry are reviewed in this section. It is unlikely that these few discussed here are all-inclusive of what managers, designers and marketing specialists use, but they are believed to be wholly inclusive of those that have been publicly documented in some form and available to the author for study.

3.3.2.1 Productivity Indices

McMasters and Cummings (January-February 2002) combine factors of cruise speed, useful load and maximum takeoff weight to estimate the efficiency of commercial transport aircraft in the productivity index they cite in one of their assessments of the progress of the aviation industry. Though Boeing employees, the figure of merit is not necessarily attributable to Boeing nor to the authors themselves, so it will be referred to here as PI_1:

$$PI_1 = \text{Cruise Speed} \cdot \frac{\text{Useful Load}}{\text{Maximum Takeoff Weight}} \qquad \textbf{(3-13)}$$

Unfortunately this measure of transport capacity neglects attributes of importance to the business aviation community such as airplane range, runway field length, and the comfort of passengers. And, though it may prove useful for studying the advancement of transport aircraft through history, Figure 27 clearly shows that the productivity index cannot demonstrate any consistent changes in the business aviation industry. In this figure the productivity indices for the major business aircraft included in the research database (see Chapter 2) are graphed as a function of the year each aircraft was first shipped. This figure indicates no advances in productivity/value over the last 40 years of the business aircraft industry – a result that is at variance with reality.

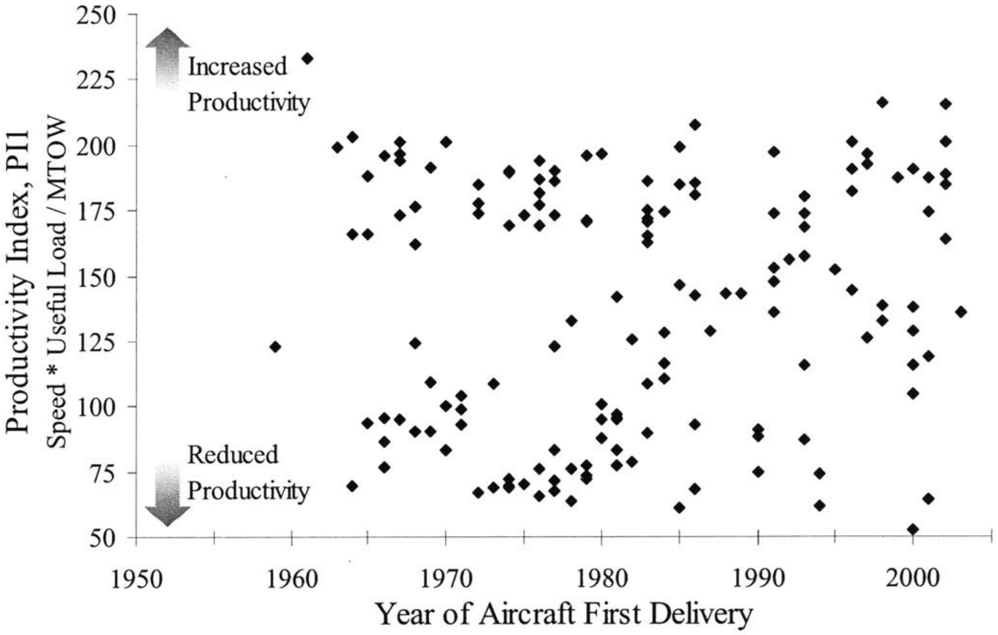


Figure 27: Historical Productivity Index, PI_1 for Business Aircraft

An interesting feature of the PI_1 figure of merit is that it does tend to show increases in the level of productivity with increasing size and price of business aircraft, as shown in Figure 28. This is a trend that will be desirable in the figure of merit sought for this research as it will be shown in Chapter 4 that product price and the figure of merit should both increase in concert.

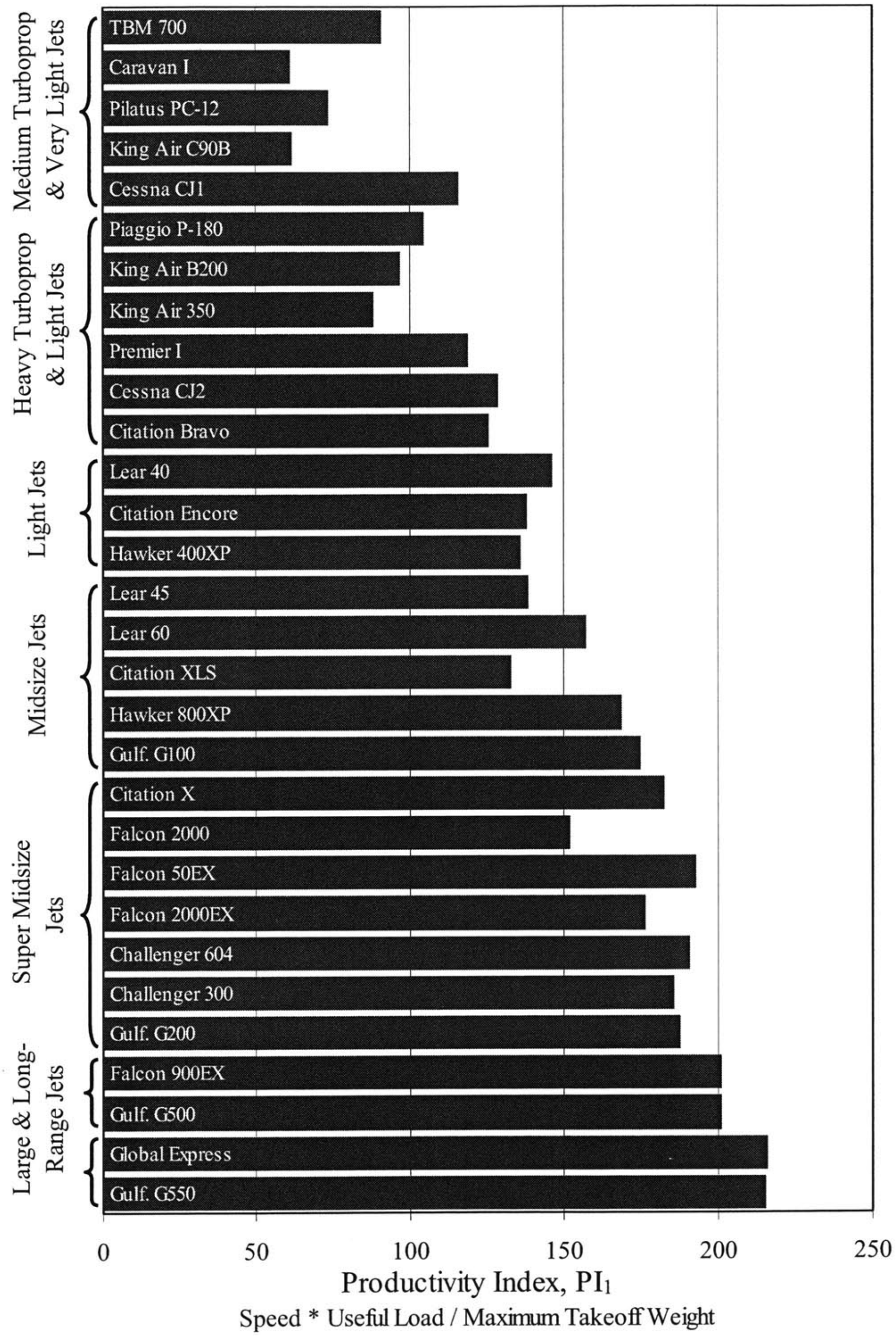


Figure 28: Productivity Index, PI_1 for 2004 Business Aircraft Market

Mead, Coppi and Strakosch (June 1980) propose another measure of productivity specifically for jet-driven business aircraft that also includes the airplane purchase price:

$$PI_2 = \frac{\text{Purchase Price}}{\text{Passengers} \cdot \text{Range} \cdot \text{Cruise Speed}} \qquad \textbf{(3-14)}$$

Conventional economic theory, however, indicates that productivity (or value) should be weighed against price rather being a function of price [Nicholson (1995)], and one should also note that the form of this index counter-intuitively indicates a lower value of PI_2 for more highly productive products.

The productivity index for historical business aircraft indicates an attractive trend as shown in Figure 29. However, this trend indicates a continual decline in average productivity over time (note again that lower PI_2 indicates increased productivity), and the trend is almost solely due to increases in product prices over time.

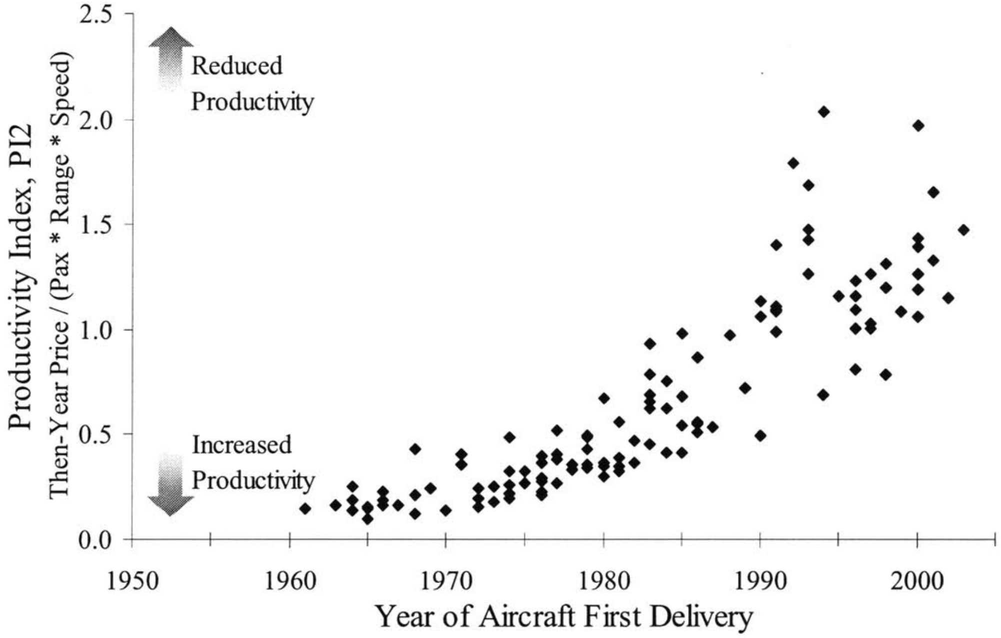


Figure 29: Historical Productivity Index, PI_2 for Business Aircraft (Then-Year Price)

If the aircraft list prices are adjusted to year 2004 prices using the Consumer Price Index (see Appendix D for details) then, once again, there is little demonstration of advancement over time in the productivity of business aircraft (Figure 30).

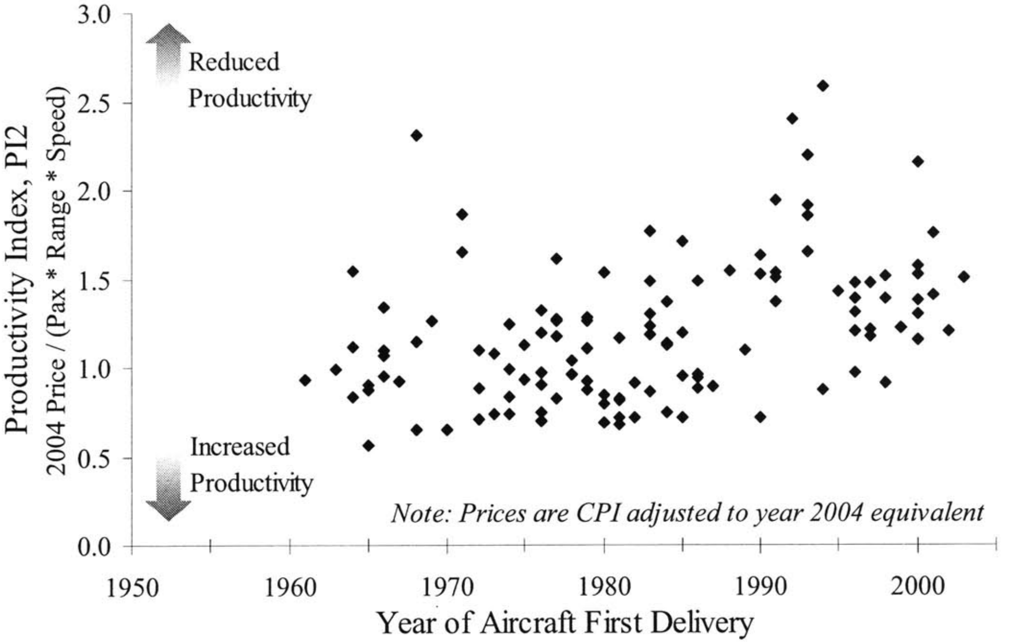


Figure 30: Historical Productivity Index, PI_2 for Business Aircraft (2001 Adjusted Price)

There is also little correlation between the PI_2 figure of merit and business aircraft characteristics such as size and price as indicated by Figure 31.

3.3.2.2 Gulfstream Ownership Experience Index

An interesting recent development in business aircraft figures of merit is the Gulfstream Aerospace Ownership Experience Index (OEI) as first noted by Padfield (May 2003). This proprietary method rank orders same-segment business aircraft based on multiple attributes that range widely, from technical performance such as speed and range, to customer support levels characterized by the number of dealer service centers, to the levels of advanced technology with which the aircraft is equipped such as cockpit avionics and cabin entertainment systems.

The multi-attribute utility function used in the OEI calculation is additive, with each attribute weighted according to importance, and then with the attributes grouped into four major categories that are likewise weighted according to importance: traditional value, technology, service and support, and cost of ownership. Though details of the algorithms involved in the OEI calculation are proprietary, the utility of each attribute is based on a simple linear utility function that ranges from 0 to 1 with the attribute levels that represent the utilities of 0 and 1 being set by Gulfstream product experts.

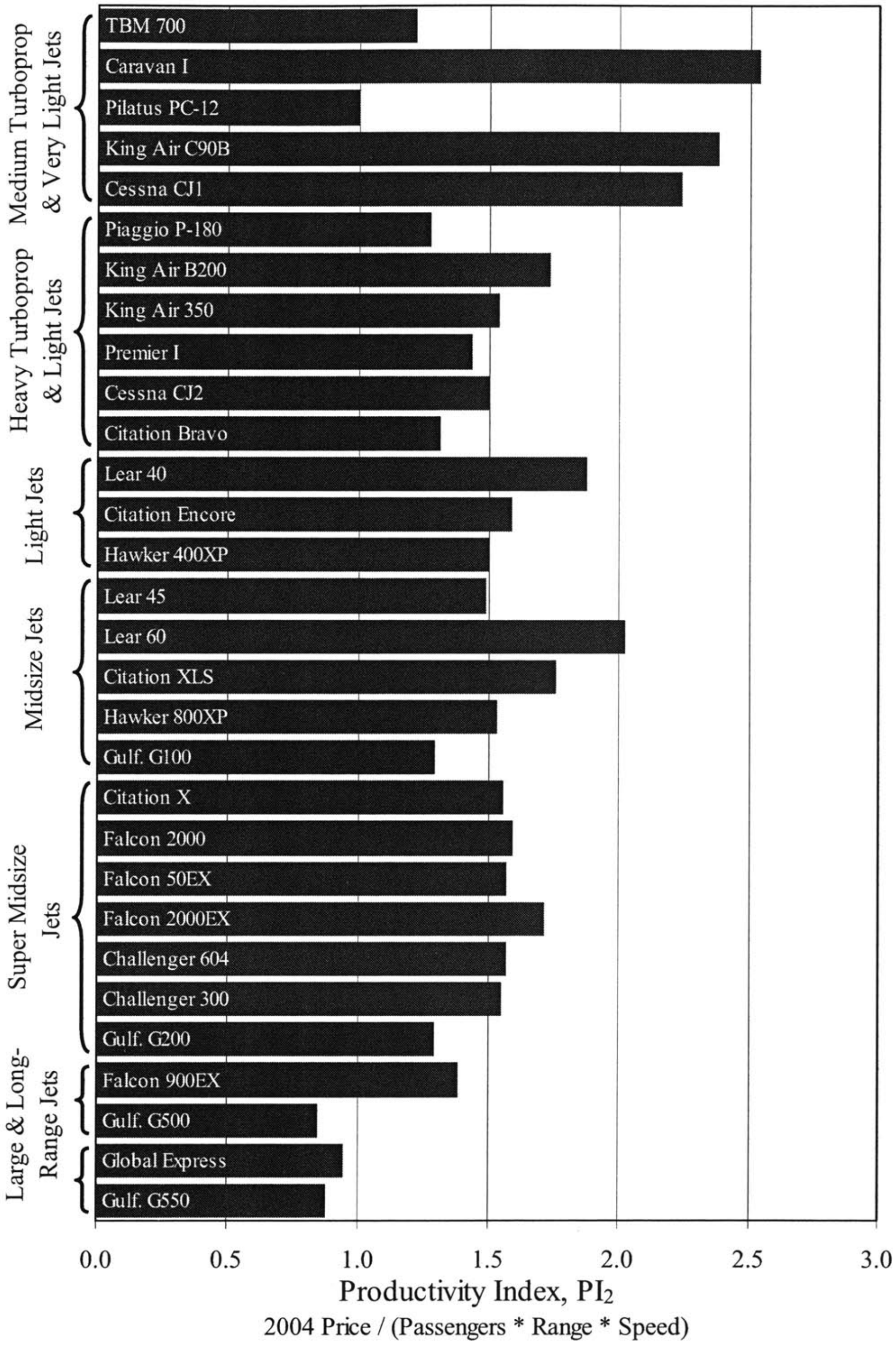


Figure 31: Productivity Index, PI_2 for 2004 Business Aircraft Market

According to Gulfstream managers interviewed for this research, the resulting OEI utilities, scaled to take on values from 0 to 100, are currently used by the company solely for marketing and sales purposes. The OEI method was first developed in the late 1990s by the marketing and sales groups within Gulfstream, without input from engineering groups. The OEI ratings have not been calibrated with actual market sales experience and are not used for any engineering design activities. There is some reason for concern, then, that highly subjective utility ratings have been used in the OEI to arrive at a deceptively quantitative rating that may not have a strong relationship to actual consumer value or market performance of the product.

3.3.2.3 Traditional Value Index (TVI)

In the business airplane industry the most common figure of merit is the Traditional Value Index (TVI), a mathematical model first publicly documented by Norris (January 1999, February 1999) but widely used for decades:

$$\mathrm{TVI} = \frac{\text{Range} \cdot \text{Speed} \cdot \text{Cabin Volume}}{\text{Takeoff Field Length}} \tag{3-15}$$

A variant of the TVI includes the aircraft list price as well:

$$\mathrm{TVI} = \frac{\text{Range} \cdot \text{Speed} \cdot \text{Cabin Volume}}{\text{Takeoff Field Length} \cdot \text{Price}} \tag{3-16}$$

The “value” of a proposed or existing business airplane in terms of technical utility and consumer appeal may ostensibly be assessed using the TVI approach. The appeal of the TVI is obvious; the mathematics are straightforward and the data required is minimal and readily accessible for existing business airplanes in publications such as *Business & Commercial Aviation*. The weaknesses of the TVI include the inability to weight the importance of the attributes relative to one another, and the high correlation of the attributes used in the model, making redundant much of the information provided by the model’s parameters (e.g., range and cabin volume, $r = 0.94$; field length and speed, $r = 0.84$; based on business airplane data in *Business & Commercial Aviation* for the 2004 market).

The fundamental value/price trend reflected in the TVI results, shown in Figure 32 for the 2004 business airplane market, is also problematic. The figure indicates a strong exponential relationship between product value and price, implying that products of increasing value can be delivered with diminishing price increases (at the extreme, infinite value may be delivered at some asymptotic price; approximately $50 million in this case). This observation holds true even if entire upper-level segments were to be neglected. The theoretical ability of a manufacturer to profit by pursuing improvements in technical performance is strictly limited by the TVI approach. Price restrictions such as this, analogous to a "sound barrier" for aircraft speed, were popularly believed in the late 1950s when the first million-dollar business aircraft were introduced. Today the million-dollar business aircraft barrier has been shattered by 45+ million dollar long-range luxury airplanes and may be pushed beyond the $100 million mark by several proposed supersonic business jets.

"B/CA Equipped Price" in Figure 32 refers to the *Business & Commercial Aviation* equipped price; see Chapter 2 for details on this price metric.

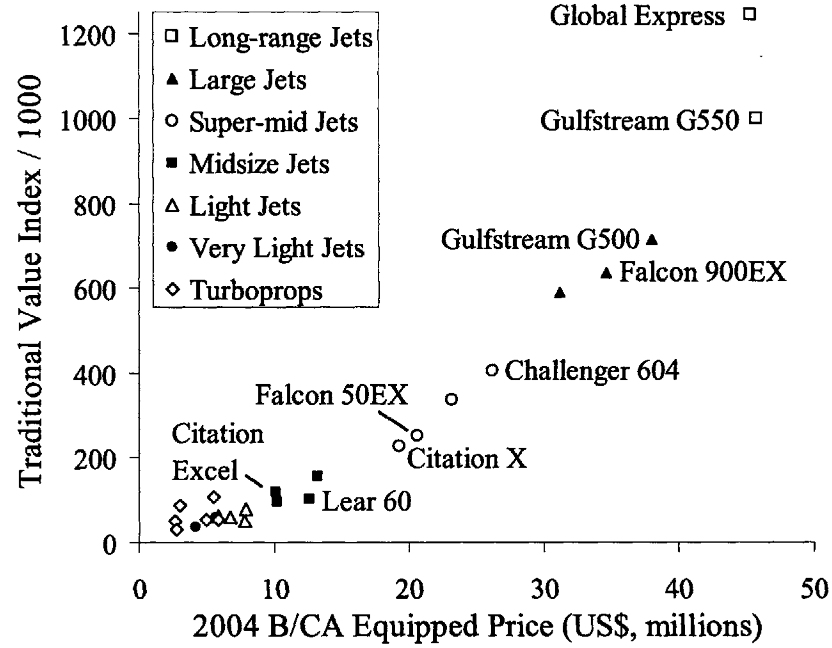


Figure 32: Traditional Value Index for the 2004 Business Airplane Market

In contrast, an attractive feature of the model is an historical trend of higher value business aircraft over time as new product segments are introduced and improvements in technology are leveraged in product lines (Figure 33).

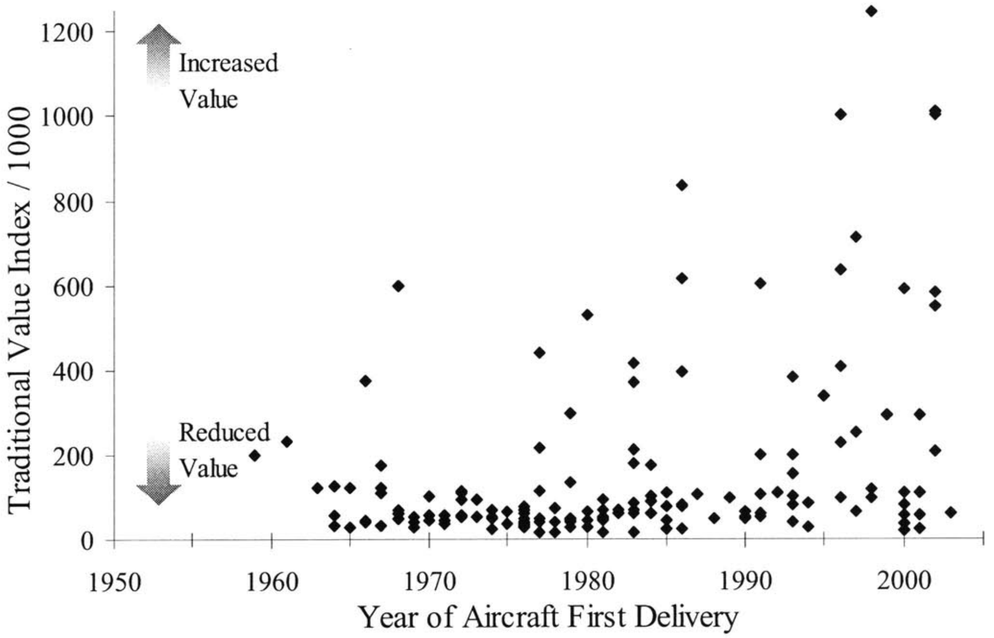


Figure 33: Historical Traditional Value Index for Business Aircraft

Despite the trend in Figure 33, another concern is that the TVI model does not accurately represent some important historical events, calling into question its suitability for forecasting industry developments. One such example is the ascendance in the late 1960s of the first generation of jet-driven business airplanes (for example, the Lockheed JetStar and the North American Sabreliner) over established heavy turboprop models. Figure 34 indicates that, had contemporary designers used the TVI model to assess the potential of business jet designs, those designers would have concluded that higher-valued, similarly-priced heavy turboprops adapted from airline use, such as the Dart Herald and Super Convair, had equivalent value and much lower price than the Sabreliner and Jetstar and thus should continue to dominate the business airplane market. Students of history know, however, that within five years of their introduction in 1965 the first generation of business jets had completely driven their heavy turboprop competitors from the business airplane market.[*]

To make a direct comparison possible, all prices in Figure 34 have been adjusted to a 1970 price level; thus some prices in the figure have been adjusted using the Consumer Price Index, CPI.

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[*] See for evidence, *Business & Commercial Aviation* (various years), Pattillo (1998).

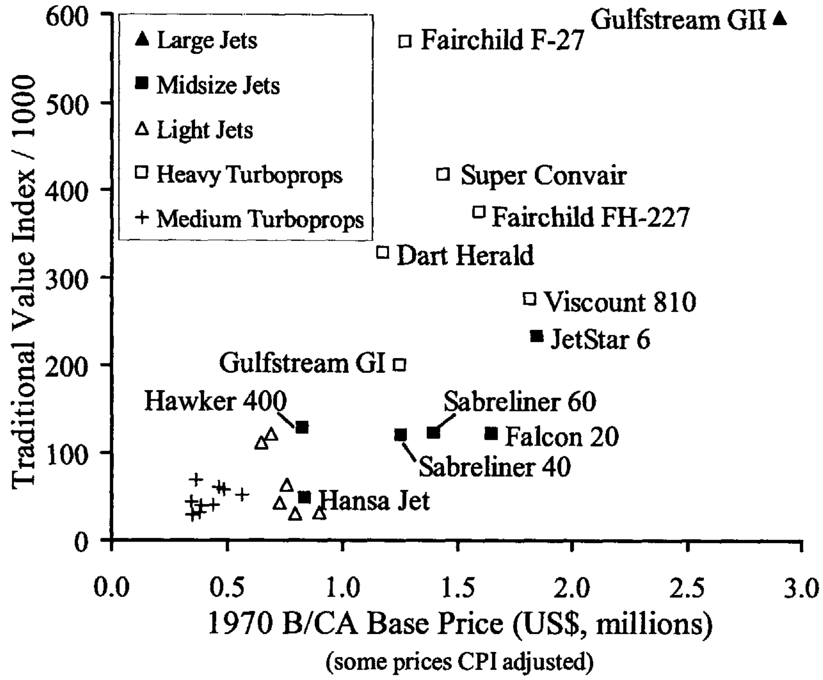

Figure 34: Traditional Value Index for the Business Airplane Market, 1965-1970

3.3.3 Cook's S-Model

Harry Cook, a professor at the University of Illinois at Urbana-Champaign, has spent more than 10 years researching in the area of product quality and value assessment. He and his colleagues have published over a dozen papers and two major texts on the subject. His research has culminated in two major approaches to product evaluation: the Direct Value, DV, method and the S-Model for product valuation. The methodology proposed in this thesis builds upon this foundation.

The DV method was designed as an alternative to conjoint analysis surveys that, as previously observed, suffer from high levels of complexity and problems of respondent fatigue. The DV survey provides "cardinal, customer values of options and features relative to a baseline. The value of a proposed option or feature can be compared to its variable cost for assessing its financial merit, price, and demand" [Cook, Qualls and Wu (2005)]. While addressing some problems associated with conjoint analysis, the DV method still utilizes complex logit and probit models for data analysis and relies on consumer stated preferences, with the inherent limitations noted in §3.3.1.5.

Cook's S-Model focuses on a compositional approach to product assessment and is applied in his research to automobiles. This research does not mark the first foray into multi-attribute automobile evaluation [Agarwal and Ratchford (1980)], but it does show considerably greather flexibility and a solid basis in economic and consumer behavioral theory (consistent with the principles of §3.2), while maintaining simplicity of form and function.

3.3.3.1 Compositional vs Decompositional Approach

Before continuing, it is appropriate to briefly highlight the differences between a compositional and decompositional approach to product value. As Wilkie and Pessemier (November 1973) have observed, preference models may draw upon either a compositional or decompositional approach. In the first approach the part-worths or utilities of each attribute are assessed separately and then combined into a multi-attribute utility function [Bettman, Capon, and Lutz (March 1975), Shocker and Srinivasan (May 1979), Roberts and Urban (February 1988)]. This is the approach taken by Cook in the development of his S-Model, and will be utilized in this study to develop the structure of the Relative Value Index method.

In the second approach the objective is to decompose a set of overall responses to "total" product profile descriptions so that the utility of each product attribute can be inferred from the respondent's overall evaluation of the products [Green and Rao (August 1971), Green and Wind (1973), McFadden (1974)]. This is the approach taken for random utility models in matching market share estimates to actual consumer choices, and will also be the method utilized in this study for determining attribute weighting factors based on empirical market data.

3.3.3.2 Features of the Model

Cook's "Simple Market Model," or S-Model, was first published in a two-part paper series in 1991 focusing on product quality and cost, and their impacts on return on investment for manufacturing enterprises [Cook and DeVor (1991), Cook (1991)]. Since then, the S-Model has been extended to unify "Taguchi methods, value engineering, and QFD into an integrated tool-set having a common formalism for guiding the planning, design, and development of new products" [Cook and Wu (2001)].

The mechanics of the S-Model are perhaps best summarized by Cook (1996) and (1997). The model estimates product value through a compositional approach, where total product value is based on part-worth contributions of value from numerous attributes such as automobile turning radius, interior noise, and interior passenger space. Each attribute value is assessed relative to a baseline attribute level at which value is unity, thus avoiding problems associated with combining or comparing different units of measure. Unlike other multi-attribute utility methods that rely on utility curves developed from extensive user surveys, Cook's value curves are constructed based on simple estimates of maximum and minimum attribute levels of practical use to consumers combined with an estimate of the importance of each attribute relative to the other attributes. The method is explored in greater detail in Chapter 4.

Kolli and Cook (1994) use the S-Model to demonstrate the value of automobile component redesigns, and Cook and Kolli (1994) estimate pricing strategies and profits resulting from the component redesigns. The method is used for component value assessment of automobile interior room, acceleration, fuel economy, and interior noise in Simek and Cook (1996), McConville and Cook (1996), and Pozar and Cook (1998). The value assessments in these two studies are compared to data from surveys of consumer satisfaction for a favorable evaluation of the reliability of the S-Model estimtes. Donndelinger and Cook (1997) aggressively apply the S-Model to whole-product valuation using a total of 41 automobile attributes to directly assess the value of family sedans in the 1993 car market. Evaluations of some of the tools used in this 1997 study are also documented in Monroe and Cook (1997) and McConville and Cook (1997). The relationship of value and market segmentation is also studied by Monroe, Silver and Cook (1997).

Early in his value research Cook closely linked the S-Model to product quality and specifically to the Quality Function Deployment, QFD, method [Cook (1992), Kolli and Cook (1994)]. Research in this area continues as Cook extends the S-Model to link QFD to market share and profit estimation [Cook (2000)].

The S-Model method seeks to balance simplicity of the model's structure and use with the rigor of a method firmly rooted in theories of product quality, economics, and consumer behavior. Although the S-Model has been entirely developed and evaluated under the supervision of one principal researcher at one institution, the underlying structure of the method appears flexible enough to be expanded in the scope of attributes and products considered. At the same time, the method shows promise for remaining simple enough to be easily explained to engineers, marketing specialists, and managers alike, and also straightforwardly implemented on conventional PC platforms using common spreadsheet software. The method also appears to be well-suited for use under conditions when product data is sparse and uncertain; typically the case in the early fuzzy front-end of product development.

3.3.4 Utility Theory

The mathematical basis for the utility-based theory of consumer demand was first advanced by Norwegian economist Ragnar Frisch in 1926, setting in motion decades of efforts in the field of empirically measuring utility.[*] In 1944 von Neumann and Morgenstern first introduced the axiomatization of utility theory in what is now considered one of the seminal works in the field of utility and game theory. Since that time, consumer utility theory has undergone tremendous development in research, and may be found in hundreds of applications, from studies of store discount coupon utility [Green and Rao (1971)] to automobile materials selection [Field and de Neufville (June 1988)]. Utility theory composes the underlying framework of many of the marketing science methods presented in §3.3.1, including the particularly well-developed conjoint analysis technique, and represents a key component of others, such as random utility models (§3.3.1.4). It also represents the foundation for the base framework of Cook's S-Model approach to product value assessment presented in §3.3.3. As such, it is appropriate to consider the fundamental axioms upon which utility theory is based.

3.3.4.1 Axioms of Utility

The existence of a unique utility function is predicated on the following six axioms:[†]

1. Complete Preorder: For every possible pair of consequences, an individual will either prefer one to the other or will find them to be equally preferable. This is equivalent to the assumption that people can make choices and express their preferences.
2. Transitivity: For any three possible sets of consequences, X_1, X_2 and X_3, if $X_1 \succ X_2$ and $X_2 \succ X_3$, then the preference is transitive such that $X_1 \succ X_3$.
3. Monotonicity: Individuals always prefer more of a good thing to less of a good thing. Conversely, individuals always prefer less of a bad thing to more of a bad thing. Though this assumption is reasonable in many cases, it will be shown in §4.1.2.1 that special

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[*] This brief history follows from Stigler (1950) and Katzner (1970)
[†] Following from de Neufville (1990)

considerations must be made in using Cook's value assessment method because of this axiom.

4. Existence of Probabilities: In uncertain situations, the probability of possible consequences exists and can be quantified.
5. Monotonicity of Probabilities: Individuals prefer a higher probability of a benefit than a lesser probability.
6. Substitution: A person's preferences are linear in probability. In essence, equals can be substituted for one another.

As a consequence of these axioms, utility may be treated as an analytical function measureable on a cardinal scale where units of utility are meaningful relative to one another, and the zero value of utility has meaning.

While the development of Cook's Relative Value Index in Chapter 4, these axioms will be revisted to ensure that the value approach respects the requirements of utility theory.

3.3.4.2 Stability of Utility Functions

It has been noted that weighted index utility functions that are normalized are subject to instability in the resulting preference rankings from the functions. Field and de Neufville (1988) demonstrate the subtleties of how changes in the normalizing parameters of weighted index functions can dramatically alter the preference rankings, rendering the rankings meaningless for any serious decision-maker. The value assessment functions pursued in this study utilize a normalization technique subtly distinct from that considered by Field and de Neufville, but will nevertheless require rigorous testing to ensure freedom from the stability problems that characterize other methods.

3.4 Summary: The Need for a New Value Assessment Method

Theories and models abound for how humans make the hundreds of decisions necessary in a typical day. The types of decisions of interest to this research are assumed to be based on careful, information-based choices over extended periods of time. Choices based on so-called "fast and frugal heuristics" are not considered in this research.

Consumers are assumed to assess a "value" in making their choices, against which they weigh the cost, or price, of making the choice. "Value" is a term that is often only loosely defined in vague terms of benefit/cost ratios, and thus is problematic to operationalize in practical applications. In this research, value assumes a well-defined link to economics and is based on a linearized demand function that varies with price.

A number of methods exist to aid in assessing the value of products to consumers. Marketing science methods focus on using value assessment to evaluate potential market share, product diffusion, and for screening products to identify those most likely to be "successes" in the market. The existing methods documented in the research literature focus on attributes exogenous to the product itself, such as advertising budget, management support, and degree of development project funding. The value of the product tends to be more closely linked to attributes inherent in the product itself in the marketing survey method known as "conjoint analysis." In this process, consumers are asked to identify product features of importance to them and to rate how they would trade off such features. An offshoot of conjoint analysis, random utility models, bases such ratings not on the subjective input of consumers, but on the demonstrated market performance of multiple products. Unfortunately, conjoint analysis techniques can be complex and time-consuming, requiring the supervision of experts in the methods and the use of complex mathematical codes for analysis. Marketing science methods, though complementary to other value assessment methods, are not well-suited to the rapid developmental studies required in the early phases of product development.

Figures of merit are less computationally intensive than some marketing science methods, but also tend to be over-simplified and not firmly rooted in choice theory or economics. At least four figures of merit have been identified as being used in the aviation industry. The productivity indices presented in this chapter do not cope well with historical or current business aviation industry products and market events. The Ownership Experience Index developed by Gulfstream Aerospace is proprietary and not yet linked to empirical market data, but shows the most promise for continued future development. The most widely used figure of merit in the business aviation industry, the Traditional Value Index, also does not cope well with historical market events, has serious problems with highly correlated parameters, and demonstrably indicates exponential price/value trends contrary to basic marketing theory.

A new value assessment method is required for the business aviation industry that is based in consumer choice theory and economics, vetted with empirical market data, and that meets John Little's criteria for decision models: simple to use, robust, easy to control, adaptive, complete on important issues, and easy to communicate with (see Chapter 7). Harry Cook's decades-long endeavor to develop a model that meets these criteria appears to present the best foundation, among those evaluated in this chapter, for further exploration of value assessment techniques and for extension in scope to the business aviation industry. The next chapter will focus on the theoretical underpinnings of Cook's S-Model and will extend elements of that method for this research. The method will be uniquely applied to the aerospace industry in Chapter 5 and further extended to apply to product competition over time in Chapter 6.

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4 DEVELOPMENT OF THE RELATIVE VALUE INDEX

The previous chapter highlighted the importance of consumer choice modeling and introduced a number of existing value assessment techniques. These existing techniques demonstrate that, from a measurement standpoint, the parameters for assessment models can be obtained either from a compositional or decompositional approach. In the first approach the part-worths or utilities of each attribute are assessed separately and then combined into a single figure of merit (e.g., the Traditional Value Index).[*] In the second approach the objective is to decompose a set of overall responses to products (or stimuli) so that the value (or utility, quality, etc.) of each product attribute can be inferred from the respondent's overall evaluation of the products (e.g., the conjoint analysis approach).[†]

As mentioned in the introduction to this research, we are interested in formulating a product assessment method that is *descriptive*, in the sense that it helps us understand how consumers make decisions, that is *generalizable*, in the sense that it can be formulated in terms not specific to particular circumstances, and that is *operational*, in the sense that the model is based on parameters that may be measured and that results may be computed from the model and analyzed. To fulfill these goals, this research will utilize both the compositional (§4.2) and decompositional (§4.3) approaches to product assessment in developing a new figure of merit more suitable to the early product development phase than those currently in use.

Cook's extension of Taguchi's "loss function" approach to quality control is referred to in this study, for clarity, as the Relative Value Index (RVI). Folowing Cook and Devor (1991), the original "quality loss" and extended "value loss" function methods are developed in detail in the first section of this chapter. The single attribute value function of the first section is then extended to a multi-attribute value function in the second section, with additional discussion of adding value options and the merits of absolute versus relative value. In the third section a methodology for estimating weighting factors in the RVI model is developed based on revealed consumer preferences. Limitations of this new methodology are noted and alternative approaches are briefly discussed.

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[*] See for example: Bettman, Capon, and Lutz (March 1975); Shocker and Srinivasan (May 1979); Roberts and Urban (February 1988).

[†] See for example: Green and Rao (August 1971), Green and Wind (1973), McFadden (1974).

4.1 The Loss Function Approach

In 1943 Taiichi Ohno joined the wartime Japanese firm Toyoda (later Toyota Motor Corporation) which was then heavily invested in the production of military trucks for the war effort.* Ohno quickly became an expert in the automobile manufacturing process and played a key role in post-war Toyota's pioneering of what is now referred to as "lean manufacturing" or the "Toyota Production System."† Lean manufacturing focuses on producing high quality products using the least resources possible and has seen widespread application in the worldwide automobile industry, and more recently the North American aerospace industry.‡ The more general approaches of reducing inefficiency enterprise-wide, known as "lean methods," are now being applied in non-manufacturing sectors such as engineering design and even the healthcare industry [Greenwood, Bradford, and Greene (November 2002)].

Dr. Genichi Taguchi has pioneered many of the approaches, both qualitative and quantitative, for implementing the lean methods first developed by Taiichi Ohno at Toyota. Known generically as "Taguchi methods," these include designing experiments for most efficiently determining the effects of changing experimental parameters ("design of experiments," or DOE) as well as methods for statistically analyzing data for quality improvement [Taguchi, Yokoyama, and Wu (1993)]. Taguchi's methods, in their original presentation, focus on manufacturing quality control but are now being applied to a wide range of problems outside the manufacturing sector such as multidisciplinary optimization and, in Cook's research as well as this thesis, to product value modeling.

One of the concepts developed by Taguchi involves identifying the loss of quality in a part or product as the result of a deviation from a nominal or ideal specification. Taguchi refers to this method as the "loss function," and it is now commonly referred to in the quality literature as the "Taguchi loss function."

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* An excellent history of Toyota's development and Ohno's early work can be found in Togo and Wartman (1993).

† The seminal documentation of the Toyota Production System is to be found in Womack, Jones, and Roos (1990). An excellent prologue for setting the scene is Dertouzos, Lester, and Solow (1989).

‡ One of the best encapsulations of the aerospace industry's use of lean methods may be found in Murman, et al (2002).

4.1.1 Taguchi's Loss of Quality

Traditional manufacturing practices strive to produce products within a specification ±Δ of a nominal attribute level, g_0. A loss of quality, $L(g)$, is assumed only when products fall outside the specification and is typically quantified in terms of the repair cost A (Figure 35). As long as the attribute g is within $g_0 \pm \Delta$ then the quality level is treated as if it were at g_0. For example, if a television power circuit transforms 220V AC into 115±20V DC, then traditionally the manufacturer does not consider a loss on the production line unless the power circuit functions below 95V or above 135V during quality assurance tests. If the power circuit falls outside the specification then the television must be repaired or scrapped at a cost of A (note that this is the *cost* to repair or scrap the television, not the residual or scrap *value* of the television).

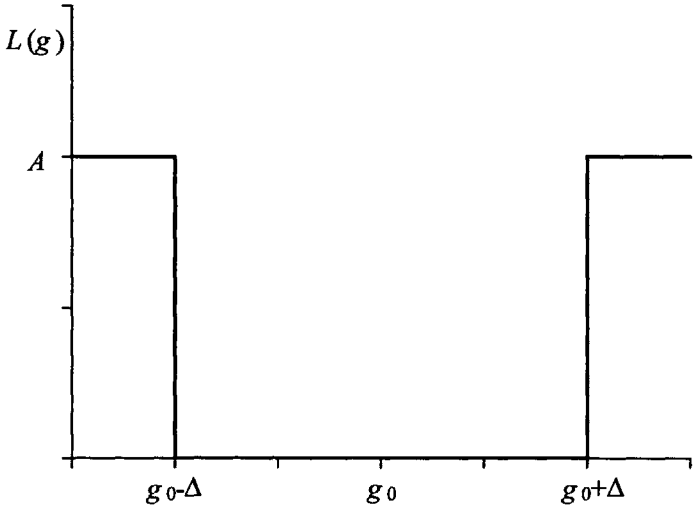

Figure 35: Loss Out of Specification

Taguchi repudiates the mindset that loss only occurs when a product falls outside the specification limits ±Δ. Instead, the importance of producing products as close to the nominal specification as possible is emphasized in the *loss function* by representing a continual loss of quality due to any deviation from g_0 (Figure 36).

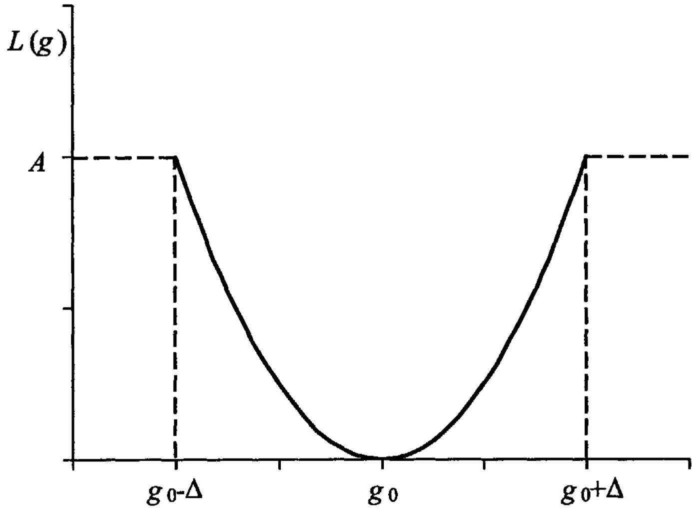

Figure 36: Loss In and Out of Specification

Note that in this approach Taguchi is now considering not solely the loss to the manufacturer but also the loss to society of both in and out-of-specification products. In the case of our television power converter, although the component may function within specified tolerances, the picture on the television may be darker or brighter than ideal, thus resulting in a loss to the consumer.

4.1.1.1 Mathematically Representing Loss

The loss caused by deviations from g_0 is given by the Taylor series expansion of $L(g)$ about g_0:

$$L(g) = L(g_0) + \frac{L'(g_0)}{1!}(g - g_0) + \frac{L''(g_0)}{2!}(g - g_0)^2 + \ldots \tag{4-1}$$

Without loss of generality we may let $L(g_0) = 0$. Since $L(g)$ is a minimum at g_0 then $L'(g_0) = 0$ and the loss function is approximated by the resulting quadratic:

$$L(g) = \frac{L''(g_0)}{2}(g - g_0)^2 \tag{4-2}$$

Assuming that the loss is equal to A when $g = g_0 \pm \Delta$ then

$$L(g) = \frac{A}{\Delta^2}(g - g_0)^2 \tag{4-3}$$

The results of Equation (4-3) are represented by the sketch in Figure 36. The total quality of the product may then be represented based on the loss of quality from an ideal quality level, Q_I:

$$Q(g) = Q_I - \frac{A}{\Delta^2}(g - g_0)^2 \tag{4-4}$$

The total quality based on the level of attribute g is shown in Figure 37. Note that in this case Q_I has been selected such that some residual non-zero quality exists even at $g = g_0 \pm \Delta$.

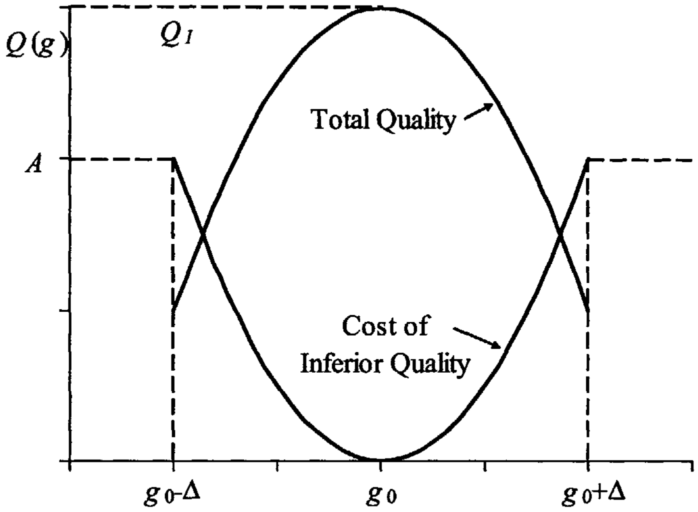

Figure 37: Total Quality and the Cost of Inferior Quality

4.1.1.2 Types of Quality Attributes

Before turning to the next section on extending Taguchi's loss function approach to value modeling, it is appropriate to first briefly discuss the three types of quality attributes: nominal-is-better (NIB), smaller-is-better (SIB), and larger-is-better (LIB).

The loss function of Equation (4-3) and Figure 36 represents a NIB attribute where the highest quality is attained at a nominal attribute level, g_0. Examples of NIB attributes where it is desirable not to deviate from either side of a target value include our television power circuit function, where larger transform voltages result in television pictures that are too bright, and lower values result in dark picture screens.

An attribute of the SIB type attains highest quality (minimal loss) at a minimal attribute value of $g_0 = 0$. Examples of SIB attributes may include auto exhaust pollutant levels and the number of assembly line defects. Loss from such an attribute is represented by the following relationship and is sketched in Figure 38:

$$L(g) = \frac{A}{\Delta^2} \cdot g^2 \tag{4-5}$$

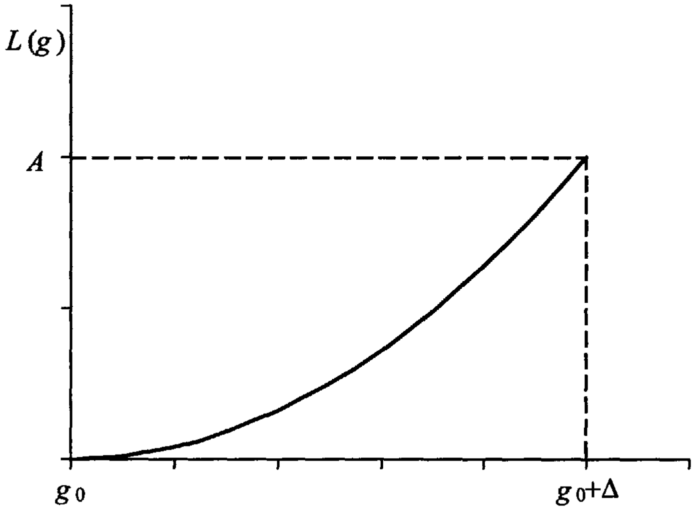

Figure 38: Taguchi Smaller-is-Better Type Attribute

An attribute of the LIB type attains maximum quality at $g = \infty$. Examples of LIB attributes may include material tensile strength and truck cargo capacity. A Taylor series expansion may be made of the reciprocal of g analogous to the operation of Equation (4-1). Considering that $L(\infty) = 0$ and $L'(\infty) = 0$, and setting the loss $L(\Delta_0) = A_0$, then the loss function for LIB attributes is given by:

$$L(g) = A_0 \Delta_0{}^2 \cdot \frac{1}{g^2} \tag{4-6}$$

The loss for a LIB attribute is sketched in Figure 39.

4.1.2 Cook's Extension to Loss of Value

In Figure 37 it becomes apparent that quality should be represented by some quantitative metric (e.g., dollars) for purposes of convenience in discussing losses. In studying Taguchi's quality loss work in the late 1980s and early 1990s, Cook realized that the approach employed for representing product *quality* could be directly translated into product *value* [Cook (1997)]. In this section Cook's extension of Taguchi's loss function to attribute value will be described and a number of important considerations in selecting product attributes will be noted.

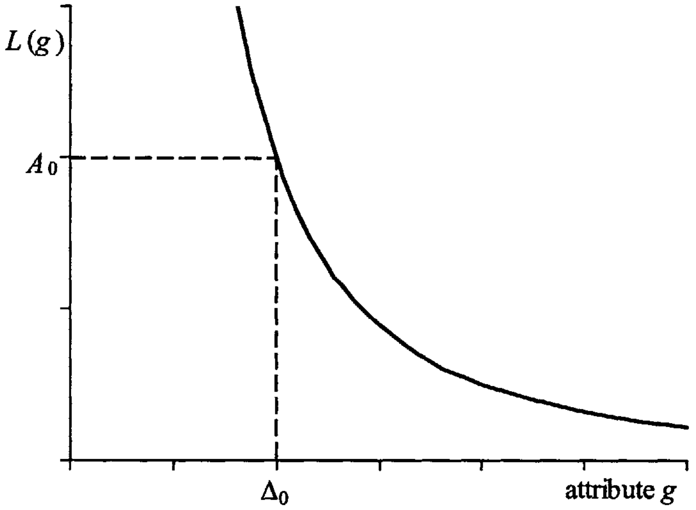

Figure 39: Taguchi Larger-is-Better Type Attribute

4.1.2.1 Developing Attribute Value Curves

Value, typically considered as exchanges of utility or worth [Murman, et al (2002)], is commonly expressed in the easily understood terms of money. In the television power circuit example of the previous section the repair cost may be represented as A = \$200 and the ideal value of the product to society V_I = \$300. A value representation of the Taguchi loss function is mathematically represented in Equation (4-7) and graphed in Figure 40. In this case the curves represent the total value of the television set to society as it is degraded by an off-specification power circuit.

$$V(g) = V_I - \frac{A}{\Delta^2}(g - g_0)^2 \qquad \textbf{(4-7)}$$

In his extension of the Taguchi loss function approach, Cook made a number of contributions to the manner in which value may be modeled for products. In addition to nominal attribute levels, g_0, Cook introduced the concept of an ideal attribute level, g_I, and a critical attribute level, g_C. The requirement for specifying an ideal value, V_I, was also eliminated by referencing value to a baseline product. Each of these contributions is discussed in turn.

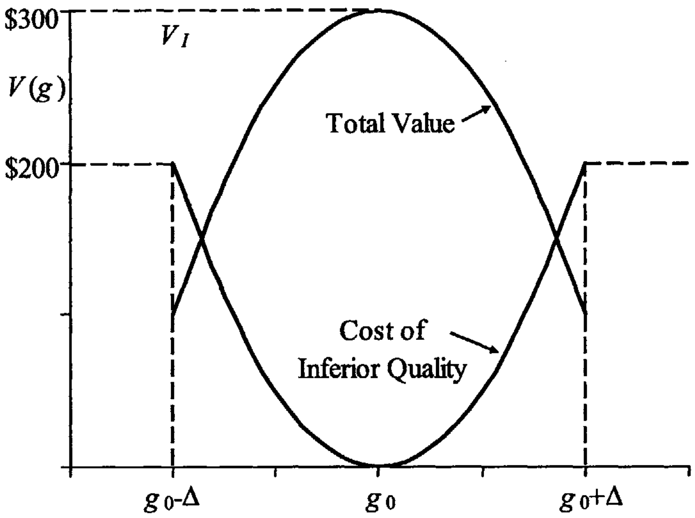

Figure 40: Total Value and the Cost of Inferior Quality

The baseline attribute level, g_0, is considered to be the average level at which the product is currently available to consumers. Take as an example the attribute of interior noise level in a car while driving at highway speeds. One might consider a noise level of 60 dB to be approximately the average level for standard mid-size cars; thus $g_0 = 60$ dB.

The critical attribute level, g_C, is the level at which further degradation in the attribute renders the product as a whole worthless to the consumer. In the case of our car interior noise attribute a noise level beyond approximately 100 dB would become painful to the car's occupants and would render the car unusable. (Note that this is a *degradation* in the noise attribute since noise is a smaller-is-better attribute. See §4.1.1.2) For this case $g_C = 100$ dB.

The ideal attribute level, g_I, is the level at which further improvement in the attribute is of no additional value to the consumer. For the car interior noise, levels of approximately 40 dB would allow occupants to converse in soft voices. Further reductions in noise levels would be of no practical value in allowing the occupants to converse and would usually be overridden by ambient noise, thus $g_I = 40$ dB.*

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* Note that the ideal and baseline attribute levels (and perhaps the critical level as well) almost certainly will change over time with advancements in technology and the state-of-the-art in product offerings. This will shift the overall product values across an industry, but should not affect the relative standing of products in relation to one another. See §6.1.3 for a sensitivity analysis regarding changing of the attribute bounds.

The relative value of a product due to a single attribute level g is then given by Cook's modified equation:

$$v(g) = \left[\frac{(g_C - g_I)^2 - (g - g_I)^2}{(g_C - g_I)^2 - (g_0 - g_I)^2} \right] \tag{4-8}$$

The shape of the relative value curve for a nominal-is-better attribute is shown in Figure 41. Note that when $g = g_0$ the relative value is $v(g_0) = 1$ by definition in using this approach.

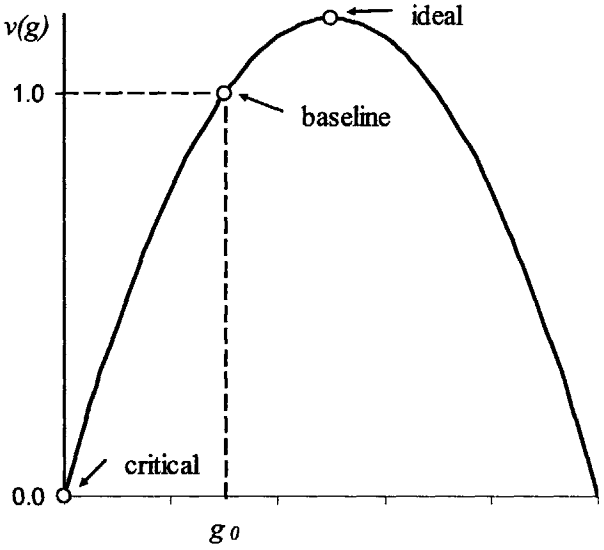

Figure 41: Relative Value Nominal-is-Better Type Attribute

With the ability to now specify ideal and critical attribute levels there is no requirement to rewrite the loss function equations for SIB and LIB type attributes. In other words, the requirements that $L(\infty) = 0$ for LIB and $g_0 = 0$ for SIB type attributes are no longer true. Instead of using unique equations for each attribute type, the same relative value equation for NIB attributes will be used (Equation (4-8)) but, in the case of LIB attributes, only the left side of the parabola will be used (Figure 42).

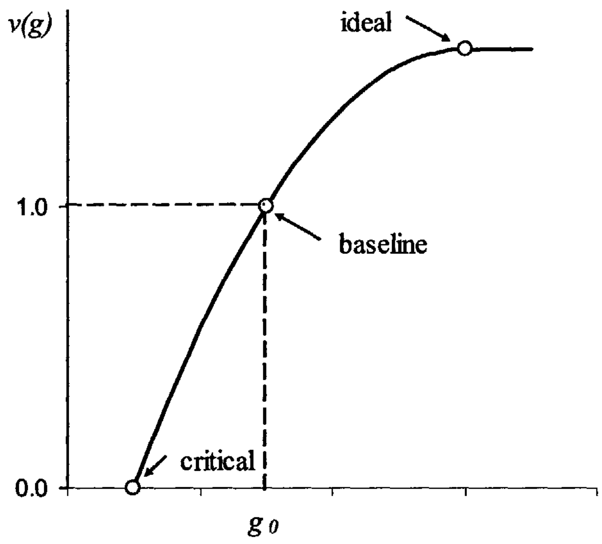

Figure 42: Relative Value Larger-is-Better Type Attribute

Similarly, in the case of SIB attributes only the right side of the parabola will be used (Figure 43).

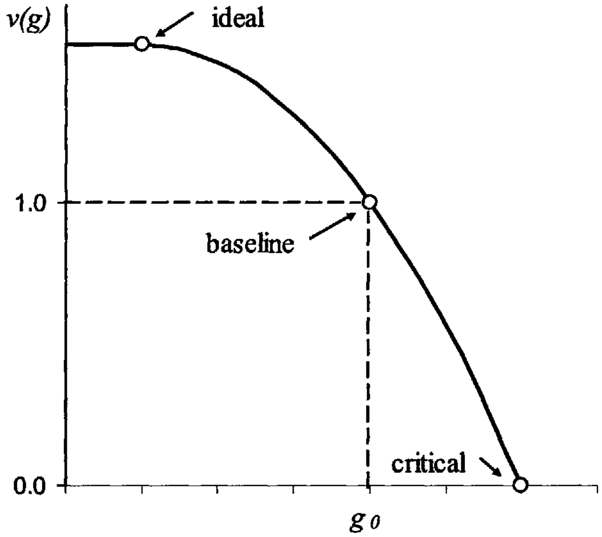

Figure 43: Relative Value Smaller-is-Better Type Attribute

Revisting the axiomatic basis for utility theory outlined in §3.3.4.1 we see that one important axiom has been violated by this approach. The nominal-is-better type attribute represents a non-monotonic function in that attribute value both increases and decreases along the function, creating a "sweet spot" of consumer preference at the apex. Utility theory requires monotonic functions to ensure unique utility (or in our case, value) assessments. Researchers in utility theory often deal with this problem by assuming that at higher levels of a particular attribute, that attribute is available but avoidable and thus the reduction in utility (value) may be avoided. As an example, many individuals prefer some sugar in their coffee, but will reach a point at which too much sugar has been added and the coffee is no longer palatable. To avoid problems with monotonicity, the assumption is made that the sugar is available on the table in larger quantities, but may be avoided by the coffee drinker once an ideal sugar level has been reached. In a similar fashion, it is assumed for the purposes of this research that consumers may reach an attribute saturation level (the "ideal" attribute bound) at which point improvements in the attribute neither add nor diminish value. In effect, *nominal-is-better type attributes are prohibited for the RVI method to comply with the axioms of utility theory.*

Note that the smaller-is-better and larger-is-better attribute relative value curves reflect the common nonlinearity of preference referred to as *diminishing marginal utility.* This concept from economic theory states that people attach less and less incremental value to each additional unit of benefit they receive, reflecting an eventual saturation with the attribute [de Neufville (1990), Nicholson (1995)]. Though economists' *utility* is considered as *value* in this study, the concept remains useful.

4.1.2.2 Attribute Identification

The number of attributes related to a particular product can be numerous. Lancaster (1971) states

> "Every objective property of size, shape, and performance is a potential characteristic. In principle, if we take an object, measure it in every possible dimension and in every aspect of performance, in every biological, chemical, and physical aspect, we have evaluated all its possible characteristics. When this is said, it becomes immediately obvious that the operational problems concerning the use of the characteristics analysis do not lie in the measuring of the characteristics… but in selecting which characteristics to measure. Even the simplest of things possesses a myriad of objective properties."

Green and Srinivasan (September 1978) similarly observe, "The more difficult and often subjective task is to reduce the number of attributes to a manageable size so that the estimation procedures are reliable while at the same time accounting for consumer preferences sufficiently well."

Clearly attribute identification is a key step in developing the product value model. The first phase of attribute identification is to list all attributes possibly relevant to consumers in forming their preferences. Green and Srinivasan (September 1978) list several approaches for this initial compilation, including preliminary data collection surveys of consumers in which primary attributes may be identified. Consultation with industry product managers, engineers and marketing managers may also prove helpful, as may reviewing relevant industry literature or consumer ratings such as those to be found in *Consumer Reports*.

A few considerations in initially selecting attributes:*

1. An attribute which is invariant over the group of products under study is currently irrelevant to the value model. For example, if all products under consideration are painted blue then the paint color attribute is irrelevant and the importance of paint color is unobservable in empirical choice data. This is not to be construed as meaning, however, that paint color is irrelevant to consumer choice. If a new product painted red is introduced, only then may the modeler begin to assess the importance of the paint color attribute to consumer choice for that product.

2. If two or more attributes are possessed by all products in fixed ratio to each other (i.e., they are highly correlated) all but one of those attributes might be irrelevant. This raises issues of multicollinearity but does not imply that correlated attributes should be eliminated from the model. See §4.1.2.4 for a more detailed discussion of this point.

3. Attributes must have relevance to consumer preference. Automobile VIN (vehicle identification) numbers or aircraft tail numbers are not likely to be relevant to consumer preference. Judgment must be used in determining whether all attributes for which data is collected and reported are truly relevant to consumer choice.

The typical modeler will iterate a number times between adding more attributes to the model, dealing with issues of multicollinearity, and checking the model for explanatory power in terms of value relative to competing products, consumer demand, and other features of interest to the modeler.

Rather than consigning attribute identification to the realm of "black art" it is desireable to seek more objective methods for selecting product features of importance. An opportunity for systematic attribute identification is that offered by Object Process Methodology (OPM); a structured method for rigorous analysis of the operand (i.e., the product), its attributes, and the primary value delivering process and its associated attributes [Dori (2002)]. In this study a thorough investigation of OPM has not been conducted in relation to the aviation industry, but the methodology is a sufficiently promising process that further study is warranted.

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* Adapted in part from Lancaster (1971).

4.1.2.3 Quantifiable and Hard-to-Quantify Attributes

As much as possible, attributes should arise from the product itself and not from people's reactions to it. As an example, the comfort of the driver's seat may be important to consumer choice for automobiles; the modeler may thus choose to assign a "comfort" attribute for automobiles and somehow establish a quantitative rating for various models on the market. A better choice from a modeling point of view, though perhaps not always feasible, would be to instead add to the value model seat characteristics that contribute to "comfort": width, legroom, material, padding, the ability to adjust the seat position, etc. An option may also be added for heated seats (see §4.2.3 on adding options).

Clearly there exist attributes that do not immediately lend themselves to quantification, aesthetics perhaps ranking among the most subjective. Brand name is another attribute considered to be of great importance in consumer preference but extremely difficult to quantify. Green and Wind (1975) dealt with brand name by assigning a binary level to the attribute (0 or 1) depending on whether product packaging in their study displayed a brand name. Urban and Hauser (1993) used perceptual maps in which consumers rated subjective attributes such as the "gentleness" and "effectiveness" of aspirin on a Likert scale. Cook (1997) similarly had consumers rate the "conservatism" or "spiritedness" of automobile models.

Some attributes relevant to consumer choice do not arise from the product itself but instead from the manufacturer or sales organization. After-market customer support such as the handling of warranty claims for an automobile is not a feature of the product but is instead an attribute that accompanies the product and arises from an exogenous source.* In the aircraft industry the customer support feature associated with a particular aircraft may change radically if the manufacturer sells the product line to a different organization or is itself merged with or acquired by another company [George (September 2002)]. The product has not been altered in any way, but a key attribute characterizing that product has changed. The modeler should be cognizant that some attributes important to consumer preference may not be found in the product itself.

Just as we later develop a market share model based on demand theory (§4.3.1.3), Bell, Keeney, and Little (May 1975) extend demand theory to base market share on a product's

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* The quantity of warrenty claims *is* a feature of the product via its reliability.

attractiveness features. Rather than utility or economics-based value, their market share attraction model estimates the "attraction value" of a product as a function of the components of its marketing mix. This is not unlike the compositional RVI approach developed in this research (§4.2) and serves as further evidence that attributes other than product technical performance may effect that product's success in the market. Mason (Winter 1990) extends market share attraction models beyond market share estimates to unit sales forecasts based on product attractiveness and the potential for market expansion; yet another feature that may alter the eventual success of a product.

4.1.2.4 Multicollinearity

It is important to note that even after relevant attributes have been identified, they cannot simply be combined into a multi-attribute value model such as that discussed later in §4.2.1. The problem of certain variables being correlated, or moving up and down together across observations (i.e., different products) must be considered. This situation is referred to as *multicollinearity* and creates problems because certain attributes may essentially be contributing redundant information to the model. The separate effects of each attribute may then be difficult to identify and the model, though perhaps demonstrating predictive ability, does not possess a great deal of explanatory power. To monitor for multicollinearity the pair-wise correlation coefficient, r, should be calculated for each attribute combination used in the value model. No single authority suggests an "acceptable" level of correlation, but some suggest that values $r \geq 0.85$ should be avoided.

The effects of multicollinearity may be reduced by eliminating all but one of a group of correlated variables (the literature suggests that the choice of which variable to retain is arbitrary) or by combining highly correlated variables into a new single variable to be used in the model. Alternatively, multicollinearity may be moderated by increasing the number of observations in the dataset, but little guidance exists as to how many more observations may be required (for purposes of planning a new survey to collect additional data, for example) and adding observations may not be an option in many practical situations.

Eliminating correlated parameters is problematic since there is little guidance available on which variables to retain, and the effect of eliminating variables is to reduce design considerations (e.g., eliminating interior noise from the parameter set prevents designers from leveraging that attribute when they study new products with the value model). This author instead suggests combining relevant but highly correlated attributes into one or more new and less correlated parameters. The mathematical literature is mute on how to combine highly correlated variables, but this author suggests maintaining some physical or real-world relationship with the new variable (something the consumer would recognize or perceive rather than a nonsensical combination of correlated attributes). Examples are provided later in this research when the value approach is operationalized in the form of a business airplane value model.

4.2 Multi-Attribute Relative Value Index (RVI)

So far Cook's value methodology has considered the effect of only one attribute on the relative value of a product; e.g., the value of an aircraft considering only its maximum cruise speed. But clearly, as Lancaster (1971) points out, the value of most complex products is influenced by a number of attributes, all of which must be considered by the relative value model simultaneously.

4.2.1 Combining Multiple Attributes

The relative value contribution from the j^{th} attribute, g_j, will be rewritten as the following:

$$v(g_j) = \left[\frac{(g_{jC} - g_{jI})^2 - (g_j - g_{jI})^2}{(g_{jC} - g_{jI})^2 - (g_{j0} - g_{jI})^2} \right] \quad \textbf{(4-9)}$$

The form of the multi-attribute model should now be considered. Some utility models, such as that proposed by Hauser and Urban (March 1979), assume a "quasi-additive" form if all attributes are utility independent (the utility of one attribute is not dependent on the level of other attributes). For the business airplane attributes used in this research, the assumption of utility independence is not valid (e.g., faster speeds are not of value if the aircraft range is only 10 miles). In addition, much of the theory related to the definition and use of "value" has its foundations in the economic and marketing demand literature (§4.3.1.1). In developing mathematical models for demand and supply, one condition for the functional form of the models is that the marginal prices, MP_j, used in the models vary with the levels of the attributes, g_j, considered in the model, Equation (4-10) [Agarwal and Ratchford (December 1980)].

$$\mathrm{MP}_j = \frac{\partial P}{\partial g_j} = \left(\frac{\gamma_j}{g_j} \right) P \tag{4-10}$$

The nonlinear multi-attribute price model with $j = 1, 2, 3 \ldots n$ attributes is required to be of the form

$$P(g_1, g_2, \ldots, g_n) = C \cdot g_1{}^{a1} \cdot g_2{}^{a2} \cdots g_n{}^{an} \tag{4-11}$$

The structure of this equation is well-known as the Cobb-Douglas form and is frequently utilized in the economics literature. With value so firmly rooted in economic concepts and closely related to price, it makes sense to adopt the same Cobb-Douglas format for the multi-attribute relative value model. Furthermore, pains have been taken to develop the concept of a critical attribute level that may render the overall product value zero. Therefore, any overall figure of merit must be zero when any one essential attribute reaches the critical level. This requires a multiplicative figure of merit with $j = 1, 2, 3 \ldots n$ attributes,* hereafter referred to as the Relative Value Index, RVI:

$$\mathrm{RVI} = v(g_1)^{\gamma 1}\, v(g_2)^{\gamma 2}\, v(g_3)^{\gamma 3} \ldots v(g_n)^{\gamma n} \tag{4-12}$$

Cook's S-Model is of this same form, but Cook has not yet established a name for the value equation itself. The Relative Value Index nomenclature is used in this study for purposes of clarity in reference and to maintain some connection with the well-known and established business aviation Traditional Value Index (see §3.3.2.3). The RVI syntax is not meant to indicate that the base framework of the RVI method is distinct from that of Cook's previous value work. This author instead claims an extention of Cook's work into a new domain, clarification of the method's links to economic theory, and the application of new evaluation techniques and uses for the value methodology. See Chapter 8 for details on the contributions of this research.

For $i = 1, 2, 3 \ldots N_k$ products competing in the k^{th} segment, the RVI will be written to indicate the i^{th} product under consideration:

$$\mathrm{RVI}_i = v(g_{i1})^{\gamma 1}\, v(g_{i2})^{\gamma 2}\, v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n} \tag{4-13}$$

Note the nomenclature where the j attributes for product i, g_{ij}, have the same basic part-worth value curves, $v(g)$, thus negating the need for a product-specific subscript on the relative

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* Girifalco (1991) makes a similar argument when formulating his figure of merit for measuring technological change.

value variable such as $v_i(g)$. Similarly, each attribute will have the same weighting factor across all products, thus there is also no need for a product-specific subscript on the weighting factors such as γ_{ij}.

The dimensionless, non-negative RVI of Equation (4-13) is the same multi-attribute form advocated by Cook (1997) but, to the best of the author's knowledge, first linked to economics theory in this work. Note that in this form the system is rendered worthless if any single attribute reaches a critical point, g_C. Thus, the effect of a specific product attribute depends not only upon its own level but also on the levels of the other product attributes.

The weighting factors, γ_j, in Equation (4-13) reflect the relative impact on the overall product RVI of the attributes g_j. Note that these exponents do not necessarily reflect the relative *importance* of the attributes on the overall product value. As will be explored in more detail later, the numerical value of the weighting factors can be based on revealed consumer data and, in that case, may only reflect the degree to which a collection of products are differentiable on a particular attribute.

The numeric values of the weighting factors are limited to non-negative values $\gamma_j \geq 0$ but, unlike some utility models, these factors are not necessarily constrained to be less than or equal to unity. The exclusion of negative numeric values arises from the prior choice of LIB and SIB attribute types which implicitly assume non-negative exponents. In other words, a LIB type attribute with a negative weighting factor is, in reality, a SIB attribute and should be chosen as such from the outset. In selecting values for the attribute weights there is also no requirement that $\sum_{j=1}^{n} \gamma_j = 1$ as is found in some utility and value models.

The influence of the weighting factor, γ, on the single attribute relative value is shown in Figure 44. As indicated in the figure, for $\gamma = 0$ the attribute has no influence on the product relative value. For $\gamma > 0$, changes in the attribute level, g, have greater effects on the product value until the ideal or critical attribute levels are approached.

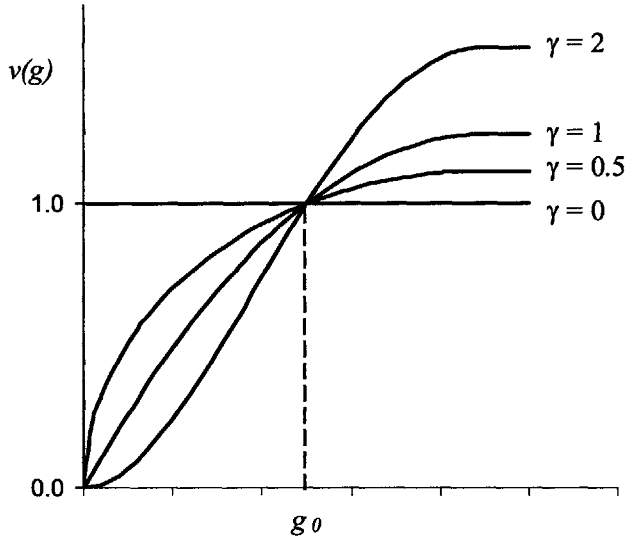

Figure 44: Effect of Weighting Factor on Relative Value of Attribute

The mathematical product of Equation (4-13) not only has strong ties to economic theory, but also is more practical than a mathematical summation figure of merit, such as is commonly used in the value literature (Equation (4-14)). As already noted, one product attribute is capable of rendering the whole product valueless to the consumer, such as might be the case if an automobile had a gas tank that could hold only one gallon, or if an aircraft had a range of only 10 miles. This accords better with reality than would the finite value resulting from a mathematical summation figure of merit. In §5.5.2 an example will be given to demonstrate the practical utility of the mathematical product rather than a summation figure of merit for value.

$$\mathrm{RVI}_i = v(g_{i1})^{\gamma 1} + v(g_{i2})^{\gamma 2} + v(g_{i3})^{\gamma 3} + \ldots + v(g_{in})^{\gamma n} \qquad \textbf{(4-14)}$$

4.2.2 Marginal Analysis

Marginal analysis is a basic form of optimization, providing a means of selecting the best choice, subject to constraints, from among many *technically efficient*[*] ways to achieve an objective [de Neufville (1990)]. With the relative value defined in Equation (4-13), the sensitivities of the value parameters may be evaluated via their *marginal values* and *marginal*

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[*] The phrase *technically efficient* is used here in the sense of its engineering analysis definition: a function representing the maximum output that can be obtained from any given set of inputs.

rates of substitution. Analogous to the marginal price of Equation (4-10), a marginal value for attribute j, MV_j, may be introduced as (subscripts designating the i^{th} product are omitted for clarity)

$$\mathrm{MV}_j = \frac{\partial \mathrm{RVI}}{\partial v(g_j)} = \frac{\gamma_j}{v(g_j)} \cdot \mathrm{RVI} \tag{4-15}$$

The marginal value is non-dimensional by virtue of the fact that $v(g)$ is non-dimensional. The marginal value reflects the marginal change in the relative value of a product, RVI, for a small additional amount of that product's j^{th} attribute value contribution, $v(g_j)$. With the marginal value in mind, the weighting exponents may more clearly be recognized as representing the non-dimensional elasticities of the product attributes.

$$\gamma_j = \frac{\partial \mathrm{RVI}}{\partial v(g_j)} \cdot \frac{v(g_j)}{\mathrm{RVI}} = \frac{\%\,\text{change in RVI}}{\%\,\text{change in } v(g_j)} \tag{4-16}$$

If only two attributes are considered, the marginal rate of substitution for the two attribute value contributions, $v(g_1)$ and $v(g_2)$, may be defined by taking the derivative of the RVI equation

$$\mathrm{d}\,\mathrm{RVI} = \frac{\partial \mathrm{RVI}}{\partial v(g_1)} \cdot \mathrm{d}\,v(g_1) + \frac{\partial \mathrm{RVI}}{\partial v(g_2)} \cdot \mathrm{d}\,v(g_2) = 0 \tag{4-17}$$

where the partial derivatives are already known as the marginal values

$$\frac{\partial \mathrm{RVI}}{\partial v(g_1)} = \frac{\gamma_1}{v(g_1)} \cdot \mathrm{RVI}, \quad \frac{\partial \mathrm{RVI}}{\partial v(g_2)} = \frac{\gamma_2}{v(g_2)} \cdot \mathrm{RVI} \tag{4-18}$$

Substituting the marginal values of Equation (4-18) into Equation (4-17) yields the marginal rate of substitution for the two attribute part-worth value contributions

$$\mathrm{MRS}_1^2 = \frac{\mathrm{d}\,v(g_2)}{\mathrm{d}\,v(g_1)} = \frac{\gamma_1}{\gamma_2} \cdot \frac{v(g_2)}{v(g_1)} \tag{4-19}$$

Unfortunately equations (4-15) through (4-19) concern the attribute part-worth value contributions, $v(g)$, and not the attribute numerical values themselves. In most practical situations the attribute numerical values, or attribute levels, would be of more interest. Substituting the attribute value contribution of Equation (4-9) into the RVI Equation (4-13) and then re-deriving the marginal value of Equation (4-15) yields a dimensional marginal value for the j^{th} attribute level, g_j:

$$\frac{\partial \text{RVI}}{\partial g_j} = \frac{-2\gamma_j (g_j - g_{jI})}{(g_{jC} - g_{jI})^2 - (g_j - g_{jI})^2} \cdot \text{RVI} \tag{4-20}$$

where the dimensions of Equation (4-20) are $1/(\text{unit } g)$. The non-dimensional elasticity of the j^{th} attribute level is then

$$\frac{\partial \text{RVI}}{\partial g_j} \cdot \frac{g_j}{\text{RVI}} = \frac{-2\gamma_j (g_j - g_{jI})}{(g_{jC} - g_{jI})^2 - (g_j - g_{jI})^2} \cdot g_j = \frac{\%\,\text{change in RVI}}{\%\,\text{change in } g_j} \tag{4-21}$$

Unfortunately the marginal rate of substitution, even for two attributes, is difficult to solve in closed form. The closed form solution is not necessary, however, because any computer code (or spreadsheet) that performs the calculations for the RVI model may also easily calculate the marginal rates of substitution for any given parameters.

A graphical example of the marginal analysis for the numerical values of two attributes is shown in Figure 45. In this figure, the RVI for a hypothetical two-attribute product has been calculated for a variety of attribute levels. The marginal values for each attribute are noted on the sketch, as is the marginal rate of substitution, which is simply the slope of the iso-RVI contour, $\mathrm{d}g_2/\mathrm{d}g_1$.

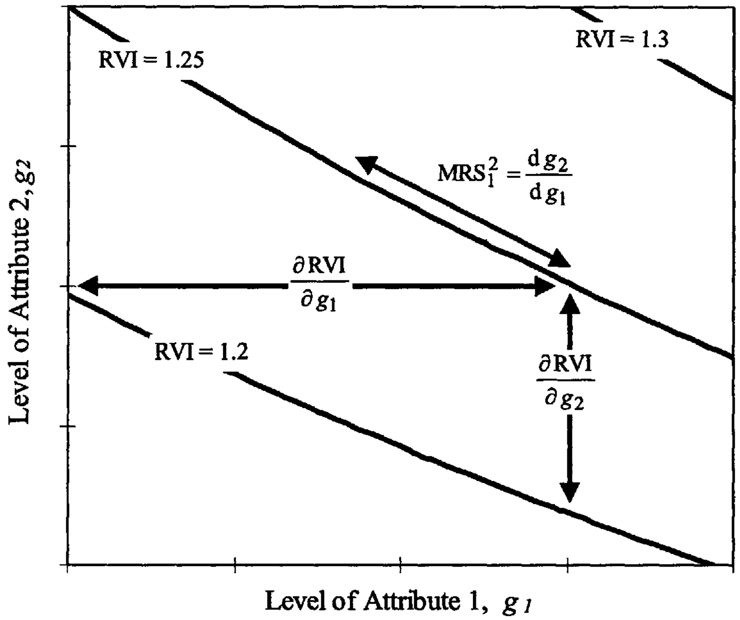

Figure 45: Sketch of Marginal Analysis for Two Attributes

4.2.3 The Value of Options

There also exist add-on attributes whose presence may add value but cannot drive the product value to zero due to their absence or ill-design. Such attributes will be referred to in this research as options (Cook (1997) and his colleagues have also proposed the addition of options in their work). Examples of automobile options may include satellite radio and heated seats; business aircraft options may include a cabin satellite communications system and thrust reversers. The relative value of adding *m* options, $\Delta v(g')$, to the $j = 1, 2, 3 \ldots n$ attributes for the i^{th} product may be mathematically represented by modifying the RVI model as follows:

$$\mathrm{RVI}_i = v(g_{i1})^{\gamma 1}\, v(g_{i2})^{\gamma 2}\, v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n} + \Delta v(g_{i1}') + \Delta v(g_{i2}') + \ldots + \Delta v(g_{im}') \qquad \textbf{(4-22)}$$

If the user feels it is appropriate, the options may also have weighting factors even though they are not shown in the equation. It is difficult to think of the value of options in a relative sense; what is the value of a satellite radio compared to heated seats? Options are more easily discussed within the context of absolute value, as will be noted in §4.2.4.

One difficulty with the form of Equation (4-22) is that the RVI may now be positive even if an essential (non-optional) attribute has reached its critical level. An example might be an aircraft with a 100 nm range that, normally, would render the aircraft worthless to the customer regardless of other attribute levels. If the manufacturer were to add optional thrust reversers to the aircraft then Equation (4-22) would suggest a positive value for the aircraft despite the fact that in a real-world evaluation the product would still be worthless to the customer. Girifalco (1991) suggests a figure of merit wherein all of the options compose a final multiplicative term in the equation:

$$\mathrm{RVI}_i = v(g_{i1})^{\gamma 1}\, v(g_{i2})^{\gamma 2}\, v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n} \left[\Delta v(g_{i1}') + \Delta v(g_{i2}') + \ldots + \Delta v(g_{im}')\right] \qquad \textbf{(4-23)}$$

In this fashion the overall product value is again rendered zero if any attribute reaches a critical level, regardless of the option values.

Note that options do not have to be exercised (i.e., the person buying the aircraft does not have to have thrust reversers installed). It is assumed, therefore, that in exercising an option the consumer believes it will add value to the overall product, and thus exercising that option should not reduce the value of the product. It is worth noting, however, that in designing a product the inclusion of options (whether they are exercised or not) may reduce the overall value of the product vis-à-vis a competing product that does not have the option designed in. Consider the option of folding wing tips on the Boeing 777 commercial aircraft. When the aircraft was designed, Boeing built in the option for pilots to automatically fold the wing tips when parked at an airport gate, thus making the aircraft wing span shorter and allowing the aircraft to be parked at a larger number of airport gates. Airlines could choose to exercise the option by having Boeing install the electronics and actuators to fold the wing tips and, presumably, the value of the aircraft would be increased since the aircraft would be able to access a greater number of airports and airport gates.

However, in designing the option into the 777, Boeing engineers had to reinforce the structure of the outer wing, thus increasing the weight of the aircraft with all the inherent penalties: lower payload weight, more stringent weight restrictions on other systems to make up for the weight of the option, higher purchase price due to the additional design effort, etc. Every 777 aircraft carries the extra weight of the folding wing tip option, even if the option remains unexercised.* Thus, one could say that the 777 with the option designed in was of less overall value than an identical design would have been without the availability of the folding wing tip option. Such considerations will not be further dealt with in this research, but should be kept in mind when comparing RVI model results for products with and without options.

4.2.4 Absolute versus Relative Value

To this point, only the *relative* value of a product, $v(g)$, has been considered. Value may also be expressed in absolute terms, such as dollars, by modifying the RVI equation with the absolute value of a baseline product, V_0 [Cook (1997)].

4.2.4.1 The Value Index (VI)

The absolute value of the i^{th} product with $j = 1, 2, 3 \ldots n$ attributes will be referred to as the Value Index, VI:

$$\mathrm{VI}_i = V_0 \left[v(g_{i1})^{\gamma 1}\, v(g_{i2})^{\gamma 2}\, v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n} \right] \qquad \textbf{(4-24)}$$

It may be easier to treat the value of a product in absolute terms when communicating with management. Many metrics used by managers involve monetary values, so product value assessed in terms of monetary units (i.e., dollars) will bring the issue closer to the comfort zone

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* To Boeing's chagrin, no airline to date has exercised this option.

of most managers. There is a danger, however, that product *value* and product *price* could become confused in such discussions. When discussing product value the issue of product price must be clearly differentiated (see §4.3.1.1 for a discussion of price versus value).

It will also be shown in §4.3.1.1 that annual demand for a new product (or, alternatively, market share) may only be estimated using an absolute value for direct comparison to product price. The section on product demand (§4.3.1.1) explains this concept in greater detail.

As noted in the previous section, discussing the absolute value of options, $\Delta V(g')$, also makes more real-world sense. It is far more intuitive to discuss the added value of installing a DVD player in a car by indicating $\Delta V_{DVD\ player} = \$1{,}000$ rather than $\Delta v_{DVD\ player} = 0.15$, for example. The value of options may be added to the i^{th} product's VI, as analogous to Equation (4-22):

$$\text{VI}_i = V_0 \left[v(g_{i1})^{\gamma 1}\ v(g_{i2})^{\gamma 2}\ v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n} \right] + \Delta V(g_{i1}') + \Delta V(g_{i2}') + \ldots + \Delta V(g_{im}') \qquad \textbf{(4-25)}$$

Similarly, options may be considered as another term in the multiplicative VI equation as analogous to Equation (4-23).

4.2.4.2 Determining the Baseline Product Value

What constitutes the value of a baseline product, V_0, now becomes the operational question. Cook (1997) suggests that the value of a product judged to be representative of typical products in a segment, or even the mathematical mean for a number of product values, may be used. This research does not follow this suggestion because it is flawed within the context of this study. First, Cook never makes the direct connection between compositional value (VI) and a top-down value assessment (referred to as Revealed Value in this study – see §4.3.2). Since we wish to establish a direct link between the bottoms-up and top-down value estimates in this study, we cannot use Cook's method of estimating V_0 based on average top-down value estimates.

Second, in his research Cook considers only one market segment of directly competing products at any one time, so the selection of an "average" for V_0 is rather straightforward. In general, because of the difficulty of determining market segments objectively (§2.2.1), it is desirable to compare products across a number of market segments; for example, to compare small business aircraft to large business aircraft, even though they do not directly compete with each other. Therefore, in this study we desire the ability to make longitudinal (across-segment) comparisons industry-wide. In addition, we wish to externally validate the RVI method through extensive historical analyses with comparisons to empirical activties. Product segments are dynamic, shifting and emerging over time, so examining single segments over long time spans would not be useful. The only viable way of externally validating the RVI method using historical data is with a method that facilitates longitudinal studies of the industry. The method for determining baseline product value, V_0, will need to be modified to enable both direct comparisons of top-down and bottoms-up value estimates and longitudinal industry studies.

As an illustrative example, consider the three product segments in Table 5 for which a consumer revealed value, RV, has been determined using the methods of §4.3. These three segments span a range of offerings in a particular market, from low-end to high-end products, for which it is desired an RVI figure of merit be developed. Designers will then use this multi-attribute RVI in our hypothetical scenario to develop new products for the market. Since the RV for the i^{th} product is known, the goal is to develop the Value Index for that product which, in turn, requires an estimate of a baseline value, V_0.

$$\mathrm{RV}_i = \mathrm{VI}_i = V_0 \cdot \mathrm{RVI}_i \tag{4-26}$$

Table 5: Hypothetical Product Segments and Their Consumer Revealed Values

	Low-End Segment	Middle Segment	High-End Segment
Revealed Value ($)	$8.2	$43.9	$93.5
	9.0	38.1	94.4
	10.2	35.6	
	8.6	47.9	
	9.1		

Consider if V_0 were one single value across all three segments; perhaps an average of all the RVs (in this example, $36.2). The resulting numerical values for RVI would be acceptable in most cases when Equation (4-26) was solved by finding an optimal set of exponential weighting factors, γ_i (see §4.3.3 for details on this approach). There is an order of magnitude difference between the low-end and high-end segments in RV that will be directly transferred to the RVI results as well. In some situations it has been found that, in using a single V_0, the numerical values for RVI are so small for low-end segments in contrast to high-end segments that comparison of products across the segments becomes problematic. Though in many cases using a single V_0 will be acceptable, we continue to explore for an approach that is acceptable in all situations.

For a second approach, consider having V_0 change for each segment. In other words, V_0 = \$9.0 for the low-end segment (the average RV for that segment), \$41.4 for the middle segment, and \$94.0 for the high-end segment. Having a different V_0 for each segment makes inter-segment comparisons impossible since the resulting RVIs will all cluster around 1.0. The RVI results will only be meaningful for comparisons within segments.

The approach used in this research is to set the baseline product value equivalent to the average RV for each segment divided by the average RVI for that segment

$$V_0 = \overline{\mathrm{RV}}_{segment} \big/ \overline{\mathrm{RVI}}_{segment} \qquad \textbf{(4-27)}$$

This approach corrects for the problem of inter-segment comparisons when only using the average RV for each segment, and also maintains the RVI results at reasonable magnitudes across all segments in all situations.

4.3 Attribute Weighting Factors

When examining the RVI of Equation (4-13) one notes that the attribute part-worth value contributions, $v(g)$, are known from estimates of ideal, critical and baseline attribute values. For the Value Index of Equation (4-24) the part-worth contributions are similarly known, and in both equations only the numeric values of the exponential weighting factors, γ, are unknown. In this section an approach to determining the weighting factors will be introduced. In short, the approach relies upon an estimate of a product decompositional Revealed Value (RV) based on demonstrated demand and price information. This RV is then equated to the product's compositional VI and the weighting factors are determined using a best fit optimization routine.

4.3.1 Estimating Consumer Demand for Products

The principal method used in this research for estimating the RVI exponential weighting factors will be based on consumer preferences, as revealed through product demand and pricing data. In this section a demand equation in terms of product price and value will be developed. A brief discussion of market segmentation is also included since the demand equation is dependent on how products are segmented. Finally, market share estimations, as opposed to unit demand, will be introduced as potentially more appropriate for some situations.

4.3.1.1 Demand Based on Value

Making a choice from an evoked set of alternatives (or down-selecting to the evoked set to begin with) necessarily requires a decision rule.[*] A number of decision rules have been proposed in the behavioral psychology literature, including dominance, satisfaction, lexicographic rules, and utility[†]. In this research, already heavily based on economic principles, we take the view of consumer demand in the economics literature and tie it to a utility decision rule based on product characteristics.

Lancaster (1971) appears to have first linked the objective characteristics inherent in products to the choices consumers make for those products (although it's proper to note that Quandt and Baumol (1966) published an earlier study on travel mode choice based on the characteristics of the modes). Lancaster's research focused on the placement of various characteristic, or attribute, combinations (i.e., products) on a Pareto front of most efficient combinations and also in rank ordering the potential demand for those attribute mixes (e.g., top seller, next best, etc.). In this research, product demand in the form of market share and unit sales is directly linked to the multi-attribute value inherent in a product.

Traditional economic theory of consumer demand holds that quantity demanded is a function of the consumer's value function (or, as it is typically called, "utility"), product prices, and constraints on consumer income [Nicholson (1995)]. To operationalize this concept a linearized consumer demand function will be developed incorporating product price, consumer value and exogenous factors such as the economic environment (i.e., budget, income, inflation rates, etc.).

Product demand as a function of product price, $D(P)$, may be expanded using a Taylor series about some reference price, P_R: [‡]

$$D(P) = D(P_R) + \frac{D'(P_R)}{1!}(P - P_R) + \frac{D''(P_R)}{2!}(P - P_R)^2 + \cdots \qquad \textbf{(4-28)}$$

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[*] See Chapter 3 for more detail on consumer choice and evoked sets.

[†] For a brief summary of each of these decision rules, see Ben-Akiva and Lerman (1985).

[‡] To avoid confusion with product quality, *Q*, in this research product demand will be denoted by the use of *D* instead of the typical economic notation of *Q* for quantity demanded.

Without loss of generality we may set $D(P_R) = 0$. Neglecting the higher order terms in the expansion will greatly simplify the mathematics and eliminate the requirement for determining the second derivative of demand with price, $D''(P_R)$. This is a desired advantage since, as it will be demonstrated later in this chapter, determining only the first derivative, $D'(P_R)$, will prove challenging in a real market. This linearization of demand restricts use of the demand curve, strictly speaking, to prices in the vicinity of the reference price, P_R. If products in the market are carefully segmented by price, and demand is evaluated only within these segments, then this restriction will not impair use of the demand model. If, however, the price range of interest is away from the reference price then the first derivative may be reevaluated at a new reference price, again not restricting the use of the demand model.

Setting $D'(P_R) = -K$ then yields the linear demand relationship given by:

$$D(P) = K(P_R - P) \tag{4-29}$$

The coefficient K may be written as a function of the *price elasticity*, E_p:

$$K = E_p \frac{\overline{D}}{\overline{P}} \tag{4-30}$$

The price elasticity, also referred to in the economics literature as the *demand elasticity*, is the non-dimensional change in unit sales given a change in the unit price of a product: [*]

$$E_p = \frac{\text{\% change in unit sales}}{\text{\% change in unit price}} = \frac{\partial D}{\partial P} \cdot \frac{\overline{P}}{\overline{D}} \tag{4-31}$$

The terms $\overline{D}$ and $\overline{P}$ in equations (4-30) and (4-31) are a reference product demand and price at which the price elasticity holds. In both cases, these reference terms are taken as the average demand and price of the market segment for which K is being estimated. This being the case, the slope K is valid only for a small region in the demand-price space; perhaps only for one particular product market segment under consideration. Marketing managers in industry will typically know (or believe they know) the price elasticity for their product line, from which an estimate of K may be made for any given reference demand and price.

The sign on the elasticity value should, strictly speaking, be negative but is often neglected in the economics literature. Any elasticity less than one (magnitude) is considered

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[*] For further discussion on price elasticity see, for example, Nicholson (1995) and Monroe (1990).

inelastic (or relatively unresponsive to prices), whereas any elasticity greater than one is considered *elastic* (or relatively responsive to prices).

Economists have developed the concept of *consumer surplus* to aid in determining the gains or losses that individuals experience as a result of price changes.[*] In his 1890 *Principles of Economics*, Alfred Marshall first proposed the concept in which the price at which consumers are willing to forego consumption of a product is treated as a measure of the value of the product to the individual. Products that are priced below this value yield a surplus of benefits to the consumer. It is therefore appropriate to consider the reference price, P_R, at which demand is zero, $D(P_R) = 0$, as the value of the product to the consumer, V.[†] The linear demand relationship is shown in Figure 23 and given by:

$$D = K(V - P) \qquad \textbf{(4-32)}$$

For any given price, P^*, then the annual product demand may be anticipated at D^*.

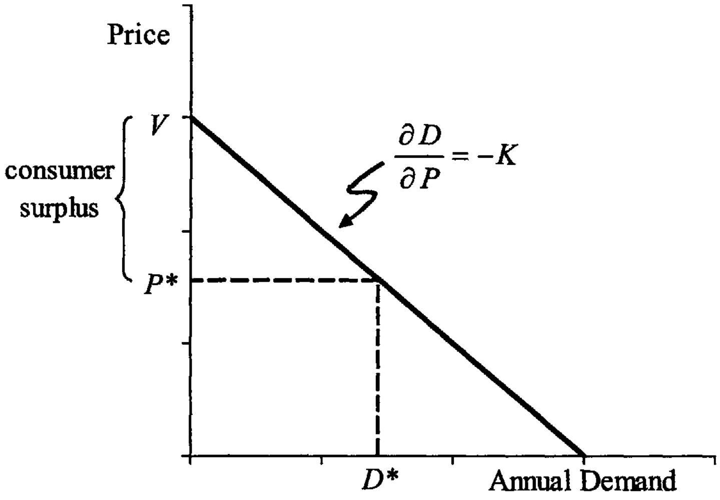

Figure 46: Demand as a Function of Price (linear approximation)

The linear demand model of Equation (4-32) neglects how the actions of competitors influence the demand for a product. Cook (December 1992) proposed an approximate method for considering the effects of competitors by reevaluating the coefficient K in terms of the total market segment demand, D_T, and the average of (V-P) over the N competitors:

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[*] There is, by analogy, also a *producer surplus* measured in part by the price at which supply of a product goes to zero.

[†] Cook and DeVor (June 1991) likewise make this assumption in their work on value.

$$K = \frac{D_T}{N(\overline{V-P})} \tag{4-33}$$

In reconsidering the issue a few years later, Cook and Kolli (June 1994) advocated instead adding a new term to the linear demand equation for the i^{th} product in a segment with N competing products:

$$D_i = K\left\{(V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l)\right\} \tag{4-34}$$

Errors in this linear model grow as competing products within a segment deviate from $\overline{D}$ and $\overline{P}$. To minimize errors it is best to consider product segment groupings as those having $(V-P)$ levels within 15-20% of the product with the largest $(V-P)$ in the segment.

4.3.1.2 Market Segmentation

In the previous section there was considerable discussion of product segments that makes it appropriate to briefly discuss the concept of market segmentation.

Research and empirical evidence in pricing and economic theory has shown that market segmentation is a key factor in maximizing profits for firms serving a market of heterogeneous consumers [Tirole (1988)]. So-called *second-degree price discrimination* is a product portfolio design strategy whereby a firm creates multiple versions of a product that deliver differing levels of value at different prices to consumers, resulting in *vertically differentiated* products. Despite the importance of such strategies there still exists considerable confusion as to what is meant by *market segmentation* and *product differentiation* and how to quantitatively define such terms. Definitions for the terms *market segmentation* and *product differentiation* will be offered here, and in Chapter 6 quantitative methods for differentiating between multiple market segments and multiple products in a portfolio will be presented.

The concept of market segmentation was first articulated in a pioneering article by Wendell Smith in 1956. This article limited the strategy of market segmentation to the development of different marketing programs for essentially the same product but for different elements of the overall market (e.g., for affluent buyers versus more budget conscious buyers). The goal of such segmentation was to increase company profits by tailoring marketing programs for the same product to different consumer groups.

Segmentation is now more broadly regarded as "the process of portioning a heterogeneous market into segments. The various segments identified should be homogenous within themselves but heterogeneous without (i.e., different from other segments)" [Loudon and Della Bitta (1993)]. The goal of segmentation is to facilitate development of unique marketing programs that will be most effective for these specific segments as well as to develop products that better meet the targeted segments' needs. Segmentation is therefore no longer concerned solely with segmenting the consumer, but also with segmenting the products for purposes of better tailoring the product itself (and not exclusively the marketing) to a particular consumer segment.

Hotelling (1929) contends that the tendency to compete among companies results in the "clumping" of products into segments. According to "Hotelling's Law," competitors tend to make their products similar, but not identical, in an effort to maximize their market share:

> "Buyers are confronted everywhere with an excessive sameness. When a new merchant or manufacturer sets up shop he must not produce something exactly like what is already on the market or he will risk a price war... But there is an incentive to make the new product very much like the old, applying some slight change which will seem an improvement to as many buyers as possible without ever going far in this direction. [This effect is] the tendency to make only slight deviations in order to have for the new commodity as many buyers of the old as possible, to get, so to speak, between one's competitors and a mass of customers" [Hotelling (1929)].

This tendency of manufacturers to "clump" their products together then creates the product segmentation articulated by Wendell Smith in 1956. However, considerable confusion exists within the marketing literature in describing and understanding the differences between market segmentation and product differentiation. Dickson and Ginter (April 1987) document the pervasive misunderstandings throughout the relevant literature, and offer a perspective on usage of the terms that will also be employed in this current research. As with Dickson and Ginter as well as Rosen (1974), in this research use of the term *market segmentation* will parallel economic demand theory in viewing products as "multicomponent packages of characteristics" [Rosen (1974)] with a distribution of value systems having "multiple regions of concentration surrounded by regions of sparseness" [Dickson and Ginter (April 1987)]. Such concentrations, or clustering, will become apparent as segments within the business airplane industry when the value and pricing of those products are studied later in Chapters 5 and 6.

In contrast to market segmentation, *product differentiation* is viewed as the variety of product price-value combinations offered by alternative goods within and among the different intra-market segments. A product is differentiated from competing alternatives when consumers are able to perceive differences in physical or non-physical characteristics, including price [Dickson and Ginter (April 1987)]. This definition is also consistent with the views of Chamberlin (1965) that the basis for differentiation could be real or imagined, arising from such disparate factors as product packaging, brand name or even distribution differences. In Chapter 6 the concept of product differentiation will be studied quantitatively using data from the business aviation industry.

4.3.1.3 Market Share

The linear demand model of Equation (4-34) yields an annual demand in units of the product; e.g., automobiles or airplanes. In many cases it will be more appropriate to determine the market share for a product rather than the unit demand. Consider that exogenous factors such as the world or national economy will influence the unit demand for products from year to year, and will act in the linear demand model through changes in the demand slope, *K*. It is assumed that the price elasticity remains approximately unchanged, though this may not always hold true, so changes in *K* arise from changes in the reference demand for the product segment. Without foreknowledge of such changes, the unit demand results from Equation (4-34) can be significantly in error when used for forecasting.

Market share for the i^{th} product, as a fraction of total demand, is given by

$$\pi_i = K\left\{(V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l)\right\} \Big/ D_T \tag{4-35}$$

This market share is for the product within its competitive segment (for which K is valid) and is a fraction of anticipated demand for all N products within that segment, D_T:

$$D_T = \sum_{i=1}^{N} K\left\{(V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l)\right\} \tag{4-36}$$

Since the coefficient K may be treated as a uniform quantity for the market segment under consideration, market share can be determined without knowledge of the actual value of K:

$$\pi_i = \left\{ (V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l) \right\} \Big/ \sum_{i=1}^{N} \left\{ (V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l) \right\} \qquad \textbf{(4-37)}$$

As exogenous factors alter D_T for the segment, the individual product demands can then be estimated using

$$D_i = \pi_i \cdot D_T \qquad \textbf{(4-38)}$$

4.3.2 Consumer Revealed Value (RV)

The Revealed Value (RV) of a product based on demonstrated consumer choices may now be determined using the consumer demand model from Equation (4-34). Writing a simultaneous set of the consumer demand equations in matrix form for $i = 1, 2, \ldots, N$ products yields the following:

$$\begin{bmatrix} D_1 \\ D_2 \\ \vdots \\ D_N \end{bmatrix} = \frac{K}{N}\begin{bmatrix} N & -1 & \cdots & -1 \\ -1 & N & & \vdots \\ \vdots & & \ddots & -1 \\ -1 & \cdots & -1 & N \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} - \frac{K}{N}\begin{bmatrix} N & -1 & \cdots & -1 \\ -1 & N & & \vdots \\ \vdots & & \ddots & -1 \\ -1 & \cdots & -1 & N \end{bmatrix}\begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_N \end{bmatrix} \qquad \textbf{(4-39)}$$

These equations may be solved for the vector of product values as given by:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{bmatrix} = \frac{N}{(N+1)K}\begin{bmatrix} 2 & 1 & \cdots & 1 \\ 1 & 2 & & \vdots \\ \vdots & & \ddots & 1 \\ 1 & \cdots & 1 & 2 \end{bmatrix}\begin{bmatrix} D_1 \\ D_2 \\ \vdots \\ D_N \end{bmatrix} + \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_N \end{bmatrix} \qquad \textbf{(4-40)}$$

These simultaneous equations reduce to the following Revealed Value for the i^{th} product:

$$\mathrm{RV}_i = \frac{N}{(N+1)K}(D_i + D_T) + P_i \qquad \textbf{(4-41)}$$

D_T is the total annual demand for the N products in the segment, Equation (4-36).

Because in Equation (4-41) value is related to the empirical demand for a product, this value is the *market perceived value* for that product. Ideally the results from Equation (4-41) and from the Value Index, Equation (4-24), would agree for existing products, therefore enhancing confidence in the RVI model for demand forecasting.

In a forthcoming text, Cook (2005) proposes an alternative value equation based on the logit model for consumer choice.* This approach to estimating Revealed Value allows larger deviations from the reference demand and price in a particular product segment; a significant shortcoming of the linear demand function approach.

$$\mathrm{RV}_i = \frac{D_T}{(N+1)K} \cdot \ln\left(\frac{D_i}{\overline{D}}\right) + \frac{D_T}{K} + P_i \qquad \textbf{(4-42)}$$

4.3.3 Fitting Value Index and Revealed Value

The compositional approach of §4.2 yielded mathematical forms for estimating product relative value, RVI, Equation (4-13) and absolute value, VI, Equation (4-24). The decompositional approach of §4.3.2 yielded another mathematical form for product Revealed Value, RV, based on empirical data, Equation (4-41) or (4-42). In these equations only the attribute exponential weighting factors, γ_i, are undetermined. Ideally the VI and RV calculations should agree for existing products. This presents an opportunity to determine the weighting factors since RV is known from empirical data. Setting RV and VI equivalent yields

$$\frac{N}{(N+1)K}(D_i + D_T) + P_i = V_0\left[v(g_{i1})^{\gamma 1}\, v(g_{i2})^{\gamma 2}\, v(g_{i3})^{\gamma 3} \ldots v(g_{in})^{\gamma n}\right] \qquad \textbf{(4-43)}$$

The weights in Equation (4-43) may be determined by a best fit (ordinary least squares or other optimization method) of individual product RV and VI results, either among competing products in one market segment or among multiple market segments. In the business aviation model the sum-squared error cost function will be minimized by varying the γ_j using a generalized reduced gradient (GRG) method:

$$J = \sum_{k=1}^{s} \sum_{i=1}^{N_k} (\mathrm{RV}_{ik} - \mathrm{VI}_{ik})^2 \qquad \textbf{(4-44)}$$

where s is the number of market segments under consideration and N_k is the number of products competing in the k^{th} segment.

Note that by equating VI to the Revealed Value, the resulting set of attribute weighting factors only indicate what attributes make products differentiable in the current market. The optimization routine leverages the attributes to minimize Equation (4-44) and only those

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* For more information on the logit form, see Ben-Akiva and Lerman (1985).

attributes that cause a product to be distinguished from another may be leveraged by the optimization. Therefore higher numerical values for weighting factors do not necessarily indicate importance of that attribute, but instead the contribution of that attribute to making products differentiable. Examples will be discussed in greater detail in Chapter 5 during development of the business aviation model.

The goodness of the fit resulting from the attribute weighting factor selection in Equation (4-44) may be assessed by calculating the multiple coefficient of determination, R^2:

$$R^2 = 1 - \frac{J}{SS_{RV}} \tag{4-45}$$

where

$$SS_{RV} = \sum_{k=1}^{s}\sum_{i=1}^{N_k} \mathrm{RV}_{ik}{}^2 - \frac{1}{N}\left(\sum_{k=1}^{s}\sum_{i=1}^{N_k} \mathrm{RV}_{ik}\right)^2 \tag{4-46}$$

where N is the total number of data points (products) across all segments in the RV sample. The multiple coefficient of determination represents the fraction of the sample variation of RV values that is attributable to the model. The F test statistic will also indicate the usefulness of the VI model in predicting RV:

$$\mathrm{F} = \frac{R^2/n}{(1-R^2)/[N-(n+1)]} \tag{4-47}$$

where n is the number of parameters (attributes) in the model. The model is useful for predicting RV if $\mathrm{F} > \mathrm{F}_{.05}(n, [N-(n+1)])$.

4.3.4 Alternative Methods for Setting Weighting Factors

The method of Equation (4-43) will be used in this research to estimate the attribute weighting factors, γ_j. But, as mentioned in the previous section, not all attributes might be leveraged by the optimization routine in minimizing Equation (4-44). Some important (but not differentiable) attributes may have zero values for their weighting factors. Additionally, some new attribute may characterize a proposed new product that is not currently available in the market, preventing an estimation of that attribute's weighting factor using a Revealed Value and the methods of §4.3.3. In these cases it will be necessary to estimate attribute weighting factors by some other means. Two alternatives are briefly discussed in this section: adjusting weighting factors by the percentage of time the attributes are experienced by the consumer, and by surveying product experts.

4.3.4.1 Consumer Experience of the Attribute

Some product attributes are directly experienced by the consumer for set durations of time. For example, a car occupant may be estimated to spend 60% of his total time in a car at highway cruise speeds. A set of attribute categories may then be developed based on the consumer's total experience using that product. In the car example, additional attributes may be added to account for lower cruise speeds (e.g., neighborhood cruise) and for periods of acceleration and deceleration. A value function considering only automobile interior noise might then take the following form:

$$\mathrm{RVI} = v(\underset{\substack{\textit{highway}\\ \textit{cruise}}}{g_{noise}})^{\gamma_{hc}}\, v(\underset{\substack{\textit{neighborhood}\\ \textit{cruise}}}{g_{noise}})^{\gamma_{nc}}\, v(\underset{\textit{accel}}{g_{noise}})^{\gamma_a}\, v(\underset{\textit{decel}}{g_{noise}})^{\gamma_d} \qquad \textbf{(4-48)}$$

Cook (1997) suggests that in these situations where attributes are easily categorized into durations of consumer experience, the attribute weighting factors reflect the fraction of time the attribute is experienced while using that product. With 60% of the occupant's time at highway cruise speeds, another 30% at neighborhood cruise speeds, and the remaining time split evenly between accelerating and decelerating, the attribute weights would then be

$$\mathrm{RVI} = v(\underset{\substack{\textit{highway}\\ \textit{cruise}}}{g_{noise}})^{0.60}\, v(\underset{\substack{\textit{neighborhood}\\ \textit{cruise}}}{g_{noise}})^{0.30}\, v(\underset{\textit{accel}}{g_{noise}})^{0.05}\, v(\underset{\textit{decel}}{g_{noise}})^{0.05} \qquad \textbf{(4-49)}$$

The method becomes problematic when attributes such as fuel economy or headroom are considered; over what fraction of time does the owner experience these attributes? Should the weighting factor automatically be 1.0 for such parameters, even if a particular attribute intuitively seems unimportant?

4.3.4.2 Cook's Subjective Estimation Method

In his forthcoming text, Cook (2005) proposes a structured method for essentially asking product experts their opinion of at what levels attribute weighting factors should be set. This method lends a quantitative element to an otherwise qualitative decision, perhaps enhancing the credibility of the final results. Cook provides no studies or data indicating the usefulness or ability of the method to develop reliable value models. For the reader's edification, the algorithm for Cook's estimation method is documented here:

1. Assemble a team of 6 to 8 persons who are familiar with customer needs.
2. Identify the baseline attribute level, g_0
3. Identify the critical attribute level, g_C
4. Identify the ideal attribute level, g_I
5. Sketch a value curve for the attribute similar to Figure 42 or Figure 43 depending on whether the attribute is of the LIB or SIB type.
6. Survey each team member using the Direct Value method of Cook (1997) to identify the neutral price, $P_N(g^*)$, for the attribute at g^* relative to the baseline attribute g_0 at the baseline price P_0. The neutral price is the price of the alternative at which one-half of the team would buy the alternative at $P_N(g^*)$ and the other half of the team would buy the baseline at price P_0.
7. Set the baseline value at $V_0 = 2 \cdot P_0$ and calculate the value of the attribute at g^* as $V(g^*) = P_0 + P_N(g^*)$
8. Compute the exponential weighting factor using

$$\gamma = \frac{\ln\left(V(g^*)/V_0\right)}{\ln\left[\frac{(g_I - g_C)^2 - (g_I - g^*)^2}{(g_I - g_C)^2 - (g_I - g_0)^2}\right]} \qquad \textbf{(4-50)}$$

4.3.4.3 Parametric Study

When considering attributes for which weighting factors are not available, or for which the existing weighting factors are in doubt, this author recommends treating the weights in a parametric fashion. When estimating the RVI (or Value Index) for a new product, make the value calculations for several different values of the attribute weighting factors and assess the sensitivity of the final result to the level of the exponential weight. The numerical values used for the weights should span or perhaps exceed any anticipated values those weighting factors could assume. The non-dimensional elasticity of the attribute, Equation (4-21), will vary linearly with the weighting factor and should also be assessed.

4.4 Summary: Implementing the Relative Value Index Approach

The RVI approach has many features and can seem complicated when first communicated. Here, the basic steps for implementing the RVI approach are listed, in order, to aid in getting started. References are made to the sections in this chapter where details on implementing the steps may be found.

1. Identify the product market of interest and perform a preliminary segmentation of the market (the market can later be re-segmented based on the outcome of the RVI analysis). Gather required information such as the market price elasticities, E_p, empirical demand data, pricing data, etc.

2. Identify attributes thought to be of importance to the product (§4.1.2.2). Address issues of multicollinearity in the attributes (§4.1.2.4).

3. Categorize the attributes as larger-is-better (Figure 42) or smaller-is-better (Figure 43). Recall that nominal-is-better type attributes are prohibited to comply with the axioms of utility theory and ensure a unique value assessment.

4. Bound the attributes by their critical, g_C, ideal, g_I, and baseline levels, g_0 (§4.1.2.1)

   Note that Equation (4-9) for the attribute part-worth value contribution, $v(g)$, is now determinant. In addition, Equation (4-13) for the Relative Value Index, RVI, is now determinant except for the attribute exponential weighting factors.

5. Determine what approach will be used for the baseline product value, V_0 (§4.2.4.2). It is suggested that Equation (4-27) be used if multiple segments are under consideration.

   Note that Equation (4-24) for the Value Index, VI, is now determinant except for the attribute exponential weighting factors.

6. Calculate the Revealed Value, RV, of the products based on empirical demand and pricing data, Equation (4-41) or (4-42).

7. Equate the Value Index and Revealed Value as shown in Equation (4-43). Depending on the form chosen for the baseline product value, V_0, an ordinary least squares regression technique may be used to determine a set of weighting factors, γ, for a best fit of the two equations (take the natural logarithm of both sides, etc.). If Equation (4-27) is used for V_0 then an optimization technique, such as a generalized reduced gradient (GRG) routine to minimize the cost function of Equation (4-44), may prove more useful.

8. Use the resulting, fully determinant RVI model of Equation (4-13) for new product design, market share analysis (§4.3.1.3), marginal analysis (§0), market segmentation, etc.

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5 DEVELOPMENT OF A BUSINESS AVIATION RELATIVE VALUE INDEX

The Relative Value Index fundamentals developed in Chapter 4 are applied in this chapter to the development of a business airplane value assessment approach using the multi-attribute RVI model. While firmly based in economics and pricing theory, the structure of this approach also finds traction in behavioral psychology as a compensatory decision rule. Decision rules are said to be compensatory when good performance on one evaluative criterion may offset or compensate for poor performance on another evaluative criterion. Loudon and Della Bitta (1993) indicate that "compensatory strategies tend to be utilized under high-involvement conditions when the number of alternatives is small and the evaluative criteria may be large, and by those with greater education." This structure is entirely appropriate for business airplane assessment where the evoked set (consideration set) is typically small, the attributes under consideration are numerous, and the purchase decision-makers are highly involved in the evaluative process. Industry marketing experts and observers interviewed for this research agree that business airplane assessment typically follows a compensatory-type strategy.

In this chapter the philosophy and structure of the approach are briefly outlined, including a rationale for choosing the business aviation industry as a test case for the methodology. Product attributes for the RVI model are identified and bounded, then set using the Revealed Value approach of Chapter 4. Finally, results for the current business airplane market are presented and discussed.

As noted in Chapter 2, the terms "business aviation industry" and "business airplane industry" are used frequently in this study. Though "business airplane" more precisely limits the topic to fixed-wing aircraft and excludes rotorcraft, the two terms will be used here interchangeably.

5.1 Philosophy and Structure of the Approach

It was of importance in this research that a firm set of applications be identified and utilized to test and exercise the theoretical concepts that were to be developed. An application-oriented plan of research was felt by the author to be of great importance to the extent that the research would make a contribution to science and industry. The author's familiarity with the business aviation industry was happily synergistic with the need for case studies and examples in the research. In this section the appropriateness of the business aviation industry for evaluating the value concepts is argued, and a case is made for why an industry-wide comparison model was developed instead of a segment-specific model.

5.1.1 Choosing Business Aviation: Organizational Buyers

Though we often refer to a "decision maker" or "consumer" in this research, these actors may be individual persons or a group of persons – an organization – such as a firm. Consumer behavior theory subdivides markets into two major categories: final consumers and organizational buyers. Final consumers purchase for their personal or household use and are represented by the average grocery shopper or car buyer. Organizational buying "is the decision-making process by which organizations establish the need for purchased products and services, and identify, evaluate, and choose among alternative brands and suppliers" [Loudon and Della Bitta (1993)]. Organizational buyers are often differentiated from final consumers as being highly knowledgeable about the products or services being bought, and strongly directed by motivations that are generally economically based.

General aviation aircraft buyers are typically segmented by industry marketing departments in a similar fashion: owner/operators who purchase and use the product personally, and professional operators who may manage a flight department with multiple aircraft for a large corporation. The owner/operator may often be thought of as purchasing a general aviation aircraft; in other words a smaller and less expensive aircraft, often piston-powered and propeller-driven, and not intended primarily for business use. Business airplane purchasers are often considered to be organizational buyers, making the purchase on behalf of a larger organization intending to use the aircraft primarily for business. Business airplanes are mostly considered to be more expensive, turbine-powered and either propeller- or jet-driven. Many argue that the more expensive aircraft are professionally maintained and operated, and thus are largely purchased by organizational buyers. These assumptions are simplistic and there are important exceptions but, at a minimum, they make choosing the business aviation industry as a study case for the RVI approach feasible if the organizational buyer is indeed driven by a more economically-driven set of motivations.*

Organizational buying may involve a number of individuals evaluating an aircraft before a final purchase decision is made, again supporting the supposition that the final decision is somewhat more objective and value based than for the typical owner/operator, to whom the purchase need not be justified to anyone but himself. Bonoma (May-June 1982) provides an illustrative example of the business airplane purchase decision.

> "The purchase process may be initiated by the chief executive officer, a board member, the company's chief pilot, or through vendor efforts like advertising or a sales visit. The CEO will be central in deciding whether to buy the jet, but he or she will be heavily influenced by the company's pilot, financial officer, and perhaps by the board itself."

Although emotional decisions are not to be neglected in this research, the business aircraft buying decision will be assumed in this study to be largely motivated by an objectively-based decision calculus.

5.1.2 Choosing an Industry-Wide Model versus Segment-Specific Model

In this study the RVI model is developed to study the business aviation market as a whole; from small turboprops to large, long-range jets. There are three reasons for treating the industry as a whole instead of developing individual models for each market segment. First, it was desired that inter-segment comparisons of aircraft be possible for purposes of studying existing and new designs. If a designer proposes a new aircraft for the upper end of the midsize jet segment, it should be possible for that designer to determine if the proposal is perhaps too close to the lower end of the next larger jet segment. Similarly, the business aviation industry is very dynamic at this point in history, with old segments fragmenting and new ones developing year-by-year. The RVI model, if developed for the industry as a whole, presents an interesting opportunity to examine these dynamics over time and see the evolution of the market. It is also important for designers to be able to recognize available market niches for new product

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* It is interesting to note that many industry marketing specialists contend that, frequently, purchase decisions are made based on emotional factors, but then are justified to a higher authority (e.g., a board of directors) based on a rational decision calculus. The underlying presumption in this study is that some element of rational decision-making occurs, even at a secondary level, since the final decision must be justified on this basis.

development. An industry-wide model is particularly suited for assessing market niches, as will be demonstrated in Chapter 6.

The second reason for developing an industry-wide model rather than a segment-specific model is to be found in the operational concerns of making the model work. In any given business airplane market segment (e.g., turbo-props, midsize, etc.) there have historically been only a handful of competing aircraft models at any single time. This arises partly from the limited market for such products and partly from the limited number of manufacturers worldwide (perhaps also a result of the limited market). A segment-specific model that, for example, focused on the midsize jet segment, might have only four competing aircraft in the segment. The reliability of the method of optimizing the fit between the Value Index and the Revealed Value equations for determining the attribute weighting factors is dependent on the number of products being compared. The statistical significance of the final result becomes problematic if the number of products being compared is significantly less than 30. Industry-wide there are typically 25 or more business aircraft competing at any single time.

A final reason for developing an industry-wide model is rooted in extending the frontiers of knowledge. To date, this author has not found an example of value methods being used for anything other than intra-segment comparisons of products. A case in point is Cook's evaluation of the midsize sedan automobile market [Cook (1997)]. The business aviation industry offers an opportunity to advance the practice of value assessment one additional small step.

5.1.3 A Note on the Data Implemented in the Approach

It was noted in Chapter 2 that the year 2001 was the last year for which complete shipments data is available for the business airplane industry. In 2002 a major manufacturer chose to cease reporting detailed shipment data for each airplane model, and instead started reporting only total shipments for the company. For this reason, any analysis requiring shipments data cannot be conducted for years after 2001.

For significant portions of this study, the yearly aircraft attribute data (i.e., speed, range, etc.), as well as list prices and unit shipments, will be averaged using a three-year rolling average (e.g., 1998-2000, 1999-2001, etc.). This is done, in part, to help smooth the data and make the analyses more robust to year-to-year errors or inconsistencies in the data reported in the published sources. A more detailed study of the effects of this averaging will be discussed in Chapter 6.

The "current market" for business airplanes will be considered in this study to consist of the 1999-2001 averaged market. As noted, this is the last three-year market for which detailed shipments data are available.

5.2 Attribute Identification and Bounding

As noted in Chapter 4, any given product will necessarily have numerous attributes that could be measured, counted, recorded and studied for a compositional approach such as the RVI method. In this section a finite number of primary attributes are identified for business aviation products. The issues of multicollinearity and unidentified or difficult-to-quantify attributes are also discussed. Bounds are placed on the final set of attributes that were selected for the model in this study.

5.2.1 Attribute Identification

Several means exist for identifying the attributes relevant to consumers in forming their preferences. Green and Srinivasan (September 1978) list several approaches, including preliminary data collection surveys of consumers in which primary attributes may be identified. In this research attributes were identified based on industry expert interviews – judgments of product managers, marketing managers, and outside consultants – and by studying what information is available to the consumer from industry trade journals. As Green and Srinivasan state: "The more difficult and often subjective task is to reduce the number of attributes to a manageable size so that the estimation procedures are reliable while at the same time accounting for consumer preferences sufficiently well."

Interviews with industry marketing and product managers indicate a wide belief that the parameters in the Traditional Value Index (TVI) model address some of the primary technical attributes of interest to the aggregate market of business airplane customers, though additional important attributes include operating costs and load carrying capability. From the discussion on consumer choice in Chapter 3, it should be recalled that there is believed to be a finite number of attributes that consumers can consider in their purchase decision. The business aircraft customer is assumed to be an engaged and intelligent consumer, so the number of attributes considered may be greater than in other purchase decisions such as automobiles. It is also assumed by most business aviation industry experts that consumers, in a first phase of decision making, sort themselves into product segments using primary attributes such as purchase price, range and payload. Once an evoked set of aircraft is developed within a segment, a more detailed analysis of the evoked set is then conducted based, again, on purchase price, range and payload, plus many of the other attributes that will be discussed here. It cannot be assumed that every customer is aware of every possible attribute for a particular product, or even that the customer is aware of the same attributes for a number of products. However, the assumption will be made here that consumers are, at a minimum, aware of the attributes published in trade journals such as *Business and Commercial Aviation.*

Unfortunately, no specific studies on the aircraft purchase decision have been published, but in this initial study the number of attributes considered for the RVI assessment will be limited to only a handful of those more easily accessible and quantifiable*. Undoubtedly there are other attributes to be considered than those currently in the TVI model, plus the aforementioned operating costs and payload. Other attributes thought to be of importance include the mission reliability of the aircraft (what fraction of the time is it available to perform the required transportation mission) and the level of after-sales support provided by the manufacturer. Cabin noise and lighting levels in flight, the level of avionics equipment in the cockpit, and systems available to passengers such as communications and entertainment are also thought to effect customer preferences in the purchase decision. A nebulous product "quality" is often raised in discussions with industry experts, and attempts to identify and quantify quality are discussed in this section as well.

5.2.1.1 Quantified Attributes and Multicollinearity

One may wish to review in Chapter 2 the itemization and critical assessment of the business aviation database that was compiled for this research. Of the attributes thought to be of primary importance, consistent and quantitative data is available for current and historical

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* It might be supposed that, since certain attributes are easily accessible in industry publications, those attributes must be of the most importance to consumers. Conversely, it could be argued that these attributes are simply those that are most easily quantified. Industry experts tend to believe the primary attributes of interest, for an aggregate market, are quantified but that some important parameters, such as reliability, remain poorly quantified.

business airplane products for the following (recall that price will be treated as an independent variable and will not have a direct effect on product value):

- maximum cruise speed (ktas)
- cruise speed for maximum range (ktas)
- maximum range with executive payload (nm)
- typical executive seating capacity (pax)
- cabin volume (cu. ft.)
- runway field length (ft.)
- fuel consumption at long-range cruise speed (lb/hr)

Refer to the database itemization in Chapter 2 for greater detail on the attributes listed here.

As mentioned in Chapter 2, estimates on operating costs are publicly available for some types of current business aircraft. Unfortunately the data is not available for an historical set of aircraft so, as a proxy for direct operating cost, the aircraft fuel consumption, in pounds of fuel per hour, is used instead (see Chapter 2 for more discussion of this choice).

As noted previously, attributes cannot simply be combined into the multi-attribute value model without first checking for correlations between the variables. The pair-wise correlation coefficient, *r*, was calculated for each possible attribute combination across observations (i.e., across the different aircraft). Table 6 shows the correlations for the aircraft offered in the 1999-2001 market.

Table 6: Pair-Wise Correlation Coefficients for Current Business Airplane Market

	Max. Range	Max. Speed	Cabin Vol.	Field Length	Fuel Consump.	Pax. Exec.
Max. Range	1	0.65	0.94	0.80	0.93	0.92
Max. Speed		1	0.57	0.84	0.78	0.66
Cabin Volume			1	0.73	0.93	0.95
Field Length				1	0.86	0.74
Fuel Consumption					1	0.93
Passengers, Exec. Config.						1

Parameters with high correlations, typically considered $r \geq 0.85$, provide redundant information and, though inclusion of the parameters may provide better predictive capability in mathematical models, they reduce the explanatory power of the model as the user is not able to properly apportion the part-worth contributions of the correlated parameters. All attributes considered for the model are important, but because of physical laws and design tradeoffs some attributes are forced into dependency with others. An example is "rate of fuel consumption" growing proportionally with "maximum aircraft range" due to a common dependence on aircraft weight. Since the attributes are not independent they are not both meaningful and should be combined into alternative, meaningful parameters with lower *r*-values. Another option is to eliminate one of the correlated parameters, but this strategy is problematic as one does not want to eliminate design considerations.

In this study, parameter correlations are addressed as much as possible by combining several parameters into three new but meaningful attributes: available seat miles (nm-pax; a measure of load-carrying capability as well as range), cabin volume per passenger (cu. ft./pax; a measure of passenger comfort), and fuel consumption per seat mile (lb/nm/pax; a proxy for operating costs as well as range and payload capability).

$$\text{available seat miles} = (\text{exec. payload range}) \cdot (\text{exec. payload seating}) \tag{5-1}$$

$$\text{cabin volume per passenger} = \frac{\text{cabin volume}}{\text{exec. payload seating}} \tag{5-2}$$

$$\text{fuel consumption per seat mile} = \frac{\text{fuel consumption for long range speed}}{(\text{long range cruise speed}) \cdot (\text{exec. payload seating})} \tag{5-3}$$

The pair-wise correlations for the new set of attributes is shown in Table 7. The pairs field length and maximum speed, and cabin volume per passenger and available seat-miles, still show a relatively high correlation while the other pair-wise combinations are relatively uncorrelated. No additional sets of meaningful attributes have been discovered to lower the correlations of the two attribute pairs with $r = 0.84$, so the five attributes listed in Table 7 will be used in the RVI developed for the business aviation industry.

Table 7: Revised Attribute Correlation Coefficients for Current Business Airplane Market

	Max. Speed	Field Length	Seat Miles	Volume/ Pax	Fuel/ Seat-Mi
Max. Cruise Speed	1	0.84	0.57	0.51	0.30
Field Length		1	0.69	0.75	0.54
Available Seat Miles			1	0.84	0.35
Cabin Volume per Passenger				1	0.55
Fuel Consump./ Seat-Mile					1

5.2.1.2 Missing or Less Easily Quantified Attributes

Industry marketing and product managers have indicated their belief that additional attributes, particularly dispatch reliability and after-sales customer support, are equally or more important to the customer purchase decision than the technical factors considered in the study up to this point. This author agrees that the RVI approach's usefulness in practical applications is limited without the inclusion of reliability and support data. Unfortunately reliability statistics have not, until very recently, been formally collected in the business airplane industry and are currently not publicly available*. Quantification of customer support levels is also difficult as they can vary widely from product to product even within the same manufacturer's product line. At least one manufacturer has tried to quantify customer support through factors such as the number of manufacturer-approved service centers in North America. This data can be obtained for the five major business airframe manufacturers, but to date adding service center data to the RVI model has failed to improve the best fit results or the explanatory power of the model. Two industry publications, *Aviation International News* and *Professional Pilot,* currently issue annual customer support surveys based on reader feedback. Unfortunately the surveys are variable in the number of participants, from as few as ten survey responses to as many as several hundred for any given airplane model. As a result the data is not statistically reliable enough for meaningful analysis in this research.

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* This is based on discussions with several industry marketing managers for the major business airplane manufacturers.

There are, however, unarguably important attributes missing from the RVI model. An analysis of model results for competitive segments throughout the past decade indicates that the products of some manufacturers are consistently under- or over-valued by the model, indicating the possibility that there are important non-technical manufacturer-related attributes not yet considered in the analysis (see Chapter 6 for details). Customer support may be one factor, and it is anticipated that price discounting, warranty packages, delivery squawks (faults) and other as-yet difficult-to-quantify features will be proven to play an important role in the product value equation.

In Chapter 6 it will be noted that a failed early business jet design, the HFB Hansa Jet from Germany, is highly valued as the RVI model is currently structured around technical attributes. The design failed, in part, from negative market perceptions due to crashes of the prototype in flight test, and also from a lack of access to the important North American market [Pattillo (1998)]. These are attributes, while difficult to quantify, that should be added to the RVI model for a full and proper assessment of the early business airplane market.

Some neglected attributes seem important based on anecdotal evidence from industry experts. Tales abound of lost sales due to inadequate fresh water or potty (toilet) capacity onboard the aircraft, and sales gained due to the newness of the avionics suite in the cockpit, the size of the cabin windows, or the intensity of the artificial lighting in the cabin. The stories are compelling, but consistent data on these and other attributes is not available, nor is there evidence that the attributes have played a role in the choices of the market in aggregate as opposed to only representing isolated personal preferences. At least two other parameters that have been mentioned repeatedly by those interviewed for this study are the installed base of customers for the manufacturer, and whether the manufacturer's factory is based outside of North America. A greater installed base of customers, most of whom are assumed to be brand-loyal by industry marketing departments, is said to improve the market potential of new products. Conversely, if the manufacturer has their factory located outside of North America it is suspected that the market potential of products is reduced. Little compelling data exists to substantiate or refute either assertion. There is a need to pursue, at least in a preliminary manner, whether some of these neglected attributes are indeed playing a role in the overall market.

It is also worth noting that some attributes are not observable, even if quantitative data is available. As an example, all turbofan-powered business airplanes today have aft-mounted engines (most are twin (Figure 47), but the Dassault Falcon 50EX, Falcon 900C and Falcon 900EX have aft-mounted tri-jet configurations). To date, no turbofan-powered business airplane is on the market with engines mounted, for example, on the wings or elsewhere (Figure 48). For this reason there is no practical way to determine with empirical data what influence the engine location has on a business turbofan's success in the market. With the limited number of aircraft offering tri-jet configurations it is difficult to assess the impact of the third engine as well. A conjoint analysis (Chapter 3) may be conducted to forecast the effect of alternative numbers and mounting arrangements using consumer stated preference data and, in this way, the exponential weighting factor of an appropriate attribute might be estimated. But empirically the effect is not observable, although this should not be construed as an indication that the effect is unimportant.

Figure 47: Typical Aft-Mounted, Twin-Engine Business Turbofan (Lear 31)

(source: Bombardier Aerospace)

Figure 48: Early Business Jet Prototype with Wing-Mounted Engines (McDonnell 119)

(source: *Business & Commercial Aviation*, April 2000)

Another factor to consider in choosing attributes is that regulations or laws are typically not considered since all products, presumably, must meet them. For example, all in-service business airplanes flying in North America must meet the Federal Aviation Administration's Stage 3 noise requirements that govern the acceptable noise levels for aircraft engines. The European certification authorities have similar regulations, so if an aircraft did not meet the regulations there would effectively be no sales of that aircraft. The practical result is that the engine noise attribute, although very important in legally operating the aircraft, is neglected since all new aircraft design proposals would have to meet the law. The exception to neglecting the attribute would be if exceeding the regulation is seen as enhancing the value of the product. An example might be exceeding the Federal standards for engine exhaust emissions in a car, which environmentally conscious consumers would be concerned about.

As a final note, it is important to recognize that the customer perception of an attribute is in most cases more important than the actual attribute level itself. As an example, single-engine turbo-prop aircraft have a perceived problem with safety since they have only one engine [Esler (October 2002)]. In decades past, engine reliability was low relative to modern engines and multi-engine aircraft added a degree of true safety for when one engine failed in flight. Modern engines are far more reliable and current accident data does not support the belief that single-engine aircraft are any less safe than multi-engine aircraft. There are only a couple of single-engine aircraft available on the current business airplane market, so it is difficult to assess the impact that safety concerns may be having on sales. It is important to understand that such perceptions could play an important role and may need to be considered when using attributes and attribute data in the RVI model.

5.2.2 Attribute Bounding

Critical, baseline and ideal levels are next determined for the attributes listed in Table 7. Baseline attribute levels, g_0, were determined based on historical averages for the industry (Table 8). Using only averages for those aircraft being marketed today would alter the baseline numbers slightly. But it was desired that the same model parameters be useful for an historical range of aircraft, and altering the bounds by a slight amount did not appreciably affect the final RVI results (Chapter 6)

Table 8: Business Airplane Relative Value Index Model Attributes

			Attribute Bounds		
Attribute	Units	Type	Critical	Baseline	Ideal
Max. Cruise Speed	ktas	LIB	61	391	2,866
Field Length	feet	SIB	10,000	4,000	3,000
Fuel Consump./ Seat-Mile	lb/nm/pax	SIB	1.0	0.4	0.0
Cabin Volume per Passenger	cu. ft./ pax	LIB	20	60	150
Available Seat Miles	pax-nm	LIB	900	21,000	100,000

The critical level for "maximum cruise speed" is based on the maximum speed of the nearest competing form of transportation most popular in North America: the automobile at 70 mph. Business aviation industry experts interviewed for this research indicate that the most frequently used airports in business aviation had runway field lengths of between 3,000 and 7,000 ft. In examining the airplane database compiled for this research it does become apparent that the industry has converged to products with field lengths less than 7,000 ft. However, the "field length" critical level of 10,000 feet in Table 8 reflects the length of some of the longest runways in North America (Figure 49) since the product would not be completely valueless to business customers until this point. The critical levels for "fuel consumption per seat-mile" and "available seat miles" were estimated as being just above the maximum fuel consumption value for the industry and just below the minimum seat-miles seen in the database. These estimates were made based on the supposition that products introduced with performance poorer than historical minimums would be likely to compete poorly in the market. The "cabin volume per passenger" attribute levels will be discussed in a moment.

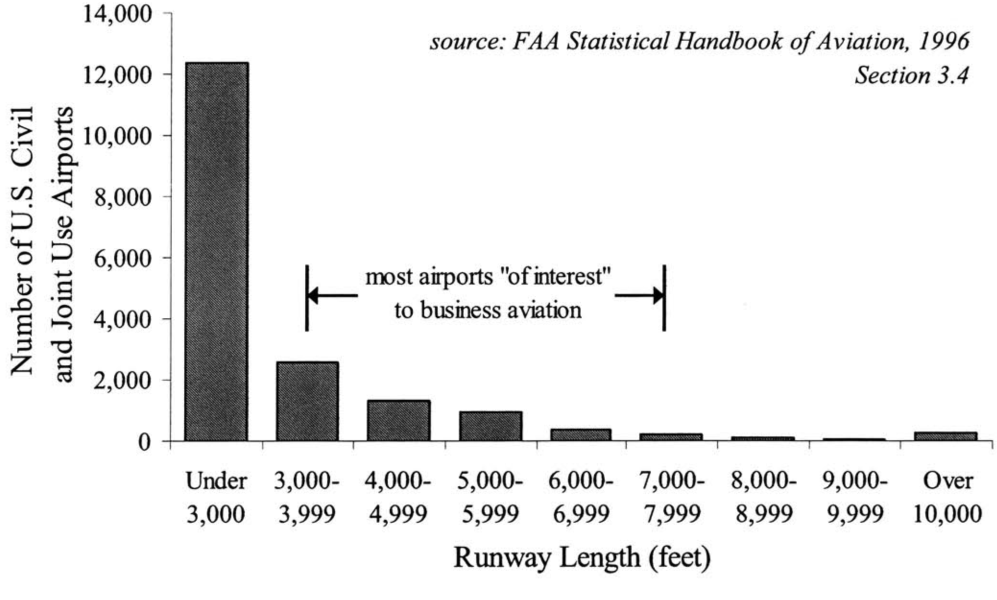

Figure 49: Runway Length Data for United States Civil and Joint Use Airports

The ideal "maximum cruise speed" attribute level is based on the requirement that an aircraft be able to reach, without refueling, any point on the Earth's surface in five hours or less. This allows for a 12 hour travel day with a minimum of two hours on the ground at the destination for a business meeting. The resultant ideal cruise speed is Mach 5.0 (2,866 ktas) at altitudes above 36,089 feet.* The 12 hour travel day to any point on Earth is often used as a goal for the design of supersonic business aircraft. It was desired that the RVI model be useful for the assessment of such proposals so the ideal was incorporated here. The "field length" level is that runway length judged to typically be the shortest for most airports that business aviation customers desire to fly into. Some business airplanes (most notably, turboprop airplanes) do have shorter field length performance for some customers that regularly need to get in and out of airports with shorter runways. The theoretical minimum of zero feet for field length could easily have been used as well, and the impacts of adjusting the attribute bounds will be addressed in Chapter 6. The theoretical minimum of zero lb/nm/pax was used for the "fuel consumption per seat-mile" attribute. The "available seat-miles" ideal level is an estimate based on historical data and reflects some effort to foresee a future dividing line between the capacity of private business aircraft versus small commercial aircraft.

All three attribute levels were developed for the "cabin volume per passenger" attribute based on historical offerings in the business aviation industry. Figure 50 shows all business aircraft in the database compiled for this research plotted as functions of their typical executive passenger capacities and cabin volumes. Two clear trends are evident in the figure for the minimum cabin volume per passenger and the maximum. The approximate slopes of the trend lines are used for the critical and ideal attribute levels, with an estimated average of 60 cu. ft./passenger used as the baseline value. Figure 50 also clearly shows a break in the lower trendline for aircraft with a typical executive configure for more than 8-10 passengers. The critical attribute level, g_C, was initially set to a dynamic level that changed based on the passenger capacity of the aircraft being analyzed; from 20 cu. ft./passenger for configurations with 8 passengers or less, to 60 cu. ft./passenger for configurations with more than 8 passengers (the baseline attribute level, g_0, changed as well while the ideal level remained unchanged). Through experimentation with the model it was found that the dynamic attribute levels did not appreciably affect the RVI results, while at the same time a fair degree of complexity had been added to the model, so the dynamic element was eventually replaced by the static levels shown in Table 8.

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* This altitude is the tropopause, which marks the end of the troposphere and the beginning of the stratosphere. Above this altitude the standard temperature is constant and, hence, the speed of sound is a constant 573.21 knots.

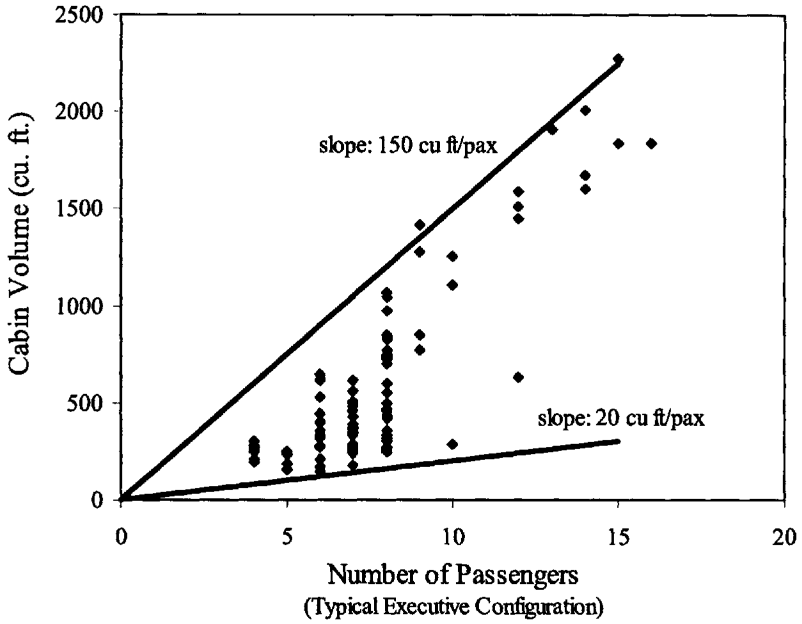

Figure 50: Historical Trend of Cabin Volume per Passenger

It was also initially thought that critical and ideal levels would necessarily change based on the length of time passengers were to spend onboard the aircraft. On short trips a small cabin would be acceptable, but less so on longer duration trips where large cabins would be preferred. However, the aircraft range and passenger capacity attributes are highly correlated ($r = 0.92$ in Table 6) so the results of using Figure 50 effectively account for aircraft range. If a new design proposal were to offer a long range aircraft with few passengers, or a short range aircraft with a large number of passengers, this "cabin volume per passenger" attribute would need to be reevaluated. The inability to place convereted commercial aircraft (e.g., the Boeing BBJ and Airbus ACJ) on Figure 50 in any consistent manner makes their inclusion in the RVI analysis problematic. Though the cabin volume of the commercial aircraft is fixed, the number of passengers accommodated is dependent on the customer's choices in configuring the cabin, and may vary greatly among customers.

5.3 Setting Attribute Weighting Factors

The Revealed Value (RV) method for setting attribute weighting factors, developed in Chapter 4, is used in this study for the business aviation RVI model. In this section the consumer RV for the business aviation products is estimated and the RVI attribute weighting factors are determined using an optimization technique as described in Chapter 4.

5.3.1 Consumer Revealed Value

The turbine business airplanes offered in the 1999-2001 market were grouped into the seven competitive segments ($s = 7$) shown in Table 9. (Note that both the Raytheon Premier I and Dassault Falcon 900C are omitted from consideration. The year 2001 was the first year of shipments for the Premier, thus insufficient data existed to determine the true market appeal for the aircraft, and the Falcon 900C experienced unusually low shipments in 2000 and 2001, perhaps a consequence of manufacturer-imposed limits and not a reflection of the true market appeal of the aircraft.)

The Revealed Value of each aircraft within the seven segments was determined from known pricing and annual unit shipments data (averaged over three years to smooth the data), and with an estimated price elasticity of $E_p = 1.5$ based on interviews with industry marketing experts. The equation for Revealed Value, discussed in Chapter 4, is reproduced below in Equation (4-42):

$$\mathrm{RV}_i = \frac{D_T}{(N+1)K} \cdot \ln\left(\frac{D_i}{\overline{D}}\right) + \frac{D_T}{K} + P_i \qquad \textbf{(5-4)}$$

The resulting set of product RVs are shown in Figure 51 with some aircraft labeled for reference. It is interesting to note that the super midsize jet segment clearly emerges as an in-demand, highly valued segment for this particular market. Conversely, one might argue that the large jet segment is currently showing weakness. Most industry experts agree that the super midsize segment is one of the fastest-growing segments today, and the truth of the actual market dynamics may be a combination of a lagging large jet segment and a surging super midsize segment. This raises the point that product absolute value can change from year-to-year without the product attributes having changed. This is made possible in the VI equation through alterations in the baseline product value, V_0.

The data in Figure 51 also shows a linear trend of value with price, which will be compared with the RVI results later.

Table 9: Current Market Competitive Segments, Prices, Shipments and Attribute Data

Segment	Airplanes	Price[a]	Shipments[a]	Max. Cruise Speed	Field Length	Fuel Consump./ Seat-Mile	Cabin Volume/ Passenger	Available Seat Miles
($s = 7$)		(US$ millions)	(units)	(ktas)	(feet)	(lb/nm/ pax)	(cu. ft./ pax)	(pax-nm)
Medium Turboprops & Very Light Jets ($N_1 = 5$)	Socata TBM 700	2.36	22.7	300	2136	0.20	49	4835
	Cessna Caravan I	1.44	18.3	186	2053	0.45	76	2284
	Pilatus PC-12	2.83	64.7	270	2300	0.19	68	8496
	Ray. K.A. C90B	2.82	42.7	247	2710	0.41	70	3810
	Cessna CJ1	3.74	58.5	377	3280	0.45	63	4093
Heavy Turboprops & Light Jets ($N_2 = 5$)	Piaggio P-180	4.64	9.0	392	2850	0.18	71	9923
	Ray. K.A B200	4.29	49.7	291	3300	0.32	60	7272
	Ray. K.A 350	5.28	40.0	311	3737	0.21	53	12192
	Cessna CJ2	4.71	24.5	407	3420	0.28	53	7719
	Cessna Bravo	5.20	46.0	400	3600	0.25	51	9829
Light Jets ($N_3 = 3$)	Bom. Lear 31A	6.41	23.0	458	3280	0.27	42	9030
	Cessna Encore	7.13	21.5	426	3490	0.31	56	10508
	Raytheon 400A	6.39	41.3	450	3906	0.32	52	8397
Midsize Jets ($N_4 = 4$)	Bom. Lear 45	8.87	59.0	456	4350	0.28	62	15080
	Bom. Lear 60	11.65	32.0	453	5450	0.44	89	13734
	Cessna Excel	9.02	67.7	423	3590	0.31	75	11860
	Raytheon 800XP	11.85	59.0	447	5032	0.38	91	19256
Super Midsize Jets ($N_5 = 4$)	Cessna Citation X	17.50	35.7	505	5140	0.41	94	24069
	Das. Falcon 50EX	18.27	14.0	457	4890	0.40	94	28719
	Bom. Chall. 604	22.51	40.3	468	5840	0.48	142	35757
	Das. Falcon 2000	20.63	31.7	479	5436	0.31	126	29165
Large Jets ($N_6 = 2$)	Das. Falcon 900EX	31.17	20.0	474	5213	0.35	132	50734
	Gulf. G-IV-SP	30.69	37.3	480	5450	0.42	143	56462
Long Range Jets ($N_7 = 2$)	Bom. Global Ex.	40.13	32.3	499	5820	0.40	150	95850
	Gulfstream G-V	40.48	33.3	488	5150	0.35	123	85358

[a] based on a 3-year average, 1999-2001

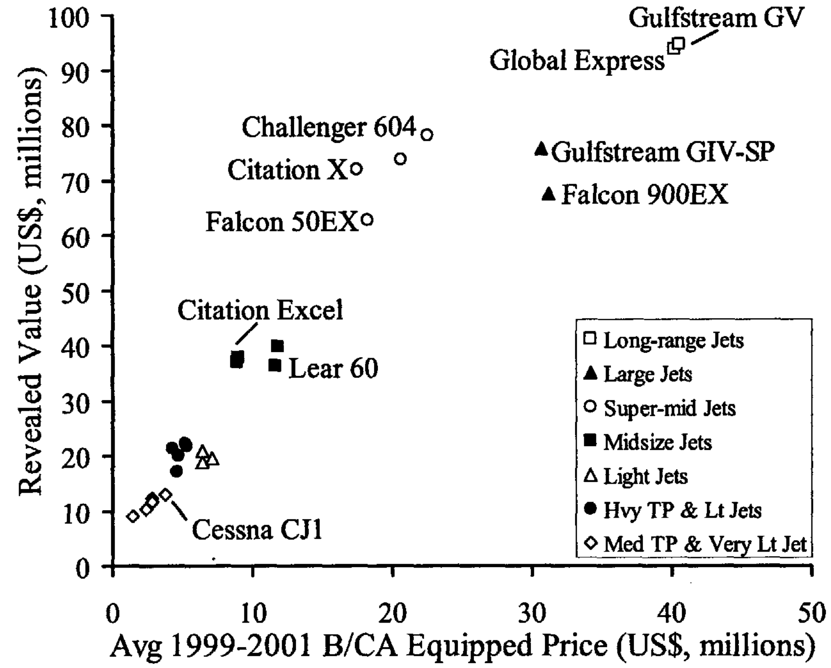

Figure 51: Revealed Value for the Current Business Airplane Market

5.3.2 Attribute Weighting by Best Fit

Given the attribute bounds in Table 8 and the information in Table 9, all parameters are known for the Value Index, developed in Chapter 4 and reproduced here again in Equation (5-5):

$$\mathrm{VI}_i = V_0 \left[v(g_{i1})^{\gamma_1}\, v(g_{i2})^{\gamma_2}\, v(g_{i3})^{\gamma_3} \ldots v(g_{in})^{\gamma_n} \right] \quad \textbf{(5-5)}$$

Excel Solver (a generalized reduced gradient optimization routine) was used to minimize the sum squared error cost function, J, by manipulating the attribute exponential weighting factors, γ_j, with the constraints that $\gamma_j \geq 0$:

$$J = \sum_{k=1}^{s} \sum_{i=1}^{N_k} (\mathrm{RV}_{ik} - \mathrm{VI}_{ik})^2 \quad \textbf{(5-6)}$$

The resulting unique attribute weights for the RV = VI best fit are shown in Table 10 along with the "goodness of fit" statistics (the sensitivities will be addressed in §5.5). Note that the optimization routine was unable to leverage the "field length" and "fuel consumption per seat mile" attributes in fitting the data for the current market. These results will be examined in §5.5.

Table 10: 1999-2001 Market Best Fit Weights and Sensitivities

Attribute	Weighting Factor	$\frac{\partial J}{\partial \gamma}$	$\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$
Max. Cruise Speed	0.25	10.75	0.019
Field Length	0.00	36.06	0.000
Fuel Consump./ Seat-Mile	0.00	62.60	0.000
Cabin Volume per Passenger	0.23	43.58	0.071
Available Seat Miles	0.15	54.42	0.058

$J = 141.9$, $R^2 = 0.99$, $F = 512.5$, $F_{.05} = 2.74$

5.4 Additional Notes on the Data Used

In addition to the careful examination of the business aviation database in Chapter 2, it is appropriate to note a few additional issues with the data used in the RVI model. For the business aviation model the "demand" data used for the Revealed Value calculations is actually unit shipments data as reported by *Weekly of Business Aviation* and the General Aviation Manufacturers Association. In reality, annual unit shipments are set by a number of factors such as manufacturer capacity and order backlogs, and may not be a true reflection of consumer demand. In times of lean orders some manufacturers may actually build "white tails," or aircraft that have not yet been sold, in hopes that the inventory will eventually be sold. Paying inventory costs on unsold aircraft can, for short periods, be less expensive than disruptions in production rates and employment levels. For these reasons, one would ideally use orders booked rather than unit shipments for "demand" data in the RV calculations, but such data is proprietary. In using shipment data averaged over three-year periods it is believed that, on aggregate, the shipments data will reflect the average consumer demand for the products.

In addition, products were not included in the segmentation groupings for particular years (such as the groupings in Table 9) unless there was at least two to three years of shipments data available for the product. Often the first year of production for a new aircraft design can include only a few months worth of shipments, may reflect the manufacturer's learning curve in producing products, or may reflect an unusually high production rate where order backlogs are being initially worked down. Typically the second or third years of production are more reflective of the steady-state interest in a new product.

The prices used in the model are those listed as average "equipped" prices in *Business & Commercial Aviation*. These prices are essentially equivalent to "list" prices for automobiles or manufacturer's suggested retail price (MSRP) for other products. As with list and MSRP, actual sales prices of aircraft may vary considerably from the published prices; up to 10-20% lower in some cases according to industry experts. Actual sales prices are closely guarded both by the manufacturers and customers, and are unavailable for this analysis.

To address the effects of some of the uncertainties in pricing and demand data, as well as possible fluctuations in the attribute data listed in Table 9, a Monte Carlo analysis will be conducted in Chapter 6 as well as a number of sensitivity analyses.

5.5 Results for the Current Business Aviation Market

Results of the RVI approach to product value assessment are presented in this section for the 1999-2001 market of business airplanes (Table 9). A sensitivity analysis of the results is also briefly discussed here, though a more detailed analysis of the historical business aviation market is included in Chapter 6.

5.5.1 Overview of Results

Sample RVI calculations for four representative modern business airplanes are shown in Table 11. Results for the 1999-2001 business airplane market are graphed in Figure 52 with some airplanes labeled for reference.

The value results in Figure 52 show an intuitive trend consistent with industry perceptions and actual sales experiences for the various airplanes. The relative value/price position of aircraft in the figure represent an approximation of actual technical and market performance experienced by each airplane relative to competing products in their market segment and also relative to non-competing market segments. Given this assessment of the current business airplane market, designers may use the RVI approach to place proposed new products or modified designs on such a graph for a rapid, intuitive evaluation of both the anticipated market and technical performance for that design. The potential consumer demand for new products may also be estimated using Equation (4-34).

Table 11: Sample RVI Calculations for 1999-2001 Business Airplanes

	Attribute level (relative value)					
Airplane	Max Cruise Speed	Field Length	Fuel Cons./ Seat-Mi	Cabin Vol/Pax	Avail. Seat Miles	RVI
Bombardier Chall. 604	468 (1.050)	5840 (1.000)	0.48 (1.000)	141.7 (1.161)	35,757 (1.073)	1.307
Cessna CJ1	377 (0.990)	3280 (1.000)	0.45 (1.000)	63.4 (1.015)	4,093 (0.767)	0.771
Gulfstream GV	488 (1.061)	5150 (1.000)	0.35 (1.000)	122.5 (1.150)	85,358 (1.161)	1.417
Raytheon 800XP	447 (1.037)	5032 (1.000)	0.38 (1.000)	91.1 (1.102)	19,256 (0.988)	1.129

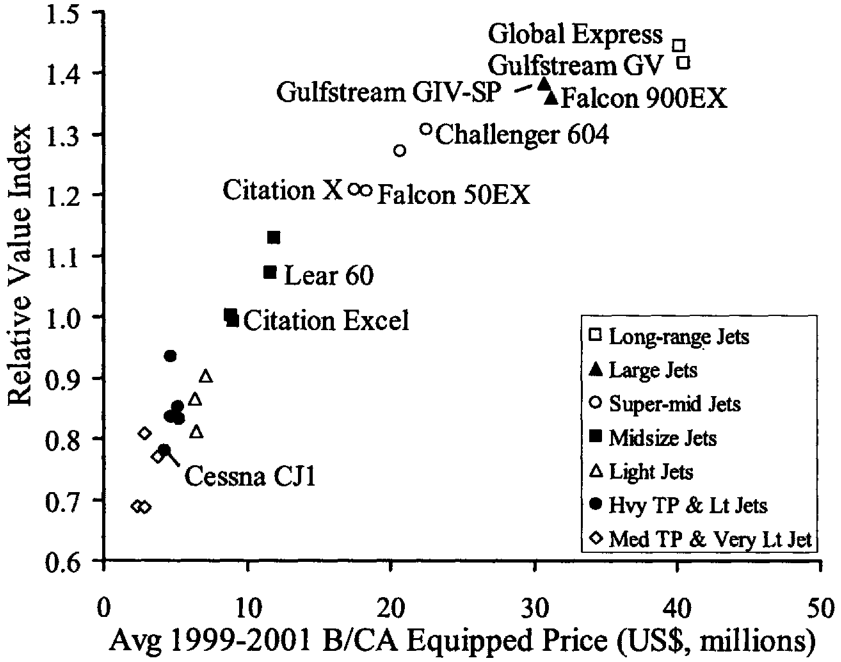

Figure 52: Relative Value Index for the 1999-2001 Business Airplane Market

The value/price relationship shown in Figure 52 is nearly linear, but more closely logarithmic. In contrast to the TVI approach (Figure 53 for the 1999-2001 market), this new method indicates a clear theoretical ability for manufacturers to profit by pursuing improvements in technical performance. The slight tendency to an asymptotic RVI level (the logarithmic shape of the curve) is attributable to the high-end segment aircraft attributes nearing the "ideal" attribute bounds. Specifically, the *cabin volume per passenger* and *available seat-miles* attributes are nearing the ideal bounds for the large and long-range aircraft segments. Assuming that the ideal bounds were properly selected, this suggests a saturation of consumer needs in these attributes (the impact of varying the ideal bound due to uncertainties in its true level will be discussed in §6.1.3).

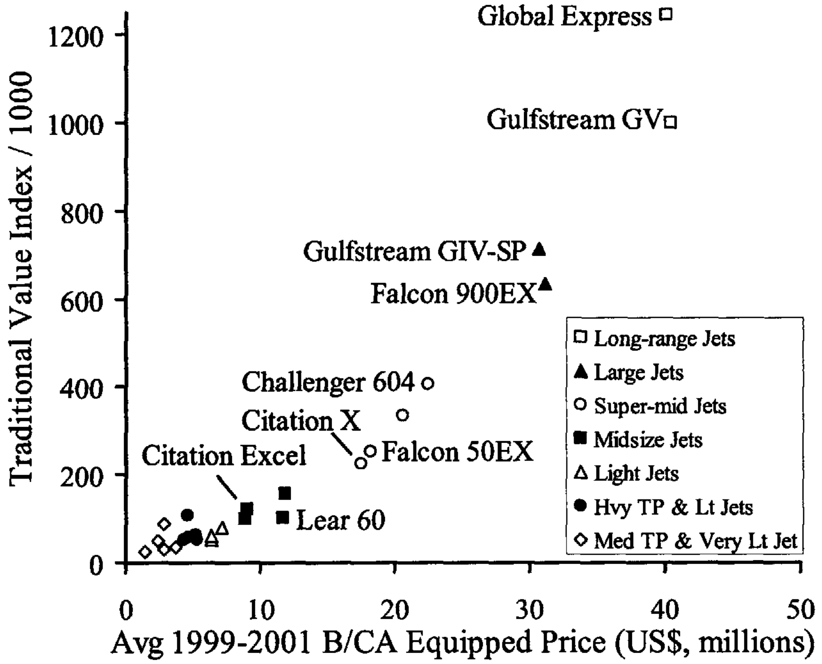

Figure 53: Traditional Value Index for the 1999-2001 Business Airplane Market

A detail view of the Figure 52 RVI results is shown in Figure 54 to enable closer examination of the lower end market segments. Attention should be brought to two problematic aircraft in the RVI results, the Piaggio P-180 and Pilatus PC-12. Both of these aircraft are turboprops (one is considerably heavier than the other, so they do not directly compete), and both are manufactured overseas in Europe and represent the single aircraft produced by each company. The data in Figure 54 indicate that these are unusually high-value aircraft vis-à-vis their segments, but the detail of the Revealed Value data in Figure 55 actually implies that their shipment/price points do not support them as unusually well-selling aircraft for their segments.

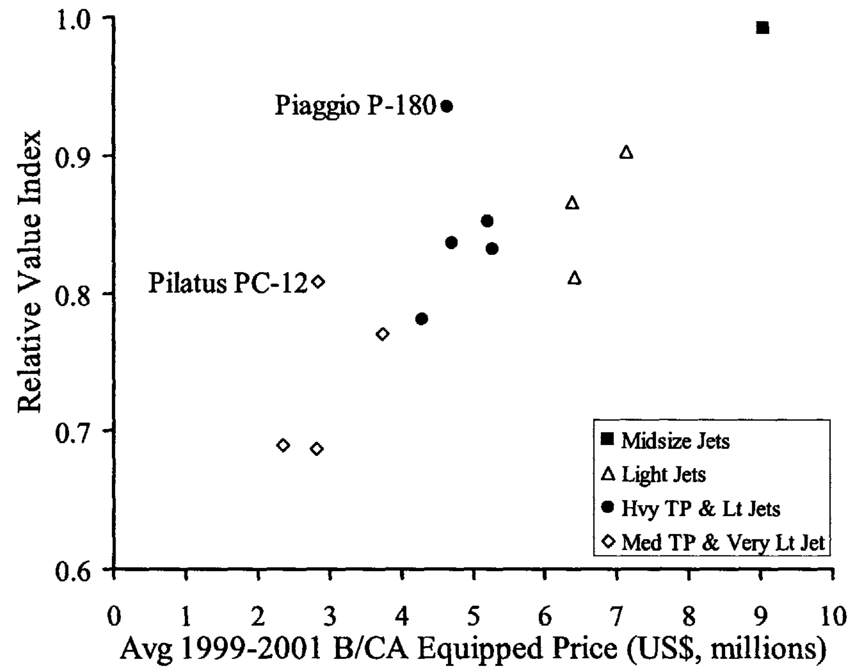

Figure 54: Detail View of RVI, 1999-2001 Business Airplane Market

As it is currently structured around technical attributes, the RVI method more highly values the Pilatus and Piaggio offerings than their sales would warrant. It is true, however, that both aircraft offer exceptional technical performance in comparison to the other aircraft in their segments. But the disconnect between the Revealed Value results (the "target" results for the RVI method) and the actual RVI ratings highlights a weakness of the current portfolio of technical performance attributes used in the approach. Though it is unclear exactly why the two aircraft do not enjoy sales commensurate with their technical performance, the RVI method obviously currently lacks some key attributes to explain this anomaly.[*]

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[*] Suggestions for the relatively poor sales include less well-developed distribution and support networks due to the fact that these are smaller companies. Mainstream media advertising appears to be at the level of competitors, and the European origins of the two aircraft are not suspected of significantly contributing to the underperformance in sales.

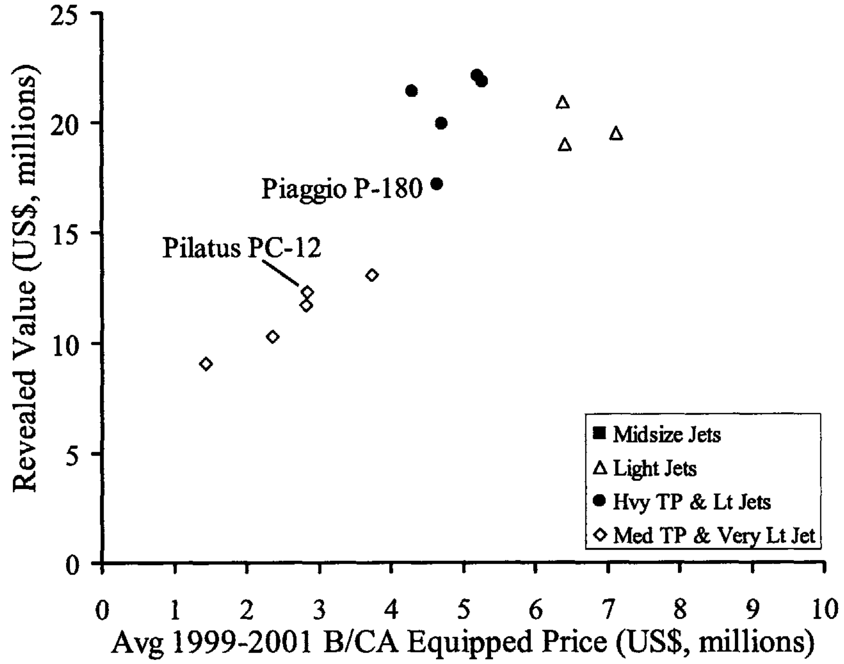


Figure 55: Detail View of Revealed Value, 1999-2001 Market

In addition to the sum-squared error cost function, J, and the other fit statistics in Table 10, another way to assess the "goodness" of the RV=VI fit is by comparing the actual product market share to the estimated market share as indicated by the RVI results. The market share concept was developed in Chapter 3 and the operative equation is reproduced here for convenience:

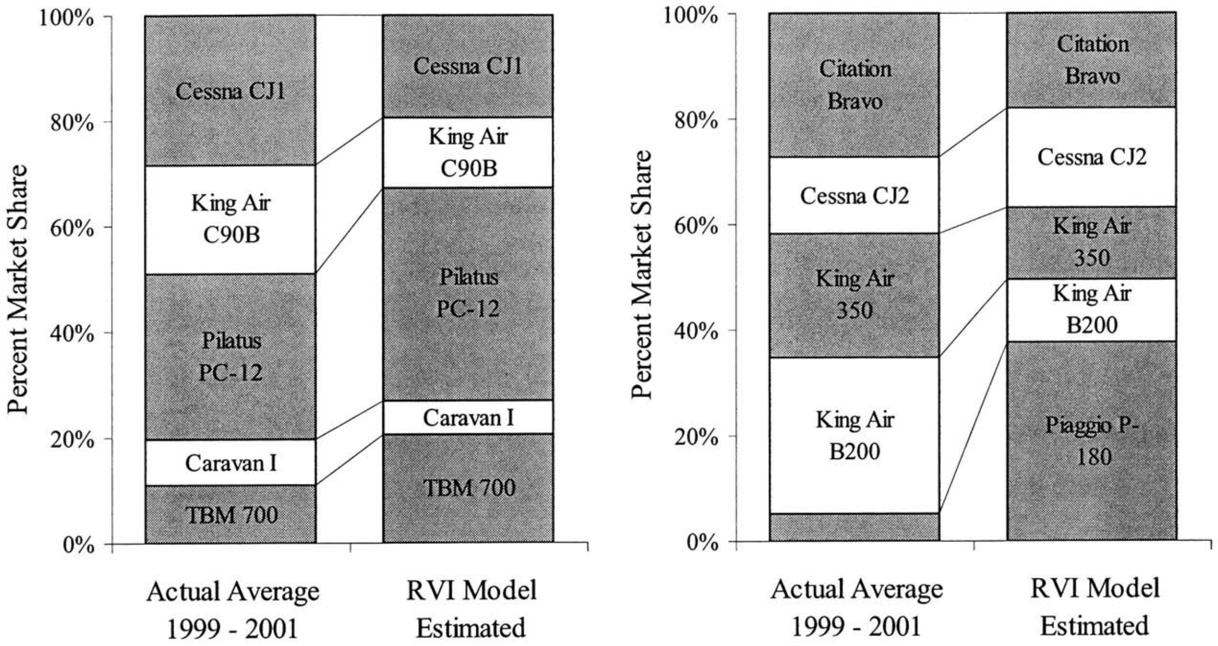
$$\pi_i = \left\{(V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l)\right\} \Bigg/ \sum_{i=1}^{N}\left\{(V_i - P_i) - \frac{1}{N}\sum_{l \neq i}(V_l - P_l)\right\} \qquad \textbf{(5-7)}$$

Market share comparisons for each of the seven segments in Table 9 are shown in Figure 56. The two lower-end segments are the most problematic due to the overestimation of the Pitatus PC-10 and Piaggio P-180 values by the RVI method. If the values were adjusted via modifications to the portfolio of RVI attributes, the remainder of the market share estimates would more closely match empirical evidence.

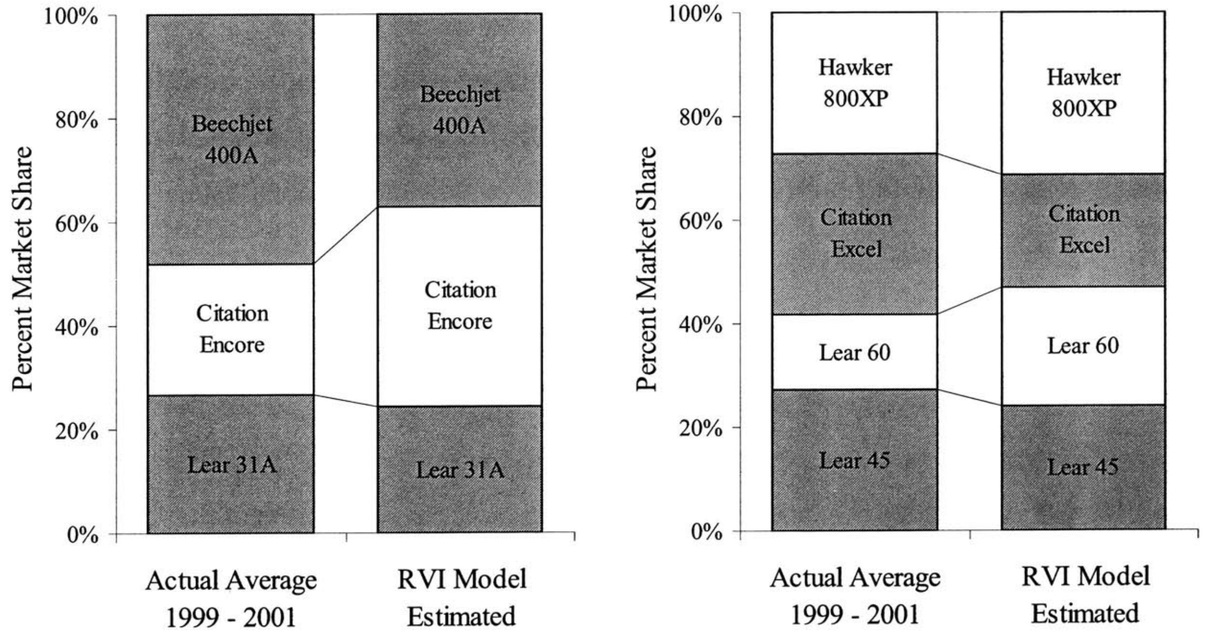
Examining the market share results provides an additional, detailed method for evaluating the model results in combination with the RVI/price and RV/price charts such as Figure 54 and Figure 55, respectively. In the market share figures it would appear, for example, that the TBM-700 (Figure 56 (a)) and Cessna CJ2 (Figure 56 (b)) values are overestimated, even considering the problems with the PC-12 and P-180. Similarly, the Cessna Encore appears slightly overvalued, and other such mismatches between empirical and estimated market shares are evident. Recall that product price is also a key parameter in the market share calculus of Equation (5-7), so the apparent over- and under-valuations in Figure 56 may in reality be due to incorrect pricing data. As noted in §5.4 and later again in Chapter 6, the pricing data used for this study is approximate, at best. Combining the market share data with RVI and RV comparisons helps in assessing the cause of the market share discrepancies. For example, the RVI and RV data of Figure 54 and Figure 55 clearly show that the PC-12 and P-180 are overvalued, resulting in the large market shares of Figure 56. The TBM-700 and Cessna CJ2 RVI and RV results appear consistent, so the problems with market share may instead be due to pricing data error.

There is no obvious criterion for judging just how close market share matches should be for the RVI method results to be considered a "good" match, but ±5-10% would seem a virtuous goal. However, with the actual sales prices of the airplanes uncertain it may be difficult, or impossible, to meet that standard. A best-case scenario would be that entire segments of the industry are relatively uniformly discounted due to market pressures to meet competitor changes in pricing, thus perhaps dropping the price discount factor out of Equation (5-7).

The need to continue investigating a more complete set of attributes, including the aforementioned customer support, distribution networks, and others, still exists so that the market share results can be improved in spite of the certain errors in pricing data.

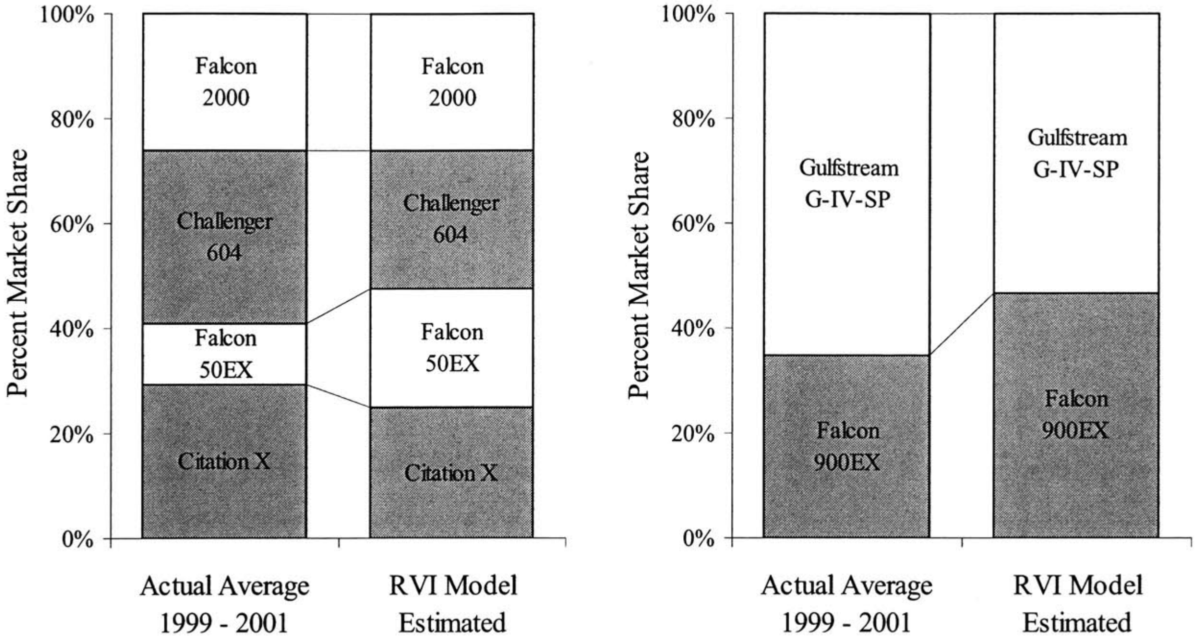


(a) Medium Turboprops and Very Light Jets (b) Heavy Turboprops and Light Jets



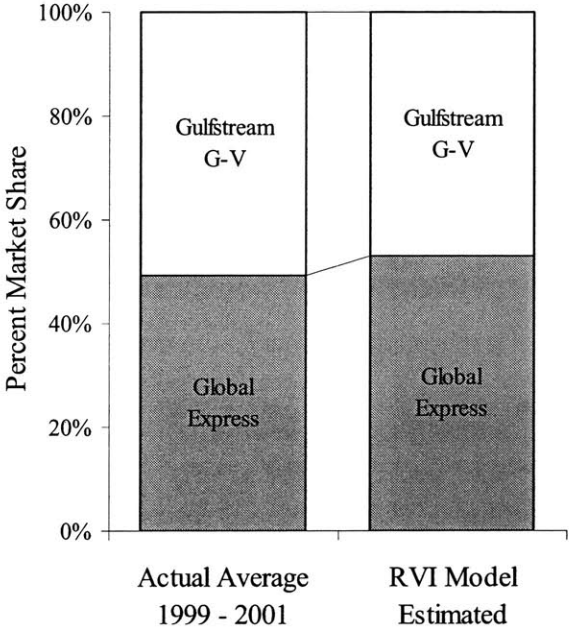
(c) Light Jets (d) Midsize Jets

Figure 56: Actual and Estimated Market Share for Current Business Airplane Products



(e) Super Midsize Jets

(f) Large Jets



(g) Long Range Jets

Figure 56 (cont.): Actual and Estimated Market Share for Current Business Airplane Products

5.5.2 Figure of Merit: Product vs. Summation

In §4.2.1 it was noted that the mathematical product figure of merit used for the Relative Value Index method, Equation (5-8), has stronger ties to economic theory than a mathematical summation such as that in Equation (5-9).

$$\mathrm{RVI}_i = \prod_j v(g_{ij})^{\gamma j} \tag{5-8}$$

$$\mathrm{RVI}_i = \sum_j v(g_{ij})^{\gamma j} \tag{5-9}$$

In addition, the RVI figure of merit, as a product, accords better with reality than does a summation figure of merit. Consider three business jets offered in the 1999-2001 market; the Cessna CJ1 (a very light jet) and the Gulfstream GV and Bombardier Global Express (both long-range jets). The attribute levels and compositional value contributions are shown in Table 12 with an important change to the Gulfstream aircraft. The range of the aircraft has been modified to the absurdly low value of 10 nautical miles, resulting in only 140 available seat-miles for this aircraft (assuming 14 passengers) and an associated zero part-worth contribution from that attribute. Using the mathematical product of Equation (5-8), the overall RVI of the Gulfstream is 0.0, but the summation figure of merit indicates a non-zero value for the aircraft that, although lower than the competing Global Express, is not much lower than the much smaller Cessna CJ1. In other words, the summation of Equation (5-9) would indicate the large 10 nm range aircraft holds nearly as much technical performance value to the consumer as the smaller but longer-ranged CJ1.

Table 12: Product and Summation Figures of Merit for Example Business Jets

	Attribute Level (Attribute Relative Value)						
Airplane	Speed	Takeoff Field Length	Fuel Consumption / Seat Mile	Cabin Volume / Passenger	Available Seat-Miles	$\sum$	$\prod$
Cessna CJ1	377 (0.990)	3280 (1.000)	0.446 (1.000)	63.4 (1.015)	4093 (0.767)	4.772	0.771
Gulfstream GV	488 (1.061)	5150 (1.000)	0.351 (1.000)	122.5 (1.150)	140 (0.000)	4.211	0.000
Global Express	499 (1.067)	5820 (1.000)	0.401 (1.000)	151.5 (1.162)	95850 (1.165)	5.390	1.444

Extending the absurdity of the analysis, contrast the Gulfstream GV with its primary competitor in the 1999-2001 market, the Bombardier Global Express. Using the mathematical product figure of merit, the GV would hold no market share in direct competition with the Global Express (zero RVI value against the Global Express' non-zero value). But with the summation figure of merit, the 10 nm range GV would hold considerable market share with a 4.211 value against the Global Express' 5.390 (Figure 57). The outcome of this thought experiment is clearly at variance with what reality would present, and serves as a strong argument against using summation figures of merit in value analysis.

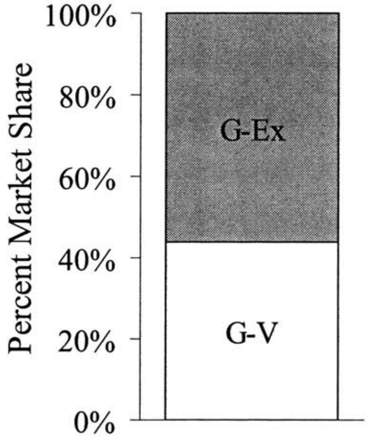


Figure 57: Market Share for 10 Nautical Mile Range Gulfstream GV using Summation Figure of Merit

5.5.3 Sensitivity Analysis

With the attribute weighting factors estimated in Table 10, the next question for users of the RVI approach should center on the reliability of the estimates. The sum squared error cost function and the multiple coefficient of determination both indicate a good fit of RV and VI equations, but do not directly speak to the consistency of the attribute weighting factors, particularly in light of uncertainties in the attribute levels themselves as well as the aircraft sales prices and demand.

The "dimensional" sensitivity[*] of the sum squared error, J, to changes in each of the attribute weighting factors, $\partial J/\partial \gamma$, is shown in Table 10. The relatively low sensitivity of the cost function to changes in the maximum speed weighting factor indicates that the airplanes under consideration are less differentiable in this model on that attribute than on the others. This results from the fact that most business jets, a considerable proportion of all business aircraft today, cruise in approximately the same speed range, Mach 0.75-0.85. These sensitivity results indicate that the maximum speed weighting factor could be set to alternative values (for example, zero) without greatly altering the stance of one airplane's value relative to another. Designers should not interpret these results as meaning that the maximum speed attribute is unimportant, but only that it is not a differentiable attribute in the 1999-2001 market. As a counter example, historically one finds that maximum speed was a differentiable attribute in the mid 1960s as the first generation of business jets was introduced.

The sensitivity in Table 10 also indicates that the best fit varies most due to changes in the last four attributes. Despite this, the optimization routine was unable to leverage the first two of these attributes ($\gamma = 0$), runway field length and fuel consumption per passenger seat mile, in finding a best fit between revealed and estimated product values. The reasons for this are different for each of the attributes. As shown in Figure 58, there is a strong correlation between increasing Revealed Value for the products in the 1999-2001 market and increasing values of the aircraft's takeoff field lengths. Higher revealed values tend to correspond to larger aircraft which, in turn, typically require longer runway distances to take off due to their higher weights. We have noted, however, that "runway field length" is a smaller-is-better attribute, so the optimization routine, at least for the products in the current market, cannot leverage this attribute to improve the RV and VI best fits.

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[*] There are no dimensions on this particular sensitivity figure only because the attribute weighting factor is dimensionless.

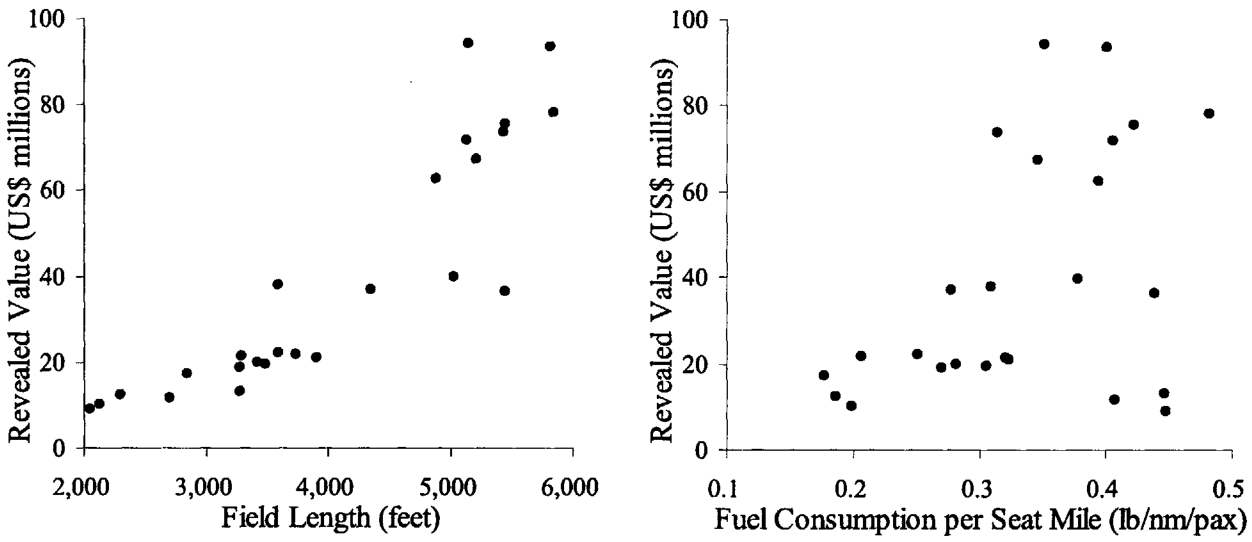
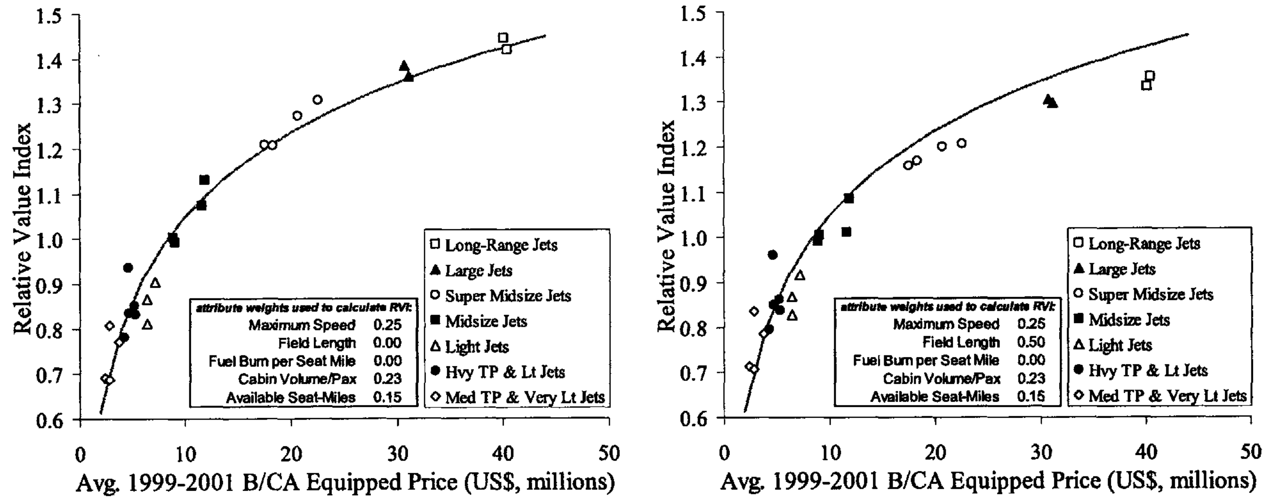


Figure 58: Correlation of Attributes and Revealed Value, 1999-2001 Market

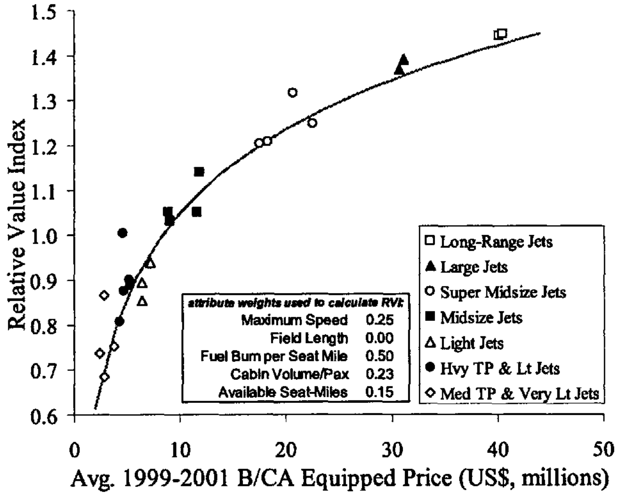
Also in Figure 58 it becomes apparent that the rate of fuel consumption per passenger seat mile is uncorrelated with Revealed Value. Fuel consumption is highly dependent on the aerodynamic properties of the aircraft (i.e., drag) and the efficiency of the engines. Turboprop-driven aircraft do tend to have higher fuel efficiencies within their low-speed cruise regimes, accounting for some of the low RV, low "fuel consumption per seat mile" data points in Figure 58. But for the majority of the jet-driven aircraft in the 1999-2001 market, no aircraft type (i.e., light jet, long-range jet) tends to have a monopoly on fuel efficiency when the parameter is augmented with passenger and range information (this tends to be the case historically as well). For this reason the optimization routine is unable to leverage this attribute in the RV = VI best fit.

In Figure 59 the effect of non-zero attribute weighting factors for fuel consumption and field length are explored to reinforce the insights from Figure 58. In Figure 59 (b) the field length attribute only serves to reduce the overall RVI results for the market in comparison with the original RVI results in Figure 59 (a) (note the identical reference lines drawn in each figure). This is particularly true for the high-end aircraft with much longer field lengths. In Figure 59 (c) the effect of a non-zero weight on the fuel consumption attribute is to scatter the product RVIs without bias to market segments (i.e., light jets, long-range, etc.). This is just as Figure 58 would predict due to the low correlation between value and fuel consumption rate per passenger seat mile.



(a) Original RVI with Reference Line

(b) RVI with Field Length Weighting Factor set to 0.50



(c) RVI with Fuel Consumption per Seat Mile Weighting Factor set to 0.50

Figure 59: Effect on RVI of Adding Non-Zero Attribute Weighting Factors

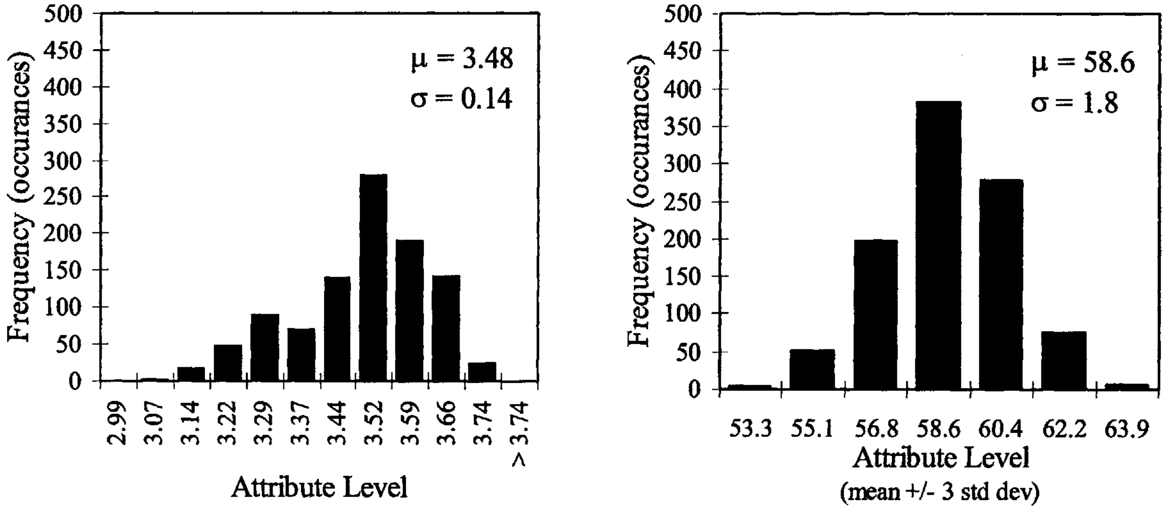
The dimensionless sensitivity factor, $\frac{\partial J}{\partial \gamma}\cdot\frac{\gamma}{J}$, also shown in Table 10 reflects the best fit sensitivity to each attribute, combined with the actual ability of the best fit routine to leverage the attribute for that particular market of aircraft. The results reinforce the conclusions drawn using the dimensional sensitivity factor, but will become particularly useful in an historical sensitivity analysis since aircraft values, and hence the best fit cost function J, will vary over time. See the sensitivity discussion in Chapter 6 for more details.

5.5.4 Monte Carlo Analysis

To address uncertainties in the attribute levels as well as in the aircraft sales prices and demand, a Monte Carlo analysis was performed to determine how the attribute weighting factors would change due to these uncertainties. Refer to the detailed discussion of Monte Carlo analyses in Chapter 6 for more information on the rationale for the analysis as well as the variable distributions.

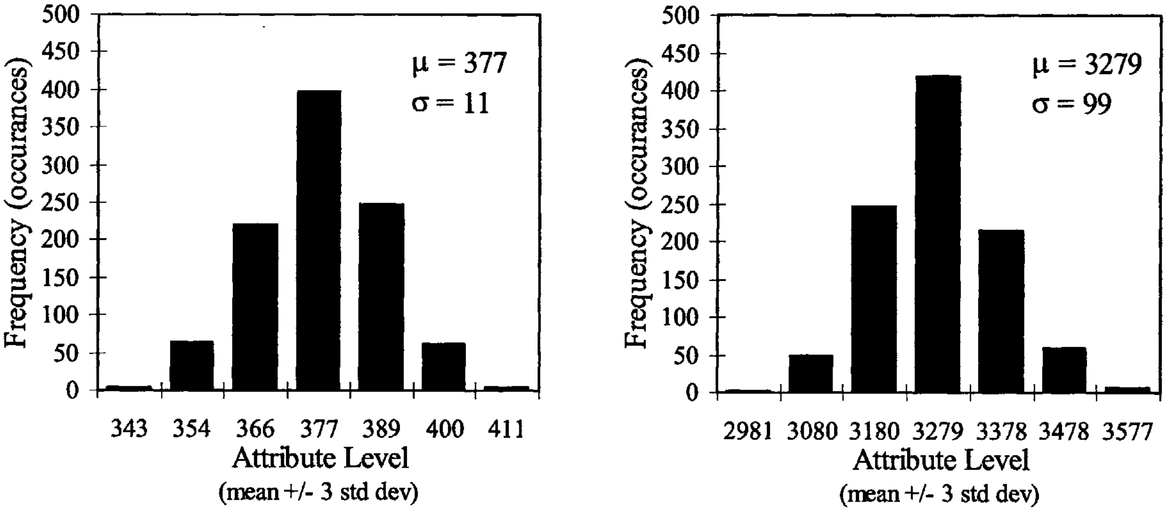
Each of the five attributes and the product demand parameter were treated as normal random variables with 90% of their values falling within ±5% of their mean (deterministic) values. Since few customers would be expected to pay more than list price, the price parameter was treated an asymmetric B(2, 4, 0, 20) beta distribution with the bounds 0 and 20% representing the discount consumers would receive on the "B/CA Equipped Price." With this distribution the average customer receives a 7% discount and 90% of customers receive a 12% discount or less. The analysis was performed by randomizing each of the seven parameters for each of the aircraft in the current market (Table 9), and then determining the new attribute weighting factors for the best fit. One thousand such randomizations and best fits were performed for the analysis.

The stochastic distributions for the seven random variables are graphed in Figure 60 and Figure 61 for two randomly selected aircraft in the 1999-2001 market. The figures indicate that 1000 Monte Carlo simulations are sufficient to properly represent the selected normal and beta distributions.



(a) Equipped Price (US$ millions)

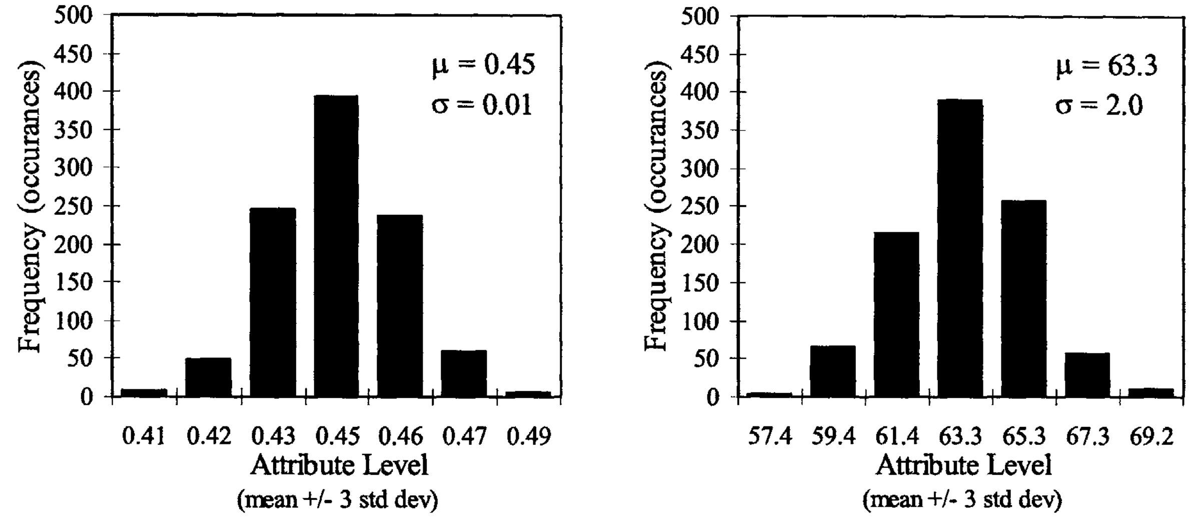
(b) Annual Unit Shipments



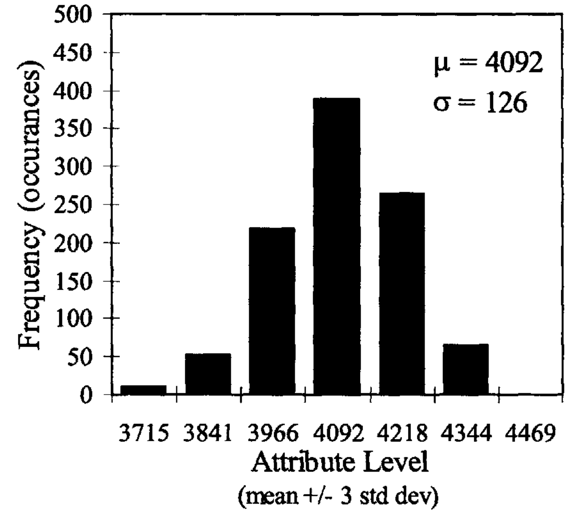
(c) Maximum Cruise Speed (ktas)

(d) Takeoff Field Length (feet)

Figure 60: Stochastic Attribute Distribution, Cessna CJ1



(e) Fuel Consumption per Seat Mile (lb/nm/pax) (f) Cabin Volume per Passenger (cu ft/pax)

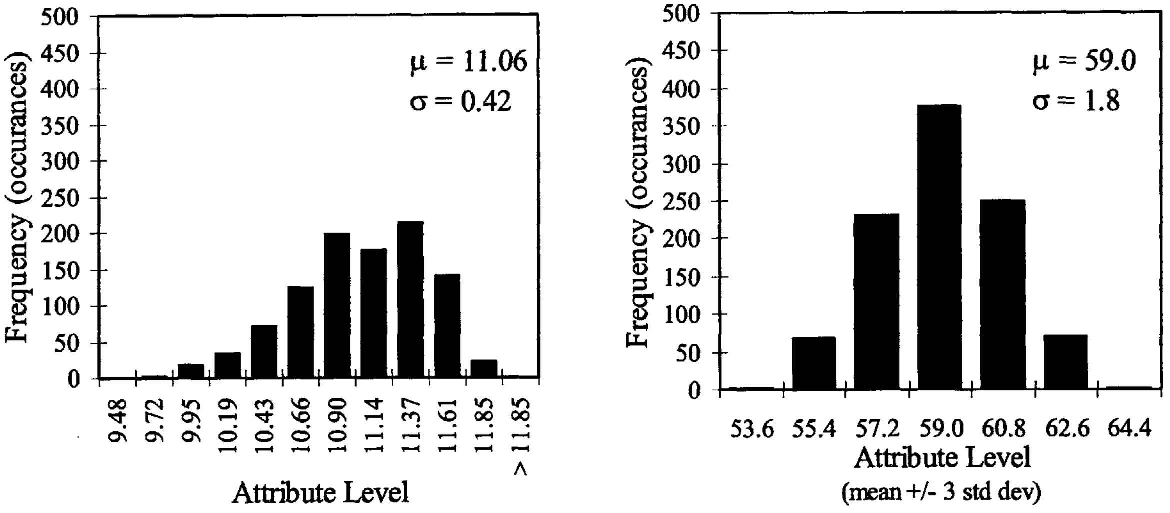


(g) Available Seat Miles (nm-pax)

Deterministic Airplane Attribute Values
Cessna CJ1
(Average 1999-2001)

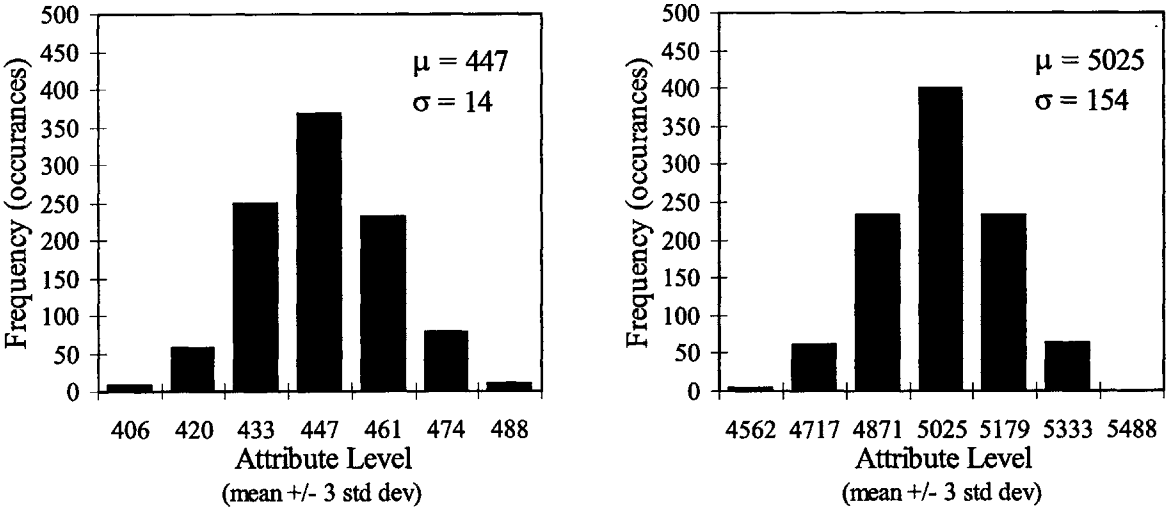
Equipped Price: $3.74 m
Annual Unit Shipments: 58.5
Maximum Cruise Speed: 377 ktas
Field Length: 3280 ft
Fuel Consumption / Seat Mile: 0.45 lb/nm/pax
Cabin Volume / Passenger: 63.4 cu ft/pax
Available Seat Miles: 4093 nm-pax

Figure 60 (cont): Stochastic Attribute Distribution, Cessna CJ1



(a) Equipped Price (US$ millions)

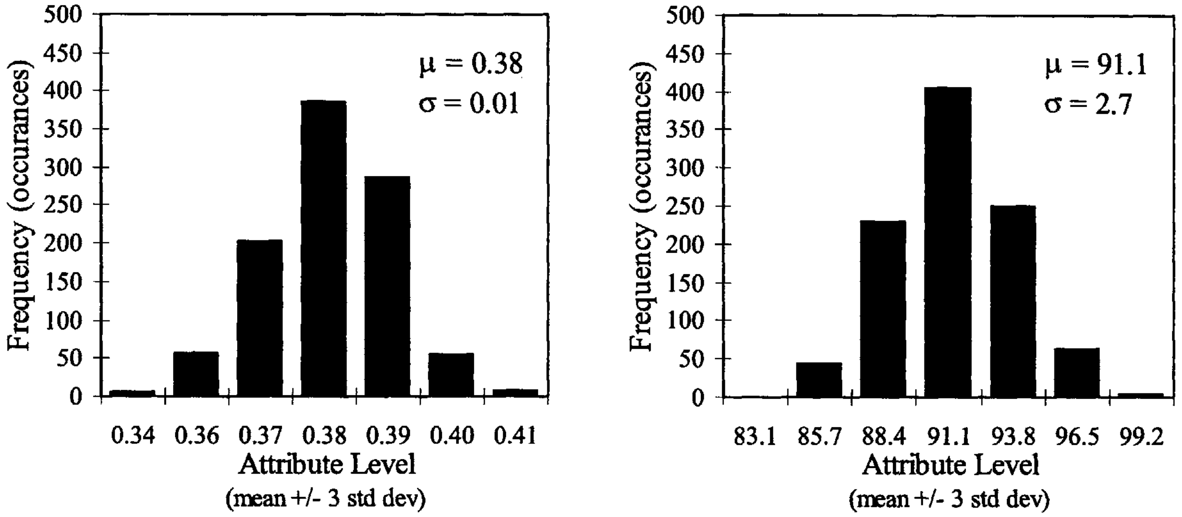
(b) Annual Unit Shipments



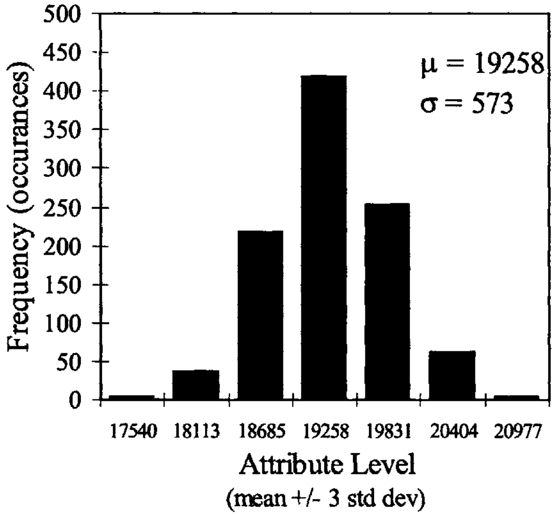
(c) Maximum Cruise Speed (ktas)

(d) Takeoff Field Length (feet)

Figure 61: Stochastic Attribute Distribution, Raytheon Hawker 800XP



(e) Fuel Consumption per Seat Mile (lb/nm/pax) (f) Cabin Volume per Passenger (cu ft/pax)



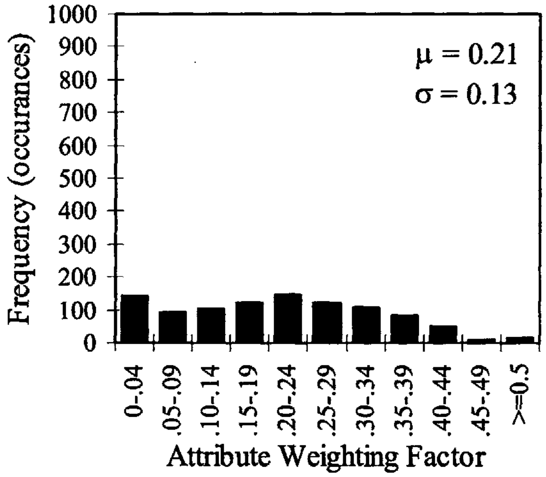
(g) Available Seat Miles (nm-pax)

Deterministic Airplane Attribute Values
Raytheon Hawker 800XP
(Average 1999-2001)

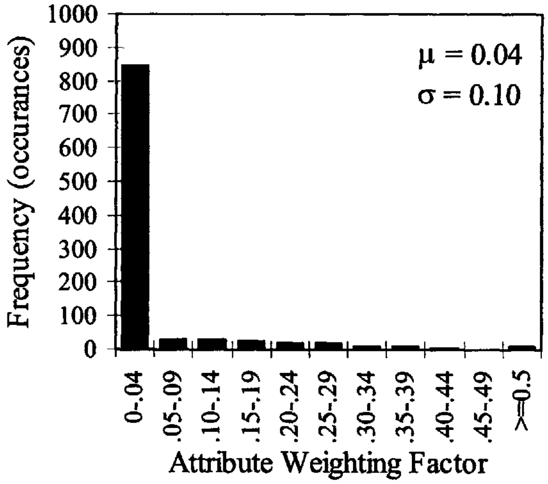
Equipped Price: $11.85 m
Annual Unit Shipments: 59.0
Maximum Cruise Speed: 447 ktas
Field Length: 5032 ft
Fuel Consumption / Seat Mile: 0.38 lb/nm/pax
Cabin Volume / Passenger: 91.1 cu ft/pax
Available Seat Miles: 19,256 nm-pax

Figure 61 (cont): Stochastic Attribute Distribution, Raytheon Hawker 800XP

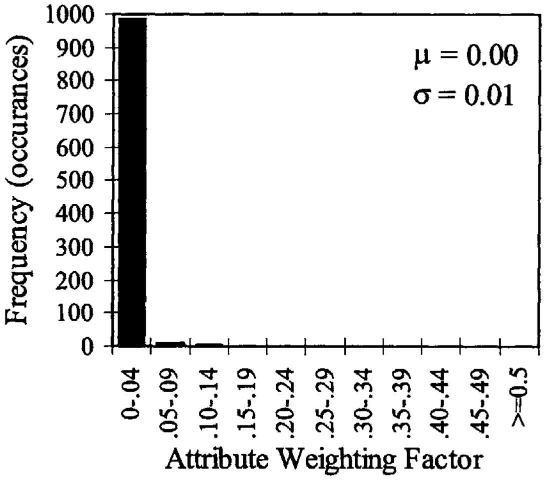
The resulting distributions for the five attribute weighting factors are shown in Figure 62 for the 1999-2001 market.



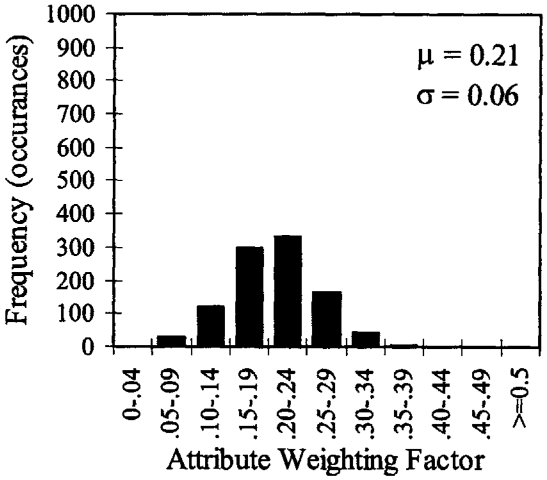
(a) Maximum Cruise Speed



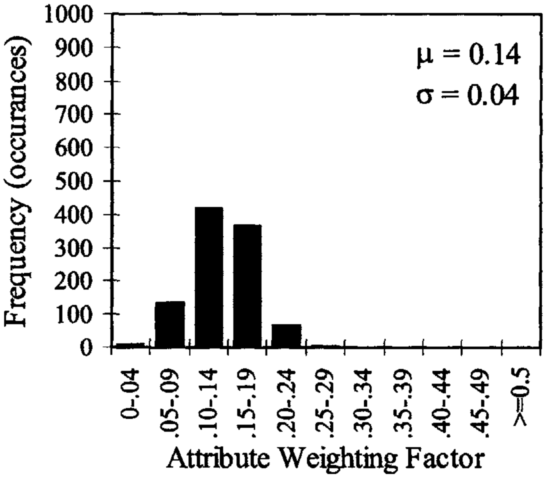
(b) Takeoff Field Length



(c) Fuel Consumption per Seat Mile



(d) Cabin Volume per Passenger



(e) Available Seat Miles

Deterministic Attribute Weighting Factors
(1999-2001 Market)

Maximum Cruise Speed: 0.25
Takeoff Field Length: 0.00
Fuel Consumption per Seat Mile: 0.00
Cabin Volume per Passenger: 0.23
Available Seat Miles: 0.15

Figure 62: Monte Carlo Analysis Results, 1999-2001 Market

The distributions for the cabin volume and seat-miles weighting factors in Figure 62 indicate that the deterministic weighting factors for each of these attributes are reliable even amid uncertainties in the model inputs. In nearly every instance, the field length and fuel consumption attributes remain unused by the best fit routine, with only rare non-zero weighting factor values. The maximum speed weighting factor demonstrates the greatest variation in Figure 62. As noted before in examining the $\partial J/\partial \gamma$ sensitivity, this attribute does not facilitate differentiation in the current business airplane market and may vary considerably without significantly impacting the RV and VI best fit. In effect, the Monte Carlo analysis serves as a confirmation of the $\partial J/\partial \gamma$ sensitivity analysis in indicating which attributes are of the greatest leverage in differentiating business airplanes in the 1999-2001 market.

5.6 Summary: A New Value Assessment Method for the Business Aviation Industry

A new product value assessment method has been developed for the business aviation industry. This industry was specially chosen due to its customer base being primarily composed of organizational buyers making objective, information-based decisions. The model also focuses on an industry-wide set of products, ranging from turboprops and light jets to large and long-range jets, enabling a unique ability to make inter-segment product comparisons.

Five primary, quantifiable attributes have been identified for implementation in the model: maximum cruise speed, takeoff field length, fuel consumption per seat-mile, cabin volume per passenger, and available seat-miles. These attributes meet the standard of relatively low correlation while also combining the principal features thought to be of importance, in aggregate, to customers. Without a doubt, some important attributes have been neglected in this initial model development, including product reliability and after-sales customer support. Unfortunately there currently exists little or no data on such attributes that can be immediately used in this study.

The attribute exponential weighting factors resulting from the Revealed Value and Value Index "best fit" optimization provide a reasonable set of product value ratings for the current business airplane market. The linear, or perhaps logarithmic value/price trend accords well with marketing and economic theory and appears to meet intuitive expectations for the current market's composition. The cabin volume and available seat-miles attributes emerge as being the primary features studied that permit differentiation of products in the current market; the final value solution is relatively insensitive to changes in the speed attribute. A Monte Carlo analysis of the data used in the model likewise confirms that all weighting factors except maximum cruise speed are relatively robust to uncertainties in the input data, the speed attribute again being penalized by its low impact on the final "best fit" solution.

The new Relative Value Index approach, while well-representing the current business aviation market, benefits from simplicity in both its mathematics and implementation, is easy to use and understand its underlying theory, and enables rapid estimation using conventional computational resources.

6 EVALUATING AND USING THE BUSINESS AVIATION VALUE METHOD

In this chapter the Relative Value Index model will be applied and evaluated in a number of different ways to determine the reliability and utility of the methodology. The results of this chapter will not only be of use to the end user of the RVI results, but also to the model builder as an aid in identifying the weaknesses and strengths of the model relative to its input parameters and structure. Future model builders may be able to use the results of this chapter in modifying the RVI approach to become more robust, and may be able to repeat the analysis with alternative products to make further judgments as to the generalizability of the approach.

6.1 Evaluations of the RVI Method

In this section Cook's Relative Value Index model will be subjected to analyses in an effort to evaluate the model in terms of the reliability of its output subject to changes in the input parameters. The 1999-2001 market weighting factor sensitivity analysis of Chapter 5 will be extended to the 40 year database of historical business airplane data to assess the "believability" of the model best fit solutions. Secondly, effects of potential inaccuracies (noise) in the historical database of aircraft input parameters (speed, field length, etc.) will be studied through use of a Monte Carlo analysis similar to that discussed in Chapter 5 for the current business airplane market. A third aspect is to determine the effects on the model of errors in estimating the attribute bounds (critical, ideal, baseline). Finally, the effects on predictions of averaging the price and shipments data over time to reduce the impact of variation will be studied.

6.1.1 Historical Weighting Factors and Sensitivities

Sensitivities for the 1999-2001 business aircraft market weighting factors were discussed in Chapter 5. Both the dimensional sensitivity factors, $\frac{\partial J}{\partial \gamma}$, and dimensionless sensitivity factors, $\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$, were examined in that chapter in terms of how changes in the weighting factors affected the sum squared error, J, for the best fit solution (Table 10). It was concluded that the best fit solution was relatively insensitive to changes in the maximum cruise speed weighting factor, while the solution was more sensitive to changes in the remaining four attributes, though the best fit was not improved when the field length and fuel consumption attributes were included in the comparisons for the market sample.

Table 13: 1999-2001 Market Best Fit Weights and Sensitivities

Attribute	Weighting Factor	$\frac{\partial J}{\partial \gamma}$	$\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$
Max. Cruise Speed	0.25	10.75	0.019
Field Length	0.00	36.06	0.000
Fuel Consump./ Seat-Mile	0.00	62.60	0.000
Cabin Volume per Passenger	0.23	43.58	0.071
Available Seat Miles	0.15	54.42	0.058

$J = 141.9$, $R^2 = 0.99$, $F = 512.5$, $F_{.05} = 2.74$

Assessing the sum squared error sensitivities to changes in the weighting factors is a way of evaluating the degree to which the resultant weighting factors may be "believed" or relied upon by the user. For example, in the Chapter 5 analysis it was apparent that the maximum cruise speed weighting factor of 0.25 could easily be changed to 1.0 without greatly affecting the best fit solution. For this reason, the model user should not consider the maximum cruise speed attribute to be of much value in differentiating the current market of aircraft (a real-world rationale for this was given in Chapter 5 as well). In this section these same sensitivities are assessed for the historical database to determine how the attributes may have changed in importance to product differentiation over time. Because shipments data is limited in the number of turbine business airplane models available before 1965, all historical assessments in this study date back only as early as 1965.

The attribute exponential weighting factors resulting from the Revealed Value and Value Index best fits for the 40 year business airplane database are shown in Figure 63. For convenience, the vertical axis scale has been limited to a maximum of 1.0, cutting off the maximum values for two of the factors, but the numerical values for each of the weighting factors may also be found listed in Appendix F.

The multiple coefficient of determination, R^2, for the historical best fits is shown in Figure 64 and indicates good fits between the RV and VI data in each of the years studied. Given this information on the quality of the mathematical best fits, and returning to Figure 63, the figure *seems* to indicate wide variations in most of the weighting factors over time. Though gradual variations over time in the ability to leverage certain attributes to differentiate a market of business airplanes could be expected, the rapid and wide swings in the magnitudes of most of the weighting factors is unrealistic but is clarified by examining the factor sensitivities.

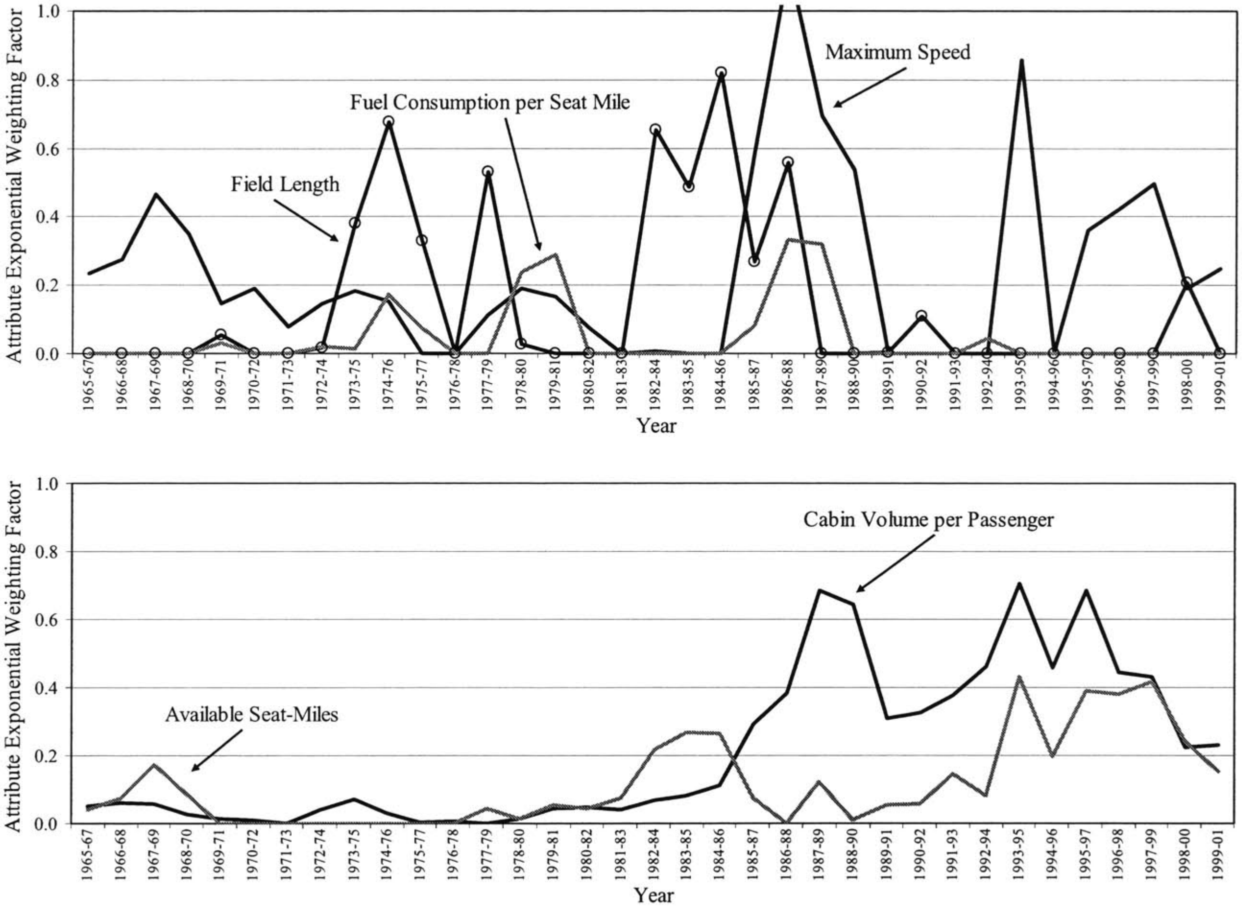


Figure 63: Historical Attribute Exponential Weighting Factors

Figure 64: Multiple Coefficient of Determination for Historical Weighting Factors

Although in Chapter 5 the dimensional sensitivity factors, $\partial J/\partial \gamma$, were discussed, these factors are influenced by product prices over time and are not useful in assessing the historical behavior of the weighting factors. Instead, the dimensionless sensitivity factor, $\frac{\partial J}{\partial \gamma}\cdot\frac{\gamma}{J}$, must be used when historical data is being examined, as shown in Figure 65. In the figure, the maximum scale on the vertical axis is limited to 0.20 for convenience, but the full set of numerical data is listed in Appendix F.

The figure shows a number of interesting trends. The maximum cruise speed attribute shows high sensitivity vis-à-vis the best fit cost function in the early years of business aviation but, with one exception in the late 1980s time frame, diminishes in importance to the product differentiation. As previously noted in Chapter 5, most business airplanes in the modern market cruise at approximately the same speed, so the model indication of no differentiation on this attribute accords well with reality. However, in the early years of business aviation the cruise speed played an important role in differentiating the new generation of business jets from the existing heavy turboprops.

Figure 65 also indicates that the field length and fuel consumption attributes have been, at best, only marginally important in differentiating products in the business aviation market over the past 40 years. Conversely, the cabin volume and available seat-miles attributes are indicated to be quite important (for some time periods) in product differentiation.

In closely examining the data in Figure 63 (indicating the relative importance of the attribute to differentiation) as well as Figure 65 (indicating the sensitivity of the solution to the attribute), one can begin to draw conclusions as to the role the attributes have played in business airplane product differentiation over the last 40 years. Figure 66 shows an example simultaneously considering the magnitude of the attribute weighting factor and the sensitivity of the best fit solution to the weighting factor.

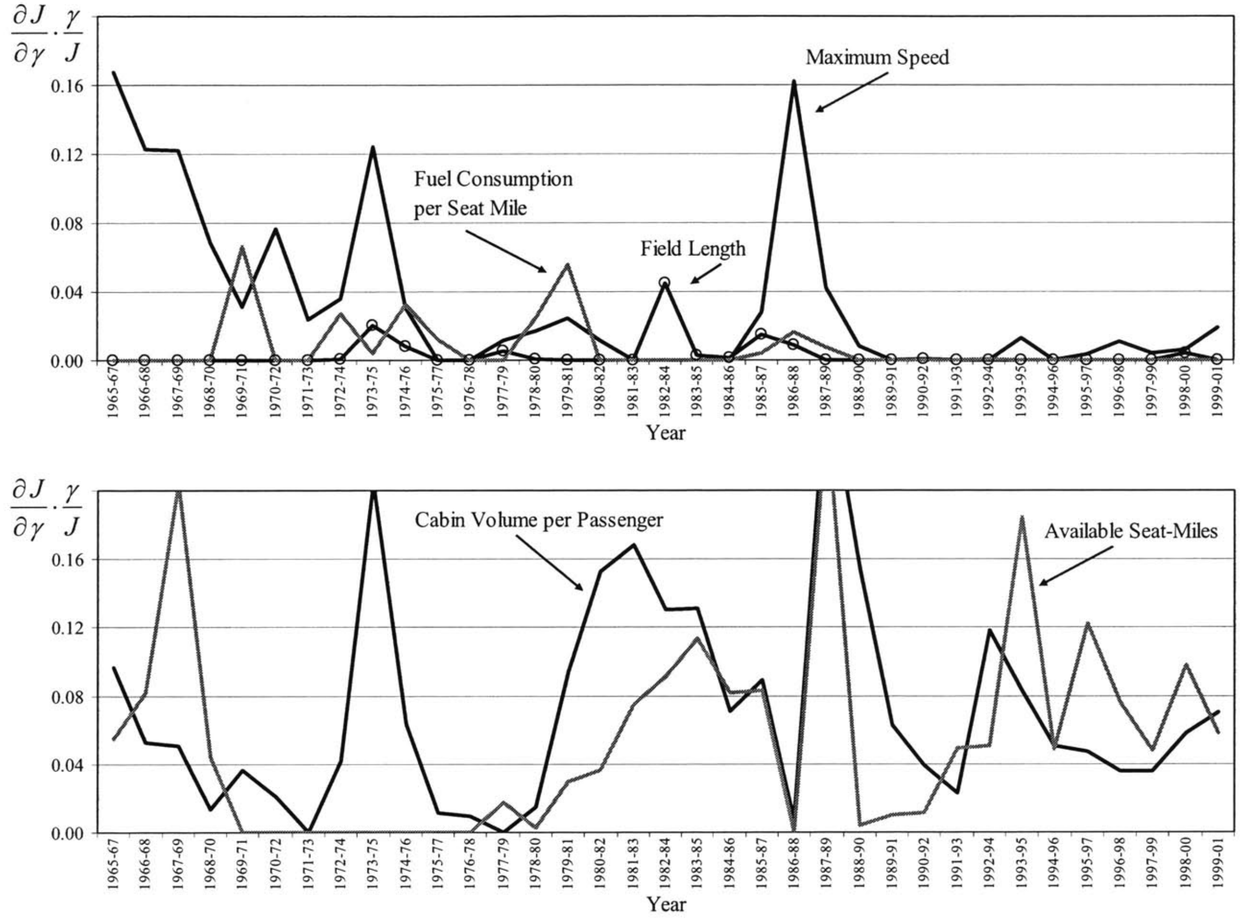


Figure 65: Historical Non-Dimensional Weighting Factor Sensitivities

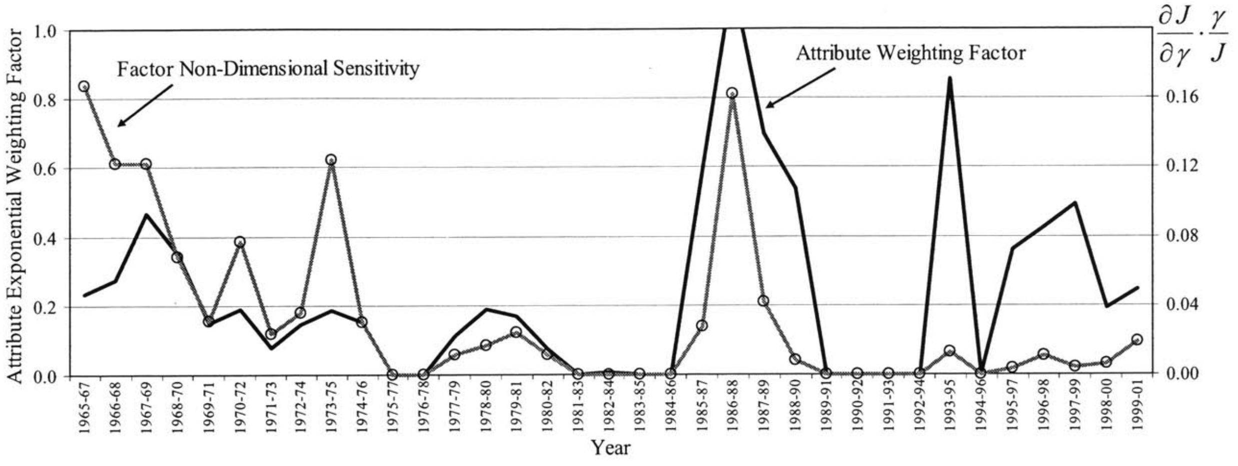


Figure 66: Comparison of Maximum Cruise Speed Weighting Factor and Sensitivity

Figure 66 shows that through the mid 1970s the best fit solution is sensitive to changes in the maximum cruise speed attribute weighting factor, while at the same time the numeric value of the weighting factor is non-zero. This indicates that the attribute is being leveraged by the model to differentiate products in the market over this time period, which may be interpreted as saying that the attribute is important in differentiating products in the market at those times. For the remainder of the time period under study the sensitivity is quite low, reflecting previous discussions of how airplane cruise speed proved important to differentiation against the legacy heavy turboprop aircraft in the early years of business aviation, but that the market has since converged on similar speeds and the attribute no longer plays a differentiation role.

There is an exception of one period in the late 1980s where the maximum cruise speed weighting factor is both non-zero and shows a significant sensitivity to the best fit solution. The importance of speed at this point in time is consistent with the introduction in the late 1980s of two new large jets, the Dassault Falcon 900 and Gulfstream G-IV, that had maximum cruise speeds 20 to 30 knots higher than the existing large jet competitors (Table 14). Soon after, the legacy large jet competitors left the market and the speed attribute was no longer a differentiable factor in the market.

Table 14: Maximum Cruise Speed for Large Jet Segment, Late 1980s

Large Jet Competitors Late 1980s	Maximum Cruise Speed (ktas)
Dassault Falcon 50	457
Bombardier Challenger 601-3A	459
Dassault Falcon 900	479
Gulfstream G-IV	488

In the model, the field length attribute has played little or no role in product differentiation over the 40 year history studied. There is an apparent role played in approximately the 1975–77 and 1984–88 time periods, but closer examination of the model results (Appendix F) reveals very low "best fit" sensitivity scores in those years. The attribute weighting factors may be changed without greatly altering the best fit or the overall model results, suggesting that field length has, ultimately, not been found to be important in product differentiation given the data at hand. This is consistent with the fact that the industry quickly converged on certain maximum runway field lengths as key to serving business customers' needs in certain segments, thus the aircraft, segment-to-segment, are not differentiable on field length. This *does not suggest* that an airplane meeting inferior field-length criteria could succeed in the market place.

The fuel consumption attribute has also played little role except, apparently again, for a few years: approximately 1976–77, 1980–81, and 1987–89. In the first time period the fuel consumption factor appears to have indeed played a material role with the introduction of a new series of light jets by Learjet (Lear 35) and Dassault (Falcon 10); see Table 15 for a comparison and note that each of these market time periods represents a three-year average. These aircraft reportedly had collectively lower fuel consumption than the previous aircraft in the light jet segment, and each appears to have enjoyed immediate success in the market in terms of large unit shipments in comparison to their existing competition. In the early 1980s a similar phenomenon appears to have occurred with a new series of large jets, the Gulfstream III and the Falcon 50, replacing their older competitors with significant associated increases in unit shipments (Table 15). The story for the late 1980s time period is less clear, though the period is marked by the retirement of several high fuel consumption models (Citation I, Lear 25D, Lear 36A). The Monte Carlo analysis in the next section will reveal that the weighting factor in this latter time period is highly sensitive to uncertainties in the aircraft parameters (price, shipments, speed, etc.), and thus the reliability of the numeric value of the weighting factor in the 1987–89 period is suspect.

Table 15: Fuel Consumption per Passenger Seat Mile and Average Unit Shipments for Selected Market Segments and Time Periods

Light Jet Segment

1973-75	lb / nm-pax	Avg. Unit Shipments	1974-76	lb / nm-pax	Avg. Unit Shipments
1123 Westwind	0.52	11.7	1123 Westwind	0.52	7.0
Sabreliner 40A	0.48	15.0	Sabreliner 60	0.33	15.5
Sabreliner 60	0.33	9.5	Lear 35	0.32	21.3
			Lear 36	0.44	5.3
			Falcon 10	0.22	29.5

Large Jet Segment

1978-80	lb / nm-pax	Avg. Unit Shipments	1979-81	lb / nm-pax	Avg. Unit Shipments
Gulf. G-II/TT	0.58	19.5	Falcon 50	0.45	23.6
			Gulf. G-III	0.44	23.0

Cabin volume appears to have played an important role in the modern markets, starting in the late 1980s. This period is indeed marked by the introduction of several new, large-cabin and high Revealed Value models such as the Gulfstream G-IV and G-V that have enjoyed considerable market success.[*]

Available seat-miles has likewise started playing a differentiation role since approximately the late 1980s. This can, in part, be attributed to the large cabin, long range models introduced and still reigning supreme in the business jet market, such as the Gulfstream G-V and Bombardier Global Express.

Both cabin volume and available seat-miles appear to have been briefly important in the mid to late 1960s. This period coincides with the introduction of a second generation of light to midsize business jets such as the Rockwell Jet Commander and the Hawker 125-400. These new aircraft were characterized by unusually large cabins for light jets with concomitant larger

---

[*] Recent introductions of a new class of entry-level light jets (Raytheon Premier I, Cessna CJ1 and CJ2) also appear to have a large market appeal with significantly smaller cabins, so the current trend may be for cabin volume to be less of a differentiator in market sales. It is still too early to draw definitive conclusions on this issue given the data at hand.

passenger capacities. It took another 3-5 years for the market to stabilize on the larger standard cabins and more passengers, after which Figure 65 indicates the cabin volume per passenger and available seat-miles attributes were no longer important differentiators in the market.

6.1.2 Monte Carlo Analysis for Aircraft Data

Uncertainties necessarily exist in the data used in the RVI model. The attribute data (cruise speed, fuel consumption, etc.) has been consistently reported by a single source, ***Business & Commercial Aviation***, but varies year-to-year according to what manufacturers report to the publication. As manufacturers better learn the actual performance of their aircraft as they gain experience "in the field," the data reported to B/CA may subtly change. The issue of using aircraft shipments instead of actual consumer demand (via orders booked, for example) has already been mentioned in Chapter 5 and is another source of uncertainty for the model. Finally, the list prices used in the model reflect the only public source of pricing data, but undoubtedly do not represent the majority of the actual sales prices. Interviews with marketing managers indicate that actual sales prices can, in some instances, be discounted as much as 20% below the list price.

There is a need not only to address these uncertainties, but also to determine the reliability of the model results in the presence of possible "noise." The sum-squared error cost function, J, and the multiple coefficient of determination, R^2, both indicate the goodness of fit of the RV and VI equations, but do not directly speak to the consistency of the attribute weighting factors, particularly in light of uncertainties in the attribute levels themselves as well as the aircraft sales prices and demand.

To address uncertainties in the attribute levels and in the aircraft sales prices and demand, a Monte Carlo analysis was performed to determine how the attribute weighting factors would change due to these uncertainties. Each of the five attributes and the product demand parameter were treated as normal random variables with variations about their deterministic numeric values, treated here as the random variable mean, μ. The nomenclature for a normal random variable is $N(\mu, \sigma^2)$ where σ^2 is the variance, or the square of the standard deviation. The probability mass and cumulative distribution functions for a $N(0, 1)$ random variable are sketched in Figure 67.

The normal random variables in this Monte Carlo analysis were assumed to have 90% of their values fall within ±5% of their mean. The area under the curve in Figure 67 representing 90% is between ±1.65 standard deviations, so for these variables $1.65\sigma = 0.05\mu$. The distributions are, therefore, $N\left(\mu, \left[\frac{0.05\mu}{1.65}\right]^2\right)$. The ±5% variation was considered conservative for this analysis as most manufacturers guarantee their aircraft performance to customers within only a few percent of a deterministic value.

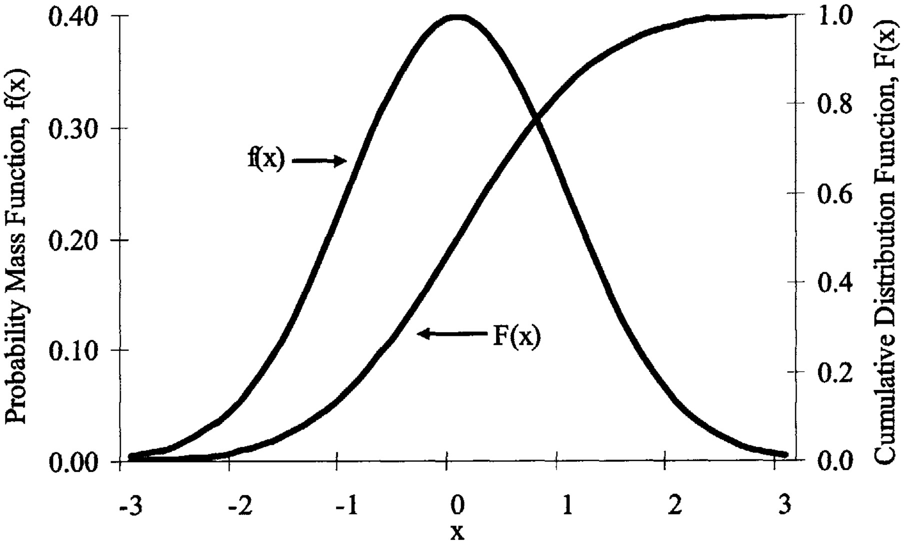


Figure 67: Normal Probability and Cumulative Distributions

Since few customers would be expected to pay more than list price, the price parameter was not treated as a normal random variable. A so-called beta distribution was instead used as it allows asymmetric distributions and also permits finite tails to be selected for the distribution (the tails in Figure 67 theoretically only approach zero asymptotically). The nomenclature for a beta distribution is B(α, β, A, B) where α and β serve as shaping parameters and A and B are the finite termination points for the left and right tails of the distribution, respectively.

The price discount received by customers was given a B(2, 4, 0, 20) distribution based on the assumption that the average customer would receive approximately a 7% discount and that very few would receive a full 20% discount (Figure 68). Resulting from this, 90% of customers receive a 12% discount or less on the "B/CA Equipped Price."

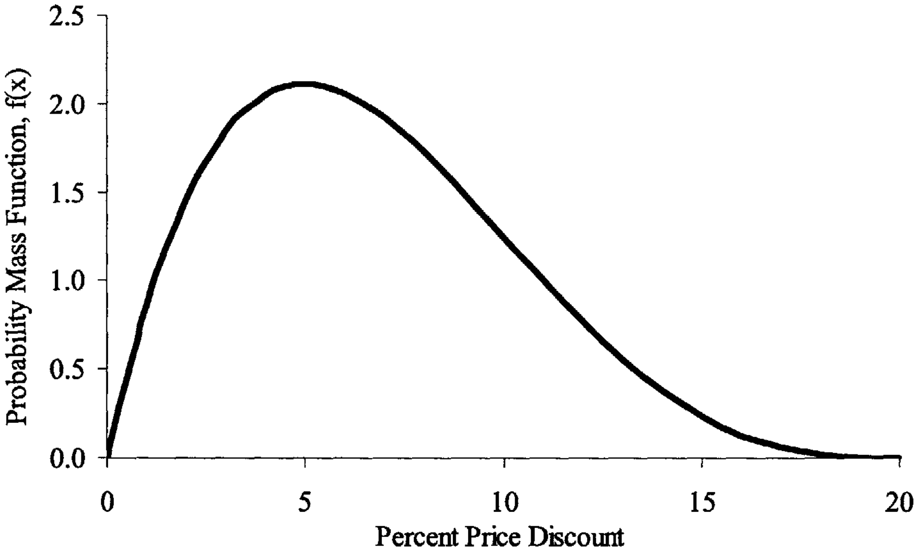


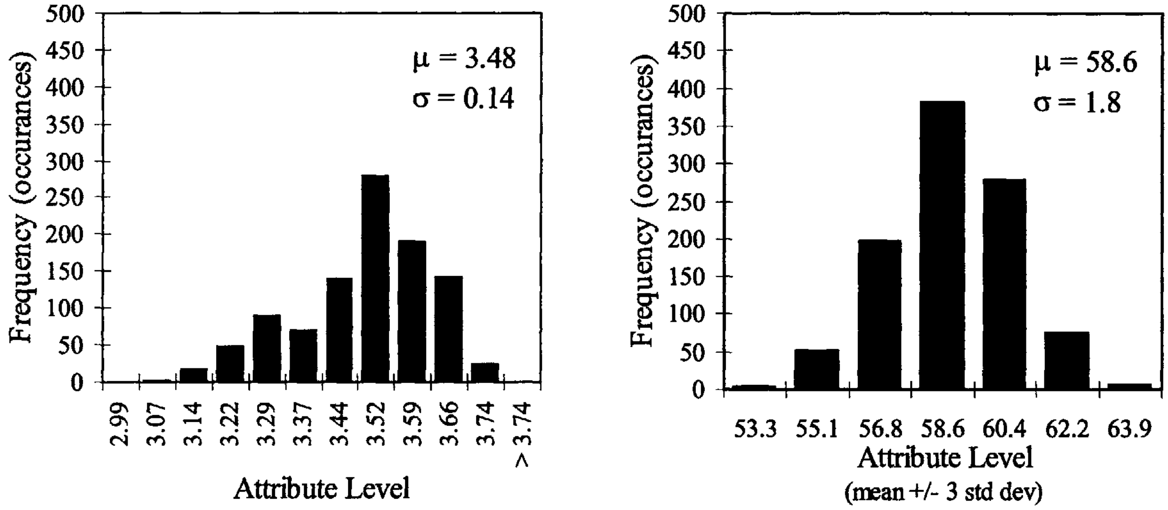
Figure 68: Beta (2, 4, 0, 20) Distribution for Price Discounting

The Monte Carlo analysis was performed by randomizing each of the seven parameters for each of the aircraft in the appropriate year's market, and then determining the new attribute weighting factors for the best fit. One thousand such randomizations and best fits were performed for the analysis. For clarity, the algorithm used is listed in Figure 69.

The stochastic distributions for the seven random variables were shown in Chapter 5 for two randomly selected aircraft. The distributions for one of those aircraft, the Cessna CJ1, are reproduced here in Figure 70 for the reader's reference. The figure indicates that 1000 Monte Carlo simulations are sufficient to properly represent the selected normal and beta distributions.

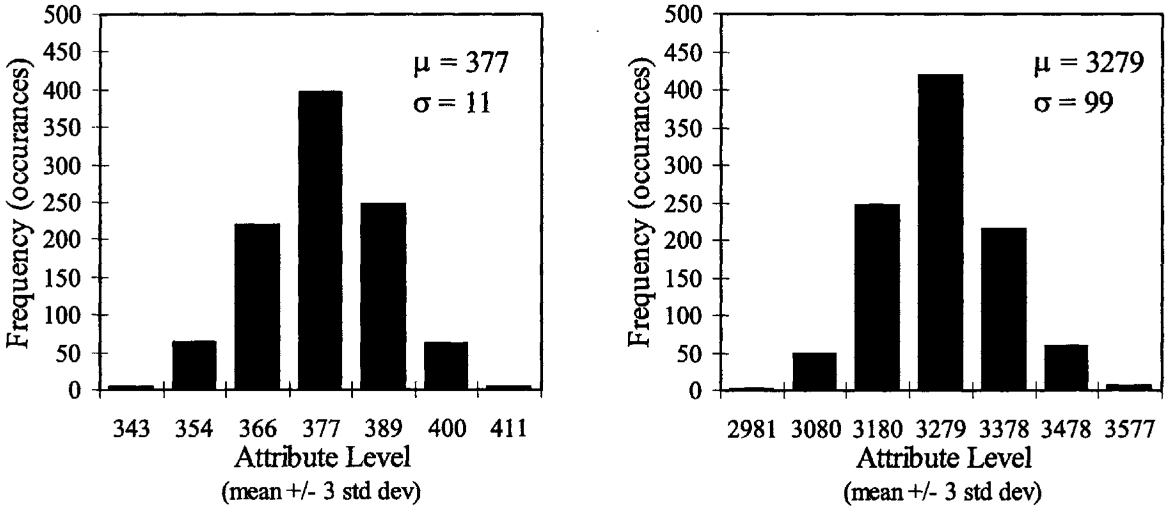
```
Do 1000 simulations
      Do for each aircraft
            Randomize Aircraft Price
            Randomize Aircraft Demand
            Randomize Maximum Cruise Speed
            Randomize Runway Field Length
            Randomize Available Passenger Seat Miles
            Randomize Cabin Volume per Passenger
            Randomize Fuel Consumption per Passenger Seat Mile
      Next aircraft
      Best fit VI = RV
      Record best fit attribute weighting factors
Next simulation
```

Figure 69: Monte Carlo Analysis Algorithm



(a) Equipped Price (US$ millions)

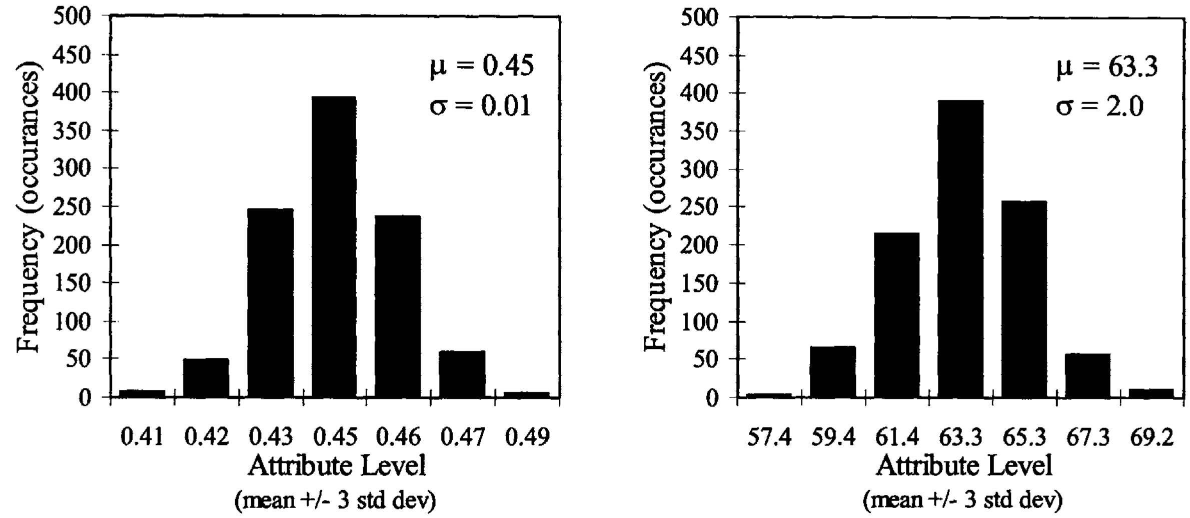
(b) Annual Unit Shipments



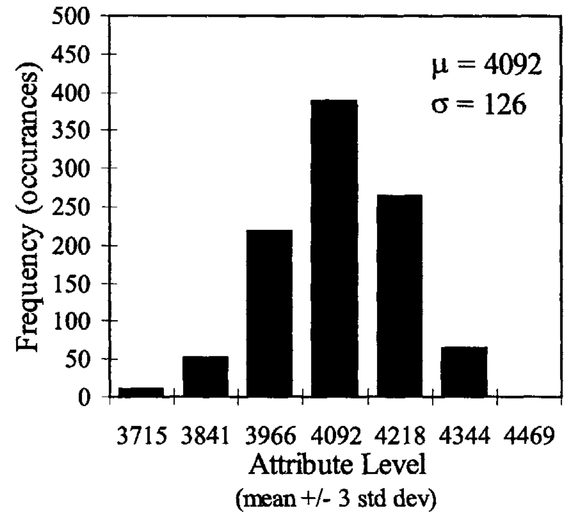
(c) Maximum Cruise Speed (ktas)

(d) Takeoff Field Length (feet)

Figure 70: Stochastic Attribute Distribution, Cessna CJ1



(e) Fuel Consumption per Seat Mile (lb/nm/pax) (f) Cabin Volume per Passenger (cu ft/pax)



(g) Available Seat Miles (nm-pax)

Deterministic Airplane Attribute Values
Cessna CJ1
(Average 1999-2001)

Equipped Price: $3.74 m
Annual Unit Shipments: 58.5
Maximum Cruise Speed: 377 ktas
Takeoff Field Length: 3280 ft
Fuel Consumption / Seat Mile: 0.45 lb/nm/pax
Cabin Volume / Passenger: 63.4 cu ft/pax
Available Seat Miles: 4093 nm-pax

Figure 70 (cont): Stochastic Attribute Distribution, Cessna CJ1

As a reminder of how the Monte Carlo analysis output appears, the resulting distributions for the five attribute weighting factors are again reproduced from Chapter 5 and are shown in Figure 71 for the 1999-2001 market. As noted in Chapter 5, the deterministic weighting factors for the cabin volume and available seat-miles attributes appear reliable even amid uncertainties in the model inputs. The field length and fuel consumption weighting factors are predominantly zero, and continue to have little influence on the final model results. The maximum speed weighting factor demonstrated the greatest variation, but continues to be indicated as unimportant to differentiation in the current business airplane market. It may vary considerably without significantly impacting the RV and VI best fit. It is of interest to now extend this analysis for the historical set of data and draw larger conclusions as to the reliability of the model results throughout the 40 year business aviation history.

The Monte Carlo analysis was conducted for a select set of data from the 40 year database; specifically for time periods at five-year intervals starting with the 1959-1961 data set. Nine sets of analyses were conducted using the same methodology for the analysis as described above for the 1999-2001 year set.

Rather than showing nine sets of charts such as in Figure 71, and leaving it up to the reader to laboriously integrate the results, the analysis outputs were instead integrated into one chart showing the attribute mean, μ, and standard deviation, σ, for each attribute.[*] [†]

It is of interest to determine what standard deviation should be considered as indicating a "robust" attribute weighting factor in this Monte Carlo analysis. As an example, Figure 71 clearly indicates that $\sigma = 0.13$ for maximum cruise speed yields a wide distribution of weighting factors and is indicative of a factor with a deterministic value unreliable amid uncertainties in the model inputs. Conversely, $\sigma = 0.04$ for available seat-miles yields a tight distribution. The number of occurrences measured at the weighting factor mean value will depend on the assumed bin size used in counting. With the bin size of 0.04 used in Figure 71, the theoretical occurrences at the mean value for 1000 Monte Carlo simulations, given a normal distribution, are shown in Figure 72. The figure indicates that at standard deviations higher than $\sigma = 0.05$ less than one-third of the weighting factor values will be near the mean value, the rest being distributed to either side of the mean (likely in a bell shaped curve unless the mean value is near zero, as for field length and fuel consumption in Figure 71). The data in Figure 72 then indicates that, for this analysis, weighting factors with standard deviations greater than 0.05 should be viewed as factors with deterministic values unreliable amid uncertainties in the model inputs.

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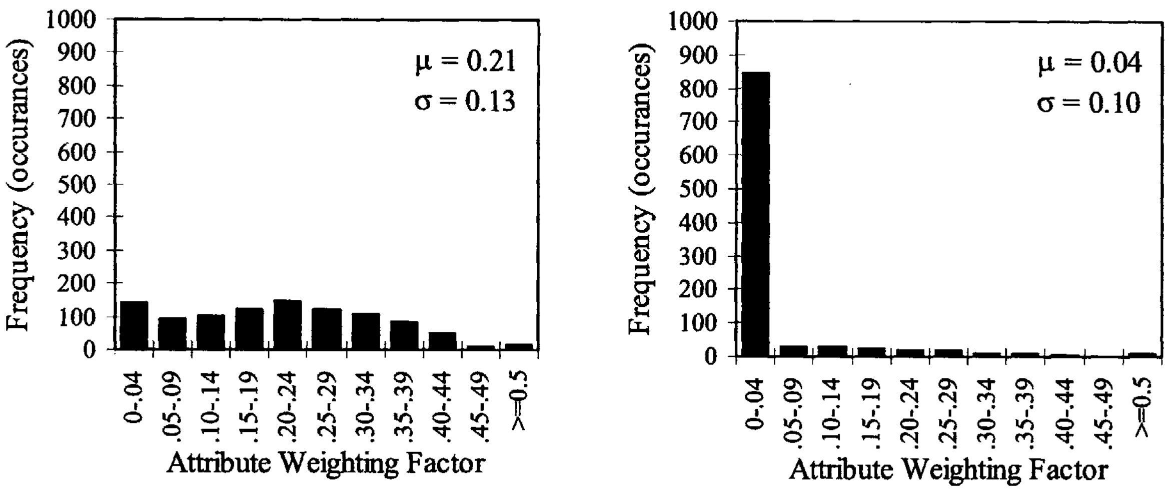
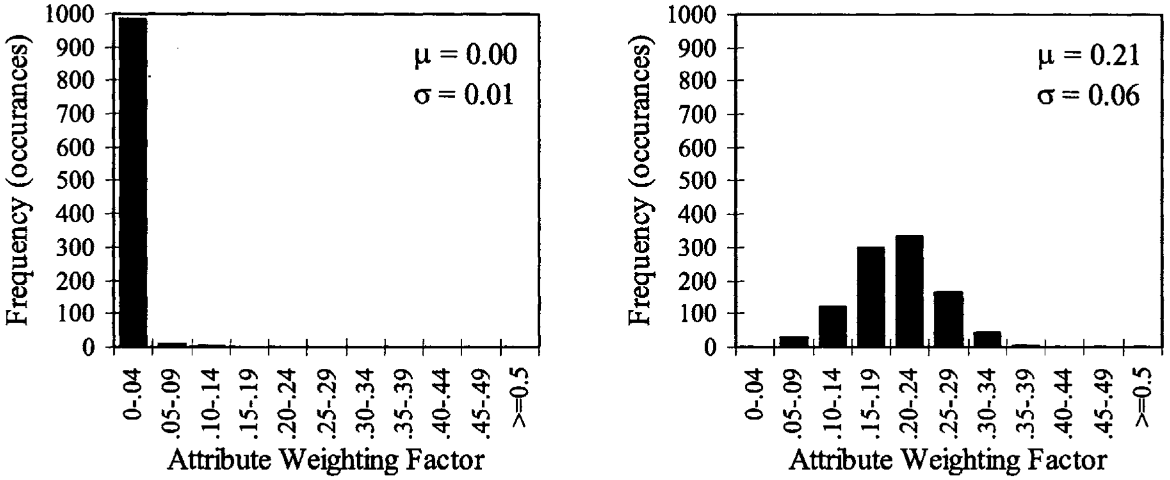
[*] When data is available in terms of (μ, σ) pairs, it is often convenient to express the results in terms of a signal-to-noise ratio, $\mathrm{SNR} = 20\log_{10}\left(\frac{\mu}{\sigma}\right)$. Unfortunately, for this analysis when an attribute mean approaches zero, the SNR approaches negative infinity, and when $(\mu < \sigma)$ the SNR is finite negative, rendering essentially nonsensical results for the traditional interpretation of signal-to-noise ratio. The (μ, σ) pair results will simply be compared on charts.

[†] For clarity, the years labeled on the charts represent the midpoints of the three-year average data sets used in the analysis (e.g., 1965 = 1964-1966 year set).



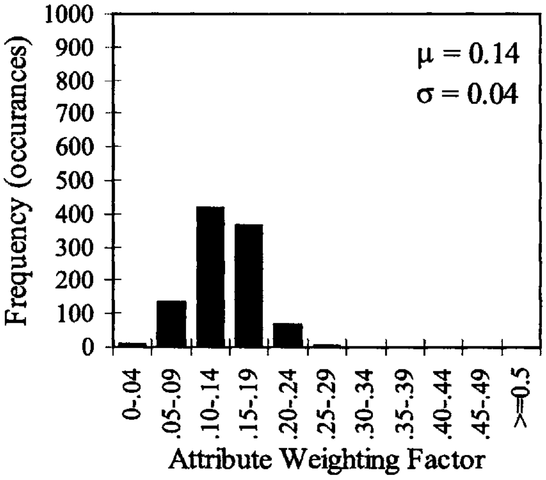
(a) Maximum Cruise Speed

(b) Takeoff Field Length



(c) Fuel Consumption per Seat Mile

(d) Cabin Volume per Passenger



(e) Available Seat Miles

Deterministic Attribute Weighting Factors
(1999-2001 Market)

Maximum Cruise Speed: 0.25
Takeoff Field Length: 0.00
Fuel Consumption per Seat Mile: 0.00
Cabin Volume per Passenger: 0.23
Available Seat Miles: 0.15

Figure 71: Monte Carlo Analysis Results, 1999-2001 Market

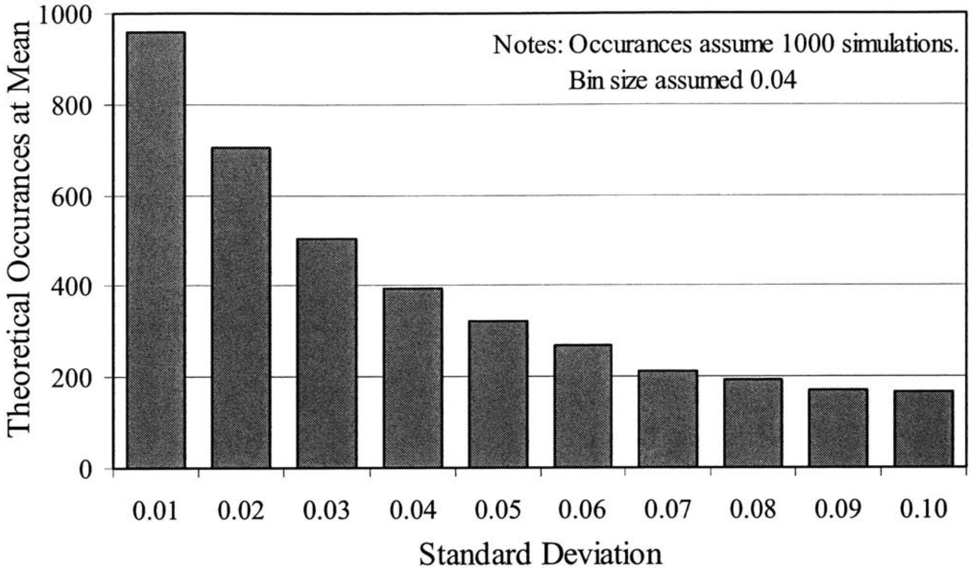


Figure 72: Theoretical Frequency of Weighting Factor Mean Values with Varying Standard Deviations

Overall, the Monte Carlo analysis appears to clarify and substantiate the conclusions previously drawn in examining the historical weighting factors and their sensitivities in the preceding section. In Figure 73 the standard deviation for the maximum cruise speed attribute weighting factor is quite large for the 1995 and 2000 time periods. This is indicative of a weighting factor for which the Revealed Value and Value Index best fit solution is relatively insensitive to the numeric value of the weighting factor, allowing high variance in the factor with stochastic input. In the 1985 and 1990 time periods the weighting factor was consistently not leveraged by the best fit routine in differentiating the market competitors, as evinced by the zero weighting factor mean and low standard deviations. Prior to the mid 1980s, the weighting factor demonstrates a regular non-zero numeric value with low standard deviation. This is indicative of an attribute consistently leveraged by the best fit routine in differentiating products in the market.

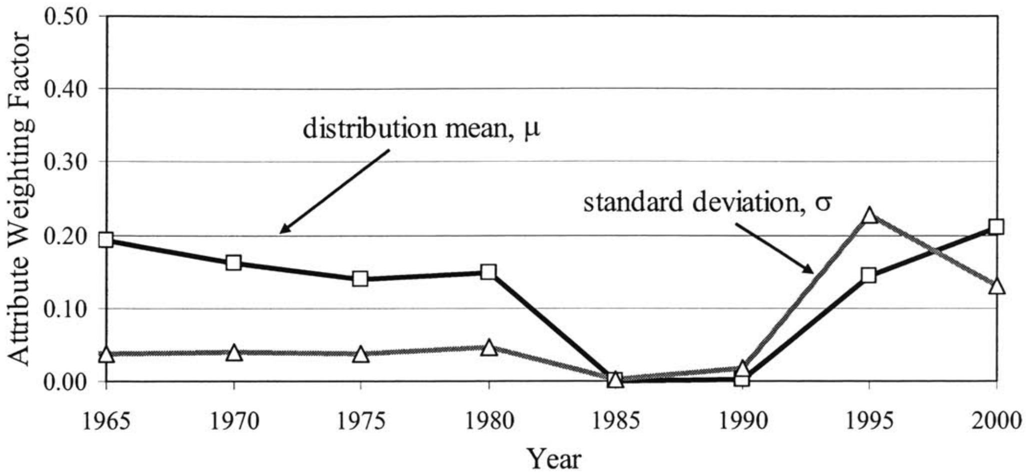


Figure 73: Historical Monte Carlo Results - Maximum Cruise Speed

Figure 74 characterizes the takeoff field length attribute as either being of little or no use to the best fit routine in differentiating the market competitors (μ ≈ 0 in 1965, 1980, and 2000 with low variance) or with sufficiently high standard deviations that the attribute is of no use in affecting the best fit solution (i.e., the sensitivity $\partial J/\partial \gamma$ is quite small). This is, again, consistent with the conclusions drawn in the previous section on the sensitivity analysis.

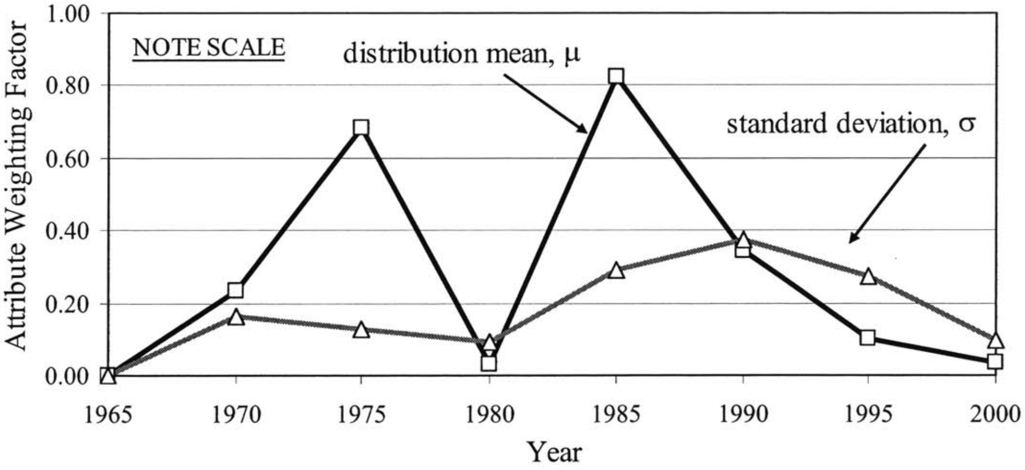


Figure 74: Historical Monte Carlo Results – Runway Takeoff Field Length

The weighting factor for the fuel consumption attribute, shown in Figure 75, demonstrates consistently low standard deviations in the weighting factor due to uncertainties in the model input data. However, only in the mid 1970s and early 1980s is the attribute able to be leveraged by the best fit routine in any significant manner to differentiate products in the market (i.e., $\mu > 0$). As discussed in the prior section on sensitivities, these periods were indeed marked by the introduction of new, more fuel efficient light and large jet aircraft.

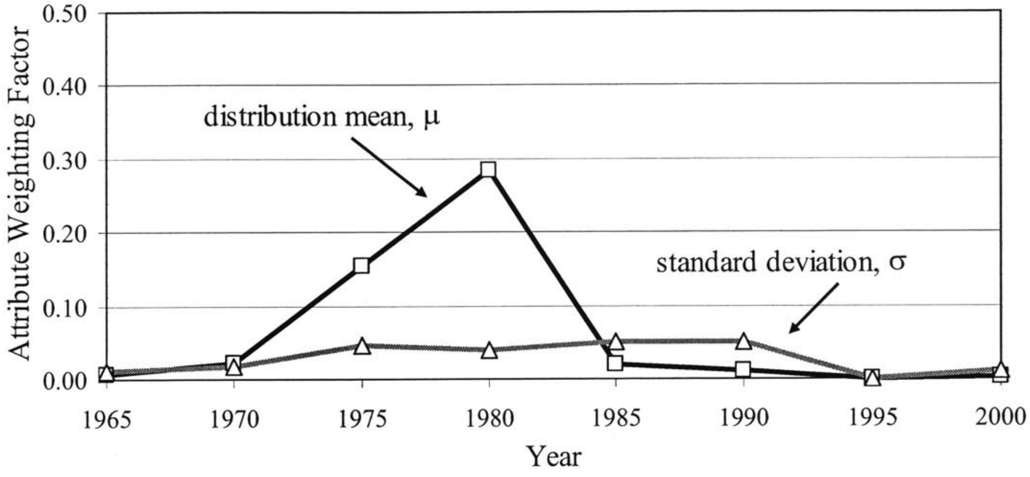


Figure 75: Historical Monte Carlo Results – Fuel Consumption per Passenger Seat-Mile

Once again, in Figure 76 the cabin volume per passenger attribute weighting factor is characterized by consistently low standard deviations throughout the time period under study. In the last 15-20 years the attribute weighting factor has grown significantly to indicate an attribute of growing importance in differentiating products. As mentioned in the prior section on sensitivities, both the cabin volume and available seat miles attributes enjoyed a brief period of differentiability in the mid 1960s with the introduction of roomier light jets with larger payload capabilities.

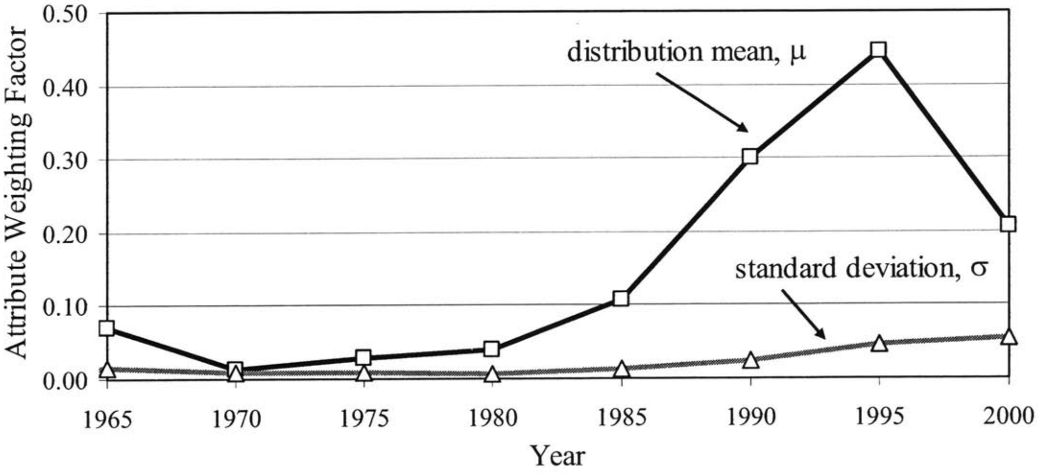


Figure 76: Historical Monte Carlo Results – Cabin Volume per Passenger

As with the "cabin volume per passenger" attribute, the "available seat miles" attribute appears to have grown in importance to product differentiation in the recent market, with a short period of prominence in the mid 1960s as well (Figure 77).

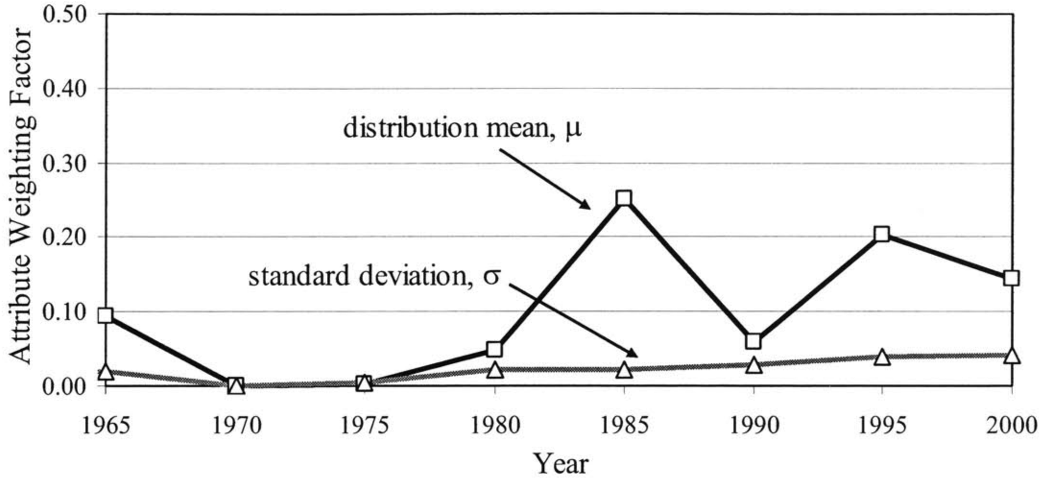


Figure 77: Historical Monte Carlo Results – Available Seat-Miles

6.1.3 Effect of Changes in the Attribute Bounds

As developed in Chapter 4, the RVI method requires that each attribute is bounded by "critical" and "ideal" attribute levels, beyond which the value of the product is rendered zero (for critical) or the value does not improve (for ideal). A "baseline" attribute value is also required to set the unity point for the part-worth relative value. Though some attribute bounds can be set through physical limits or other definitive criteria (an ideal range of half the Earth's circumference is one example), some bounds must inevitably be estimated using more subjective means. Therefore, modelers and users of the RVI method should investigate the effects of changing the attribute bounds on the final value assessment results.

Table 16: Business Airplane Relative Value Index Model Attributes

			Attribute Bounds		
Attribute	Units	Type	Critical	Baseline	Ideal
Max. Cruise Speed	ktas	LIB	61	391	2,866
Field Length	feet	SIB	10,000	4,000	3,000
Fuel Consump./ Seat-Mile	lb/nm/pax	SIB	1.0	0.4	0.0
Cabin Volume per Passenger	cu. ft./ pax	LIB	20	60	150
Available Seat Miles	pax-nm	LIB	900	21,000	100,000

The maximum cruise speed attribute for the 1999-2001 market of business airplanes (listed in Table 9) falls far away from the critical and ideal bounds, as shown in Figure 78. Adjusting the bounds will not greatly affect the part-worth value of business airplanes due to maximum cruise speed.

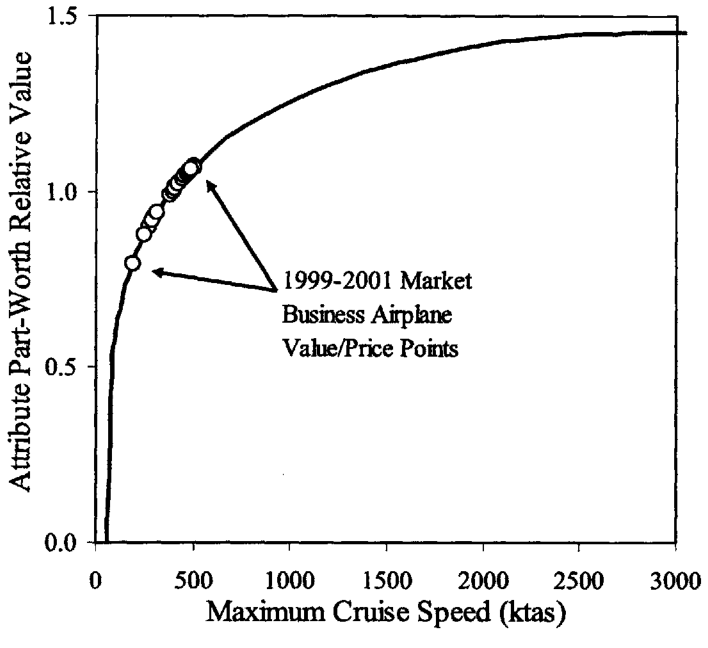


Figure 78: Part-Worth Relative Value for Maximum Cruise Speed Attribute

The cabin volume per passenger and available seat-miles attributes, Figure 79 and Figure 80, respectively, each approach or exceed the estimated ideal bounds for these attributes.

Some products, particularly those near the bounds, may be significantly affected if those estimates were to change.

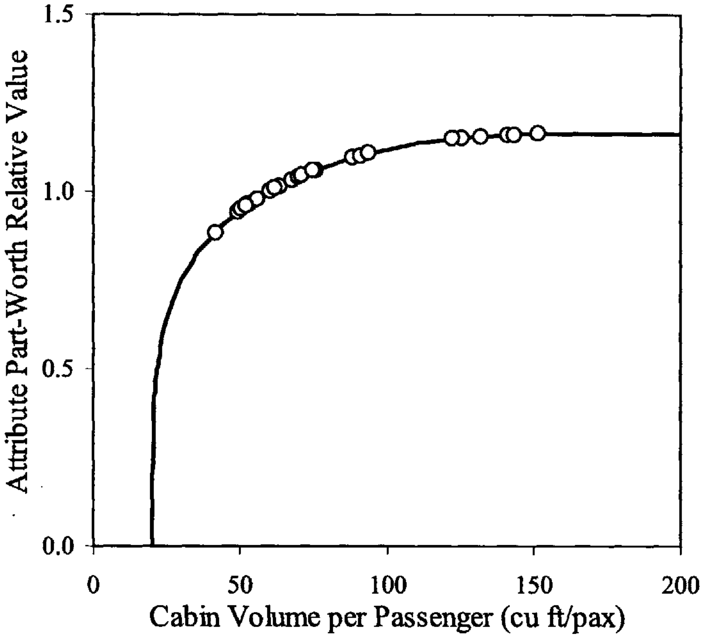


Figure 79: Part-Worth Relative Value for Cabin Volume per Passenger Attribute

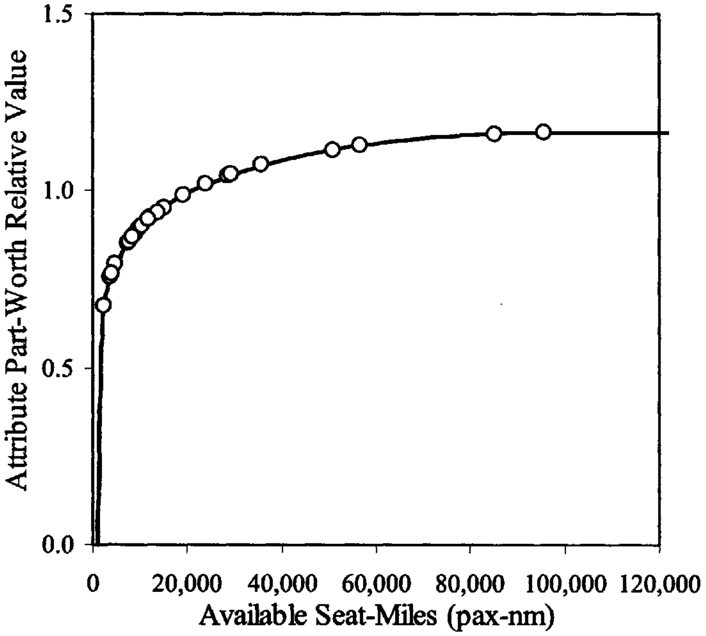


Figure 80: Part-Worth Relative Value for Available Seat-Miles Attribute

The maximum distortion for altering the part-worth contribution would be to simultaneously increase the estimates for the critical and baseline bounds while reducing the estimate for the ideal bound (or conversely, to reduce the critical and baseline estimates while increasing the ideal estimate). Such an exercise is shown in Figure 81 for the cabin volume per passenger attribute.

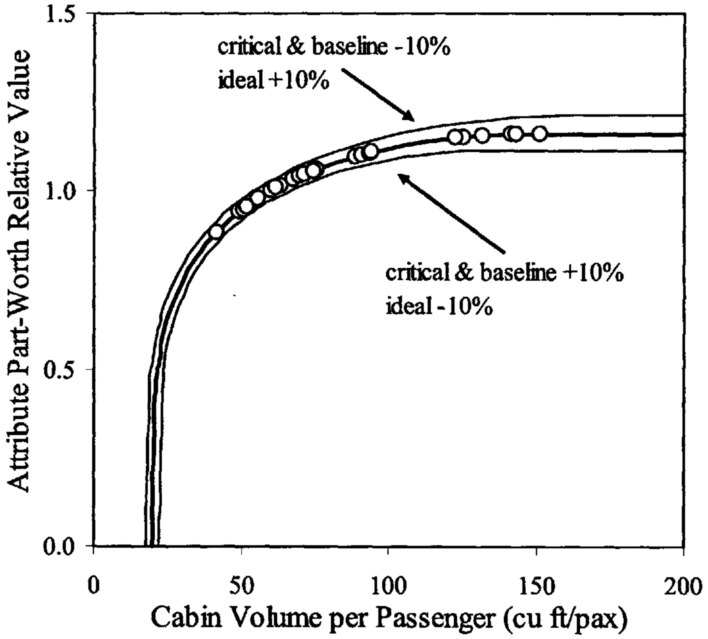


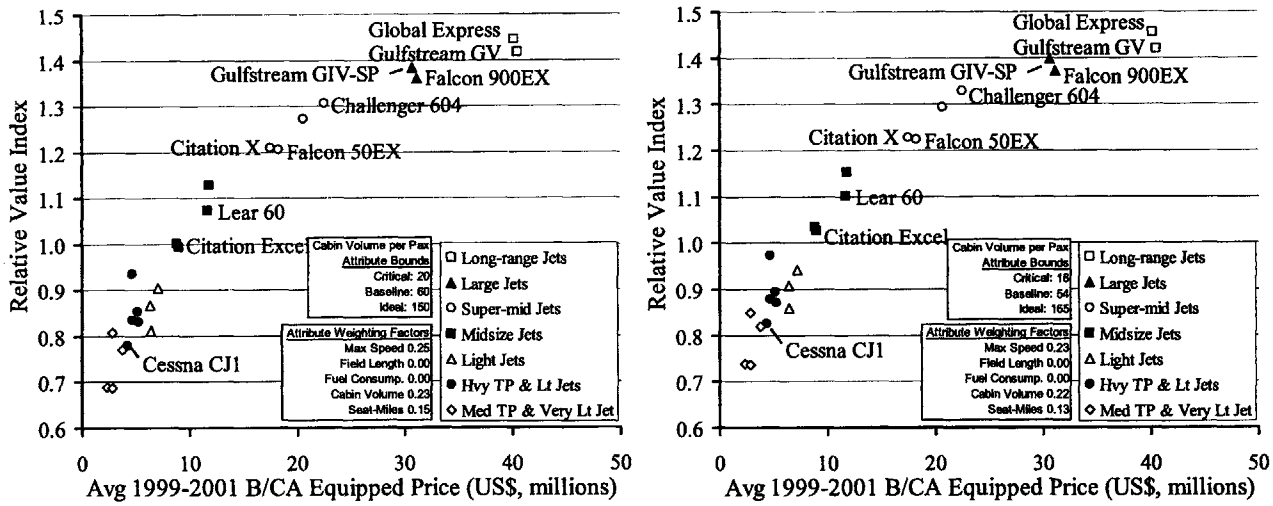
Figure 81: Part-Worths Effect of Altering Attribute Bounds

The "best fit" solution for the Relative Value Index method was determined for the two new sets of attribute bounds shown in Figure 81. The new attribute bounds are tabulated, along with the new solutions, in Table 17.

Table 17: Best Fit Solutions for Three Cabin Volume Attribute Bounds

		Critical & Baseline +10%, Ideal -10%	Nominal	Critical & Baseline -10%, Ideal +10%
Attribute Bounds	critical	22	20	18
	baseline	66	60	54
	ideal	135	150	165
Best Fit Solution	Maximum Cruise Speed	0.22	0.25	0.23
	Takeoff Field Length	0.00	0.00	0.00
	Fuel Consumption per Seat Mile	0.00	0.00	0.00
	Cabin Volume per Passenger	0.18	0.23	0.22
	Available Seat-Miles	0.18	0.15	0.13
	J	148.9	141.9	137.4
	R^2	0.99	0.99	0.99

The data in Table 17 indicates that the best fit solutions are not significantly altered by the changes in the cabin volume attribute bounds, both as measured by the new attribute weighting factors, and as measured by the sum-squared error, J, and the multiple coefficient of determination, R^2. One of the new RVI curves is shown in Figure 82 (b) next to the nominal RVI curve in (a). Horizontal lines have been drawn as reference to help the reader gauge the change in product value results. Though some products do shift in value, particularly those at lower value/price points, *the overall relationship of the products is unchanged.*



(a) Nominal Bounds

(b) Critical & Baseline -10%, Ideal +10%

Figure 82: Effect on RVI Solution of Changing Attribute Bounds

In the business aviation RVI model, 10% changes in attribute bounds does not appear to significantly alter the results. It is recommended, however, when attribute bounds are in question or are open to varying interpretations, that the impacts of altering the bounds be assessed.

As noted in §3.3.4.2, weighted utility indices that contain normalizing parameters are subject to a special form of instability in their preference rankings. Though the RVI method is normalized in a very different manner than conventional utility indices, it was thought appropriate to test the approach for this instability.

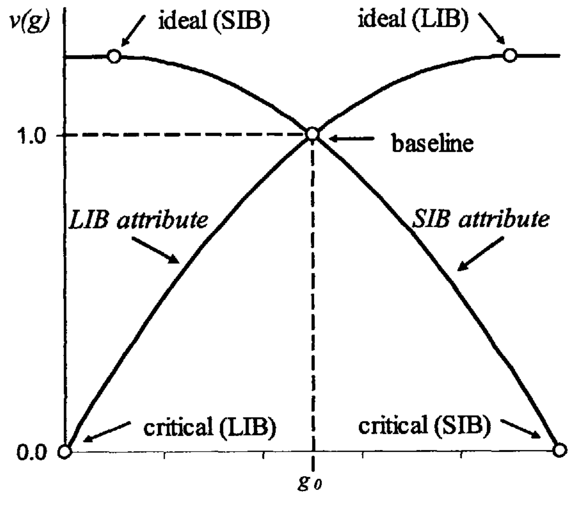


Figure 83: Compositional Value for LIB and SIB Type Attributes

Cook's RVI method is normalized via the baseline attribute level, g_0 (Figure 83). At this level the attribute part-worth value contribution is considered to be unity. To test for instability, the baseline attribute level was varied widely for the 1999-2001 market of business aircraft and the RV=VI best solution determined for each new baseline level.

Table 18 shows the baseline attribute levels used in this study. The level of g_0 was altered to be as close to the critical attribute levels as possible by setting the baseline level to the historical industry-wide minimums observed in the business aviation database (referred to as the "historic industry minimum performance" in the table). Conversely, the level was also altered to be as close to the ideal attribute levels by using the historic industry-wide maximums observed ("historic industry maximum performance").

Table 18: Baseline Attribute Bounds for Stability Study

	Historic Industry Minimum Performance	Historic Industry Average	Historic Industry Maximum Performance
Maximum Speed	180	391	512
Field Length	6800*	4000	3300†
Fuel Burn per Seat Mile	0.87*	0.4	0.2**
Cabin Volume/Pax	24	60	135††
Available Seat-Miles	1800	21000	90000††

*maximum
**minimum
† 10% above ideal bound
†† 10% below ideal bound

The resulting RVI curves are shown in Figure 84 and indicate only a shift in the RVI values without a reordering of any of the preference rankings. The RVI method is thus demonstrably free from the instability that characterizes some forms of weighted utility indices with normalizing factors.

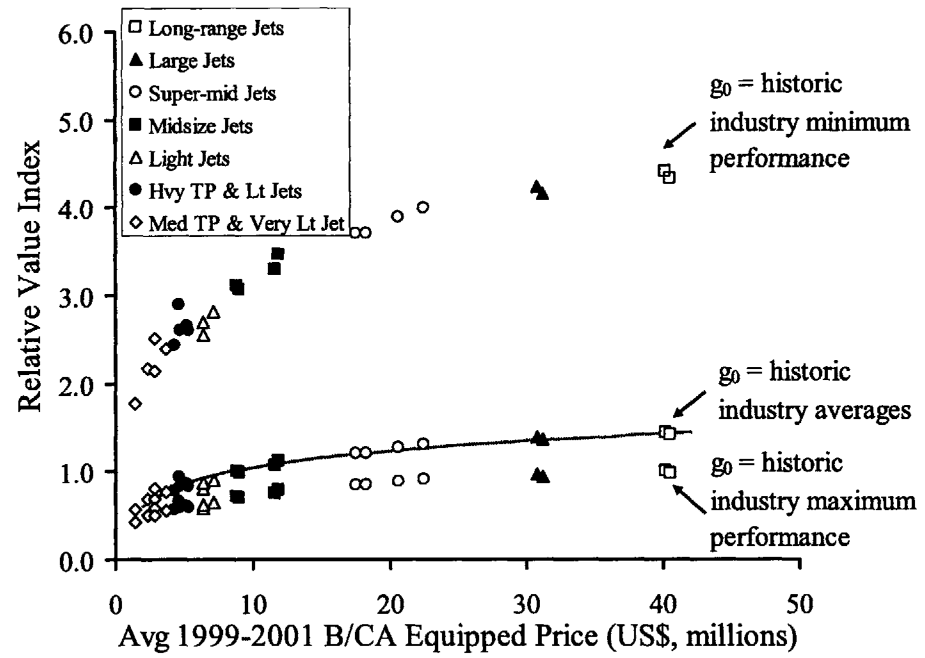


Figure 84: Effect of Altering Baseline Attribute Level on Relative Preference Rankings

6.1.4 Effect of Changes in Price Elasticity

The price elasticity, also referred to in the economics literature as the *demand elasticity*, is the non-dimensional change in unit sales given a change in the unit price of a product:

$$E_p = \frac{\%\,\text{change in unit sales}}{\%\,\text{change in unit price}} = \frac{\partial D}{\partial P} \cdot \frac{\overline{P}}{\overline{D}} \qquad \textbf{(6-1)}$$

The price elasticity factor is used to determine the coefficient *K*, (4-30), which is in turn a key parameter in the linearized demand equation, (6-3).

$$K = E_p \frac{\overline{D}}{\overline{P}} \qquad \textbf{(6-2)}$$

$$D = K(V - P) \qquad \textbf{(6-3)}$$

As discussed in Chapter 5, the value of the price elasticity for the business airplane industry is estimated in this study as 1.5, based on interviews with industry marketing experts. In addition, an unpublished study by Professor of Corporate Strategy and Executive Education Michael Rukstad, at the Harvard Graduate School of Business Administration, confirms an industry price elasticity in the 1.5-2.0 range, and finds no evidence for the factor changing for different segments. Despite this, there clearly is some uncertainty as to the exact value of the factor.

The effect of changing the price elasticity for the 1999-2001 business airplane market is shown in Figure 85 as a function of how the different segment RVI averages change with the factor. Increasing the factor appears to have little effect on the segment RVI averages, and reducing the factor lowers the high-end segment RVIs while slightly increasing the low-end segment RVIs.

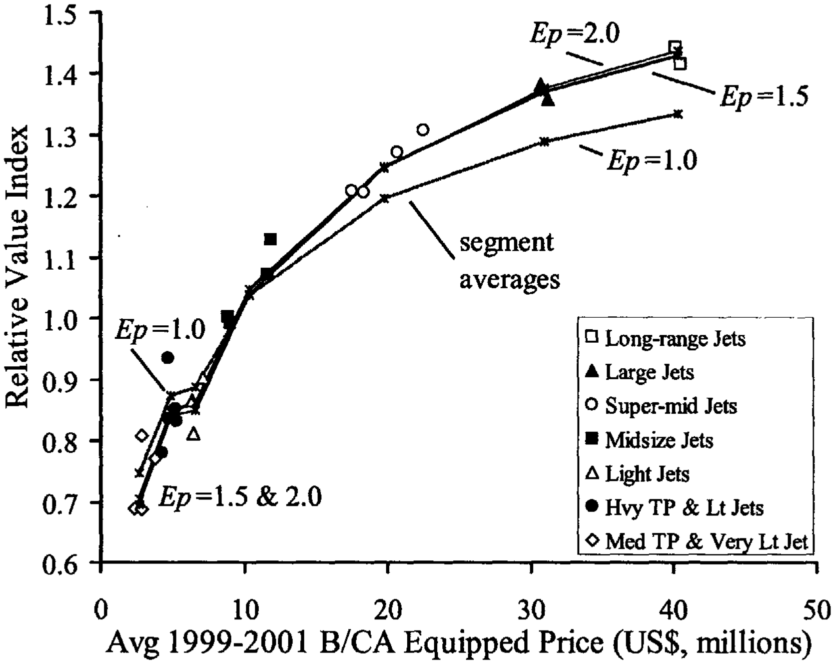


Figure 85: Effect of Changing Price Elasticity on Business Airplane RVI

Figure 86 shows the long-range jet segment average RVI as a function of the price elasticity. These results all show that the relationships of the business aircraft shown in the RVI charts is not altered by the changes in the price elasticity factor. The RVI curves are rotated slightly with changes in the factor, but the analysis results used throughout this study are not materially affected as long as E_p is constant for the entire industry.

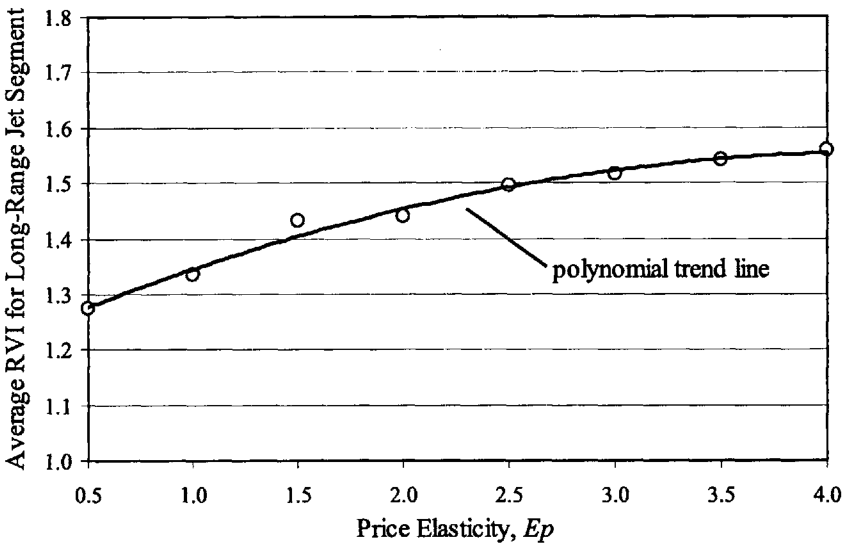


Figure 86: Effect of Price Elasticity on Long-Range Jet Segment RVI

If the price elasticity actually varied between segments in the industry (i.e., the long-range jets factor differing from the large jets factor, etc.), then the shape of the price/value trend could be altered enough to suggest a more linear, or a more logarithmic, trend. The standing of segments relative to one another would certainly be affected as the value/price trend is altered. Although the present data from the Harvard study and from industry marketing experts does not support segment-by-segment changes in the price elasticity, the impacts of such changes warrant further study.

6.1.5 Averaging the Data: One-, Three- and Ten-Year Sets

The aircraft pricing and shipments data used for the various analyses in this study cross-checked with multiple sources when possible and, to the greatest extent possible, checked for year-to-year consistency (e.g., if a shipment or price spiked in one year, reasons were sought or second sources consulted for alternative information). Still, some errors in the data may reasonably be expected due to reporting errors by the original sources. Shipments also show interesting characteristics for newly-introduced and soon-to-retire aircraft. Shipments of new aircraft are often marked by a combination of atypically low production in the first year, due to only a partial year of manufacturing or normal delays associated with production ramp-up, and often a second year of atypically high shipments due to the manufacturer "burning off" some excess backlog that built up during development. Manufacturers tend to prefer a limited production backlog that balances the need for steady production rates with customers' dislike of long waiting periods before product delivery.

In general, a 40 year database of aircraft shipments and pricing data may be expected to have occasional discontinuities or errors that have the potential for biasing analysis results for particular years. Though the Monte Carlo analysis of §6.1.2 indicates data anomalies would likely have minimum practical impact on the analysis results, in this study three-year rolling averages of the data were used to help compensate for variances in the data. In this section, the impact on the analysis results of using a three-year rolling average will be assessed against no-average, and ten-year averaged data.

Figure 87 shows the RVI maximum cruise speed attribute weighting factor determined using single year (no averaging), three-year, and ten-year averaged data. The ten-year averaged data clearly damps out most variances in the RVI results, to the extent that using such data would be harmful to the final analysis by masking a number of interesting short-term market trends. Longer-term trends, such as the importance of cruise speed in the late 1960s and early 1970s are only hinted at in the ten-year averaged data, while they are more evident in the single and three-year averaged data. The rolling three-average does not appear to have an obvious damping effect on attribute trends. It should be recalled from §6.1.1 that not all non-zero instances of an attribute weighting factor indicate that the factor is important in market differentiation that year. See the section on attribute weighting factor sensitivities for details (§6.1.1).

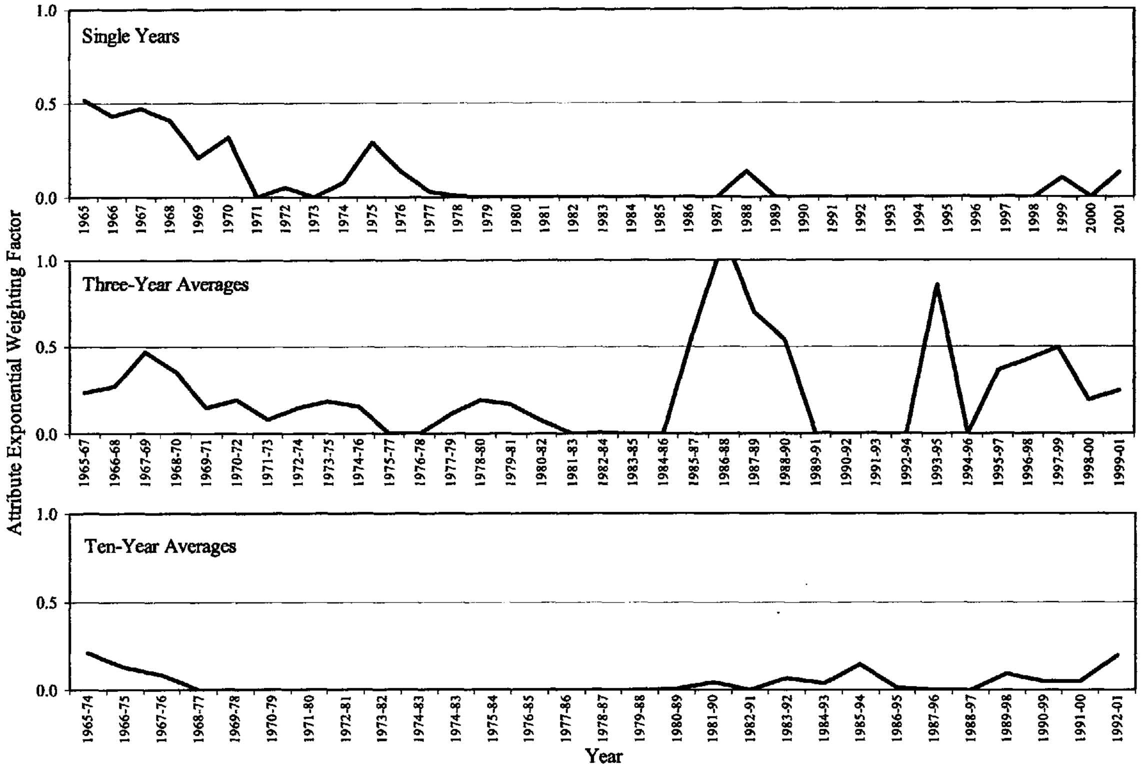


Figure 87: Impact of Averaged Data on Maximum Cruise Speed Weighting Factor

In Figure 88 the three-year averaged data does damp out a few of the shorter-term trends seen in the takeoff field length data. However, the three-year data would combine, for certain time periods, a number of competing aircraft that would otherwise not be in competition in the single year data. For example, a new aircraft might enter the market with first shipments in 1980 while a competitor ceased shipments in 1979. In the single year data these two aircraft would not compete (the last listing for one would be in 1979 while the first listing for the other would be in 1980), whereas in the three-year averaged data the aircraft would be viewed as competitors at least in one or two markets; 1978-1980 and 1979-1981. In reality, these two aircraft were historical competitors since the new aircraft would have been marketed even before shipments commenced in 1980. Sales during development in the 1970s would have affected competing aircraft that, perhaps as a result of the new entry, ceased delivery in 1979. In effect, the three-year rolling averages may be argued to more accurately represent the true competitive segments than do the single year (no averaging) data.

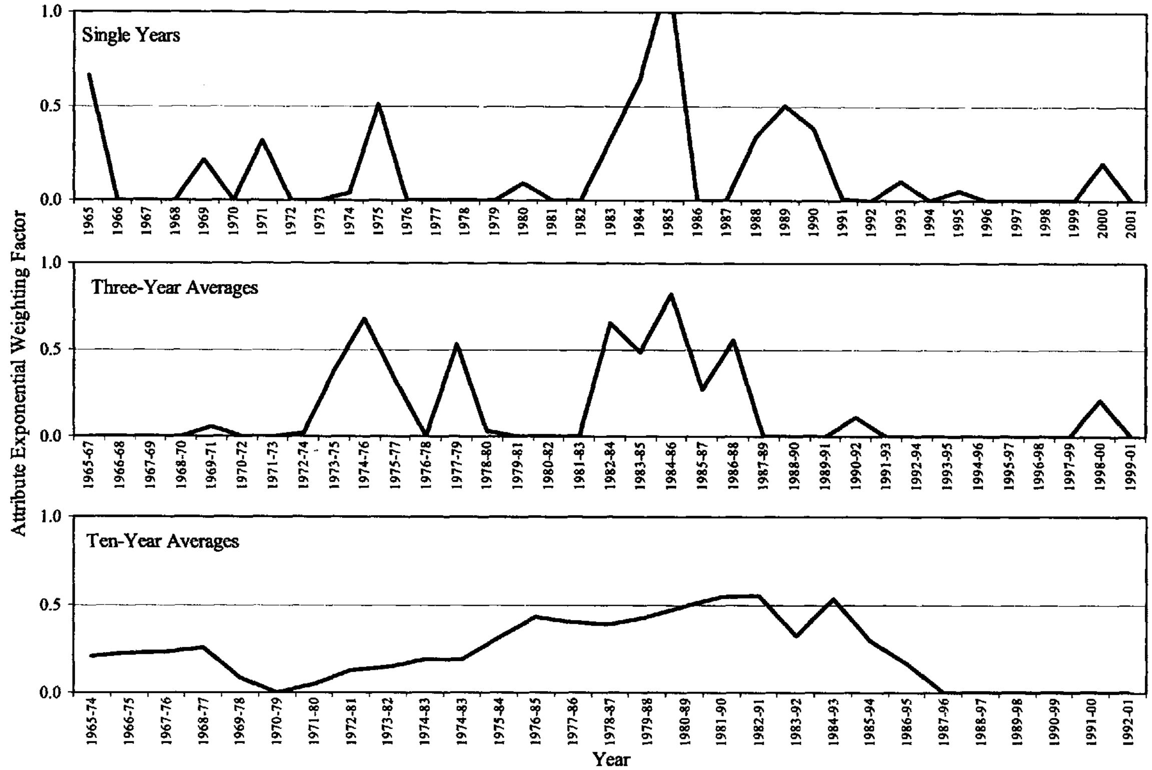


Figure 88: Impact of Averaged Data on Takeoff Field Length Weighting Factor

In Figure 89 the most important variances in the fuel consumption attribute weighting factor appear to be captured by the three-year averaged data, whereas the ten-year averages considerably smooth the data. The ten-year averages appear to combine too many aircraft into each competitive segment, some which likely never actually competed in the real-world market. Three-year averages, and perhaps five-year averages, appear to capture a good balance of eliminating noise from the data while representing true-to-life market competitive segments.

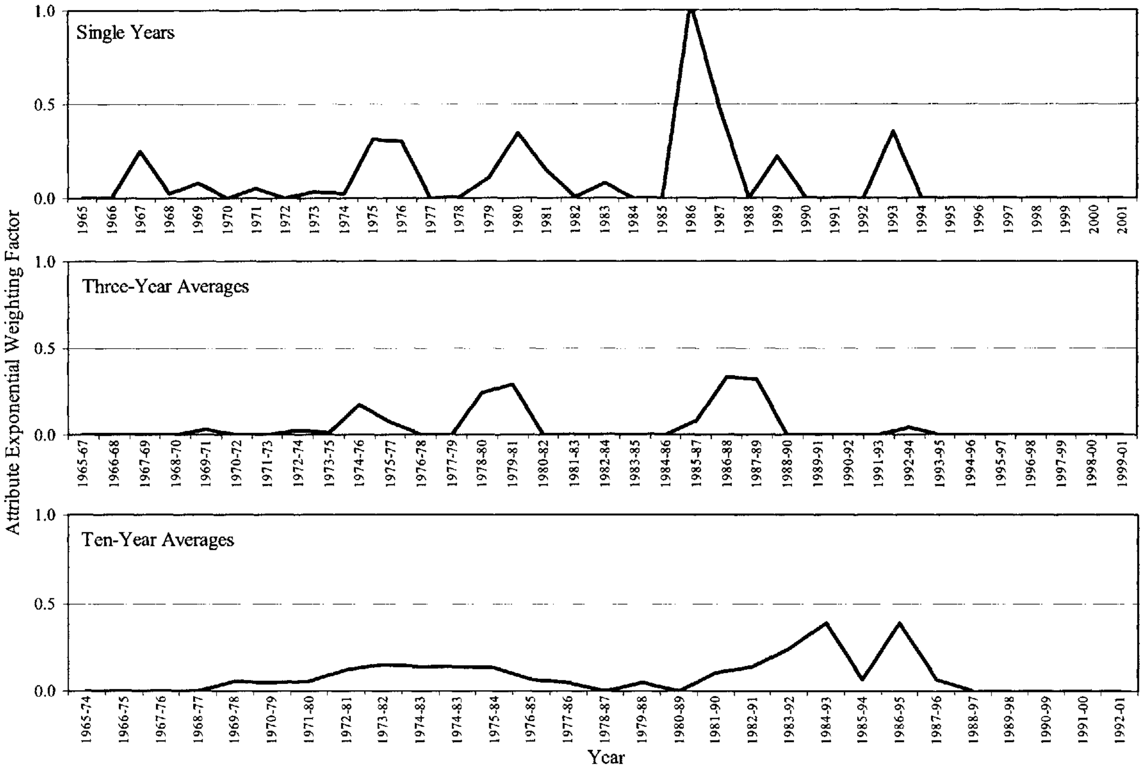


Figure 89: Impact of Averaged Data on Fuel Consumption per Seat Mile Weighting Factor

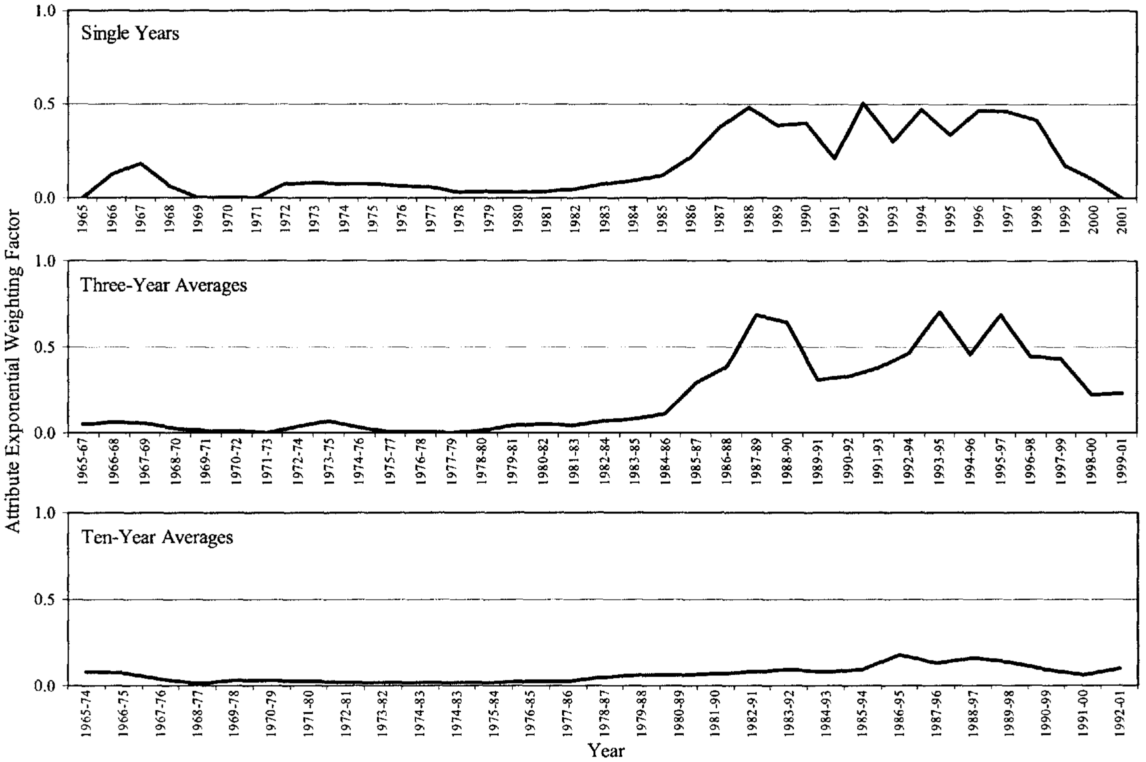


Figure 90: Impact of Averaged Data on Cabin Volume per Passenger Weighting Factor

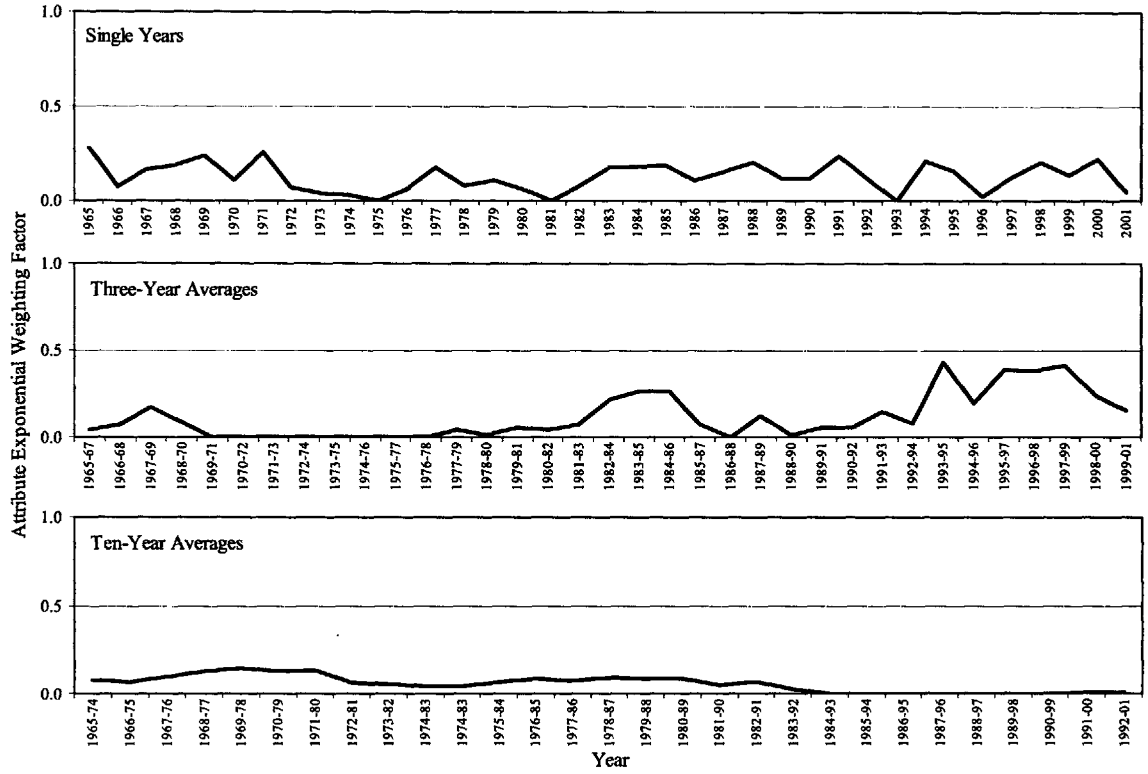


Figure 91: Impact of Averaged Data on Available Seat Miles Weighting Factor

6.1.6 Limitations of the Approach with other Applications

This study has focused on application of the Relative Value Index methodology to the business aviation industry. The aviation industry, as a whole and the business aviation industry in specific, is considered to be a "slow clockspeed" industry using Fine's (1998) terminology for measuring the rate of change, or dynamicism, of an industry. As a retrospective tool the RVI method is well-suited for analysis of slow clockspeed industries and, as will be shown in §6.2, may also be useful as an estimating tool for future industry developments. With industries that experience more rapid changes* it is uncertain that the RVI method would be as useful as an estimation tool using the RV and VI best fit approach for setting attribute weighting factors. The industry may change so quickly that attribute weighting factors based on recent empirical data may no longer be appropriate. Users should exercise caution when using the RVI metholodgy in industries that are suspected of being "fast clockspeed," or of experiencing rapid changes in their fundamental features.

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* Changes may include those occurring in the customer base, product technology, product prices and primary attributes of importance, for example.

6.1.7 Summary: Evaluation Analyses

The analyses in this section mark an important contribution in terms of an evaluation framework for assessment of models such as the one developed in this research. Sensitivity analyses such as those documented here provide an objective means, not subject to opinion or memory, of assessing historical activities in a competitive market. The role product attributes play in product differentiation become observable through sensitivity analyses. In the case of the business aviation industry, these academic findings accord well with actual historical events.

When the "critical," "baseline," or "ideal" bounds placed on the attributes are in question or open to interpretation, it is recommended that users of the RVI method investigate the impacts of varying the attribute bounds. Though it was shown here that the business aviation model does not display significant sensitivity to moderate changes in attribute bounds, this may not be generalizable to other models.

The data used in the business aviation model was averaged over three-year time periods to help compensate for possible errors and discontinuities in the data. The analysis in this section demonstrated that three-year time periods were appropriate for such averaging, with the short-term events not being overly masked by the averaging. Three-year competitive markets also present a more realistic collection of competing airplanes at any one time than single-year markets permit. Ten-year averages were seen as too prone to damping out market dynamics.

6.2 Application of the RVI Method

In this section Cook's Relative Value Index is exercised to examine the method's utility for a number of different kinds of analysis. Historical business aviation industry products and market segments are examined where the final competitive outcome is known, and future directions the market may take are also assessed using RVI results as input for such discussion. The structure of the current market is analyzed using the RVI method, and potential uses of the method as an indicator of technological progress are introduced.

Many of the applications in this section extend to the base framework of Cook's S-Model as well as to the business aviation RVI model developed in this research. Conclusions regarding the adaptability and utility of the method apply equally well to the previously cited research of Cook.

6.2.1 First Decade of Business Turbines

In the late 1950s and early 1960s, the airframe manufacturer Fairchild-Hiller made a successful penetration of the business aviation market with sales of 40 F-27 converted turboprop airliners over this period. These went to organizational buyers (typically corporations) with requirements for larger cabins and payload capacity to meet their executive transport needs. However, by the late 1960s, encountering stiff competition from the first generation of business jets, Fairchild's stretched and upgraded FH-227 could barely make a mark in business aviation, with only two confirmed sales by the early 1970s [Block (June 1971)]. Fairchild was not alone among heavy turboprop manufacturers, most of whom found demand for their products drying up virtually overnight. Figure 92 shows that the number of heavy turboprop models specifically marketed to the business aviation community sharply declined as the number of turbojet aircraft in the market increased. (Note: aircraft are often listed in B/CA while still in development, thus some turbojets are observed in Figure 92 before first shipments occurred in the mid 1960s.)

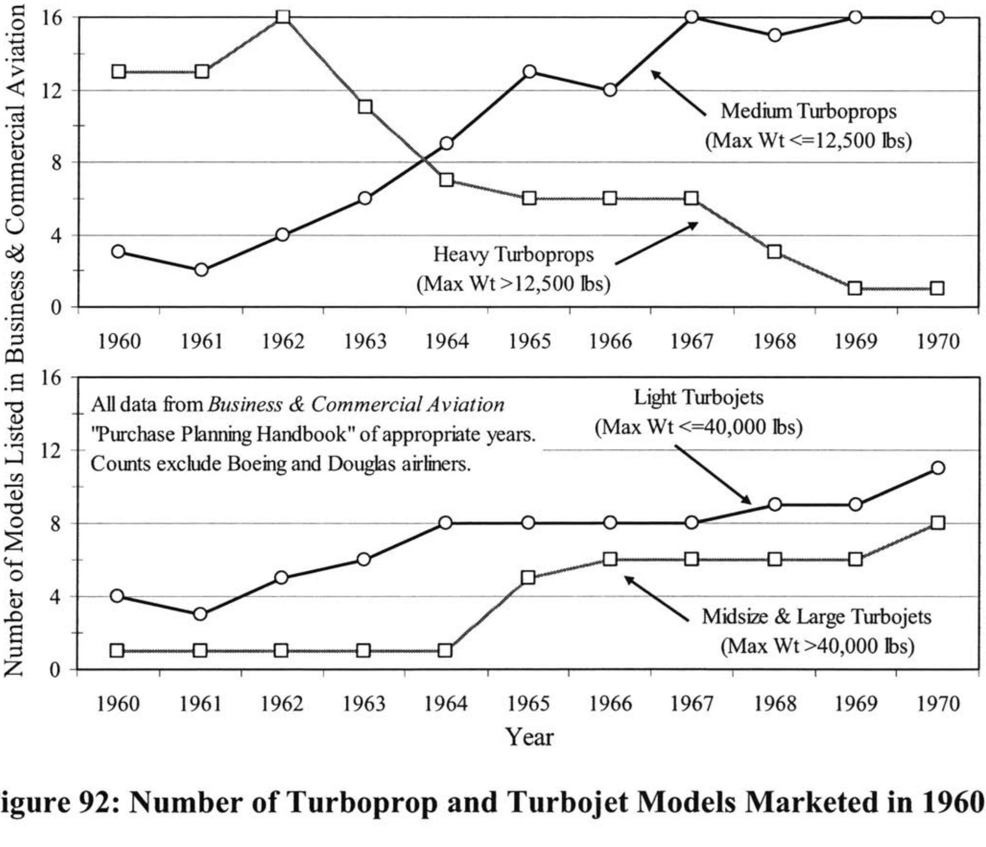

Figure 92: Number of Turboprop and Turbojet Models Marketed in 1960s

With Figure 92 come a few caveats. Actual shipments data (or ideally, sales data) is not available for many of the heavy turboprop airplanes, so a direct comparison of turboprop and turbojet sales through this period is not possible. It seems reasonable to expect that reductions in the number of models offered indicate a decline in overall sales. For a second caveat, the figure only indicates how many models were listed in B/CA as being marketed directly to the business aviation community. When heavy turboprop models drop off the B/CA list they are not necessarily withdrawn from production since most of the models were primarily marketed to the airlines (the exception would be the Gulfstream G-I, which was marketed only to the business aviation community). Conversely, at this same period in time the airlines were moving in large numbers to the new generation of commercial jet airliners (Boeing 707, 727, Douglas DC-8 and DC-9, etc.). The withdrawal of heavy turboprops from the B/CA might indeed reflect a general withdrawal from production for some of the airplanes, the cause of which might not strictly be due to pressure from business turbojets.

Nevertheless, the data in Figure 92 indicates a rapid ascendance of jet power over propeller-based thrust in the decade of the 1960s. Included in this observation in obsolescence is the Gulfstream G-I, a heavy turboprop business aircraft that was itself replaced by the Gulfstream G-II turbojet aircraft when the company correctly interpreted the coming of the jet age. This event marks an important watershed in the business aviation industry for which it would be desired that a product assessment approach could anticipate. Previously noted in Chapter 3, the Traditional Value Index (TVI) is incapable of demonstrating the higher value of the first generation of business jets, as shown in Figure 34.[*]

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[*] A discussion in Chapter 7 on the issue of modifying the TVI will reveal that the method cannot be revised to better deal with such historical data without major changes that still leave the TVI falling short of the Relative Value Index method.

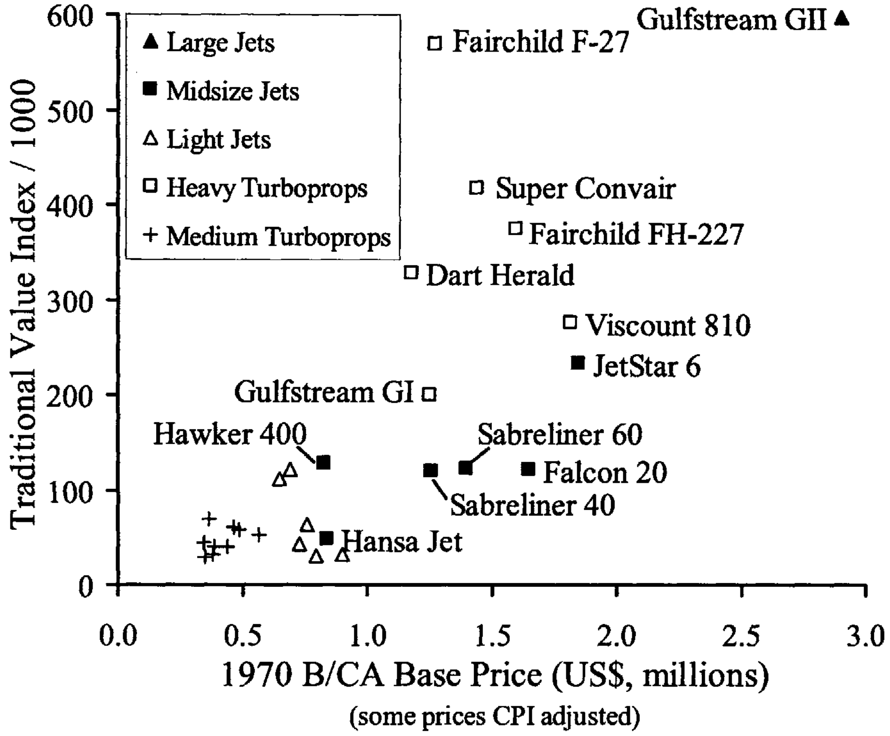


Figure 93: Traditional Value Index for the Business Airplane Market, Late 1960s

The attribute weighting factors determined by a best fit of Revealed Value and the Value Index (see Chapters 4 and 5), using the averaged 1964-1966 market data, are listed in Table 19. These weighting factors are the earliest that may be determined with statistical significance given the sparse business aircraft shipments data for the early 1960s. Business jets had just been introduced at this time, so the weighting factor data does include some initial effect of the jets' introduction. Although it could be argued that the RVI results will be retrospective and only reflective of what the market actually decided regarding the value of the new business jets, it is felt that the data is still useful in showing a forecast of the coming effect the business jets would have on the existing heavy turboprops. At a minimum, the RVI method is capable of showing this effect, whereas existing methods such as the Traditional Value Index are not capable of showing it.

Table 19: Attribute Weighting Factors, 1964-1966 Market

Maximum Cruise Speed	0.19
Takeoff Field Length	0.00
Fuel Consumption per Seat Mile	0.00
Cabin Volume per Passenger	0.07
Available Seat-Miles	0.10

Using the weighting factors in Table 19, the RVI for the same group of airplanes found in Figure 34 was calculated and graphed against 1970-equivalent list prices (some prices were adjusted using the Consumer Price Index). The data in Figure 94 shows that the RVI method better indicates higher values for the emerging midsize business jet segment over the existing heavy turboprop segment, and is thus consistent with the actual historical events.

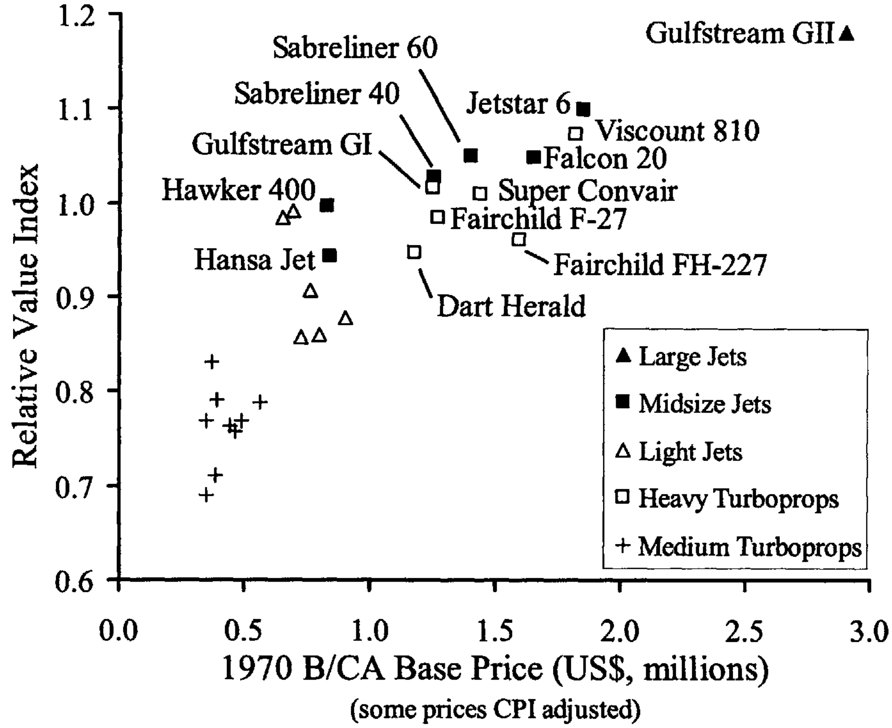
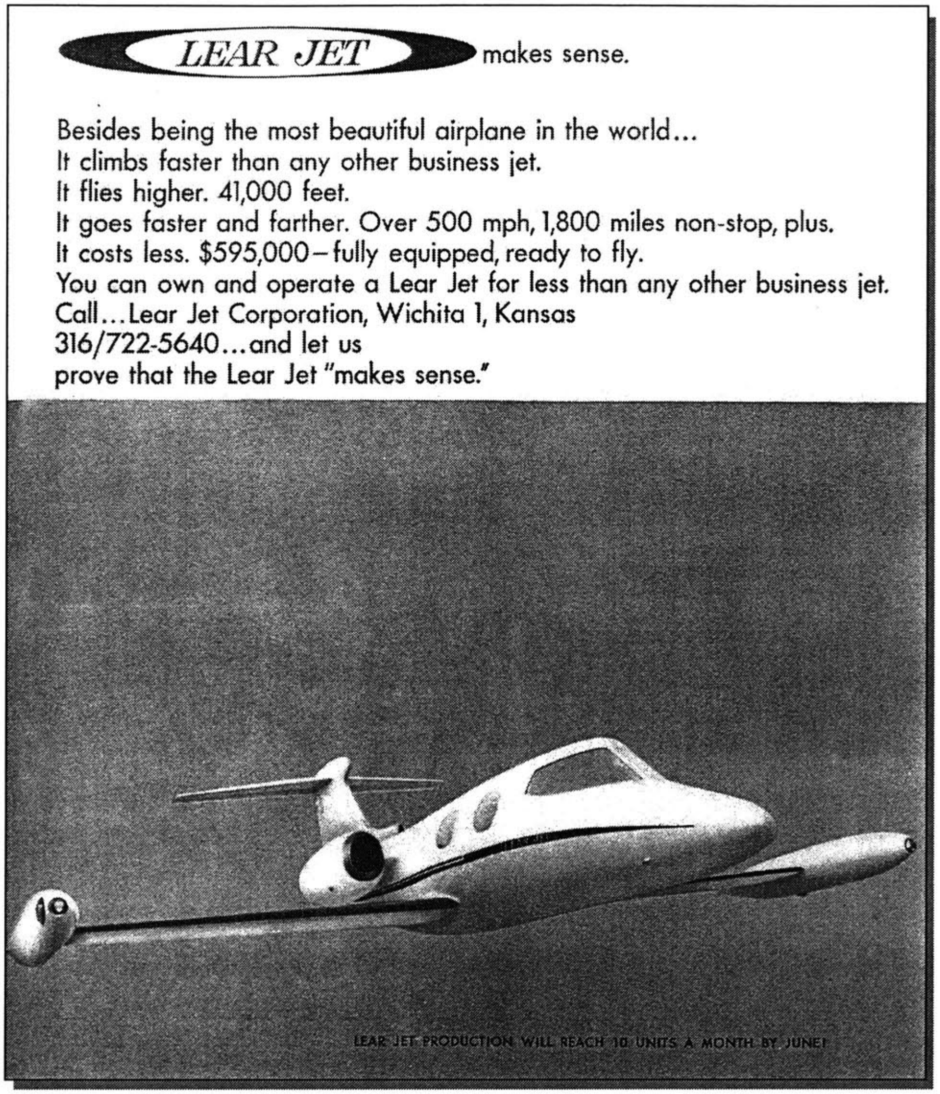


Figure 94: Relative Value Index for the Business Airplane Market, 1965-1970

The differentiating attributes, based on the "best fit" of market data to the part-worths value equation, appear to be a preference for greater speed over comfort, fuel economy, and even range. A study of the 1960s era industry literature and media ads shows a clear emphasis on the "jet fighter-like" speeds and performance of the new generation of business jets, perhaps playing in many ways to the ego or sex appeal of consumers. An April 1965 advertisement for the Learjet 23, the epitome of small cabins, calls attention to the fast climb rate and 500 mph speed of the airplane (Figure 95). Although the 1,800 statute mile range in the ad is respectable for the early jets, it does not approach the 2,500+ statute mile ranges of the heavy turboprops.



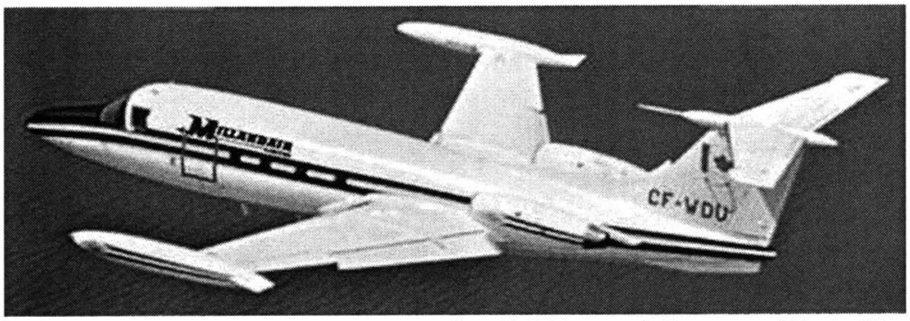
LEAR JET makes sense.

Besides being the most beautiful airplane in the world...
It climbs faster than any other business jet.
It flies higher. 41,000 feet.
It goes faster and farther. Over 500 mph, 1,800 miles non-stop, plus.
It costs less. $595,000–fully equipped, ready to fly.
You can own and operate a Lear Jet for less than any other business jet.
Call...Lear Jet Corporation, Wichita 1, Kansas
316/722-5640...and let us
prove that the Lear Jet "makes sense."

LEAR JET PRODUCTION WILL REACH 10 UNITS A MONTH BY JUNE!

Figure 95: Learjet Advertisement Emphasizing Speed and Price, April 1965

In Figure 94 the placement of the Hansa Jet midsize jet should be noted. This business jet was the first and only business aircraft offered by Hamburger Flugzeugbau (HFB) of Germany (Figure 96). This business jet entered production but faired poorly in the market, selling only a handful of aircraft to the German government and, reportedly, one to a private company in the United States [Pattillo (1998)]. In contrast, the RVI for the Hansa Jet shows a rather attractive airplane for its price/value point on the graph of Figure 94. The RVI method is currently structured around technical performance attributes that do indeed favor the Hansa Jet, which was a technical success and performed admirably in terms of cruise speed, cabin size, etc. However, the HFB design was marred by crashes of two of the prototypes during development which discouraged most potential customers, and the manufacturer suffered from a lack of access to the all-important North American market [Pattillo (1998)]. (Though one might suspect the unconventional configuration might have had something to do with its market failure, the early literature does not support this supposition.) Neither safety or market access are attributes currently represented in the RVI approach, but both would be in an extended analysis, as discussed in Chapter 5.



source: http://1000aircraftphotos.com/GeneralAv

Figure 96: HFB Hansa Jet

Nevertheless, even with the caveats, the RVI approach to product assessment shows capability for more accurately portraying important historical events in the business aviation industry than any other existing methods. Tests, such as this one for the first generation of business jets, serve to "observationally break" the model in some areas (such as for the Hansa Jet) and will ultimately lead to a stronger RVI method as improvements are made.

6.2.2 Product Differentiation in the Business Aviation Market

Concepts surrounding product differentiation were introduced to the literature, along with market segmentation, by Wendell Smith in 1956. Product differentiation is viewed as the variety of product price-value combinations offered by alternative goods within and among the different intra-market segments. A product is differentiated from competing alternatives when consumers are able to perceive differences in physical or non-physical characteristics, including price [Dickson and Ginter (April 1987)]. This definition is also consistent with Chamberlin's view that the basis for differentiation could be real or imagined, arising from such disparate factors as product packaging, brand name or even distribution differences [Chamberlin (1965)].

Researchers have established that humans have upper and lower limits of responsiveness to physical stimuli such as sound and light [Sanders and McCormick (1993), Wickens, Gordon and Liu (1998)]. Weber's Law* postulates that the magnitude of what is a *perceptible* change† in a stimuli, ΔS, corresponds to the original magnitude of the stimuli, S:

$$K = \frac{\Delta S}{S} \tag{6-4}$$

This, for example, has resulted in the development of the *bel* scale for sound measurement (typically measured at 1/10th magnitude, or in *decibels*) where changes in sound pressure are measured proportionally to a reference sound pressure at the threshold of hearing, P_{ref}:

$$decibel = 20 \log_{10}\left(\frac{P}{P_{ref}}\right) \tag{6-5}$$

In the literature on consumer behavioral psychology, Weber's Law has been extended to non-physical stimuli such as prices, where research suggests that buyers perceive price differences in proportional terms rather than in absolute terms [Monroe (1990)]. Thus a $20 price increase on a $200 product (10% change) would have less impact on the buyer than a $20 price increase on a $20 product (100% change). This approach will be used here to examine the changes in price and value required to differentiate business airplane products.

Assuming that the products in one manufacturer's product line have been ranked in ascending order of price (i.e., the lowest priced product is ranked 1), the price of the second product in the line, $P(2)$, may be represented as a fractional increase, α, over the price of the first product in the line:

$$P(2) = [1+\alpha]\cdot P(1) \tag{6-6}$$

Assuming also that products may be ranked in order of ascending value (or any other differentiable attribute), and that there are $i=1, 2, 3, \ldots N$ products in the line, then equation (6-6) may be more generally stated for the i^{th} product in the product line:

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* See Sanders and McCormick (1993), Wickens, Gordon and Liu (1998)

† Often referred to as the *just noticeable difference*

$$\phi(i) = [1+\alpha]^{(i-1)} \cdot \phi(1) \tag{6-7}$$

This relationship has been used in the research literature to determine the fraction α to be used in evenly spacing (*N* - 2) products between a given maximum and minimum price [Monroe (1990)] as follows:

$$\alpha = \left(\frac{P_{\max}}{P_{\min}} \right)^{1/(N-1)} - 1 \tag{6-8}$$

This strategy makes the assumption that (*N* - 2) products can be sufficiently differentiable between a maximum and minimum price (or any other attribute of interest) at the fractional level of α. Surprisingly little research has been published in documenting empirical values of the psychometric detection point, α, for differentiation between two products. One notable exception includes Monroe, Silver and Cook (1997), wherein α was measured at values ranging from 0.14 to 0.35 for the four-door family sedan product lines of seven automotive manufacturers. Loudon and Della Bitta (1993), based on research focusing on grocery merchants, postulate a 15% change in price heuristic for consumers as a value for the psychometric price detection point.

The empirical differentiation in prices, values and other attributes between successive products in a product line may be determined by taking the logarithm of equation (6-7):

$$\begin{aligned} \log[\phi(i)] &= (i-1) \cdot \log[1+\alpha] + \log[\phi(1)] \\ &= \log\left[\frac{\phi(1)}{[1+\alpha]} \right] + i \cdot \log[1+\alpha] \\ &= \kappa + i \cdot \log[1+\alpha] \end{aligned} \tag{6-9}$$

where κ is simply the slope-intercept constant and $\log[1+\alpha]$ is the slope of the line when $\log[\phi(i)]$ is graphed versus *i=1, 2, 3, ...N*. In Figure 97 the logarithm of business airplane prices* is graphed for five products offered in the 1999-2001 market by one major manufacturer. The slope of the resulting line (0.1997) indicates an average price differential of 58% between each of the products in this manufacturer's business airplane portfolio. The data in Figure 97 is a decent straight line on the log plot and is thus consistent with a ratio theory of price differentials in the business airplane industry.

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* Equipped prices, based on information in Business and Commercial Aviation. See Chapter 2 for details and critical assessment.

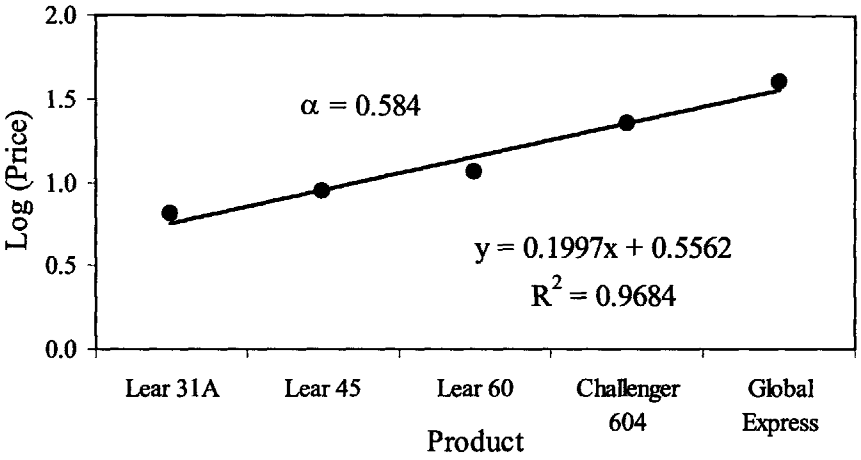

Figure 97: Differentiation within a Product Portfolio Based on Price (Bombardier Aerospace, 1999-2001 Market)

In Table 20 the price differentials for the five major business airplane manufacturers are summarized along with the percent differentials based on the products' Relative Value Indices. In each case, the differentials are based on the manufacturers' complete business airplane portfolio for the 1999-2001 market (see Chapter 5 for a listing of all airplanes studied in this market).

Table 20: Differentiation within Product Portfolios by Business Airplane Manufacturers, 1999-2001 Market

	Percent Differentiation	
Manufacturer	By Price	By Relative Value Index
Bombardier	58.4 (34.7*)	15.2 (14.9*)
Cessna	41.2	10.7
Dassault	30.6	6.2
Gulfstream	31.9	2.4
Raytheon	38.6	11.6

**Based on Lear series only*

Table 20 indicates that a ratio theory of both price and value differentials within business airplane product lines exists, though the ratio appears to vary somewhat among manufacturers. Bombardier clearly has the highest price ratio at 58.4%, with the rest of the industry maintaining 30-40% price ratios. However, Bombardier is unusual in that their product portfolio skips the large jet segment (see Figure 98) and moves from the super midsize segment (Challenger 604) directly to the long-range segment (Global Express). In addition, the Challenger 604 is priced at the highest end of the super midsize segment and thus presents an unusually wide price gap between itself and the Lear 60. As a result, the slope generated in Figure 97 is higher than it would be for manufacturers that had product portfolios with contiguous segment entries. If only the Lear series of business jets were considered for Bombardier, the price differential would be reduced to 34.7% in line with the other companies.

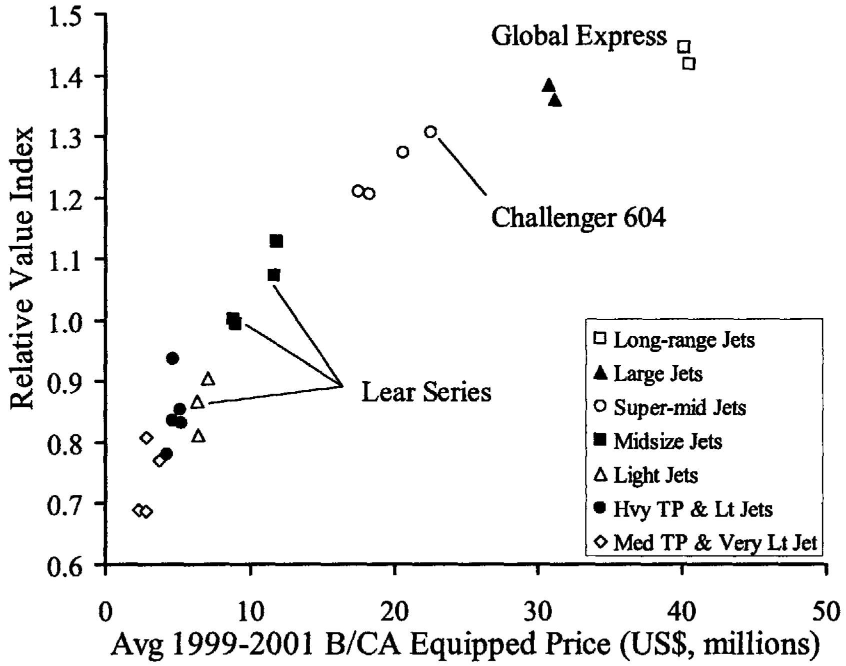

Figure 98: RVI and Price of Bombardier Products, 1999-2001 Market

Both Dassault and Gulfstream have the lowest average price ratios, perhaps as a result of competing only in the high-end product segments (large and long-range business jets; see Figure 99). Cessna and Raytheon compete only in the lower price segments (super midsize and below) and both show evidence of price ratios of approximately 40%. This data may indicate that in the higher priced business airplane segments, the price differentials cannot be maintained at the 40% of the lower segments. This is not necessarily a reflection of customers' unwillingness to pay higher prices, but instead may indicate that niches develop at price ratios of less than 40% in which customers are still able to differentiate between products on price. In other words, the ratio theory of price differentials may break down at higher prices.

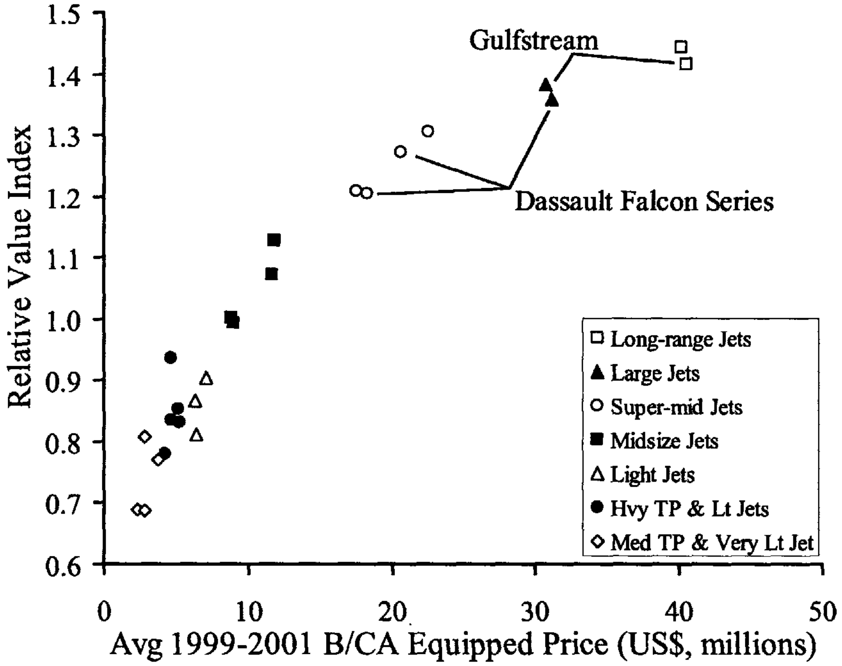

Figure 99: RVI and Price of Dassault and Gulfstream Products, 1999-2001 Market

The data in Table 20 also indicates a ratio theory in business airplane product value, as based on the model-estimated Relative Value Index for each manufacturer's portfolio. Some of the same issues arise for the value ratios as with the price ratios. Gulfstream and Dassualt products demonstrate the lowest value ratios, again perhaps because they compete only at the highest end of the market. Bombardier products indicate the highest value ratio, but this time using only the contiguous Lear series of aircraft the ratios remain relatively high compared to the Cessna and Raytheon product lines. The RVI ratio for the mid to lower segments appears to be 10-15%.

The average price and average RVI for each of the seven business airplane segments studied for the 1999-2001 market were calculated and then graphed as logarithms in Figure 100 and Figure 101, respectively. In Figure 100 the spacing of segments by price appears to closely conform to a ratio theory of differentiation, with an average 59% price change between segments. For the very highest segments (large and long-range) the price differential appears to be lower, thus supporting the prior supposition that ratio differentials may break down at higher prices. The data in Figure 100 cannot definitively confirm this supposition, however.

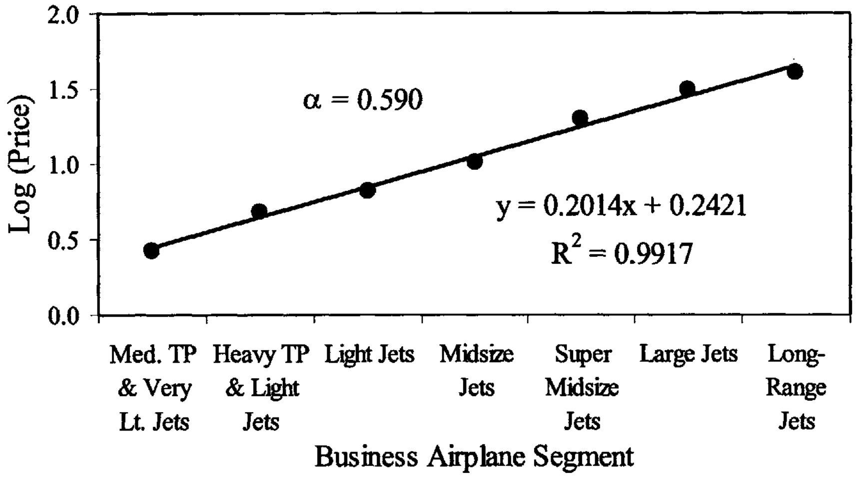

Figure 100: Differentiation Across Business Airplane Segments Based on Price, 1999-2001 Market

The 59% segment price differential from Figure 100 is significantly higher than the average product price differential of 30-40%. This is due to the fact that, within the lower segments, Cessna, Raytheon and Bombardier all offer multiple products within a single segment. For example, Cessna has the CJ2 and Caravan I within the "medium turboprop and very light jet" segment, Raytheon offers the King B200 and 350 within the "heavy turboprop and light jet" segment, Bombardier has the Lear 45 and Lear 60 within the "midsize jet" segment, etc. These multiple entries within segments cause the price differential between products to be lower, but do not affect the segment price differential from Figure 100.*

In Figure 101 the RVI differential between business airplane segments is shown. The average 13.1% differential in the figure corresponds well with the data in Table 20. but Figure 101 clearly shows variations in the actual segment-to-segment RVI differentials. Some of these variations in the lower segments likely result from the RVI model itself not being an entirely accurate representation of the demonstrated market values. Recall that the model itself is the product of a "best fit" between part-worths value contributions and demonstrated market performance of the airplane products, and that the "best fit" between the two is not perfect.

At the high-end market segments the RVI model, as discussed in Chapter 5, does indicate the possibility of a logarithmic shape to the RVI-price curve. Possibly the result of technical

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* By positioning multiple products within the same segment, some manufacturers are pursuing an interesting sales strategy. A basic-performance, low price model is being offered for those customers that may be budget constrained, but a higher performance model at a slightly higher price is also offered for potential "step-up" sales where the customer has more budget flexibility and may be willing to buy excess performance.

performance limitations in the aircraft, the tendency to approach an asymptotic RVI with increasing price is also reflected in Figure 101 where the high-end segments indicate a diminished value ratio.

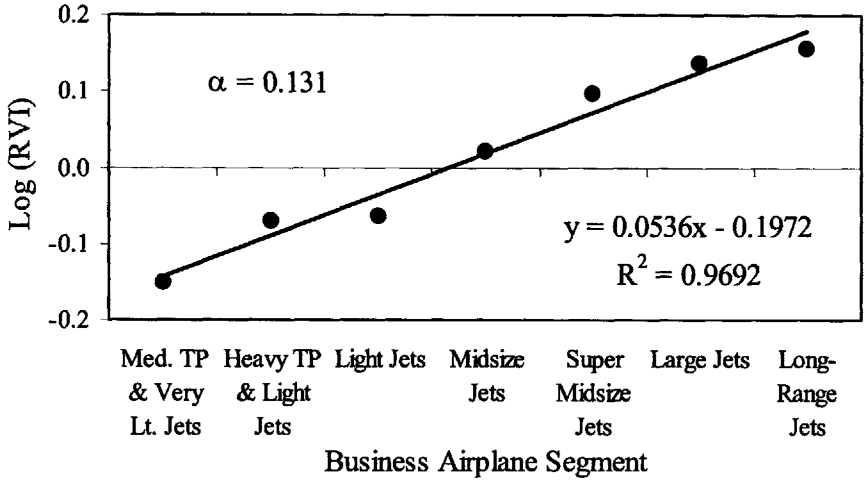

Figure 101: Differentiation Across Business Airplane Segments Based on Relative Value Index, 1999-2001 Market

In summary, the analysis in this section supports the existence of a ratio theory of both price and value differentiation in the business airplane industry. Prior to this research, only two other studies [Monroe, Silver and Cook (1997), Loudon and Della Bitta (1993)] had presented empirical evidence of a pricing ratio theory in other industries, despite the prevalence of the theory in the pricing literature. The important contribution this current research makes to the pricing ratio theory is the extension to present evidence of a ratio theory of product value utilizing the RVI model results.

6.2.3 Demand Forecasting

Ithiel de Sola Pool, in his 1983 classic *Forecasting the Telephone*, noted that technology assessment or forecasts, such as those that appeared for the nascent telephone between 1876 and 1940, may be highly variant in their accuracy. In his study, the author concluded that "in successful technology assessment, market and technical analyses must be brought to bear simultaneously. Alone either of them fails; together they can produce some very prescient forecasts." In this research the merging of market factors and technical performance is attempted via the exponential weighting factors fit and the technical attributes.

6.2.3.1 Estimating Market Share

Once again, we note that demand, *D*, for a product may be linearized as a function of the product value, *V*, and price, *P*:

$$D = K(V - P) \qquad \textbf{(6-10)}$$

It is not recommended, however, that demand forecasting be performed using Equation (6-10) or any of a number of permutations presented in Chapters 4 and 5. Numerous exogenous factors, such as a nation's economic performance, may combine to affect the actual demand for a product. It would be more appropriate to estimate the product market share based on a ratio of the estimated product demand and the total segment demand:*

$$\pi_i = \left\{ (V_i - P_i) - \frac{1}{N} \sum_{l \neq i} (V_l - P_l) \right\} \Bigg/ \sum_{i=1}^{N} \left\{ (V_i - P_i) - \frac{1}{N} \sum_{l \neq i} (V_l - P_l) \right\} \qquad \textbf{(6-11)}$$

Such market share estimates were shown for the 1999-2001 market in Chapter 5. A number of factors were noted that create inaccuracies in the estimate, including errors in pricing data and in the RVI assessments themselves. Clearly, any forecasts should be regarded as estimates only.

The remaining challenge is then to convert the market share estimates into unit demand estimates for use in planning manufacturing costs, delivery rates, etc. To meet the challenge, a simple unit shipments model was developed to combine with the market share estimates.

6.2.3.2 Development of a Model for Unit Shipments

A model was developed for predicting the total unit shipments of all business turbines over the past 30 years, with the assumption that the industry had by 1975 become fairly stable and established for such a model fit. Various annual economic indicators were examined for the model, including the Dow Jones Industrial Average, the United States Gross Domestic Product, crude oil prices, the U.S. prime interest rate, and the U.S. inflation rate. The Dow Jones and inflation rate data proved to be the most useful in developing a model to accurately match empirical shipments data since 1975. While the inflation rate contributes the essential fit

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* This has also been suggested by Cook, et al.

information for the inflationary period of the 1970s,* the Dow Jones average appears to provide a good fit for the post 1980s markets. Corporate performance, roughly indicated by the Dow, seems then to be a good predictor of future business airplane orders. Statistics for the shipments model are listed in Table 21.

Recall from basic statistics that, when curve fitting data, the null hypothesis is assumed that the parameter coefficients are not statistically different from zero, $H_0 : \beta_i = 0$. The region for rejecting the null hypothesis (i.e., for determining that the coefficients are indeed non-zero) is $|t| > t_\alpha$ where α is the confidence interval. At a 95% confidence interval (α = 0.05) the magnitude of the parameter *t* statistics in Table 21 must be greater than $t_{0.05} = 2.06$. From the data in the table, the test fails to reject the null hypothesis only for the intercept coefficient. This coefficient is non-zero only at confidence levels of 63.9% and lower. The resulting model for unit shipments is then

$$shipments = 0.070 \cdot (\text{Dow Jones}) + 97.820 \cdot (\text{Inflation Rate}) \qquad \textbf{(6-12)}$$

Table 21: Parameter Estimates and Fit Statistics for Unit Shipments Curve Fit

Parameter	Parameter Estimate	t-statistic (one tail) for H_0:parameter=0	t-statistic rejects H_0 at significance level
Intercept	-30.450	-0.359	0.361
Dow Jones	0.070	6.721	0.000
Inflation Rate	97.820	8.662	0.000

α = 0.05, DoF = (2, 25), $R^2 = 0.763$
$F(2, 25) = 40.143$, $F_{0.05}(2, 25) = 3.39$, $t_{0.05} = 2.06$

Because $F(2,25) > F_{0.05}(2,25)$, as shown in the table, the model is judged to be useful in predicting unit shipments, and the results are shown in Figure 102.

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[*] Far from dampening airplane orders in the 1970s, the high inflation rate created a speculative market that increased sales and shipments. Many customers would purchase aircraft only to sell them at significantly inflated prices a short time later [Pattillo (1998)].

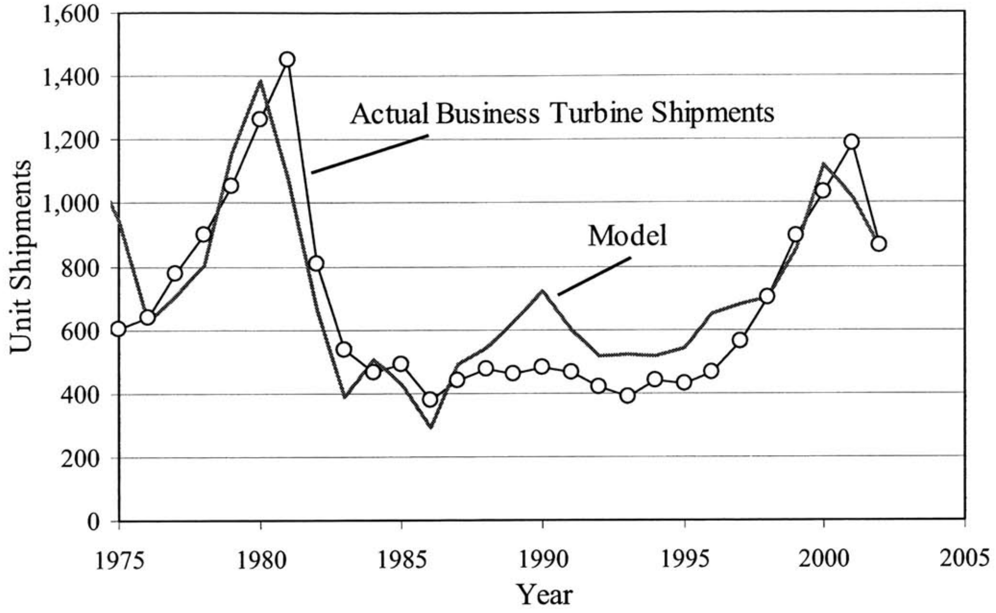

Figure 102: Actual and Predicted Unit Shipments, 1975-2002

From industry experience, it is known that the business aviation industry typically lags the leading economic indicators by one to two years. The economic data used in the model of Equation (6-12) and Figure 102 represents conditions on January 1 of the year indicated, while the shipments data represents the end-of year totals. Therefore, the shipments data in Figure 102 does appear to lag the economic indicators as anticipated.

6.2.3.3 Putting it Together

The market share estimates of Equation (6-11) may be combined with the turbine unit shipments model of Equation (6-12) to arrive at an estimate of unit demand:

$$D_i = \pi_i \cdot D_T \qquad \textbf{(6-13)}$$

The major challenge of this method is to be found in dividing the total turbine shipments among the seven market segments; light jets, large jets, etc. Apportionment may be based on empirical data, or there are several industry observers (Teal Group, Forecast International, Honeywell) that release annual estimates of future market demand upon which one may also base an allotment scheme for the various segments.

Such unit demand estimates may then be used, for example, in the strategic planning role as indicators of potential product manufacturing costs. Any forecasts would, of course, be subject to changes in the economic indicators used in the shipments model, casting a degree of uncertainty into the shipments forecasts. Users of this method would benefit from either treating the economic indicators (or simply the total unit shipments forecast) parametrically, or by subjecting the forecasts to a thorough Monte Carlo analysis.

As Ithiel de Sola Pool noted 20 years ago, both technical and market factors must be considered in forecasting. The RVI approach is well-suited to merging both factors in forecasting product market as well as technical performance.

6.2.4 Exploring the Product Design Tradespace

Cook's approach to product assessment was first investigated with the thought of using the method for engineering-type preliminary design studies. A myriad of alternative uses for the method have since emerged, but the ability to rapidly explore the engineering design tradespace remains a powerful application for the Relative Value Index.*

In demonstrating the use of the RVI method as a tradespace exploration tool, a specification for a hypothetical new midsize business jet has been developed and is shown in Table 22. In the very early stages of new product development (the fuzzy front-end, as it is often called), a product proposal may not be vastly more detailed than what is shown in the table. In this phase, engineers, marketing specialists, and product managers are trying to assess the "optimal" combination of features for the new product, and need to rapidly explore the tradeoffs inherent in altering some of those attributes. The utility of the RVI method in value and price differentiation, and in market share forecasting, is demonstrated elsewhere in this chapter. This section focuses on the engineering tradeoffs.

Table 22: Nominal Attribute Values for Hypothetical Midsize Business Jet

Maximum Cruise Speed	460 ktas
Takeoff Field Length	5,142 ft
Fuel Consumption per Seat Mile	0.40 lb/nm/pax
Cabin Volume per Passenger	86 cu ft/pax
Available Seat-Miles	14,561 pax-nm

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* This is valid for Cook's base framework in his S-Model as well.

Figure 103 shows the response surface for the RVI results when the cabin volume per passenger (passenger comfort) and maximum cruise speed attributes are traded off against each other. The three-dimensional surface in the figure is perhaps less useful for practical studies than the associated contour lines shown in Figure 104.

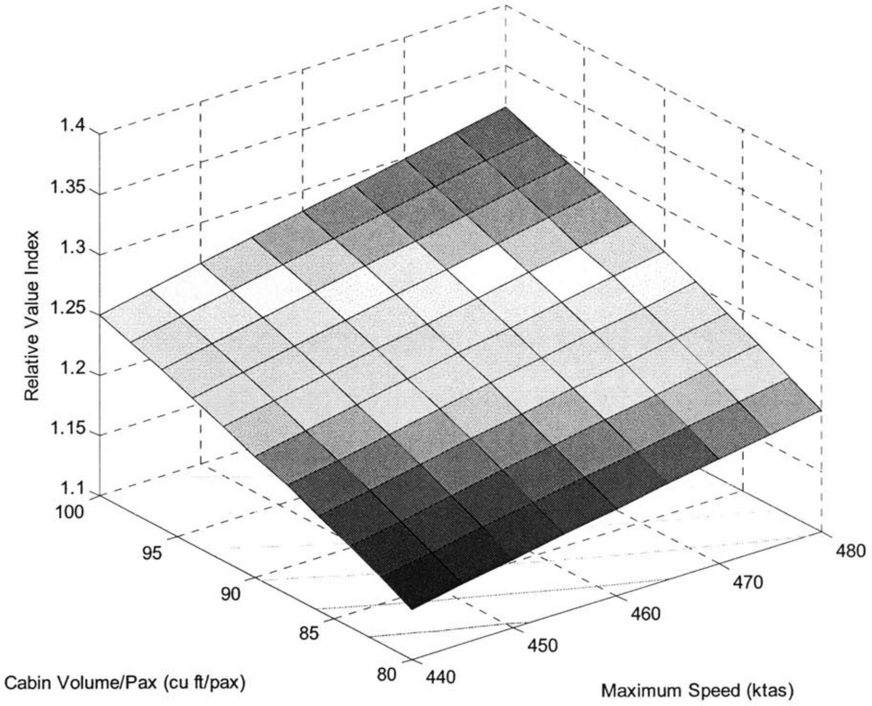

Figure 103: Speed and Passenger Comfort Tradespace Exploration

The data shown in Figure 103 and Figure 104 was generated by holding the "best fit" model solution for the 1999-2001 market (i.e., the attribute exponential weighting factors) constant and varying only the attribute levels for the proposed new airplane design. Changing the attribute levels, individually and in combination, yields differing RVI results for the design, as shown in the figures.*

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* The calculation itself is relatively straightforward, and may easily be performed using MS Excel's "data table" function.

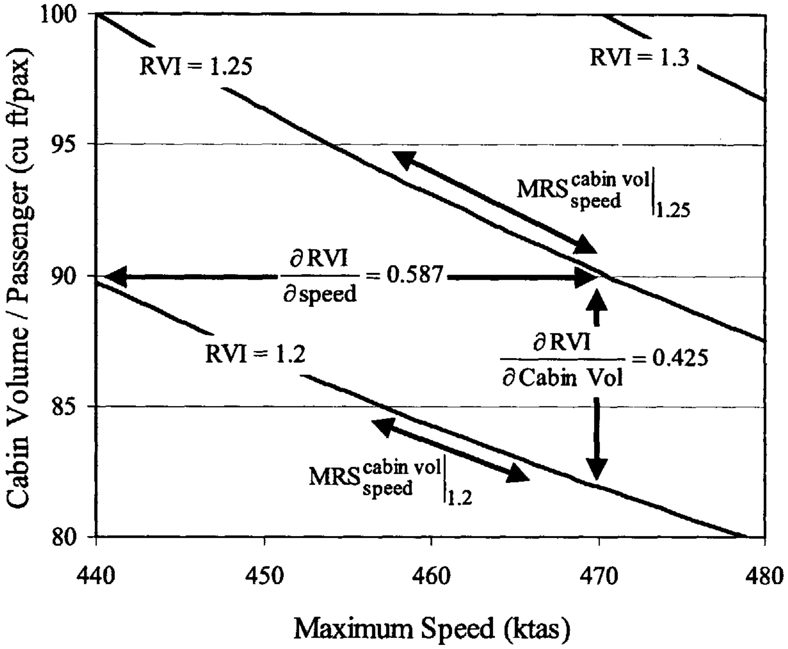

Figure 104: Contour Lines for Speed and Passenger Comfort Tradespace Exploration

The theoretical development of "marginal analysis" using the RVI approach (Chapter 4) touched on some facets of design tradespace exploration. As shown in Figure 104, the change in RVI with changes in the two attributes represents the "marginal value" of those attributes:

$$\frac{\partial \mathrm{RVI}}{\partial g_j} = \frac{-2\gamma_j (g_j - g_{jI})}{(g_{jC} - g_{jI})^2 - (g_j - g_{jI})^2} \cdot \mathrm{RVI} \qquad \textbf{(6-14)}$$

For example, a 10% change in maximum cruise speed, from 440 to 484, yields a 5.87% increase in RVI, from 1.2 to 1.27. Similarly, a 10% increase in cabin volume per passenger yields a 4.25% increase in RVI. Perhaps of more interest is the marginal rate of substitution, MRS, indicating how the two attributes trade off against each other. As shown in Figure 104, for the RVI=1.25 and RVI=1.20 contour lines the marginal rates of substitution are:

$$\mathrm{MRS}_{\text{speed}}^{\text{cabin vol}}\Big|_{1.25} = 0.310 \frac{\text{cu ft/pax}}{\text{ktas}} \qquad \textbf{(6-15)}$$

and

$$\mathrm{MRS}_{\text{speed}}^{\text{cabin vol}}\Big|_{1.2} = 0.249 \frac{\text{cu ft/pax}}{\text{ktas}} \qquad \textbf{(6-16)}$$

Each of these marginal values and rates are valid only within the local vicinity of the nominal design point: 460 ktas and 86 cu ft/pax. Variances greater than perhaps 5-10% would require resetting of the "nominal" RVI design point.

The brief analysis in this section was generated, using conventional PC computing resources, in less than an hour. More sophisticated, automated routines may generate vast quantities of such analyses in even shorter time periods. The RVI method is particularly suited to such rapid tradespace exploration for the very early phases of new product design when relatively little is known about proposed products. Marginal values and rates, such as those shown here, allow designers to assess the impacts of modifications to early specifications in terms of how the products will compete against existing portfolios via the RVI figure of merit. The RVI results may also be used to assess the impacts on potential market share using methods discussed elsewhere in this chapter.

6.2.5 Pricing Strategy and Value Pricing

Pricing strategy is often based on a combination of competing product prices and estimated development and manufacturing costs for a new product. The RVI method for product value assessment enables the reversal of this process for a new approach to pricing strategy called value pricing. In value pricing, the target price is based on an estimate of value, not costs. The target price then drives decisions about what costs to incur, rather than the other way around [Nagle and Holden (1995)].

Once the Relative Value Index of the product is set via the part-worths composition, then the approximate price the market will accept for that product is known, as shown in Figure 105.

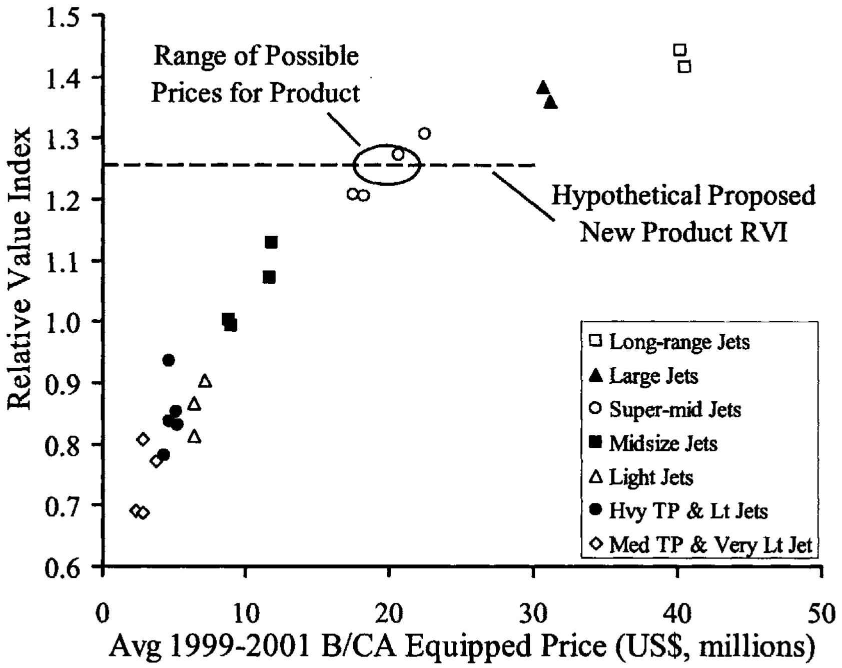

Figure 105: RVI Placement Implies Pricing Strategy

The linearized demand equation of (6-17) then sets the forecast annual demand, *D*, for the product in terms of the price, *P*, and value, *V*.

$$D = K(V - P) \tag{6-17}$$

Based on a set production rate, the costs associated with producing a product should be known, and a profit margin may then be determined given the price and demand estimates. This approach, a result of the value method proposed in this research, is in contrast to cost-plus pricing where costs are often assumed with little knowledge of potential demand, and prices are set at a margin above cost.

According to Nagle and Holden , value pricing eliminates the need for price discounting and other flexibilities in the markups typically seen in both the aircraft and automotive industries. Value pricing is only possible, however, when methods such as the RVI approach are available for estimating the value of a product independent of price and demand.

6.2.6 Model-Based Evidence of Enterprise-Related Attributes

Product value assessment is approached from two different directions in this research. The Value Index (VI) results in an absolute value (in dollars, for example) for a product based on a part-worths build-up of the value. In other words, attributes such as speed and fuel consumption contribute directly to the overall product VI. On the other side, a Revealed Value (RV) assesses value (again, in dollar terms) based on the market performance (i.e., shipments) of a product coupled with the product's price. The VI and RV are then "best fit" by manipulating the VI equation's attribute exponential weighting factors. Chapter 4 has details on the method, but an important fact of the best fit is that it is "best" and not "exact;" there exists some remaining error between the RV and VI assessments once the solution has been found. The degree of error may be evaluated, in part, by the magnitude of the sum squared error cost function, *J*.

Product-by-product the errors may be examined by calculating the percent value error:

$$\text{Percent Value Error} = \frac{\text{Revealed Value - Value Index}}{\text{Revealed Value}} \qquad \textbf{(6-18)}$$

This error is normalized to a percent error to avoid biasing the results for manufacturers such as Gulfstream that only market high value airplanes, and thus might demonstrate artificially high errors. Products that have an RV and VI error but that do not have many sales in the market should perhaps be weighted less than those that have an error and high sales rates. A weighted percent value error may also be calculated with this in mind:

$$\text{Weighted Percent Value Error} = \frac{\text{Revealed Value - Value Index}}{\text{Revealed Value}} \cdot \text{shipments} \qquad \textbf{(6-19)}$$

The business airplane products in the 1999-2001 market were grouped by manufacturer, and the percent value error calculated, to investigate if trends emerged for the manufacturers (Figure 106). Averages for each of the manufacturers are also noted in the figure and connected by lines.

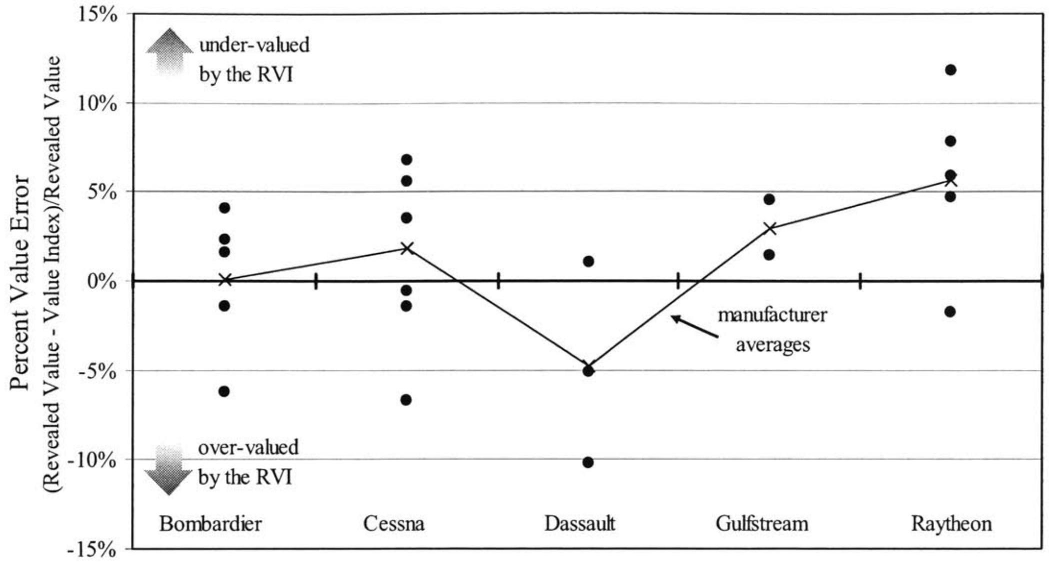

Figure 106: Percent Value Error by Manufacturer, 1999-2001 Market

Dassault's average indicates a tendency for its products to be over-valued by the RVI method, meaning that the part-worths value build-up implies a higher product value than market sales demonstrate. Although this over-valuation is mitigated slightly by shipments in the weighted percent value error (Figure 107), Dassault is the only manufacturer with over-valued products.

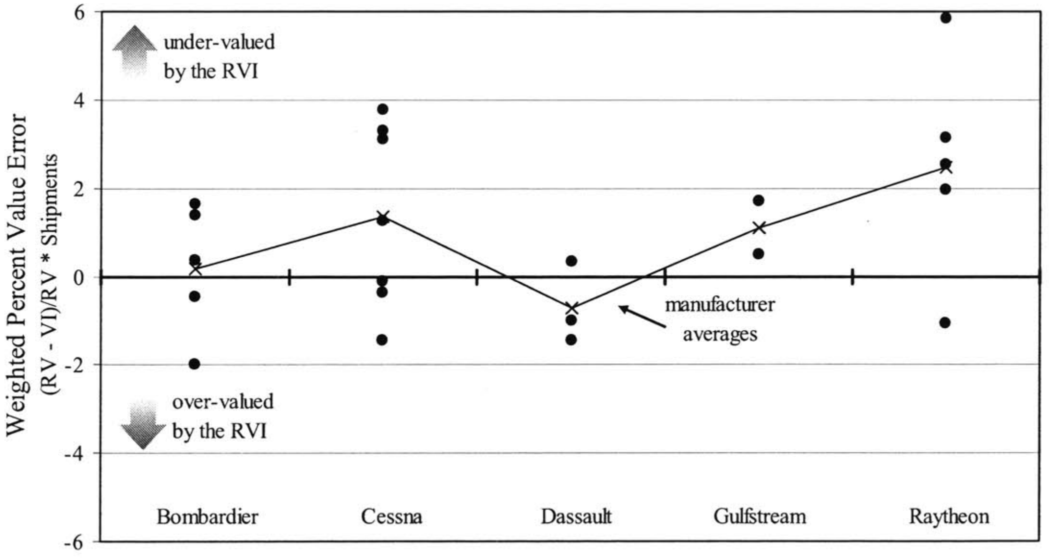

Figure 107: Weighted Percent Value Error by Manufacturer, 1999-2001 Market

It would be premature to form conclusions around the data in Figure 106 and Figure 107 alone, so the average value errors for the five major manufacturers were calculated using RVI results for the past decade. The average percent value error for each manufacturer is shown in Figure 108, with the average weighted errors shown in Figure 109.

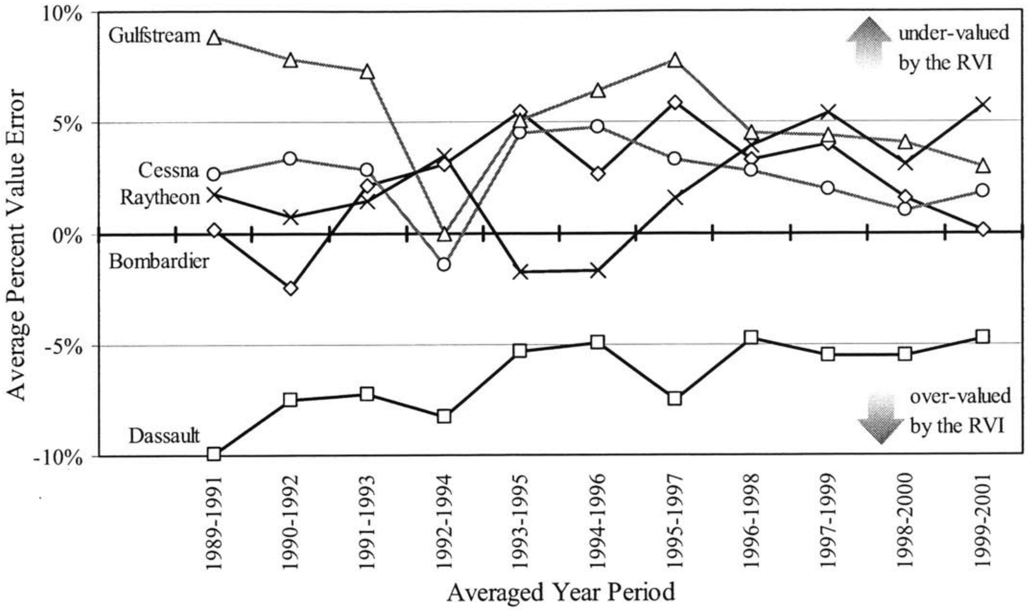

Figure 108: Average Percent Value Error by Manufacturer, 1990s

A consistent over-valuation of Dassault's products is evident in the figures, indicating that the manufacturer's products are underperforming in the market compared to what their technical merits would suggest. Although Dassault is the only major overseas producer in the business aviation industry, it is unclear whether this plays a role in the trends of Figure 108 and Figure 109. Anecdotal evidence suggests that, though known for having good technically performing products, Dassault is also known for a lackadaisical attitude toward customer support. However, this is not supported by the customer service data shown in §7.2.2, though this data is admittedly not scientifically rigorous.

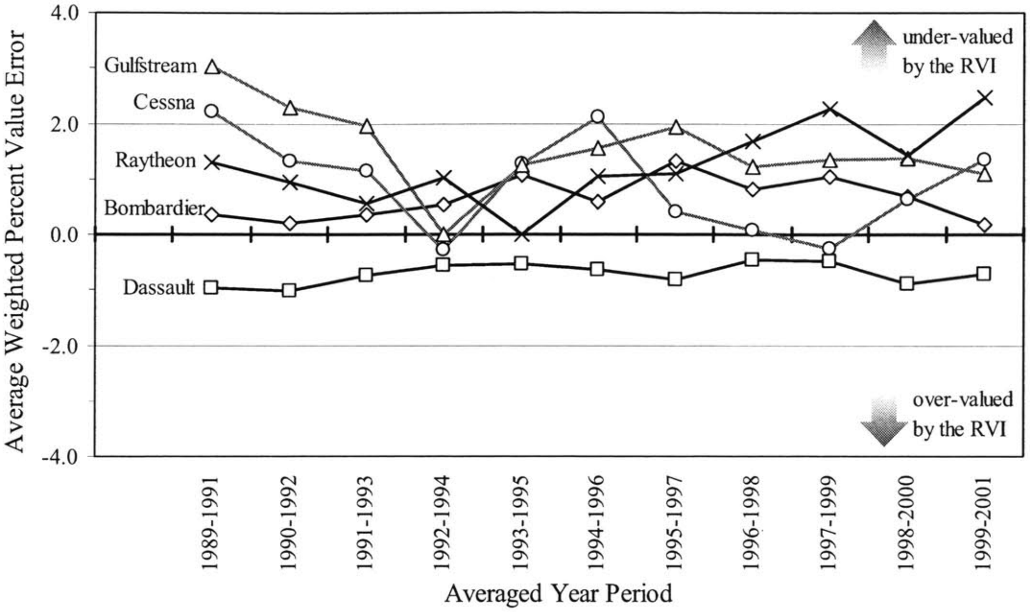

Figure 109: Average Weighted Percent Value Error by Manufacturer, 1990s

Whatever the reason, there does seem to be a consistent and clear differentiation in how the RVI method is able to fit the Dassault products' technical performance and market performance in comparison to those of the other major manufacturers. With the other four producers, the picture is a bit less clear. Gulfstream is known for offering superior customer support and, although the Gulfstream averages in the figures are typically among the highest, they are not distinctly different. One interesting result is Raytheon's growing averages in the late 1990s. Raytheon has experienced great difficulties with its customer support, particularly in supplying spare parts, in the past decade. The manufacturer has re-focused efforts on improving its support in the past few years which might account for the growing trends in Figure 108 and Figure 109.

The data in the figures indicates a strong possibility that there may be enterprise-related attributes that affect the product value as viewed by the customer. Although after-sales customer support has been the focus of the discussion here, other attributes may exist at the enterprise level such as density of distribution networks and even aggressive marketing. The data does not exist here to definitively root out the enterprise-related attributes that may be contributing to the consistent over- or under-valuations indicated in the data, the topic is worthy of continued study.

6.2.7 Near-Term and Future Product Assessments

The Relative Value Index provides a powerful approach to assessing new product proposals, as has been demonstrated previously in this chapter. In this section, two entirely new business airplane segments will be explored using the RVI method: micro-jets and supersonic business jets. The micro-jet segment is a recently emergent category with several new proposals in development, anticipated for entry-in-service in 2006. The supersonic business jet category has long been a goal of the industry, but has consistently been plagued by issues of immature technology, an uncertain regulatory environment, and wide ranging estimates for the market size.

The analyses in this section will use the 1999-2001 market attribute weighting factors as listed in Table 23, but the comparisons will include business aircraft competing in the 2004 market. As previously noted, complete shipments data is not available for years past 2001, but the emerging micro jets and supersonic business jet will be competing in a more current business airplane market. The analyses of §6.1 indicate that the weighting factors for the 1999-2001 market can likely be used for near-term markets without producing significant error.

Table 23: Attribute Weighting Factors, 1999-2001 Market

Maximum Cruise Speed	0.25
Takeoff Field Length	0.00
Fuel Consumption per Seat Mile	0.00
Cabin Volume per Passenger	0.23
Available Seat-Miles	0.15

6.2.7.1 The Emerging Micro-Jet Segment

The design that launched the micro-jet segment is the Eclipse 500, announced in 2000 as the brainchild of former Microsoft executive Vern Raburn and his startup company Eclipse Aviation. Since that time, so many startup micro-jet designers have come and gone that one easily loses track. Of the perhaps dozens of paper designs, three have currently emerged as being most likely to reach production status: the Eclipse 500; the Adam 700, an evolution from the piston twin Adam 500; and the only entry from a major business airframe manufacturer, the Cessna Mustang (Figure 4). The Safire Jet has also gained notoriety but now appears defunct due to lack of financing. The Honda Jet has garnered a great deal of press due to its origins with the

Japanese auto manufacturer, but Honda continues to assert that the aircraft is only a flying testbed for their new Honda jet engine and will not enter production. Only the entries from Adam, Cessna and Eclipse will be considered in this study.

The attribute values used for this analysis are listed in Table 24 as well as Appendix A and C, along with the other aircraft characteristics and prices.

Table 24: Attribute Values for 2004 Micro-Jet Competitors

	Adam 700	Cessna Mustang	Eclipse 500
Price (US$ millions, 2004)	1.995	2.295	1.175
Maximum Cruise Speed (ktas)	340	340	375
Takeoff Field Length (feet)	2,950	3,120	3,100
Fuel Consumption per Seat Mile (lb/nm/pax)	0.508	0.508	0.460
Cabin Volume per Passenger (cu ft/pax)	65.8	56.7	60.0
Available Seat-Miles (pax-nm)	4,400	4,264	4,198

(a) Cessna Mustang (b) Adam 700

Figure 110: Two Emerging Micro-Jet Competitors

The three micro-jet competitors are shown in Figure 111 along with the other 2004 market segments. There are considerably more business aircraft pictured in the figure than previously seen in the 1999-2001 market, but not all the aircraft in Figure 111 have reached production. The 2004 market includes several aircraft that are currently being marketed by manufacturers, but are not scheduled for first shipments for up to another year.

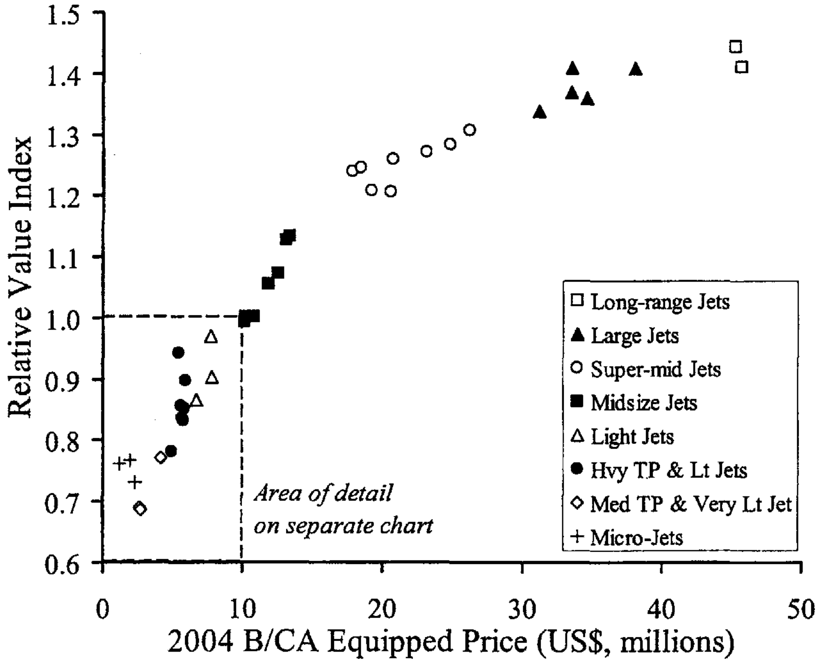

Figure 111: Micro Jets in 2004 Competitive Market

A detail view of the lower-end market segments is shown in Figure 112. The three micro-jet competitors appear to pose a threat to the medium turboprop/very light jet segments (assuming they meet their target attributes in Table 24). In particular, the RVI method suggests that the micro-jets offer higher value and lower prices than the reigning medium turboprops; the Raytheon King Air C90B and the TBM-700 (the competing Pilatus PC-12 and Piaggio P-180 are not shown due to the tendency of the RVI method to overvalue these products, as noted in Chapter 5).

The RVI method has been tailored for the executive transport mission, and the emerging micro-jets do indeed likely pose a threat to the medium turboprops for this mission. The King Air C90B and TBM-700 will not likely be displaced for special missions such as utility cargo transport that requires operations from rugged fields, or for missions that require long loiter times over targets (a specialty for which propeller-driven aircraft are well suited). But the micro-jets were specifically designed to offer jet speeds for short range executive transport missions with four or fewer passengers, and in that role the RVI method implies success for the leading micro-jet contenders.

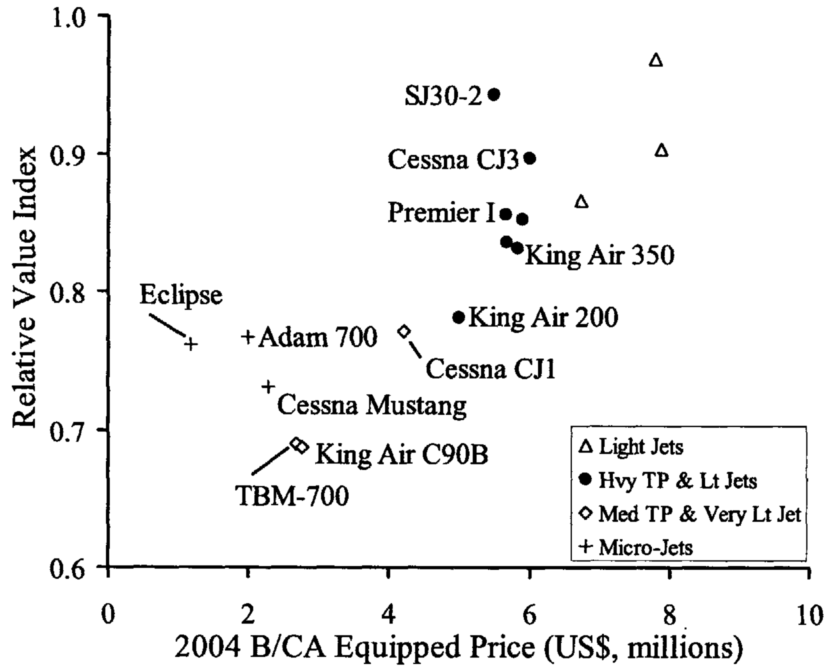

Figure 112: Detail of Micro Jets in 2004 Competitive Market

It is curious that Cessna has positioned the Mustang so close to the CJ1 in terms of technical performance. The CJ1 offers a slightly larger cabin and a marginal advantage in speed over the Mustang's advertised performance, but for a typical four passenger mission the two aircraft are quite similar in the RVI attributes. One aspect not considered in the RVI is the level of avionics and cabin interior appointments, both of which may be of higher quality for the CJ1 than the Mustang. Such additional attributes may place the CJ1 further above the Mustang in value.

Note the significantly lower price point for the Eclipse 500 entry. Some industry observers doubt that Eclipse Aviation's actual sales price for the aircraft will be able to be maintained below $2 million as currently advertised, but the data in Figure 112 reflects the most current information available from the manufacturer. If Eclipse is indeed able to deliver the high value of Figure 112 at lower costs than competitors, the RVI results indicate the potential for a very successful product.

Although only time will reveal the true success of the emerging new micro-jet segment, the RVI method does indicate results consistent with industry expectations of the segment's potential appeal and chief existing competition.

6.2.7.2 Potential for a Supersonic Business Jet

For decades a supersonic business jet (SSBJ) has existed as a gleam in the eyes of both manufacturers and business travelers. At the 1989 Paris Air Show, Gulfstream and Dassault unveiled plans to investigate the market for an SSBJ, and few months later joint ventures were established between Gulfstream and Russian military manufacturer Sukhoi, as well as the British and Russian engine makers Rolls-Royce and Lyulka. In the early 1990s, after several years of intensive technical and marketing studies, Gulfstream and Rolls-Royce left the partnership to focus on Gulfstream's long-range GV.

Various NACA[*], NASA and university projects had been proposing SSBJ designs since the 1950s, but every serious proposal by a major airframe manufacturer has eventually been shelved. Reasons for delaying the projects are typically attributed to immature propulsion and sonic boom mitigation technology, an underdeveloped supersonic flight regulatory environment, and uncertainties regarding market demand [George (July 2000)]. Even so, in 1999 the aviation industry analysis corporation Teal Group forecast a 50-percent chance that someone would launch a supersonic business jet in the next 15 years. With the future of an aging Concorde supersonic airliner fleet looking dim, Teal looked toward a future in which, "... an SSBJ would be the only choice for people wishing to travel supersonically" [Harrison (June 18, 2001)]. With the October 2003 Concorde retirement, the future appears to have arrived early.

In the late 1980s and 1990s the technological base for civil supersonic flight matured considerably with programs such as the high-speed civil transport (HSCT), DARPA's Quiet Supersonic Platform (QSP), and commercial initiatives such as the previously-mentioned joint Gulfstream-Sukhoi study, and more recent investigations by a Gulfstream-Lockheed partnership and by Dassault. Such programs have also identified the limits of current technology and led to a relaxation of certain unrealistic constraints, such as reducing cruise speeds from Mach 2.2+ to 1.6-1.8. In the 1990s, the emergence of fractional ownership programs, for the first time, established a reliable customer base with sufficient resources to place critical mass launch orders. Fractional programs also lowered the bar for aircraft ownership, with the potential of transforming an $80 million aircraft into 1/8 shares at a more palatable $10 million. Some of the

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[*] National Advisory Committee on Aeronautics, the predecessor of NASA (National Aeronautics and Space Administration).

larger fractional programs have expressed interest in adding a significant number of supersonic aircraft to their fleets.

In 2004 it is felt that propulsion systems and sonic boom mitigation techniques have matured to the point that an SSBJ may soon be a reality, although regulatory issues and market demand remain uncertain factors [MIT Aircraft Systems Engineering Team, (May 2001)]. As recently as October of 2004, two new startup companies have announced plans to introduce a supersonic business jet within the next six years [*Aviation International News Online*, October 11, 2004 and October 12, 2004].

The basic parameters of a 2001 MIT-proposed SSBJ aircraft are laid out in Table 25, and correspond closely to typical industry assessments of feasible SSBJ designs. These parameters have been utilized for analysis of an SSBJ using the RVI method.

Table 25: Supersonic Business Jet Parameters for RVI Study

NBAA IFR Range	4,200 nm
Cruise Mach	1.6
Max Take-off Weight	≤ 100,000 lbs
Design Payload	8 passengers, double club cabin
Crew	2 + 1 cabin attendant
Cabin Size	1,000 cu ft
Balanced Field Length	≤ 6,000 ft
Market Price	Approx. $80 million ($2004)
Direct Operating Costs	≤ 4,200 $/hr ≤ 6 $/nm

The RVI results for the SSBJ are shown in Figure 113. The MIT cabin volume of 1,000 cu ft is smaller than some industry studies that plan cabins approximately the size of a Gulfstream GV. Though the MIT study makes good technical and human factor arguments for the smaller cabin, the 2,000 cu ft cabin SSBJ is also shown in Figure 113 for comparison ("small cabin" and "large cabin;" the large cabin SSBJ results in the higher RVI in the figure). There is not a great deal of increase in SSBJ value due to the larger cabin resulting from the fact that the cabin volume per passenger attribute is already near the ideal attribute bound for the 1,000 cu ft cabin. The 2,000 cu ft cabin pushes the passenger comfort attribute beyond the ideal bound, limiting the additional value added by enlarging the cabin. The attribute bound was set based on estimates using existing industry data, so there is some uncertainty in what the actual ideal bound should be. This example illustrates why a parametric treatment of attribute bounds, as suggested in §6.1.3, is useful where uncertainty exists.

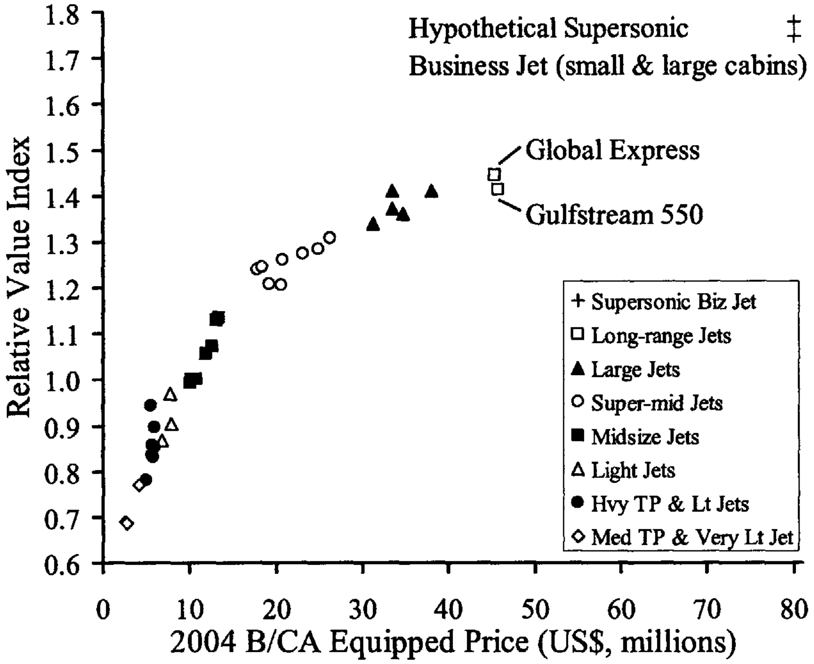

Figure 113: Supersonic Business Jet in 2004 Market

The RVI results in Figure 113 show that the SSBJ value/price point follows the established business airplane value/price trend fairly well. The assumed $80 million price represents a considerable leap in average business airplane prices (even for the Boeing and Airbus converted bizliners) so it is difficult to say with certainty what the actual value/price trend is in the $80 million area. However, the established trend suggests that an even higher price *might* be tolerated in the market given the additional value offered by the SSBJ. Most industry observers believe that a $100 million price would be the maximum allowed by the market. Extending the data in Figure 113 indicates that a $100 million SSBJ would fall nearly on the established value/price trend.

As a contrast to the RVI results, the Traditional Value Index has also been used to evaluate the hypothetical SSBJ, as shown in Figure 114 for the 2004 business airplane market. Again, the small and large cabin SSBJ is shown, neither of which falls near the established exponential TVI trend for existing business airplanes. The small cabin SSBJ appears woefully inadequate to contend in the business airplane market, offering significantly less value than even large jets offered by Dassault and Gulfstream. This is because the TVI method weights all of its attributes equally, and the SSBJ suffers by virtue of its small cabin and longer takeoff field length. The RVI method, by comparison, does not overly penalize the smaller cabin and longer field length, but rewards the considerably higher cruise speed of the SSBJ. The SSBJ TVI result does benefit from the larger cabin; Figure 114 shows the SSBJ establishing a new value/price trend for the business aircraft market according to the TVI. By contrast, the RVI method indicates a continuance of the established trend that already showed some technological limitations (see Chapter 5 for discussion) and thus appears once again superior to the TVI.

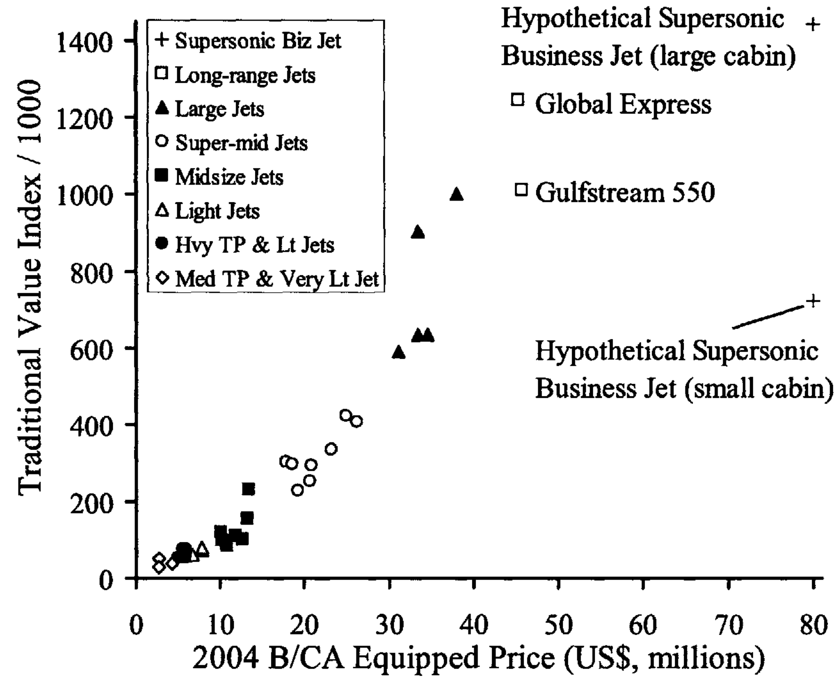

Figure 114: Traditional Value Index for Supersonic Business Jet

As with the emerging micro-jet segment, only time and experience will demonstrate the actual SSBJ configuration and Revealed Value via aircraft sales. The RVI method appears to place the hypothetical SSBJ design in line with established value/price trends for the industry, whereas the TVI method, at best, shows an entirely new s-shaped trend being established by the SSBJ. The RVI method also indicates that the proposed $80-100 million price for an SSBJ would likely be acceptable to the business aviation market based on established price trends. The TVI results suggest that such high prices would be unacceptable to the market.

6.3 Summary: Assessing the New Value Method

This chapter has essentially served as a tool by which to grade the performance of the Relative Value Index approach to product assessment. The method has been evaluated in its ability to cope with uncertainties in the input parameters and has emerged as robust to reasonable stochastic assumptions. The applications in the second section of this chapter have also served to demonstrate the RVI method's utility in the fuzzy front-end of product development for engineers, marketers, and managerial decision-makers alike.

The analyses of §6.1 are the first of their kind and make useful contributions to the literature on value-based modeling. One contribution is the utility of such analyses in assessing the usefulness of model parameters in arriving at the model solutions (i.e., the sensitivity of product attributes to the "best fit" solution), and in evaluating the reliability of the model results in the face of uncertain inputs. Perhaps an even more valuable contribution is the utility of the sensitivity analyses in presenting an objective means, not subject to opinion or memory, of assessing historical activities in a competitive market. The Monte Carlo and weighting factor sensitivity analyses proved well suited for describing the evolution of business airplane attributes over the 40 year history of the industry, independent of prior knowledge about that industry.

The RVI approach demonstrates a better ability to represent important historical events in the business aviation market in the analysis of §6.2.1. The first generation of business turbojets evince a better price/value ratio than do the competing heavy turboprops of the 1960s, presaging the ensuing decline in the heavy turboprops.

The differentiation study of §6.2.2 presents evidence to support a ratio theory of prices and value. The analysis indicates that product pricing and value (in terms of the Relative Value Index) increase by ratios (or percentages), rather than by absolute dollar amounts, as one progresses through the product portfolios of the major business airplane manufacturers. Such a ratio theory of differentiating products had, up to now, largely been confined to supposition in the theoretical pricing literature. This is the third known study to present empirical data supporting the ratio theory. Similarly, market segments appear to be differentiated by price and value ratios, with both ratios possibly breaking down only with the very high-end, high-dollar product segments.

The utility of the RVI method to both marketers and engineers is demonstrated in §6.2.3 and §6.2.4. with market share and design tradespace exploration studies. The RVI method, as well as Cook's base framework of the S-Model, is well suited to market share forecasting for new products, though the actual unit demand forecasts must be modified for GDP and other economic environmental factors. The method also lends itself to rapid exploration of the technical tradespace, allowing engineers and decision-makers to quickly estimate value/attribute and attribute/attribute tradeoffs. Such studies are often referred to as "marginal analysis" in the economics literature.

As previously noted, a number of important attributes have likely been neglected in this initial implementation of the business aviation RVI model. The analysis of §6.2.6 supports the supposition that there exist product attributes that arise from the manufacturing and support aspects of the enterprise. Such attributes may include product support, reliability, and even access to the product if an adequate distribution network does not exist. Though the analysis of this chapter supports the theory of enterprise-related attributes, sufficient data does not yet exist to determine the nature of these attributes, and the subject warrants further study. One approach might be to consider utilizing the value approach of this thesis in combination with conjoint analysis, as suggested in §7.1.1.3.

The analysis of near-term and future products in §6.2.7 demonstrates the RVI method's potential for new product assessment, both as an engineering performance analysis tool and for product placement and pricing strategy development. Though the actual outcome of the products studied in §6.2.7 will be unknown for years and perhaps decades, the assessment approach is flexible enough to allow it to be modified and improved as empirical evidence becomes available. At this stage of knowledge, the RVI methodology indicates significant potential for both microjets and supersonic business jets if they can achieve the attributes assumed possible in this analysis.

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7 DISCUSSION

The theoretical underpinnings of the Relative Value Index approach to product assessment have been thoroughly studied in Chapter 4, and the industry-specific applications of Chapters 5 and 6 have shown some of the potential applications for the new method. In this chapter, the approach is specifically compared and contrasted to the other value assessment methods that were introduced in Chapter 3. After the merits of the new approach have been scrutinized, the generalization of the RVI method is discussed in §7.2. The chapter is completed in §7.3 with an examination of why we seek to build models of systems, some of the limitations and misuses of models, and how, or if, models may be "validated" or "verified." A discussion of what qualifies as a "good" model follows, with hallmarks of "good" empirical models noted, with an emphasis on standards set forth by philosopher Karl Popper and marketing scientist John Little.

7.1 Comparison of the Value Approach to Existing Assessment Methods

A number of existing product evaluation methods were presented in Chapter 3 as an introduction to the state-of-the-art in value assessment. Existing methods were categorized into two groups: marketing science methods and figures of merit specific to the business aviation industry. The limitations of each method were noted in Chapter 3, and the conclusion was reached that a new assessment method was required. In this section, these methods will be directly compared and contrasted to the Relative Value Index approach.

7.1.1 Marketing Science Methods

Four common and distinctly different marketing science approaches were presented in Chapter 3 as potential product assessment methods: market share/product diffusion, product screening, conjoint analysis, and random utility models.

7.1.1.1 Market Share and Product Diffusion

As noted in Chapter 3, little work has been done to model characteristics of the product itself using existing market share and product diffusion methods. In other words, the existing models do not directly relate market share or diffusion to attributes inherently possessed by the product. To date, much of the work has focused on exogenous factors such as product advertising budget and price [Urban (February 1969), Roberts and Urban (February 1988), Roberts (1989)]. Massy's early work in this area [Massy (1968)] did include generic "product appeal" considerations, but was so generic as to not be well suited for real-world implementation.

The classic Lotka-Volterra equations [Bhargava (1989), Pistorius and Utterback (1995), (1996) and (1997)] present a method for estimating market share capture by a new product or technology given an existing product or technology. Unfortunately the equation parameters, including a number of variables representing symbiotic interactions between two technologies or products, have not been well-enough-defined to allow one to estimate their values given empirical or hypothetical observations.

As shown in the theoretical development of Chapter 4, Cook's RVI approach is well-suited to determining market share for an array of competing products. In studying market shares (both existing and potential shares for future products) one would be capable of making an estimate of diffusion rates for proposed new products. Unfortunately, the shipments data used in this research is too aggregate (annual) to allow practical study of business aircraft diffusion rates, which appear to be quite fast. In contrast to the Lotka-Volterra equations or, for example, Massy's methods, the manner in which the RVI parameters are to be used for analysis is well-defined for practical application.

7.1.1.2 Product Screening for Product Development

Cooper's NEWPROD is the best-developed of several methods found in the literature for screening proposed new products and development projects. The purpose of the screening is typically to identify those new products with the highest potential for realizing market "success" once they are introduced, with "success" typically being defined in financial terms. NEWPROD is specifically claimed by its developer as enjoying extremely high success rates in correctly choosing new projects and products.

There is no way within the confines of this study to quantitatively compare NEWPROD and the RVI approach to product screening (we do not have potential products at our disposal to screen and then observe the final development outcomes). Whereas NEWPROD screens on parameters such as the degree of management support for the new product and the product's synergy with existing products, the RVI approach specifically addresses product-related attributes. While the RVI method evaluates products relative to other product portfolios, it does not directly render verdicts on the potential success or failure of new products as NEWPROD does. The RVI method presents the relative standing of products and enables users to modify proposed products, known as exploring the design tradespace, to observe the effects vis-à-vis competing products. The NEWPROD method does not directly allow users to perform such a tradespace exploration, though modification of the input parameters could allow users to observe the change in the model's success rating for the product. NEWPROD was not developed with the intention of allowing users to directly compare competing products, whereas the RVI approach was developed specifically with this in mind.

7.1.1.3 Conjoint Analysis

It's an undeniable fact that, for new product launches, conjoint analysis techniques can be quite useful in tailoring the design and marketing programs for the product. This is particularly true for novel products that incorporate new features or technologies not yet introduced to the market. Conjoint analysis clearly has a place working in conjunction with the RVI approach as well, serving as a valuable resource in determining primary attributes, attribute bounds and, in the case of novel attributes, potential attribute weighting factors.

The reader should not infer by this research that the RVI approach should, or is even capable of, wholly supplanting conjoint techniques. Instead, the value assessment methods studied here have an important role to play in complementing and bolstering conjoint analysis in the course of new product design and development.

The RVI method has, in this research, demonstrated value as a technique for rapid tradespace exploration and for providing an objective lens through which to view the evolution of markets over time. One of the key contributions of the RVI method is its ability to show the impacts of attribute changes in a short period of time, as is often necessary in the fuzzy front-end of product development when time is at a premium. In contrast, a useful conjoint analysis may take weeks to execute and analyze. Furthermore, proper analysis of survey results typically requires someone with considerable education and experience working with conjoint studies. As the head of one in-house marketing department for a major business airframe manufacturer commented, "we don't have many Ph.D.s on staff here (to analyze conjoint analysis results)."

Typically conjoint studies are contracted to consulting firms with experience in such surveys, but this then creates a potential problem with internal firm understanding and with management buy-in for the study results.

Another major weakness of conjoint studies is the issue of respondent fatigue, as noted in Chapter 3. The number of attributes and attribute levels that one can study are very limited, and continue to be so even with the use of cutting-edge techniques such as hybrid conjoint analysis, Hierarchical Bayes, and adaptive choice-based conjoint analysis. The use of such techniques, most of which employ complex "black box" mathematical routines, violate Little's criteria for being simple, easy to control, and easy to communicate with. The RVI approach allows one to study the effects of multiple attributes at nearly unlimited levels quickly, and using common PC computing resources.

Along with the issue of respondent fatigue is the number of survey participants required for statistically meaningful results. The worldwide business aviation customer base is measured in the thousands, in comparison to the millions of automobile consumers in the United States alone. In conducting a conjoint analysis survey a company runs the risk of annoying a significant percentage of its customer base with potentially fatiguing surveys. Such analyses are not to be conducted without thorough prior planning, and will be limited in how often they may be conducted. These limitations again make the conjoint analysis method unsuitable for broad attribute exploration in the early product development phase.

Finally, conjoint analysis relies on stated preferences whereas the RVI techniques for "best fit" to market data rely on revealed preferences. While the debate continues as to the pros and cons of using SP and RP data, the RVI approach has demonstrated its ability to well match revealed business aviation market events and preferences.

It is again important to stress that the Revealed Value Index method has its niche and is not advanced as a replacement for conjoint techniques. The RVI approach conforms to Little's criteria, is not limited by issues of respondent fatigue, and allows for rapid exploration of the design tradespace. The RVI methods may be viewed as a complement to existing conjoint techniques, possibly as a way to narrow the number of attributes of interest and the number of attribute levels to study in-depth using the marketing science methods.

7.1.1.4 Random Utility Models

As noted in Chapter 3, the greatest limitation of RUM methods vis-à-vis this study is the way in which the method handles product prices. Prices must be integrated into the utility function for them to enter into the choice equation, yet consumer choice theory clearly states that consumers maximize utility while under budget constraints. In other words, consumers directly weight utility (benefit) against price (cost) in making choices. RUM methods prove unsatisfactory not only because they prevent a direct benefit/cost comparison, but also because of their complex probit and logit forms for choice that make the methods difficult for non-specialists to understand and implement.

There is no way to directly compare the RVI and RUM methods for accuracy or ability to anticipate market activitites. A RUM utility function could be developed with the same five attributes used in the RVI model, and could be either a summation or mathematical product of the attributes.

$$V = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n \tag{7-1}$$

$$V = x_1^{\beta_1} x_2^{\beta_2} \cdots x_n^{\beta_n} \tag{7-2}$$

Either utility function could be used in the probit or (shown here) logit form for choice:

$$P_n(i) = \frac{e^{\mu V_{in}}}{e^{\mu V_{in}} + e^{\mu V_{jn}}} \tag{7-3}$$

The difficulty with direct comparison lies in how price is treated. Without price to directly compare to value, the RVI method cannot forecast demand (i.e., consumer choice). If price is to be integrated into the RUM utility equation, a weighting factor, β, would have to be developed for price, and if the relative attribute value curves of Cook (1997) are to be used, "critical" and "ideal" prices have to be determined. Choices on any of these three parameters will significantly affect the RUM choice probability results, thus making direct comparison to RVI results of little value.

The RVI method should be considered as an alternative to RUM methods, with greater ease of use and simplicity of theory, while demonstrating an adequate ability to anticipate market activities and choice. RVI methods would appear to pose greater potential in enabling better communication between managers, marketing specialists, and engineers due to its inherent simplicity.

7.1.2 Industry Value Methods

Existing industry value methods were categorized in Chapter 3 as general productivity indices, the company-specific Gulfstream Ownership Experience Index, and the so-called Traditional Value Index.

7.1.2.1 Productivity Indices

Two productivity indices were introduced in Chapter 3: one published by McMasters and Cummings (January-February 2002), Equation (7-4), and another by Mead, Coppi and Strakosch (June 1980), Equation (7-5).

$$PI_1 = \text{Cruise Speed} \cdot \frac{\text{Useful Load}}{\text{Maximum Takeoff Weight}} \tag{7-4}$$

$$PI_2 = \frac{\text{Purchase Price}}{\text{Passengers} \cdot \text{Range} \cdot \text{Cruise Speed}} \tag{7-5}$$

As was noted in Chapter 3, the McMasters and Cummings method showed little promise when used to indicate technical progress in the business aviation industry over the past 40 years, but did at least present a trend of increasing productivity with increasingly larger business aircraft (Figure 28). The index advanced by Mead, et al. showed no discernable trend among aircraft in the 2004 market, and also produced no evidence of increasing productivity over the past 40 years once the price data was adjusted for inflation.

These two productivity indices, which were the only ones found in the literature and specific to aircraft, appear to have little utility in accurately assessing the value of business aircraft, particularly within the context of historical data. But it is worth considering if they might be modified in any way to become comparable to the Relative Value Index approach.

The principal concern with the PI_1 equation is its focus on commercial aircraft attributes of interest to airlines: load carrying capability as a fraction of total weight. Little evidence points to this attribute being of importance to business aviation customers who appear to focus on travel time and comfort, among other attributes. The analysis in Chapter 3 also revealed no evidence for increased productivity in the business aviation industry over the past 40 years using this index. The PI_1 equation tends to indicate that the business aircraft of 2004 are no more or less productive than their 1965 predecessors. Such results neglect 40 years worth of gains in cruise speeds, fuel efficiencies, cabin space per passenger and other improvements that the RVI method currently considers.

As noted in Chapter 3, the PI_2 equation is inverted in terms of the fact that it indicates increased productivity with diminishing magnitudes of the index (higher prices yield lower productivity, all else remaining equal, etc.). With most value methods it is also desirable to hold price as an exogenous variable against which to compare the product value. After the equation is inverted and price is removed, PI_2 remains problematic because of the high correlation of the range and passengers parameters. As shown in Chapter 5, these two variables have an r-value of 0.92 using data from the 2004 market of business aviation airplanes. These variables would need to be recombined into alternative, relatively uncorrelated parameters before the productivity index would take on any explanatory power (i.e., one could not separate the contribution to productivity from passenger capacity and range if the two variables are highly correlated). Once these changes are made, and perhaps attribute exponential weighting factors are added, the PI_2 approach begins to resemble the RVI approach, but without the key concepts of "ideal" and "critical" attribute bounds. Little would seem to be gained from such an extensive modification of this existing method. Similarly, the PI_1 equation would also have to undergo extensive revision to better accommodate historic market evolution and current business airplane trends. The RVI approach shows significant advantages over these existing methods.

7.1.2.2 Gulfstream Ownership Experience Index

The Gulfstream Ownership Experience Index (OEI) offers perhaps the most promising counterpart to the RVI approach. Like the RVI approach, the OEI is highly flexible, focuses on product-related attributes rather than programmatic and management issues (characteristic of screening methods), and the OEI meets many of Little's criteria for ease of use and simplicity. The OEI is most obviously characterized by two major weaknesses when directly compared to the RVI; the method has not been calibrated to any empirical data, and the OEI lacks the concept of "ideal" and "critical" attribute bounds.

The OEI's developers concede that product rankings from the method have not been compared to current or historical market data. As part of this research, access to proprietary rankings for the current super-midsize jet segment were granted and, when graphed against product list prices, the rankings did not appear to generally follow recent shipment data, presumed to approximately represent market demand for the products. There clearly is potential for the OEI approach to be calibrated with market data through modification of the attribute weighting factors in the model. This would still leave unresolved at least one other major difference between the OEI and RVI methods.

The introduction of "critical" and "ideal" attribute bounds is viewed as key to the RVI method accurately reflecting consumer preferences based on product attributes. Without these bounds, consumer preference based on a single attribute can grow unabated with improvements in the attribute, even once "saturation" has occurred. The limited usefulness of extremely long aircraft ranges is one example of such saturation not compensated for in the OEI approach.

It would have been ideal to have greater access to the OEI method for a more full comparison to the RVI approach to product value. Exploring market developments such as the first decade of business jets, or the potential for a supersonic business jet, using both the OEI and RVI methods would have made for an interesting analysis. The OEI developers at Gulfstream have shown interest in the RVI approach, but have not indicated a concrete vision for the future development or use of the OEI.

7.1.2.3 Traditional Value Index

The Traditional Value Index (TVI) is currently the most widespread and well-known value assessment model in the business aviation industry. As such, many have asked if it cannot simply be modified to better fit historical data, obviating the need to develop the RVI method. The answer is that the TVI could indeed be modified, but the revisions necessary would be extensive and still lack some advantages of the RVI approach.

Parameters in the TVI equation could be assigned weighting factors, much as in the RVI method:

$$\mathrm{TVI_{mod}} = \frac{\mathrm{Range}^{\gamma_r} \cdot \mathrm{Speed}^{\gamma_s} \cdot \mathrm{Cabin\ Volume}^{\gamma_{cv}}}{\mathrm{Takeoff\ Field\ Length}^{\gamma_{tofl}}} \tag{7-6}$$

Mathematically, of course, the "takeoff field length" attribute weighting factor would be < 0, calling into question the true nature of the weighting factors (perhaps only their magnitudes would be used as indicators of the importance of the attributes).

A more serious problem with the TVI method, and what prevents the simple addition of weighting factors to improve the method, is the high correlation of some of the variables that make up the equation: range and cabin volume, $r = 0.94$; field length and speed, $r = 0.84$; based on business airplane data in *Business & Commercial Aviation* for the 2004 market. These parameters need to be recombined into alternative, relatively uncorrelated parameters, as was done with the RVI method in Chapter 5. With such high correlations between parameters, the TVI might have high predictive power (although that is called into question when certain historical scenarios are examined; see Chapter 6), but the method lacks explanatory power. How one can separate the effects of range and cabin volume, for example, becomes an issue when studying the TVI results for a product portfolio.

Even with the addition of exponential weighting factors and alternative, relatively uncorrelated parameters, the modified TVI method would still lack the "ideal" and "critical" attribute bounds viewed as key to properly representing consumer preference behavior. The unmodified TVI method was noted as indicating exponential growth in value while approaching an asymptotic list price (see Figure 32). Without attribute bounds reflecting saturation of preference with improvements in attributes, value will grow unabated with the attributes. Conversely, products that are valueless in the real world (airplanes with 10 mile ranges) will still indicate a non-zero value using any approach without a lower attribute bound.

7.2 Generalization of the Relative Value Index Approach

Cook's value assessment approach described in Chapter 4 is generalizable to any conceivable product that may be described by one or more attributes. As Lancaster (1971) notes, "Even the simplest of things possesses a myriad of objective properties." It is important to recognize that the term "product" may denote physical as well as service products. Though this research has focused a great deal of attention on physical products from the business aviation industry, the RVI method has a broad range of potential applications beyond those studied here. In this section two additional RVI models will be developed to demonstrate the generalizability of the approach. The first model, briefly described here and fully presented in Appendix E, will be for another physical product; sport utility vehicles in the automotive market. The second model will be developed for a service product; to evaluate the business aircraft support programs that are sold with the aircraft. Both models will be quite simple, but should be sufficient to demonstrate the significant potential for the RVI approach.

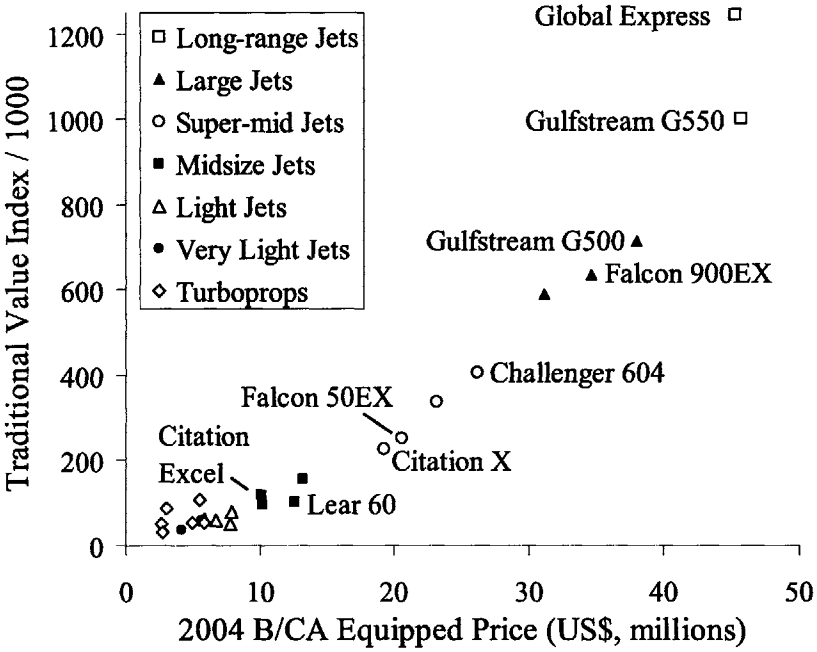

Figure 115: Traditional Value Index for the 2004 Business Airplane Market

7.2.1 Sport Utility Vehicle Model Development

Prior work with Cook's base framework for value assessment (the S-Model) has been, as far as is known, limited to the automotive industry. Thus our extension to the business airplane industry is a first demonstration of generalizability. In Appendix E, the approach developed in Chapter 4 for estimating the attribute weighting factors based on market demand and price data is carried out for the automotive industry. This shows directly the generalizability of this new approach to another industry, in addition to the generalizability of the base framework of the RVI method.

The appendix shows that, for the sport utility vehicle market, there is not a high correlation between Revealed Value (based on price and demand) and the MSRP for the vehicles. This is likely due to unknown discouting, special financing, and other incentives that alter the "true" price of the SUVs. As a consequence, the resulting RVI model for the SUV market reflects a poor fit of the selected vehicle attributes and the market Revealed Value. It is concluded that additional data reflecting the true price of the vehicles is required, as is information on additional attributes of importance such as consumer access to distributorships.

7.2.2 Aircraft Product Support Model Development

A simple RVI analysis was constructed based on a business aircraft product support and service survey found in the trade journal *Aviation International News* (August 2003). Data from the survey is shown in Table 26, where 11 business jet aircraft are rated on seven factors on a scale of 1 (marginal to inadequate) to 6 (very good). The survey results reflect aircraft operator opinions of the year 2002 product service and support packages associated with the aircraft listed in Table 26. "AOG Response" in Table 26 indicates customer satisfaction with the manufacturers' responsiveness to "Aircraft on Ground" situations where a flight-critical item is broken and must be fixed before the aircraft can be flown with passengers.

It should be noted that the survey is unscientific in nature and is based on evaluations returned from flight department managers, pilots, maintenance chiefs and mechanics. The number of responses received for any particular aircraft may vary greatly, although at least 10 responses were required for any particular aircraft to be included in the survey results. No specific model of Cessna Citation or Dassault Falcon was specified in the survey results (there are a number of "Citation" and "Falcon" business jets) so the Citation X and Falcon 900EX were assumed. The impact of making these assumptions will be briefly discussed later.

Each of the seven factors rated in the survey was used as an attribute of importance in rating the service and support packages offered with the particular aircraft. All attributes were considered LIB type attributes, and bounds were set at critical = 1, ideal = 6, and baseline levels equivalent to the averages for each attribute (Table 26).

The service and support packages are not sold separately from the aircraft, but instead come standard with the product purchase. There is, therefore, effectively no demand data for the individual service and support levels and no Revealed Value may be determined for a best fit of exponential weighting factors. Alternative marketing techniques, such as those discussed in Chapter 3, become useful in cases such as this since the weighting factors must be determined by other means. In this situation, there is no indication from the survey how one factor might compare to another in importance, so in the absence of other data, all weighting factors were set to 0.5.

Table 26: Data Available from Product Support and Service Survey, 2002

Manufacturer	Model	Fairness of Parts Policy	Parts Avail-ability	Cost of Parts	AOG Response	Warranty Fulfillment	Tech Manuals Ease of Use	Tech Rep Response
Bombardier	Challenger	4	3	3	4	5	5	6
	Global Express	4	2	2	4	5	4	6
	Learjet	4	4	3	5	5	4	6
Cessna	Citation	5	5	4	5	5	5	5
Dassault	Falcon	4	5	3	5	5	5	5
Gulfstream	GIV	5	6	3	6	6	6	6
	GV	5	6	3	6	6	6	6
	G100	5	6	4	6	5	5	6
	G200	5	6	4	6	5	5	6
Raytheon	Hawker	4	4	3	4	5	4	5
	Beechjet	3	4	2	4	4	4	5
Averages		4.4	4.6	3.1	5.0	5.1	4.8	5.6

source: *Aviation International News*, August 2003, p.38

Results for the service and support RVI model are shown in Figure 116 graphed as a function of the aircraft price. In the business aviation industry, the level of after-sales support does tend to increase with the price of the aircraft, so comparing the RVI ratings to aircraft purchase price is appropriate.

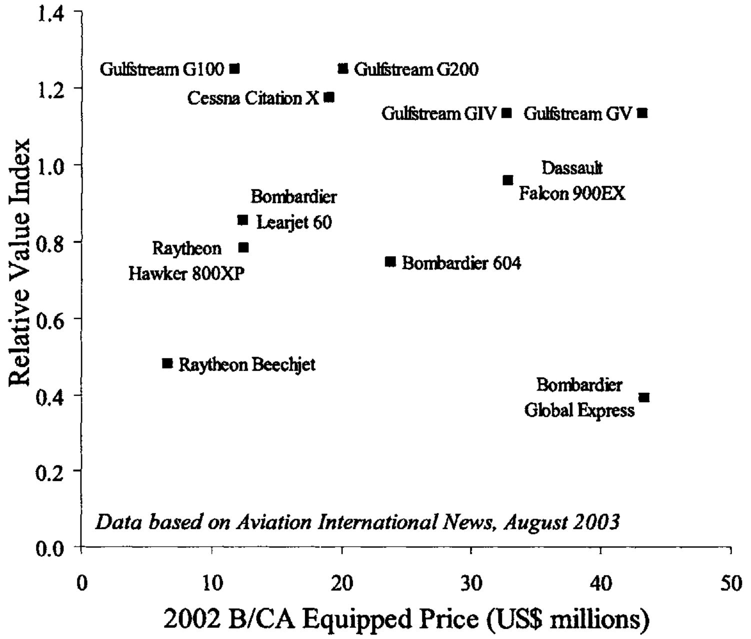

Figure 116: RVI Results for Product Support and Service, 2002 Market

With the exception of the Bombardier Global Express support package, Figure 116 indicates a trend of higher support levels with higher aircraft purchase prices. The manufacturer Gulfstream is known for their exceptional customer support for all levels of their product line, so it is not surprising to see high Relative Value Indices for their less expensive G100 and G200 products. The Bombardier Global Express support package received exceptionally low ratings for the parts availability and pricing associated with the aircraft. The manufacturer is known for this particular problem in its support packages, though it is interesting to see that the ratings for its Learjet 60 and 604 products were not quite as low in these areas. The RVI rating for the Global Express does improve if the weighting factors on the two parts attributes are lowered (if the attributes are judged to be of less importance to customers), but the relative standing of the Global Express remains inferior to the rest of the market since the RVI ratings of all products improve at the same time.

As mentioned before, it was assumed that the survey responses for the Cessna Citation and Dassault Falcon referred to specific aircraft from those manufacturers. This assumption only affects the price point at which these aircraft are placed in Figure 116. The top-line aircraft, in terms of price, for each manufacturer was selected for purposes of determining a price point in Figure 116. The impact of changing the aircraft considered would be not to affect the RVI rating but rather to change the horizontal positioning (to the left; lower price) of the aircraft in the figure. The range of possible prices is shown in Figure 117. The trend of higher RVI ratings with higher aircraft prices would not seem to be diminished with lower price points on either of the manufacturers' aircraft considered.

7.3 Practical and Philosophical Considerations in Modeling

Models surround us in our daily lives, even if we don't perceive them as such. As March and Simon (1958) point out, some sort of model is always used in decision making, namely, the decision maker's definition of the situation. But why do humans create models, and what are the limitations of their use? This question is addressed this section, along with a discussion of how to evaluate whether models are "good." Hallmarks of "good" empirical models will be specifically addressed as the Relative Value Index model relies heavily on empirical data.

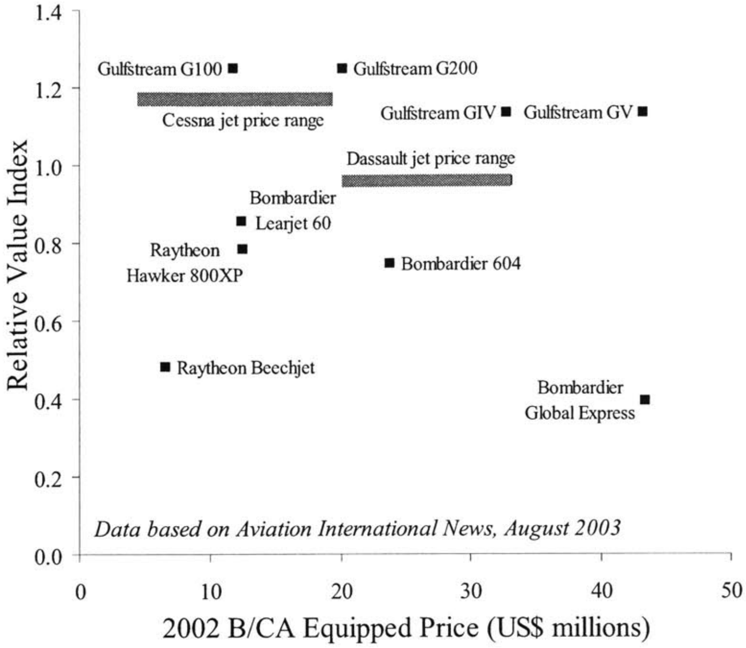

Figure 117: Price Ranges for Cessna and Dassault Jet Products, 2002 Market

7.3.1 Reasons for Modeling

In their paper "The Nature of a Computer Simulation Model," Kornbluh and Little (1977) advise that “a model is a vehicle for arriving at a concise and structured view of a system. It is an intellectual tool for distinguishing the possible from the impossible. It is also an analogy.” Models are representations, or approximations, of certain aspects of complex systems that serve to illuminate and clarify the interrelations of the component parts of the system.

Models, at heart, tell stories to explain how things work. At some level all new stories are variations on old ones, “reworkings of the universal themes underlying all human experience” [Magretta (May 2002)]. Similarly, product assessment models, such as those introduced in Chapter 3, are variations on assessing the underlying value streams that the product delivers to its stakeholders. In the field of business models, Magretta contends that when models don’t work “it’s because they fail either the narrative test (the story doesn’t make sense) or the numbers test (the P&L doesn’t add up).” Although value models don’t necessarily have profit and loss numbers to add up, the concept is the same. A good model should support a self-consistent, sensible story and the numbers (on market demand, on financial returns, etc.) should add up.

Models do not have to exist outside of our own imaginations. So-called "mental models" are formed through our experience, knowledge and intuition and help us to interpret and survive in the world around us. However, mental models quickly become inadequate as the complexity of the system under study increases.

Normative approaches to decision making emphasize the importance of making formal models, and the use of such models has become a hallmark of systems analysis and operations research [Morris (1967)]. There are a number of advantages to formal models, as explained by Kornbluh and Little (1977):

- They impose a logical discipline which forces precise statements of problems and objectives. Formal models require that the system being described be explicitly divided into its major components and major interrelationships among these components.
- Models can provide novel and critical insights into system behavior, sometimes even counter to what was expected.
- Formal models provide a framework within which experiments can be conducted, sensitivities of the system to changes in variables and their interrelationships can be studied.
- The nature of various risks may be clarified and options for risk mitigation formulated.
- Models may be used as educational devices for teaching decision makers as well as researchers.
- The development and implementation of models may lead to more open communication and understanding regarding the system among stakeholders.

The subjects that are modeled, and the manner in which the models are implemented, are as varied as the individuals, corporations, or organizations that create the models. Models may simulate personal cash flows as someone works out a budget on an envelope, while other models may represent international conflicts and arms controls strategies on multi-million dollar supercomputers for purposes of government policy evaluation (one such model is the Raytheon Strategic Model, documented by Abt, et al. (1962)). However, all models have the same purpose: to aid in learning and exploring.

Learning from experience alone can be costly, slow (long time constants), dangerous, or impractical for all these reasons. In many cases, learning may not occur at all due to long time delays in feedback. To compensate for these deficiencies, humans tend to take small steps due to uncertainties in the real environment, adjust their mental models, formulate new strategy and decision rules, make decisions and then implement the next small step (Figure 118). Experience, though it's all that humans have had for literally millions of years, is fraught with dangers that may be overcome, in part, with the use of "good" models.

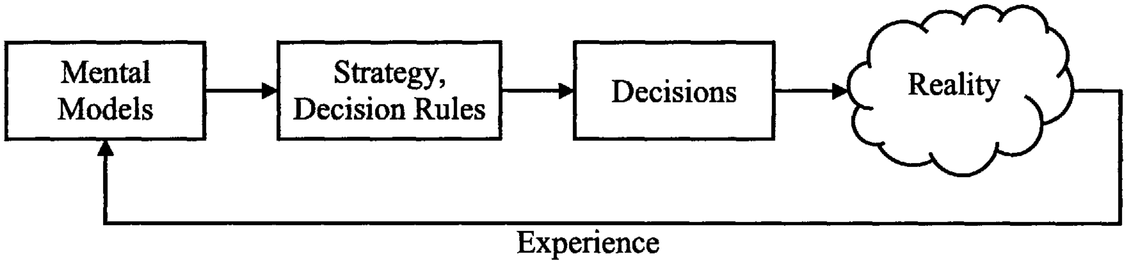

Figure 118: Learning Through Experience

Virtual worlds, as John Sterman (2000) calls them, allow for immediate feedback. Modelers can push their assumptions, strategy, and decision rules to extremes to see what happens ("challenge the clouds" as Sterman refers to it) (Figure 119). A budget allows the individual to explore how new car payments would affect his savings account balance without having to actually risk his financial security. The Raytheon Strategic Model allows actors to explore international arms control policy, and even the ramifications of all-out thermonuclear war, without the obvious consequences of actually enacting such policies in the real world.

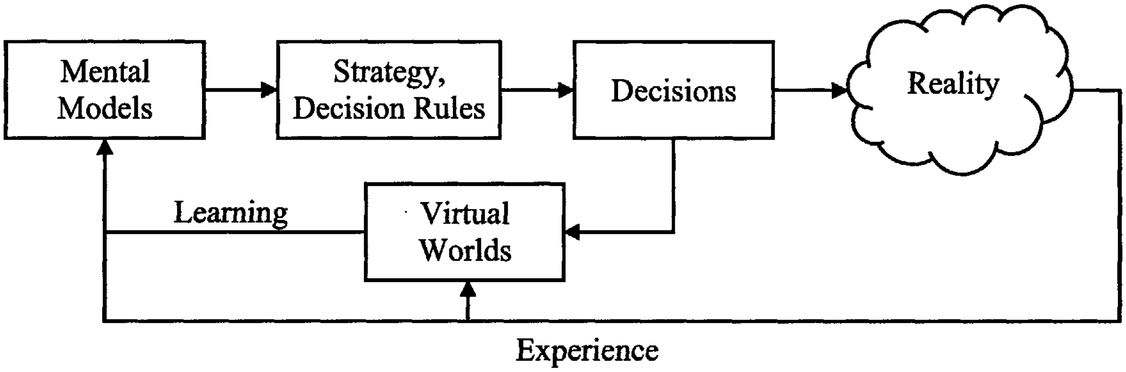

Figure 119: Learning Through Virtual Worlds

The most attractive benefit of modeling is not the end result, but is instead the depth of understanding of his problem that the designer gains through developing and testing the model. Papert (1980) contends that the most valuable learning due to modeling comes from creating the model, getting it wrong, and learning more about the system being modeled as fixes are sought. Papert refers to models as "microworlds" which are incubators, or "growing places" for specific species of powerful ideas or intellectual structures. In microworlds, one can learn about relationships, such as are involved in mathematics or Newtonian physics, as well as discover and reconcile contradictions, such as those commonly found between personal knowledge, assertions of others, empirical data, physical laws, and so forth. "The process of model development may be usefully viewed as a process of *enrichment* or *elaboration*. One begins with very simple models, quite distinct from reality, and attempts to move in evolutionary fashion toward more elaborate models which more nearly reflect the complexity of the actual management situation" [Morris (1967), emphasis in original].

7.3.2 Limitations, Misuses and Validity of Models

> "A man would do nothing if he waited until he could do it so well, that no one would find fault in what he had done."
>
> – John Henry Cardinal Newman (1801-1890)

Perhaps the most profound limitation, or danger, of modeling is the paralysis it threatens to impose on decision makers as they wait for one more bit of data; for that last piece of information that will suddenly render the world from shades of grey to the crystal clarity of black and white. Modelers and decision makers would do well to remember, as G. T. Jones said, that "surely some information is better than total ignorance; and if we are reasonably careful about the way in which the result of a simulation analysis are generated and used, we will have guarded against the situation where the results are downright misleading" [Jones (1972)].

There are limits to the use of formal models. Schon (1983) contends that formal models "have generally failed to yield effective results in the more complex, less clearly defined problems of business management, housing policy, or criminal justice." Similarly, in the Relative Value Index model we are trying to formally represent less clearly defined areas of customer choice and value. But Schon points out that modelers have reacted to such challenges by postulating formal models as probes or metaphors to at least explore the less clearly defined areas as a first step to spanning the "gap between professional knowledge and the demands of real-world practice." That would, at a minimum, be an admirable goal for the research conducted using the RVI model.

Formal models are also limited by their ability to represent tacit knowledge, or knowledge in practice, that the practitioner may not even know he has. As Schon (1983) remarks

> "The workaday life of the professional depends on tacit knowing-in-action. Every competent practitioner can recognize phenomena – families of symptoms associated with a particular disease, peculiarities of a certain kind of building site, irregularities of materials or structures – for which he cannot give a reasonably accurate or complete description. In his day-to-day practice he makes innumerable judgments of quality for which he cannot state adequate criteria, and he displays skills for which he cannot state the rules and procedures. Even when he makes conscious use of research-based theories and techniques, he is dependent on tacit recognitions, judgments, and skillful performances."

In this research we try, in part, to leverage tacit knowledge regarding customer attribute preferences and formalize it to what extent possible.* For example, industry marketing experts strongly suspect that customers purchase business airplanes based in their speed, range and other tangible attributes. But there is some question as to how large a role styling, prestige and other less tangible attributes play. Successful, experienced sales specialists and marketers claim that they can almost unconsciously determine what customers are positively reacting to in a new airplane and leverage it to make a sale. But it is sometimes difficult for them to verbalize what combination of attributes upon which they believe the customer made the purchase decision, or to weigh how much each attribute contributed. Value modeling and assessment of product features will always have an important tacit element that cannot be adequately formalized.

Modeling error, or limitations in utility, will occur due to simplifications of the real system being modeled. A model is always a simplification of the system it represents due to assumptions made by the designer, inclusion in the model of only those variables and interrelationships deemed critical, aggregation, and other methods. There is always a danger of oversimplification. The data needed by the model to assign parameter and variable values is also subject to simplifications as well as errors such as in format or transcription. As Kornbluh and Little (1977) state, "The reliability of and validity of the model data should never be taken for granted." And, even with the best of intentions to accurately represent a system, there are still practical considerations that a modeler must contend with. These may include limitations on available computer resources or human expertise in designing the model, as well as limits on the time available to develop the model. Model designers must make tradeoffs in model accuracy given limited resources and should carefully note the nature of such tradeoffs for those who will

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* Schon calls this "reflecting in practice," or thinking about what you're doing as you do it.

be using the models. The attempt has been made in this study to document all of the assumptions and simplifications made in developing the RVI model so that future users and decision makers are aware of potential sources of error and limitations of the model.

In complex mathematical models there exists the risk that decision makers will have difficulty placing confidence in "black box" methods. Kornbluh and Little (1977) categorize models into three types: mental models, physical models and symbolic models. Mental modeling is the natural capability of humans to interpret and survive in a complex world. Physical models are constructed from tangible materials and may include architectural mockups and aircraft wind tunnel models. Symbolic models use symbols to represent the components and interrelationships of a system, and include mathematical models. One of the greatest limitations of mathematical models, noted by Kornbluth and Little, is the potential unfamiliarity of many decision makers with advanced mathematical symbology and manipulation. Since these decision makers may be the intended audience for the model output, care needs to be taken in the design and implementation of the model to ensure the decision-makers' confidence in using the model.

Similarly, to enhance confidence in the results, formal models should be based on real-world problems and vetted through the use of empirical data. Schon (1983) cautions

> "Driven by the evolving questions of theory and technique, formal modeling has become increasingly divergent from the real-world problems of practice. And practitioners who choose to remain on the high ground have continued to use formal models for complex problems, quite oblivious to the troubles incurred whenever a serious attempt is made to implement them."

It is for this reason that a 40 year historical database of business airplanes has been compiled and utilized with this research. As Kidera and Hoff (1977) note, "A mathematical model, when constructed, is little more valuable than a map with a road network but no printed data. Therefore, data must be acquired to qualify the relationships that have been described in the model." With such data, however, another limitation of formal models is uncovered. Results of any model analysis are dependent on the quality of the data used in the model. Collection of data is perhaps the single most important part of a successful analysis.

Models such as the Relative Value Index model are easily misused, even when the modeler or decision maker have the purest of intentions. Hammond (March-April 1974) points out three common misuses of models:

1. Sometimes work with a model becomes a substitute for good, hard thinking about assumptions and alternative courses of action. It becomes an unimaginative ritual just as the annual planning cycle becomes the rite of fall.
2. If many alternatives are tested with the model, the one that finally is selected sometimes takes on vaunted status because it has been so rigorously tested. Thereafter, it may be followed too rigidly under changed conditions.
3. In many organizations, planning is an advocacy process. In such settings, models are sometimes used to justify, rather than to explore, the implications of actions.

Another potential misuse is to assume that the RVI model is capable of predicting the future. The RVI model is not intended for prediction, but is proposed for elucidation and education. House (1977), in speaking about business simulations, hits upon the core difference between predictive models and analysis models such as the RVI method:

> "Models designed as tools for systems analysis should concentrate more upon appropriate structure, including approximations, and less upon precise statistical significance than prediction models. By experimenting with the model containing both 'hard' and 'soft' variables, valuable understanding of system behavior can be obtained. The analyst can observe the consequences of proposed changes without disturbing the real system, determine the degree of sensitivity of system performance to variables, isolate bottlenecks, and evaluate decision rules as a result of his simulation studies."

Though a fair amount of time is spent in this study examining the statistical significance of the model results in the light of uncertainties, users of the RVI approach should keep in mind that the method is intended as an investigative and design tool, and not as a way of predicting future aviation industry developments. Although this model can be used to determine a market demand forecast, more importantly the model defines the interrelationships between the attributes of importance via the RVI result. Thus the model becomes even more useful because we can study marginal values of attributes, sensitivities, market segments, product differentiation, and so forth.

A number of tests and sensitivities analyses have been conducted to determine the RVI model's utility under differing circumstances of uncertainty and empirical events. But, as with testing any model, one should look for multiple instances of correlation with existing data. Kidera and Hoff (1977) note

> "When seeking verification of a model, care must be used to avoid pitfalls such as a one-time only correlation. For example, a square drawn on a piece of paper might represent a two-dimensional figure. It might also represent a cube being viewed in only one plane. Additional information is needed to determine what the square is meant to represent."

It is for this reason that a great deal of time in this study has been spent on sensitivities analyses and in comparing the model results to historical data. But, once the analyses are complete, just what constitutes "verification" of a method or model? Verification, according to Strauch (1977) is "the process in which the researcher assures that the model performs as he intended it to, that it is free of problems, and that its structure is the one he had in mind when he started building it – or as he has since decided that it should be." Validation is the requirement of a model to meet specified criteria before it is used as a theory or policy-testing tool. A general guideline for validity is the capability of the model to explain the past accurately. It is also important that the data used in validation be different than the data used to adjust the model parameters initially[*] [Strauch (1977)].

In the RVI model, unfortunately, it has not been possible to be as rigorous about separating data used for verification and that used for initially adjusting the model parameters. But the nature of the RVI model verification is a bit unusual. The business airplane database has been used to develop an historic set of parameters for the model (the attribute weighting factors) which have, in turn, been used to objectively tell the story of the industry's development. The real-world story itself serves as the independent set of data by which the model results are tested. In conducting such tests can the RVI model ever really be validated? It is unlikely, as there will always be exogenous influences not accounted for in the model that will prohibit true validation. The impact of the tragic events of 9/11 on the U.S. economy and the resulting decline in aircraft shipments is one such exogenous event with which the RVI model is simply not capable of contending. It should also be noted that, in this study, the RVI approach attempts to simulate a natural system. One may never be entirely sure that such models are valid as, for example, exogenous influences abound. But the RVI approach does show promise, so it's worthwhile to continue with the research. The methodology is certainly capable of "observational breaking" but is flexible enough to be repaired and emerge better than before.

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[*] A prime example is in the training and testing of neural networks, where the training data must be different from the data used to test the network.

In another manner, a model's validity may be measured by its "organizational validity." The model must be developed in conjunction with a wide range of stakeholders within the organization that will use the model. A crucial determinant of the actual use of a model appears to be the goodness of the fit between the model and the user organization. Schultz and Slevin (1974) refer to this compatibility of the human organizational environment and the model as the "organizational validity" of the model. Organizational validity of the model is achieved principally through the model design,* where stakeholders in the application and results of the model are involved in formulating the structure and parameters of the model and in collecting the data to be used in analysis. The goal would be to surmount or avoid issues arising from differing cognitive styles of individuals in the organization, attitudinal variables, and interactions between user groups. As an example, if a manager's job performance hinged on the model results it would be important to involve that manager in the model design and testing to help avoid later situations where that manager might be inclined to undermine the model results.

In attempting to validate a model, the researcher should, above all, be explicit about the assumptions, conclusions and reasoning that went into the formulation of the structure of the model and the choice of its parameter values. "The only way to explain one's model and to open it to constructive criticism and evaluation is to state explicitly for the reader the rationale behind the selection of the structure, the values of parameters, the assumptions made, the underlying reasoning, and the conclusions. The researcher should welcome reasoned and informed criticism, for it will advance the state of the art of simulation modeling as well as our understanding of problems investigated by simulation" [Strauch (1977)].

7.3.3 How Good is "Good"?

Kornbluh and Little (1977) propose the following criteria for judging the goodness of models:

1. The degree to which the model duplicates past system behavior using historical data.
2. The degree to which the model behavior conforms to existing and relevant theory.
3. The degree to which the model is found acceptable to other model-builders
4. The degree to which the model is found acceptable to those who will use it

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* Although Schultz and Slevin also contend that changes in the organization may be made to better fit the model. This would seem more appropriate for policy simulations than for the model developed here.

Most importantly, a model should also be judged by reference to the feasible alternative approaches. The RVI approach proposed in this research has been vetted against historical industry data and in comparison to alternative approaches currently used in the business aviation industry (Chapters 5 and 6). The approach is simultaneously firmly rooted in economic, marketing and engineering theory, as demonstrated in the development of Chapter 4. The degree to which the approach will be found acceptable to model-builders and consumers of the results is yet to be demonstrated on a large scale, but the relative simplicity of the structure and theory behind the RVI method should make it attractive. By these measures, the RVI approach to product assessment should be evaluated as a "good" alternative to existing methods.

7.3.4 Hallmarks of "Good" Empirical Models

Literally dozens of models exist for assessing products and their components (some are reviewed in Chapter 3). Only a small subset of those models is empirical in the sense of having been tested with real-world observations [e.g., Cook (1997), Cooper (August 1981)]. Karl Popper (2002) and John Little (April 1970) describe various hallmarks that characterize empirical models that are useful for scientific inquiry. Each of these criteria will be discussed as it relates to the Relative Value Index model developed in this research as well as to other existing value models to be found in the literature.

7.3.4.1 Popper's Criteria

In his book *Logik der Forschung* (*The Logic of Scientific Discovery*), the 20th Century philosopher Sir Karl Popper (1902-1994) challenges scientists to analyze the logic of their own scientific procedures, namely the process of constructing hypotheses and testing them against experience by observation and experiment. Popper asserts that constructing systems (e.g., hypotheses, theories, or in the case of this current research, models) based on induction is a faulty approach to the scientific method. In other words, fitting models to match observation and then declaring the model as a universal statement of truth is unjustified. "No matter how many instances of white swans we may have observed, this does not justify the conclusion that *all* swans are white" (emphasis in original). Instead, Popper contends that useful scientific systems must be characterized by two traits: they must be consistent and they must be falsifiable.

By consistent, Popper means that the empirical system may not be self-contradictory. "The importance of the requirement of consistency will be appreciated if one realizes that a self-contradictory system is uninformative. It is so because any conclusion we please can be derived from it. Thus no statement is singled out, either as incompatible or as derivable, since all are derivable."

By falsifiable, Popper means that the empirical system must be capable of being refuted by experience. "Thus the statement 'It will rain or not rain here tomorrow' will not be regarded as empirical, simply because it cannot be refuted; whereas the statement 'It will rain here tomorrow' will be regarded as empirical." The strength of falsifiable systems is that, in the process of being falsified, they can lead to improved systems which do fit better with the actual world. The criteria of consistency and falsifiability, Popper contends, enable us to distinguish between the empirical sciences on the one hand and pseudo science and metaphysics on the other.

Consistency

A good empirical model should not be capable of delivering any result the user desires, but should instead provide insights into the true state of the system under study. One must consider, of course, that the user may construct the model from the beginning to deliver preconceived notions of "the true state of the system." In the case of the RVI model, the identification of attributes (e.g., speed, fuel economy), their bounding (e.g., ideal and critical attribute levels), and their exponential weighting factors may be controlled such that any results are conceivable. For example, in considering the SUV model developed in Appendix E, the user might have selected only the fuel economy attribute for the model. In this case the user is able to derive an inverse relationship between price and SUV value since the smaller SUVs are the most fuel efficient automobiles (Figure 120).

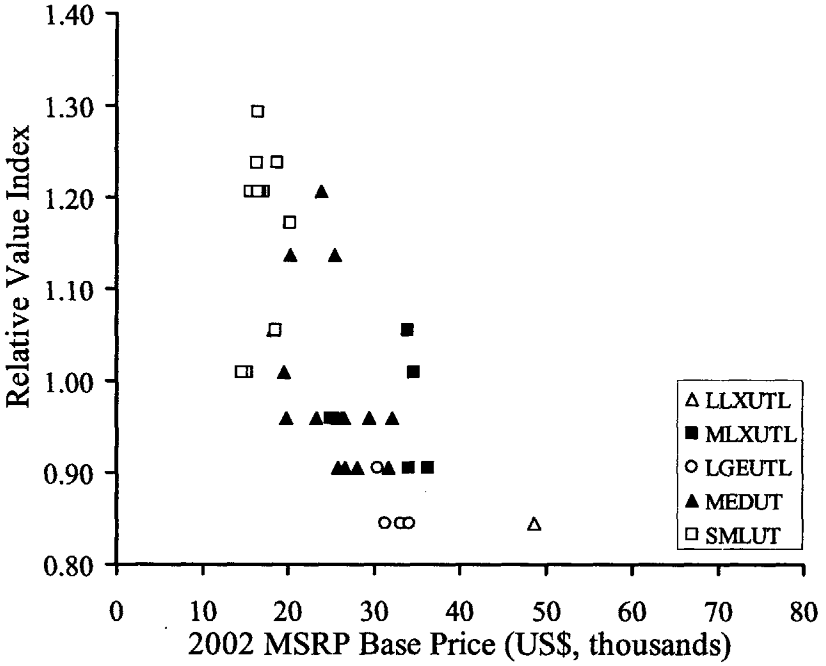

Figure 120: SUV Value Considering only the Fuel Economy Attribute

However, once the model has been constructed in this way it is not possible for the user to manipulate the model to derive a result contradictory to this inverse relationship. Given the single fuel economy attribute the model is not capable of also showing a positive price/value trend, nor is it capable, for example, of indicating large luxury SUVs as higher value products than the small SUVs. This is what Popper means when stating that good empirical systems may not be self-contradictory. The model, without undergoing fundamental alterations, may not be capable of delivering inconsistent results. Any model, however, may present inconsistent results if the underlying assumptions and/or algorithms are altered, and the RVI model presented here is no exception. This characteristic, non-unique to modeling or simulation in general, does not disqualify the model developed in this research under Popper's criterion for consistency.

Note that Popper's criterion for consistency conflicts with Little's decision calculus for models which are "easy to control." This will be discussed further in the section on Little's decision calculus.

Falsifiability

The aim of testing the falsifiability of models "is not to save the lives of untenable systems but, on the contrary, to select the one which is by comparison the fittest, by exposing them all to the fiercest struggle for survival" [Popper (2002)]. In this pursuit the questions need to be asked of each model "In what ways can the model be used to misrepresent empirical data?" and "What empirical results does the model preclude?"

As discussed in the previous section, the identification of attributes, their bounding and the selection of their weights are key steps in constructing a relative value index model of worth. Improper identification of attributes can result in models that show, for example, the inverse relationship between price and value in Figure 120. Although for some sub-segments of consumers the relationship in this chart may be valid (they highly value fuel economy), for the SUV segment as a whole the relationship should not be valid. Economic theory argues that in a *sustainable* market products of lower value should not command higher prices and vice versa.* If the model reflected in Figure 120 were a true representation of the SUV market, the large luxury SUV models would not be economically viable products and would not long survive before being withdrawn from the market. Therefore, the attributes key to the aggregate SUV market have not been properly identified in Figure 120.

The "ideal" and "critical" attribute levels in the model may also be misidentified, thus improperly bounding the attribute. As an example, if the SUV model developed in §7.2.1 were to be applied to truck segment data, the relative values for many large trucks would certainly be underestimated when compared to their MSRP (an actual model has not been developed). One could argue that the attributes themselves stand correct; that truck buyers consider the same factors that SUV buyers consider (cargo volume, horsepower, etc.). However, the attributes may not be properly bound for the truck market as some of the larger trucks have very high towing capacities (up to 10,000 lbs in the case of the GMC Sierra Denali). The "ideal" towing capacity in the SUV model was set at 4,000 lbs, thus the larger trucks would not be credited in the RVI for their larger towing capacity. Some truck customers make purchase decisions based on the larger towing capacity†, so the SUV model would not be correct for the truck segment in neglecting these higher towing capacities.

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* One might argue that the computer market is an exception, where high performance Pentium IV models are now offered at lower real prices than less capable models such as an early 286 PC (i.e. the Pentium has higher value but is offered at a lower price). The weakness of this argument is that Pentium IV and 286 PCs are not currently offered side-by-side on the mass consumer market. If they were, it is not difficult to believe that sales for the 286 would not be sustainable at higher prices (excluding special-purpose niches such as military applications).

† Horse show buyers and big boat trailers are known segments that make purchase decisions based on horsepower.

It is in the identification of attributes, their bounding and in the selection of their weights that the model may be made to misrepresent empirical data. However, as discussed in the previous section on consistency, this is not a unique quality of the RVI model developed in this research but instead characterizes all modeling approaches.

Use of Cook's RVI approach should not be abandoned based on the fact that it is possible to misrepresent empirical data. In fact, Popper contends that it is the very fact that we can examine data such as that in Figure 120, and throw the validity of the model into question, that makes the modeling approach a good empirical system. The strength of the approach lies in the ability to compare the model results to empirical data, economic theory or simple common sense to reveal errors.

Cook's modeling approach used in this research also precludes at least three different empirical results: products with infinitely increasing value, finite values for products containing no real value, and problems of ill-scaling. The RVI approach enables setting "ideal" and "critical" attribute levels that serve to both limit the maximum product value and also allow for zero-value products. Although these qualities are discussed in greater detail in Chapter 4, consider two examples here concerning aircraft range. If an aircraft with a 30,000 nm range were to be offered on the market, all else being equal, traditional assessment models (e.g., the traditional value index, see Chapter 3) would value more highly this aircraft than a competitor with a 25,000 nm range (20% higher value with the traditional value index). The "ideal" attribute level used in the RVI model would allow the user to essentially state that aircraft ranges greater than half the circumference of the earth (approximately 25,000 nm) are of no additional value to the customer, and thus the 30,000 nm aircraft is not of higher value than the competing 25,000 nm aircraft due to the range attribute alone. A customer can use the 25,000 nm aircraft to reach any point on Earth simply by flying in the proper direction.

Similarly, the "critical" attribute level would allow the model user to indicate that aircraft with ranges below a certain threshold are of no value to the customer regardless of other attribute levels. In traditional value models an aircraft with a range of 10 nm would still have finite value (perhaps quite low, however) indicating that the aircraft had some residual value to the customer. It is absurd to assert that such an aircraft would be of value to any customer regardless of other redeeming attributes (a speed of Mach 5.0, extremely luxurious cabin appointments, etc.). The

RVI model precludes such a result by allowing the user to set the critical level of attributes at reasonable values for the market segment under consideration.

Problems of ill-scaling are also inherently precluded by the non-dimensional (relative) treatment of attributes. Consider a value model in which a vector of attributes is summed for an aggregate product value. If attributes for an aircraft were to include Mach number and range, for example, a problem with ill-scaling could easily result if the model user were not diligent. Aircraft range is typically expressed in quantities three to four orders of magnitude greater than Mach number: 1,000 nm versus Mach 0.10, for example. Without due diligence to such scale effects, a doubling of speed (a high value change, presumably) could easily be masked by very slight (and low value) changes in aircraft range. Thus, attributes of unusually high and low value could be masked using such a model. One could rectify this situation by implementing a scale factor (say, multiply the Mach number by 1,000) but this requires careful attention as well as qualitative judgments on the part of the model builder. (What if range can vary from 100 to 10,000 nm – what scale factor should be implemented then?) By reducing all attributes to values relative to a baseline level the problem of ill-scaling and the masking of some attribute levels is inherently avoided.

7.3.4.2 Little's Decision Calculus

In 1970 John D. C. Little published his expository paper "Models and Managers: The Concept of a Decision Calculus" in which he set forth his "decision calculus" of six attributes for good model-building:

1. *Simple* – the model is easy to understand; important phenomena are included and unimportant ones left out.
2. *Robust* – it is difficult to get absurd answers from the model.
3. *Easy to control* – a user should be able to make the model behave in a predictable and desired fashion.
4. *Adaptive* – the model can be adjusted as new information becomes available.
5. *Complete on important issues* – important phenomena are included even if they require judgmental estimates of their effect.
6. *Easy to communicate with* – users can quickly and easily change inputs and obtain outputs.

This decision calculus has since become a litmus test not only for management science models but for any model used in the pursuit of discovery, education or decision-making. Cook's base framework, and extensions made in this research, meet Little's criteria quite well. Each of Little's six points will be briefly addressed vis-à-vis the Relative Value Index approach.

Simple

The underlying structure of the RVI model is quite easy to build and comprehend. Useful models may be based of half a dozen or less easily understood attributes (e.g., speed, range, cabin size). The requirement for bounding such attributes ("ideal" and "critical" values) is clear and the effect of a weighting exponent on each attribute is easily communicated through a simple chart such as Figure 121.

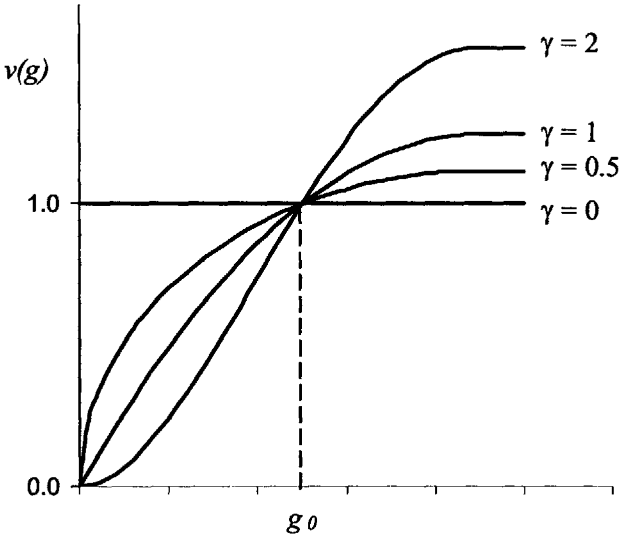

Figure 121: Affect of Attribute Weighting Exponent on a Larger-is-Better Attribute

The model has no requirement that certain product attributes be included (e.g., physical dimensions or market size) or that others be excluded (e.g., qualitative attributes). The user is entirely free to include attributes judged to be of importance while omitting those attributes considered negligible.

In addition, research indicates that judgments between two stimuli are better made on a relative basis, and thus the concept of evaluating products relative to each other yields RVI model results intuitively easier to comprehend than absolute comparisons[*] (note that absolute values are not precluded by using the RVI model; see Chapter 4 on converting relative values to absolute quantities). For example, humans can more easily judge between two products when one is clearly half again as good as another (1.5 value versus 1.0) rather than by stating absolute values ($37,500 versus $25,000). As noted in Chapter 4, absolute values are more easily understood under some circumstances such as when evaluating product options, and the RVI model quite easily accommodates those instances as well.

Finally, the RVI algorithms themselves are easily accessible by those with basic mathematical training. Higher-level mathematical skills, such as calculus, are not required to understand the fundamentals of a continual loss function or the impact of changing an attribute weighting level.

Robust

In the prior section on falsifiability it was noted that certain absurd results are precluded by the model structure's use of "ideal" and "critical" attribute levels as well as the use of relative values. It was also noted that any model, if improperly conceived, is capable of yielding absurd results. The RVI model, however, tends to readily indicate development errors to the user such as the the inverse price/value trend in Figure 120.

Easy to Control

This element of Little's decision calculus appears to conflict with Popper's criterion of self-consistency. It is best to quote Little in his own defense:

> "A user should be able to make the model behave the way he wants it to. For example, he should know how to set inputs to get almost any outputs. This seems to suggest that the user could have a preconceived set of answers and simply judge the inputs until he gets them. That sounds bad. Should not the model represent objective truth?
>
> Wherever objective accuracy is attainable, I feel confident that the vast majority of managers will seize it eagerly. Where it is not, which is most of the time, the view here is that the manager should be left in control. Thus, the goal of parameterization is to represent the operation as the manager sees it. I rather suspect that if the manager cannot control the model he will not use it for fear it

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[*] See discussions on human information processing and judgment in Sanders and McCormick (1993) and Wickens, Gordon and Liu (1998).

> will coerce him into actions he does not believe in. However, I do not expect the manager to abuse the capability because he is honestly looking for help."

The differences between Little and Popper are a result of differing philosophies on what is "useful" in a model: Little defines useful models as those that are most likely to be implemented (but also subject to the rest of his decision calculus) whereas Popper believes that usefulness stems from the truisms the model reveals about the state of the world. Surprisingly, the RVI model appears to meet both of these requirements. The model may be constructed such that a preconceived set of answers are derived, ala Little. Managers are free to select attributes and attribute bounds such that many value results are possible (e.g., the SUV model that favors small, fuel efficient vehicles noted previously). However, once Little's sincere manager constructs the model, it is self-consistent in the results that it provides. The SUV model developed in Appendix E does not favor fuel efficient vehicles because of the selected attributes and their weights. The model cannot be self-inconsistent and favor smaller SUVs given only a change in input parameters (e.g., attribute levels, demand or prices).

See discussions on Popper's criteria of consistency and falsifiability for additional information on these last points.

Adaptive

As has been noted previously, the model user may easily omit or include attributes at will, in addition to modifying the bounding or weighting exponents on those attributes. The underlying structure of the model is also accommodating to changes, such as making the weighting exponent time-dependent, ($\gamma_i(t)$. This might reflect, for example, higher fuel prices making the fuel economy attribute of greater importance this year than in past years.

$$v(g_j) = \left[\frac{(g_{jC} - g_{jI})^2 - (g_j - g_{jI})^2}{(g_{jC} - g_{jI})^2 - (g_{j0} - g_{jI})^2} \right]^{\gamma_j(t)} \tag{7-7}$$

In addition, coding of the model is straightforward and may easily be accomplished using commonly available computer tools such as Microsoft Excel spreadsheets. Depending on how the user structures the computer model new data should be easily accommodated by the code (e.g. new aircraft products or new attributes for existing products).

Complete on Important Issues

In this point Little emphasizes that factors judged to be of importance should not have to be neglected in the model even if they are qualitative in nature, or require judgment on the part of the user. The RVI approach developed in this research is entirely accommodating of qualitative attributes, largely because the model deals with relative values to begin with. If an attribute can be judged in terms relative to a baseline condition it can be coded using the RVI approach.

Easy to Communicate With

If the RVI model has been well-implemented on a computer, users can easily vary product data as well as attribute characteristics ("ideal" levels, for example). The model results are easily displayed graphically as a relative value versus price or RVI/price versus time or in any other convenient format. Implementing the model in a spreadsheet program makes such visualization particularly easy.

The model itself does not require complex "black box" codes or expensive software to implement, and the algorithms do not require excessive amounts of memory or computer floating point calculations. The RVI model is quite easily run on modern mass-market laptops and desktops using a Windows interface and common software (such as Microsoft Excel) of the user's choosing.

7.4 Summary: A Generalizable Approach with Recognizable Merits

The analysis of Chapter 6 served to assess Cook's RVI approach based on its own performance and merits. This chapter has served to assess the methodology as contrasted with other, existing value assessment approaches. The comparisons in §7.1 demonstrate the numerous merits of the RVI method: use of well-defined, quantifiable attributes directly related to the product; simplicity of the underlying theory; utilization of relatively uncorrelated parameters, and the ability to use an unlimited number of such parameters; calibration of the parameters with empirical data; ease of implementation and use; and the potential for the method to be used simultaneously for marketing, engineering and management decision-making studies. The method also better represents historical market events and indicates current-day market price/value trends consistent with economic theory.

The Relative Value Index is a generalizable method, as is demonstrated in §7.2 with the discussion of two additional models for the automobile and product support service industries. The development of these two models is brief and not as in-depth as that of the business aviation model, and some challenges are noted that still need to be addressed before the models could be used in a practical setting. Nevertheless, the RVI approach is demonstrably generalizable to alternative physical products as well as to non-physical, service-type products.

In §7.3 a more philosophical approach is taken to considering the research documented here. Humans model systems for the purposes of learning in a safe, controlled and flexible environment without the time delays often associated with the real system. Models do have limitations in their ability to simulate systems, and misuses are common even among well-meaning users. The common question of how good a model is, or may be, is addressed by a combination of criteria from Jay Forrester and John Little, much of which centers around the degree to which the model conforms to empirical data, simplicity of purpose and use, and the degree to which other users accept the model. A number of hallmarks of "good" empirical models are presented and discussed in relation to the RVI approach, as advanced by the philosopher Karl Popper and marketing scientist John Little.

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8 CONCLUSIONS AND FUTURE WORK

The primary findings from this study are summarized in this chapter. The major contributions the study makes that add to prior knowledge in the academic and industry-oriented literature are also summarized. Brief comments are made regarding what has been learned about Cook's foundation for the value work in this study, and some of the practical considerations in using the method are discussed. A number of areas for future research are also discussed as they relate to the developments of this study.

8.1 Conclusions

The primary findings from the research are presented first in this section, serving as an extended synopsis of the study. The contributions made to the literature are summarized second. Observations on Cook's modification of Taguchi's loss function and the practical considerations involved with using the Relative Value Index method are mentioned in the final section.

8.1.1 Summary of Primary Findings

8.1.1.1 Introduction

New products are critical to the success and survival of enterprises, yet studies indicate that new product failures are both common and expensive. The majority of product characteristics, including costs and technical performance, are locked in based on decisions made in the early conceptual design phase. This early, "fuzzy front end" of product development is of paramount importance to the future success of enterprises.

In the business aircraft industry, new product development is a long lead-time activity marked by investments of as much as $1 billion or more for a new airframe alone. Though the industry claims nearly $10 billion in annual billings for turbine aircraft, its product development methods have only within the past decade employed such advanced technologies as CAD/CAM, and processes such as integrated product teams and stage-gate development systems. There are difficulties (perhaps even more than for other industries) in deciding on specific products that conform well to an overall product/technology portfolio or company strategy. Thus, new products may have specifications not reflecting the true needs of the overall market, manufacturer or suppliers, and may often be not well-aligned with the enterprise's capabilities.

8.1.1.2 Product Value and Value Assessment Methods

In problems of decision making, such as in product specification, some criterion must be established by which the proposed solution is judged. In situations where multiple attributes are judged to be of importance, a preferability (or value, or utility) function is one of the most common figures of merit used for trading off the level of one attribute against another for the purpose of achieving some objective. Numerous multi-attribute preference methods have been proposed in the literature to address various aspects of the decision-making process, but two major categories of such methods have been dominant in prior application in the business aviation industry: marketing science methods and figures of merit.

Marketing science methods have their origins in the need to solve important industry questions regarding anticipated market share for a new product, how to choose among proposed new products when making funding decisions, ways to improve product appeal to consumers, and the rate at which a manufacturer may expect new products to find acceptance within the market. Market share and diffusion models, as well as product screening methods, focus on attributes exogenous to the product itself: level of funding, managerial support, advertising budget, and such. Despite the existence of some well-researched methods, including the NEWPROD screening model, most contemporary models do not directly relate their evaluations to attributes inherently possessed by the product. On the other hand, conjoint analysis, also known as conjoint measurement, provides a means to decompose consumer preferences into the part-worth contributions of individual product features. Unfortunately, implementing conjoint analysis methods in the business airplane industry exposes a number of weaknesses of the methods. Respondent fatigue limits the number of product attributes that can be studied, the number of levels at which each attribute may be tested, and restricts the ability to study interdependences among the attributes. The relatively small number of potential buyers is an additional constraint on application in this industry. Although sophisticated methods have been developed to compensate for these weaknesses, they contribute to additional weaknesses due to their use of complex mathematics and consumer choice theory, and their requirement for "black box" computer codes for analysis. Proper evaluation of conjoint analysis results typically requires highly educated and experience marketing specialists that are experts in the theory and methods utilized. Such experts are not available on staff in typical business aviation firms, necessitating the involvement of outside consulting firms in conducting a conjoint analysis study, with the inherent problems of communication between firms and with management understanding and buy-in of the consultant's results. Conjoint analysis studies are also time-consuming and ill-suited to the rapid tradespace exploration requirements of the fuzzy front-end of product development. Some concern exists, even within marketing research circles, that sufficient external validation of conjoint study results has not been performed to validate the reliability of the results; in other words, it is uncertain that the stated preferences of consumers in the studies reflect the consumers' revealed preferences.

Figures of merit are commonly employed in the aviation industry because of their simplicity in implementation and data requirements. Several published productivity indices have been found in the industry literature, and it is likely that many more exist in the design offices of the major aerospace firms. These indices suffer from oversimplification in their neglect of attributes that are considered important to the business airplane customer, and are demonstrably incapable of showing any productivity increases in the past 40 years of business aviation products, a major concern for their ability to show future improvements. One index, incredibly, indicates reduced product productivity over the past 40 years! A proprietary figure of merit developed by one manufacturer, the Ownership Experience Index (OEI), shows great promise if development was to continue on the method, but it currently lacks any calibration with empirical data and is employed within the company only as a sales and marketing tool. Access to the model is somewhat restricted because of its proprietary nature, so it was not possible to attempt modifications to the OEI for comparison to the work developed here.

The figure of merit enjoying the most widespread use today in the business airplane industry is the Traditional Value Index (TVI). The index is widely accepted because of its intuitive price/value trends using contemporary industry products, and also due to its simplicity in calculation and meager data requirements. Unfortunately the price/value trends, while meeting intuitive expectations of increasing value with increasing price, also violate basic theories of economics by indicating limitations in acceptable market prices for airplanes, regardless of the value delivered. Such price restrictions, analogous to a "sound barrier" for aircraft speeds, were popularly believed in the late 1950s when the first million-dollar business aircraft were introduced. Today the million-dollar business aircraft barrier has been shattered by 45+ million dollar long-range luxury airplanes and may be pushed beyond the $100 million mark by several proposed supersonic business jets. Though the TVI does demonstrate a history of increased value over the past 40 years, the method does poorly in presaging the ascendance of business turbojet airplanes in the 1960s. In terms of its structure, the TVI does not allow users to place different weightings on attributes that may be judged to be of less or more importance to customers.

8.1.1.3 Development of the Relative Value Index

Taguchi's Loss Function approach to product quality is used as a foundation for developing a value assessment method for products. Harry Cook's adaptation of Taguchi's continual loss of quality establishes a firm theoretical foundation for value assessment that has roots in both economics and consumer choice theory, and well accommodates engineering-type analysis of product technical performance. Multiple attributes are combined and weighted, resulting in an overall value figure of merit for direct comparison of existing and proposed products. Provision for adding product options, where the product value is only enhanced by the added feature, is also a provision of the approach. The method, referred to in this research as the Relative Value Index (RVI), also establishes key product attribute bounds, beyond which the product value may be rendered worthless, or the value saturates and does not increase. In combining multiple attributes, model developers must be wary of the issue of multicollinearity, where multiple attributes are highly correlated and thus do not add information to the model.

This research develops a method for determining the RVI attribute weighting factors based on empirical data. Data on annual product sale prices and demand is used to estimate the Revealed Value (RV) of products in a competitive segment. This estimate is then compared to the Value Index (VI) of the product based on the part-worths compositional approach of the RVI method, augmented with a baseline product value. The two estimates are set to be mathematically equivalent, RV=VI, using a least squares optimization method that finds the RVI attribute weighting factors that minimize the sum squared error between the two estimates. The resulting set of empirically derived weighting factors then represent the attributes that have proven useful in differentiating products in market competition.

8.1.1.4 Development of a Business Aviation Relative Value Index

A 40 year database of product technical characteristics, prices and shipments for the business airplane industry has been compiled for use in this research, marking the first time such a comprehensive database of business turbines has been published. This database is used in an extensive implementation of the RVI approach for product and industry assessment, as well as for evaluating the merits of the approach itself. Business aviation was specifically chosen for this analysis because the customer base is composed primarily of organizational buyers making rational, information-based decisions favored by the RVI approach.

Five principal attributes were identified and quantified for the business aviation implementation of the RVI method. A number of additional attributes are suggested as also being important to the customer decision calculus, but have not yet been quantified and/or published by the industry. Such attributes include mission reliability of the product, the distribution network of the manufacturer, passenger comfort factors such as cabin noise, and the level of technology onboard the aircraft, including avionics and in-cabin entertainment and communication systems. It is recommended that companies trying to use this approach encourage industry initiation or continuation of existing efforts to collect such information. One major business turbine manufacturer has chosen to stop releasing detailed annual unit shipments data, restricting the ability of analysts (outside the company in question) to make future calibrations of the RVI method using empirical data. Competing companies must encourage industry agreement about data availability or lose access to a potentially valuable approach.

For the current market of business turbines, the RVI method presents intuitive price/value trends that, unlike the TVI method, do not present limits to airplane prices. The trends do indicate a reduced increase in product values with product prices, indicating a potential technological limitation being approached by modern long-range jets, or possibly indicating the absence of additional product attributes that would further increase the RVI rating (e.g., mission reliability, cabin noise, and other such factors previously mentioned). The set of weighting factors resulting from the optimization "best fit" also fit well with industry perceptions and empirical data for which attributes play the greatest role in differentiating products in the modern market. Aircraft maximum cruise speed is non-differentiating, while the two attributes of "cabin volume per passenger" and "available seat-miles" do act as differentiators. The "takeoff field length" and "fuel consumption per passenger seat-mile" attributes are also not differentiating in the current market.

8.1.1.5 Evaluating and Using the Business Aviation Value Method

Analyses of the attribute weighting factors' sensitivity to uncertainties in input data indicate robustness as a quality the RVI approach possesses in addition to flexibility and its firm theoretical foundation.

The sensitivity of the optimized error, J, between the RV and VI estimates to changes in the attribute values themselves, as opposed to the attribute weights, emerges in this research as a valuable tool for objective analysis of the market evolution. Low sensitivities to changes in the attribute values indicate non-differentiating attributes, and an historical sensitivity analysis provides results that agree well with actual industry history. Aircraft cruise speed was an initial differentiating factor when turbojets were first introduced to the business aviation industry. The industry quickly converged on high subsonic speeds, at which time the speed attribute no longer acted as a differentiator in aircraft value. Similarly, fuel consumption and takeoff field length have played temporary differentiating roles throughout history as new, more fuel efficient or high performance models were introduced, and before the industry converged on the new de facto standards.

A Monte Carlo analysis of the sensitivity of the attribute weighting factors to uncertainties in the input data (aircraft speed, takeoff field length, price, etcetera) similarly emerged as a tool useful not only in establishing the robustness of the RVI method, but also in assessing the historical industry evolution. Relatively large standard deviations in the weighting factor numerical values indicate inabilities of the attributes to affect the optimal "best fit" solutions, and thus indicate little differentiability on that attribute. The Monte Carlo results are in agreement with the historical results in terms of the importance of aircraft speed and the other attributes throughout the past 40 years.

When developing RVI models, it is recommended that attention be paid to setting the attribute bounds, as the analysis results can be sensitive to the attribute "ideal" and "critical" bounds. In situations when the bounds are uncertain, they should be treated parametrically or with stochastic methods. It is also recommended that consideration be given to averaging the input data over several years to compensate for potential errors and discontinuities in the data. Averaging has the added benefit of placing more products in direct competition in the RVI method, since more products will overlap in the years they were marketed. Such overlaps, especially for long lead-time items such as aircraft, more realistically simulate the true competitive environment since many models are marketed years before the product is first shipped.

The RVI approach is applied in this study in a number of ways to evaluate the usefulness of the method in practical product analysis. Unlike the TVI figure of merit, the RVI method is capable of indicating the superior value of the first generation of business turbojets over the existing heavy turboprop aircraft in the mid 1960s. Contemporary designers using the RVI method to assess the first generation of turbojets would have been justified in viewing the new jets as an emerging threat to the existing market of turboprops.

The RVI results for the modern market of business turbines confirm that a ratio theory of product differentiation exists in the business airplane industry. Though researchers have long postulated that consumers perceive product price differentials in terms of percentages rather than absolute dollar amounts, little empirical evidence has been published to support the theory. In the business aircraft industry, product prices show a clear trend to increase in fixed percentages rather than fixed dollar amounts, with the percentages varying slightly among manufactures and between market segments. Similarly, the RVI ratings for products also show a ratio theory of differentiation in product value, with the percentages again varying slightly between manufacturers and market segments. The analysis indicates that the ratios may break down at very high product values and prices, with the possibility of an absolute dollar amount and an absolute value emerging as the differentiable factors (perhaps $10 million, for example).

The RVI approach is demonstrably suitable for estimating product market share, with the estimates appearing to be limited more by errors in price data than by inaccuracies in the structure of the method itself. The RVI method enables detailed analysis of product market share as it is affected by competing products and also by changes in the levels of the product attributes. It is recommended that market share be the forecast factor rather than product unit demand, as unit demand is subject to a number of exogenous factors such as economic conditions. A simple model of total unit demand for business turbines is developed in this study for use in converting the market share estimates into unit demand estimates. It is found that total turbine demand over the past 25 years has been most sensitive to the U.S. prime interest rate and the Dow Jones Industrial Average. Increases in the prime rate in the 1970s created a speculative market, for which the interest rate data compensates, and the Dow Jones average is indicative of corporate performance and the apparent willingness of companies to make capital investments such as the purchase of new business aircraft.

The original motivation for pursuing the RVI method, rapid engineering-type explorations of the product design tradespace, is realized in a demonstration of the method's utility for marginal analysis. The marginal value (value/attribute tradeoff) and marginal rate of substitution (attribute/attribute tradeoff) factors are quickly and easily determined using the RVI approach, and common tools such as MS Excel enable designers to visualize the tradeoffs for making design decisions.

Once the RVI of the product is set via the part-worths composition, then the approximate optimal price the market will accept for that product is known. The market demand for the product may also be forecast, and manufacturing costs estimated based on desired production rates. The estimated costs and maximum price imply possible profit margins for the product. If the profit margins are deemed inadequate, the RVI method may be used to iterate the product design and associated costs to enhance the estimated margins. As a result of this value pricing method, the target price drives decisions about what costs to incur, in contrast to cost-plus pricing in which costs drive the final price. Users must, of couse, be cautious of using these methods as a forecasting tool, and appropriate sensitivity analyses should be performed to address uncertainties in the input parameters.

Evidence of the existence of enterprise-related attributes contributing to customer value in a product is introduced via the RVI method. The approach of matching Revealed Value and part-worths value contributions reveals consistent trends in over- and under-valuation of particular business airplane manufacturers. Dassault is consistently over-valued by the RVI method, indicating that the company's products are not as successful in the market as their pure technical attributes would imply. Enterprise-based attributes, such as distribution network, warranty packages, and customer support, are suggested as possible additional factors that need to be quantified and added to the RVI method. The remaining four major business airplane manufacturers present a mixed bag of results in terms of enterprise-related attributes, though the historical data indicates possible improvements in Raytheon-related attributes over the past decade. Gulfstream products have consistently been under-valued by the RVI method over the past decade, which seems to confirm industry perceptions that the manufacturer offers superior customer support for its products.

The emerging micro-jet segment is assessed using the RVI method and appears to present a serious threat to the executive transport role of some smaller turboprop models currently on the market. The small, four-passenger jets offer faster speeds at moderate ranges with adequate passenger comfort as measured by cabin space per passenger. If additional attributes were quantified, such as vibration and cabin noise, the new micro-jets might present even higher value results than their turboprop competitors. Specialty missions, such as utility transport and long loiter missions, will likely continue as niches for the smaller turboprops.

A potential supersonic business jet (SSBJ) is shown by the RVI method to offer value consistent with forecast prices for the aircraft. In contrast, by using the TVI method a supersonic business jet appears wholly unattractive given its price/value point, or at a minimum appears to establish an entirely new price/value trend if a larger SSBJ is assumed at the same price. In contrast, the RVI approach to product assessment shows the SSBJ as falling near established price/value trends, confirming industry observer predictions that an $80-100 million SSBJ may be acceptable to the market. The RVI method also indicates for designers' consideration that a large Gulfstream-style cabin may not add considerable value to the SSBJ over a smaller midsize cabin. The attribute bounds for the cabin volume per passenger should be examined in greater detail before such conclusions are definitively accepted, however.

8.1.1.6 Comparison to Existing Assessment Methods

The RVI assessment approach evinces a number of merits when directly contrasted to existing assessment methods. The Relative Value Index utilizes attributes directly related to the product itself, with the flexibility of adding any number of exogenous factors deemed important to customer and enterprise-related decision-making. Conjoint analysis methods may be well-complemented by the use of RVI assessment to narrow the number of attributes and attribute levels for more detailed conjoint studies, thus helping to alleviate issues of respondent fatigue. The RVI method is more suitable, however, to rapid exploration of the attribute tradespace and for use by typical aviation industry staff using commonly available computing resources. The RVI method is also more easily understood in its underlying theory and mathematics than most aspects of conjoint analysis.

In contrast to the oversimplified productivity indices found in the literature, the RVI method includes key attributes considered to be of importance to the customer decision-making process, while remaining simple in structure and implementation. In comparison to the TVI method, the RVI approach is demonstrably more capable of explaining historical industry events such as the rapid rise of turbojet aircraft in the 1960s. The modifications required to recast the productivity indices or TVI as more accurate and complete in scope would be relatively extensive, including, at a minimum, the addition of exponential weighting factors and new attributes. The methods would still lack the key features of the attribute bounds that more realistically simulate lessons learned from consumer choice research. Modification of the existing figures of merit, in other words, would need to be extensive enough to essentially recreate the RVI method in its entirety.

8.1.1.7 Generalization

The RVI method is flexible enough to be adapted to any number of new situations. This is demonstrated through generalization of the approach to service products through an assessment of business airplane product support ratings. Though these ratings were not considered useful in the major airplane assessment of this study, the assessment of the ratings themselves versus aircraft purchase price revealed that at least one manufacturer offered significantly less value in its customer support for the price point of its product. The ratings data made recently available, and used in this generalization, may prove useful over time in adding new attributes to the major business aircraft RVI model developed in this study. In addition, prior efforts by Cook and associates and in this thesis show applicability to a variety of automotive products.

8.1.1.8 Practical and Philosophical Considerations in Modeling

Approaching the research in a more philosophical direction, the question is asked, "Why do we create models?" Humans make literally hundreds of decisions each day, and many are based on models, both informal and formal, of the systems of interest. The reasons for developing models are numerous, and include the fact that humans require representations, or approximations, of certain aspects of complex systems to illuminate and clarify the interrelations of the component parts of the system. Formal models can provide novel and critical insights into system behavior, sometimes even counter to what was expected. The nature of various risks may be clarified and options for risk mitigation formulated, and models may be used as educational devices for teaching decision makers as well as researchers. Learning from experience alone can be costly, slow, dangerous, or impractical, and models can help overcome these deficiencies. And, perhaps ironically, the most attractive benefit of modeling is not necessarily the end result, but can instead be the depth of understanding of the problem that the designer gains through developing and testing the model.

Despite their benefits, models have their limitations as well. Perhaps the most profound limitation, or danger, of modeling is the paralysis it threatens to impose on decision makers as they wait for one more bit of data; for that last piece of information that will suddenly render the world from shades of grey to the crystal clarity of black and white. Formal models also have not yet yielded solutions to many complex problems such as housing policy or criminal justice, but as Schon (1983) points out, modelers have reacted to such challenges by postulating formal models as probes or metaphors to at least explore the less clearly defined areas as a first step to spanning the "gap between professional knowledge and the demands of real-world practice."

A model is a simplification of the system it represents, and there is always a danger of oversimplification to the point that the model is not longer useful for simulating the real system. The data needed by the model to assign parameter and variable values is also subject to simplifications as well as errors such as in format or transcription. Model designers must also make tradeoffs in model accuracy given limited resources and should carefully note the nature of such tradeoffs for those who will be using the models.

Modelers must guard against common misuses of their creations, by themselves and their intended audience, alike. Sometimes work with a model becomes a substitute for thinking about assumptions and alternative courses of action. Extensive testing of alternatives may also cause the chosen course of action to assume greater stature in the eyes of decision-makers because it was so thoroughly tested. The danger exists that it may be followed too rigidly under changed conditions. There also exists the very real risk that models will be used to justify, rather than to explore, the implications of actions. Another potential misuse is to assume that the RVI model is capable of predicting the future. The RVI model is not intended for prediction, but is instead proposed for elucidation and education.

Standards for the "goodness" of a model or assessment method are difficult to establish, but in general the method should be judged by reference to the feasible alternative approaches. Criteria should include how well past system behavior is duplicated using historical data, how well existing and relevant theory is conformed to, and the degree to which the method is found acceptable to users and other model developers.

The philosopher Karl Popper, and prominent marketing scientist John Little, both propose a number of criteria as hallmarks of "good" empirical models. Popper contends that a good empirical model should be consistent, not capable of delivering any result the user desires, but instead should provide insights into the true state of the system under study. In the RVI model, the identification of attributes, their bounding, and their exponential weighting factors may be controlled such that any results are conceivable, but once the model has been constructed it is not possible for the user to manipulate the model to derive simultaneous sets of fundamentally contradictory results. This is what Popper means when stating that good empirical systems may not be self-contradictory.

Popper also asserts that models should be capable of being falsified, or tested to explore the ways in which the model can be used to misrepresent empirical data. The identification of attributes, their bounding, and the selection of their weights are key steps in constructing a relative value index model of worth. Improper identification of attributes can result in models that show impractical or impossible results, and it is the burden of the modeler to test models for such characteristics. It is a merit of the RVI method, through the attribute bounds and its use of non-dimensional relative value scales, that it precludes at least three different empirical results: products with infinitely increasing value, finite values for products containing no real value, and problems of ill-scaling.

John Little contends that decision model should be simple in their structure and use. The underlying structure of the RVI method is quite easy to comprehend, useful models may be based of half a dozen or less easily understood attributes, and the requirement for bounding the attributes is intuitive and yields clear results. In precluding certain absurd results, and through the Monte Carlo treatment of uncertainties in input parameters, the RVI approach demonstrates a level of robustness that meets another of Little's criteria. Furthermore, the method is easy to control in terms of making it do what the modeler wants it to do. Seemingly in conflict with Popper's criteria of self-consistency, this issue of Little's is more about having the method be as useful to decision-makers as possible, letting them have enough control to easily manipulate the model parameters and witness the results.

The RVI approach to value assessment meets Little's criteria that good empirical models be adaptive. The model user may easily omit or include attributes at will, in addition to modifying the bounding or weighting exponents on those attributes. The underlying structure of the model is also accommodating to changes, and the method easily accommodates new empirical data in determining the attribute weighting factors. Little also emphasizes that factors judged to be of importance should not have to be neglected in the model, even if they are qualitative in nature, or require judgment on the part of the user. The RVI approach is entirely accommodating of qualitative attributes, largely because the model deals with relative values to begin with. If an attribute can be judged in terms relative to a baseline condition it can be coded using the RVI approach. The easy of communication with the RVI method is dependent, in part, on the manner in which the method is implemented on the computer. Using common computer resources, such as MS Excel, enables users to easily manipulate input data, attribute bounds, and to quickly visualize the output using charts.

In summary, the Relative Value Index approach to product value assessment is firmly based in theory while being thoroughly vetted with empirical data. The method provides a number of advantages over existing value methods, including its suitability for rapidly exploring the tradespace of product design, its basis in attributes inherent in the product itself, its versatility and adaptability, and its better ability to represent past and present trends in the business aviation industry. Sensitivity analyses have emerged not only as good methods for evaluating the "goodness" of the model, but also as valuable extensions to the RVI assessments of historical and current market conditions and trends. The uses of the approach in the fuzzy front-end of product development are numerous, and the method demonstrates a great deal of potential for further extending its application, and for producing better and more accurate results, in early product analysis.

8.1.2 Research Contributions

Four primary objectives, outlined in §1.1, were met through the course of this research: identification and extension of a generalizable method for quantitative new product search and preliminary design, evaluation and use of the method with empirical data, development of tools to evaluate the reliability and robustness of value methods, and exploration of practical and philosophical considerations in value modeling. The major contributions to knowledge as a result of this research are noted in this section.

Methods for quantitative product valuation have been examined broadly across two major fields: marketing science and engineering. The major existing methods are found to be lacking in a number of areas, making their application to the fuzzy front-end of product development problematic. In contrast, it has been determined that Cook's adaptation of Taguchi's loss function shows great promise for further development, but has not been applied outside of Cook's own pioneering research, and has specifically only been applied to the area of automobiles and their components. This study represents the first independent assessment of Cook's research, extends that line of quantitative valuation to a new domain, and rigorously evaluates the method in light of both theoretical and practical considerations.

In preparation for extending the previous work, a 40 year database of business aircraft characteristics, prices and shipments has been compiled for use with the value method. This information is assembled from numerous sources and has been rigorously checked for consistency among those sources as well as consistency across the product lines and years represented in the database. This is a more comprehensive and extensive compilation of business aircraft data than has ever before been published in one location.

The value research of Cook has been extended to the new domain of business aviation products, modified with new attributes never before considered with the method, and for purposes of clarity particularly in the business airplane industry, named the Relative Value Index. The RVI method is applied in this study to a new class of organizational buyers and high-dollar industrial products never before considered with equivalent value assessment methods. In the domain of business aviation, the RVI method represents an entirely new approach to quantitative product assessment.

In examining Cook's RVI method, its strong links to economics theory have been noted. The form of the RVI multi-attribute metric is itself similar to the well-known and accepted Cobb-Douglas form. In addition, the individual attribute value curves (smaller-is-better and larger-is-better) reflect the economic principle of non-linearity of preferences, or "diminishing marginal utility" as it is often referred to.

A top-down approach to calibration of Cook's value methods with empirical data has been developed in this study. Aggregate market data is used to make estimates of attribute importance to product differentiation via the best fit of the attribute exponential weighting factors. This method utilizes revealed preferences rather than the somewhat more controversial stated preference data in making the calibration.

In combination with the 40 year historical database, value methods have been considerably broadened in scope to assess industry developments over a longer time span than ever before. In fact, this study represents an examination of effectively the entire history of turbine-powered business aviation airplanes, and nearly the entire history of business aviation itself. The scope of value assessment has also be extended in this study to encompass the evaluation of products industry-wide, including all segments across that industry; from turboprop airplanes to long-range jets.

To comply with the axioms of utility theory and ensure a unique value assessment result, nominal-is-better type attributes (containing "sweet spots" of consumer preference) are prohibited. This is a common practice in consumer utility research, and in most situations is a reasonable assumption.

To allow industry, rather than just segment, analysis (a limitation of prior work by Cook and his associates), a new approach was developed for baseline product value estimates, V_0. Cook's method of estimating this baseline product value from an average of Revealed Values creates a problem of circular logic in this study because of the way Revealed Value is now used to estimate the attribute weighting factors. It is suggested instead that baseline product value be estimated from the segment-by-segment average Revealed Value normalized by the average RVI result, creating a parameter that is valid for across-segment comparisons and that enables external validation of the RVI method via historical analysis.

New methods for evaluating value models such as the Relative Value Index have been developed in this study. The sum-squared error cost function sensitivity analysis and Monte Carlo study represent new applications of these sensitivity analyses to the assessment of value model robustness and reliability via an examination of the attribute weighting factors and the use of the attributes in the Revealed Value and Value Index best fit optimizations.

It is fortunate that these evaluation techniques have also led to new methods to objectively extract findings of industry market activities. Many of these events are commonly known and accepted by industry observers, such as the convergence of business airplane cruise speeds. But these new evaluation techniques provide a unique, objective approach to quantifying the evolution of attributes, not subject to personal opinion or memory. Furthermore, the RVI method is a demonstrably better technique for extracting these findings than existing industry figures of merit.

Finally, a number of interesting findings have been made with regard to the business aviation industry, but may have wide-ranging implications beyond the industry alone. Empirical evidence has been developed to support the existence of a ratio theory of product price differentiation. Though this finding is not directly dependent on the RVI method, this study does appear to constitute only the third time data supporting the price ratio theory has been published. For the first time, however, a ratio theory of product value differentiation has been established with supporting evidence from the RVI method. There is also some indication that at very high prices and values, these ratio trends in differentiation may break down as consumers begin to perceive differences in absolute terms (e.g., dollars). Also resulting from this study is quantitative evidence that some attributes contributing value to products may originate from the enterprise itself. Although marketing researchers have pursued the elusive "brand" value and other such enterprise-related attributes for some time, this study marks the first time that data has shown an indication of consistent enterprise-related attributes over an entire industry and for an extended period of time.

8.1.3 Observations Regarding Value Methods and Practical Considerations

As mentioned in Chapter 3, this study marks the first evaluation of Cook's approach to value assessment independent of the institution at which the method originated. It is appropriate, therefore, to make a few comments here regarding the theory and structure that form the foundation of the Relative Value Index. Also, this research has pushed the quantification of value into a new domain and has added a number of new tools for assessment of value methods. However, at the heart of the study has been the overarching goal to produce an application that is useful for real-world industry product development. In that respect, the study is judged by this author to have been successful, and the RVI method has garnered considerable interest within the aviation industry from managers, marketing specialists and engineers alike. A few words are written here regarding the attractiveness of the method and its potential for practical application.

Methods for screening products and for forecasting technology and product diffusion in the market are numerous in the journals of marketing science. Few of the methods appear to be developed beyond one published paper, and fewer still have been rigorously tested with empirical data. Most tend to neglect the product itself and focus on external drivers of product "success" (a vague term that is often not defined by the research). This strategy of focusing on exogenous factors would seem to indicate that even inferior products can be winners given sufficient advertising budgets and distribution networks (perhaps a truthful assertion). Conjoint analysis surveys, perhaps coupled with random utility models for analysis of the survey data, are the most well-developed methods for product assessment in the marketing science literature. On the surface, the CA methods are quite simple; measure how much an attribute contributes to the overall consumer satisfaction with a product. In some cases, do this for multiple attributes and then combine them for an overall product utility. The actual mechanics of the CA studies quickly become more complex when one decides to take a "deep dive" into the methodology. For industry to apply the methods would require keeping specialists on staff (probably expensive Ph.D.s), and few outside of those specialists would grasp the nuances of the analysis methods or would understand the limitations of the methods. CA studies and random utility models are good for occasional, every two-to-three years studies of where the market is or of how the market would respond to a very new product or product attribute. The methods are not suitable for a monthly analysis of an industry's portfolio of products or for a quick evaluation of new products.

Despite the shortcomings of marketing science methods for the early fuzzy-front end of product development, existing business aviation industry figures of merit are worse. At best, they present coherent results that appear correct, but at worst they can easily mislead decision-makers about the potential of new products or market behavior. Without any calibration to empirical data, which seems to be the case for all the figures of merit examined in this study, there is no way for users of the methods to assess the validity of the results. Savvy users of these methods understand their limitations, but are frustrated by the lack of alternatives. Several industry engineers and marketing specialists virtually sighed in relief when this author contacted them and explained that a new figure of merit was being rigorously studied for use in the industry.

This author endorses the value approach developed by Cook. Upon first reading of Cook's developments, his value method was clear in both its goals and the mechanics of implementation, and the prior application to the automotive industry was a close enough analogy to the aircraft industry that the desire to make comparisons was irresistible. The relative value curves for individual attributes are easily constructed based on very little information (critical, baseline and ideal attribute levels), which makes them quite suitable for the fuzzy front-end of product development. The method of bringing the attributes together via a mathematical product rather than a summation is easy to understand and, upon deeper research into the theory of value and economics, makes for a method more consistent with the theory than other methods currently available. The fact that a product can be rendered worthless by one particularly bad attribute always sets heads to nodding in rooms full of product managers being briefed on the method. The characteristic of a saturation point (the "ideal" attribute level) also agrees well with popular perception of how consumers respond to product attributes.

Cook's methods, once modified for the aviation industry, were compelling, but would not have been adopted if they had not stood up to more rigorous testing. The assignment of numerical values to the attribute weighting factors was problematic and was the first issue to be tackled. The value approach was easily modified to the empirical Revealed Value and Value Index fit in this study, thus supporting the perception that the method is flexible and can be easily adapted to new situations as needed. The tests and exercising of the model described in Chapter 6 confirmed that the method was robust and presented fairly reliable results, even over a long time span of industry history.

Based on this author's experience, the simplicity of explaining the theory behind the approach (relative values, critical attribute levels, etc.) is the most attractive feature of the method since it is intended to find application in industry. The ability of the method to "tell stories," such as the market evolution and the first generation of business jets related in Chapter 6, is a big selling point to industry practitioners. The theoretical rigor of the method is of secondary interest to them, though they are always happy to hear that the method conforms to economic and consumer behavioral theory.

This author has now spent a considerable amount of time implementing and testing the method, and can attest to the meager computer resources that the Relative Value Index requires. Even the most cash-strapped researchers and practitioners should be able to easily code the method in a matter of hours on a conventional PC using standard spreadsheet software. Those not satisfied to be merely "conventional" may find pleasure in implementing the methodology on workstations using C++ or JAVA, but will really gain little in terms of performance, while losing some in terms of ease of use.

Substantial work has yet to be done on identifying all the appropriate business aviation RVI attributes, and more work yet will be involved in measuring those attributes. Now that the robustness and reliability of the method has been demonstrated in this study, the potential gains to be had from continuing development of the approach appear to be considerable.

8.1.4 Practical Considerations

This research has pushed the quantification of value into a new domain and has added a number of new tools for assessment of value methods. However, at the heart of the study has been the overarching goal to produce an application that is useful for real-world industry product development. In that respect, the study is judged by this author to have been successful, and the RVI method has garnered considerable interest within the aviation industry from managers, marketing specialists and engineers alike. A few words are written here regarding the attractiveness of the method and its potential for practical application.

8.2 Future Work

As is normally found, this research has raised additional questions and opened new avenues of study even as the original questions were resolved. A number of additional areas of interest are noted in this section as a result of the research described in this document.

8.2.1 Business Aviation Attributes and Data

As noted several times previously, there exist additional product attributes not used in this study that are likely important to the customer purchase decision. Some attributes will not be directly inherent in the product, but will be more closely related to the product manufacturer or support provider. Some of the data already used in the RVI model also needs to be updated or modified to better correspond to the intention of the theory underlying the model.

8.2.1.1 Additional Product Attributes

The point has been made several times in this document that there are undoubtedly additional attributes of interest to business aviation customers beyond the five technical performance attributes used in this research. Suggestions include product mission reliability (what percentage of the time is the aircraft mission-ready when needed), cabin interior noise, level of avionics and other technology on the aircraft, and others. Once additional attributes have been identified as potential candidates for upgrading the RVI method, the implementation challenges will likely be two-fold.

First, some attributes will probably be difficult to quantify because of the nature of the attribute. How does one assign a numerical value to the technology level used onboard an aircraft, for example? Metrics for measuring the attributes will need to be developed in conjunction with industry experts, and the bounds for those metrics will need to be estimated for use in the model. The second challenge will be to collect data corresponding to the metrics that have been identified. Industry-wide data may prove difficult to obtain, as most manufacturers may only have access to data corresponding to their own products. For example, cabin noise data would likely need to be individually collected from each manufacturer by an independent industry observer. The National Business Aviation Association (NBAA) and General Aviation Manufacturers Association (GAMA) are reportedly studying the collection of reliability data industry-wide, but no data has yet become available from these sources.

It was also mentioned in Chapter 4 that Object-Process Methodology is an attractive procedure for systematic, objective identification of product attributes. Further study of OPM in relation to the aviation industry as well as the general field of value methods and the identification of attributes is warranted.

8.2.1.2 Enterprise-Related Attributes

Although the attributes studied here are inherent in the product itself (speed, fuel consumption, etc.), there likely exist additional attributes that arise from the manufacturing and/or support enterprises associated with the product. In other words, the "brand" associated with the product conveys the value. Such attributes may include the after-sales customer support, warranty package, or even the reputation associated with the brand. Difficulties in incorporating such attributes will be similar to those discussed above: how to identify metrics for quantifying the attributes, and collection of the metric data. Particularly difficult would be quantifying "fuzzy" or "soft" attributes such as reputation. Some prior research in quantifying soft attributes has previously been cited in Chapter 4.

8.2.1.3 Data, Revisited

Some of the data used in the RVI approach to product assessment should be modified to more strictly comply with the theory underlying the method's development. Empirical unit shipments data has been used as an approximation for product demand data. As noted before, sales bookings for each year would be a better approximation of demand, but would still not be an exact representation for demand as there may be customers who desire an aircraft, evaluate all products, and do not make a purchase decision because all products are found to be unsatisfactory. It is also important to the future of product value assessment methods in the business aviation industry that all manufacturers report detailed annual shipments information. The decision of Gulfstream Aerospace to cease such reporting seriously impedes the calibration of value assessment methods (except perhaps by Gulfstram analysts).

A larger problem in the data concerns the list prices ("B/CA Equipped Price") used in the RVI method. These prices comprise the only published data available on the subject of business aircraft prices, but very likely do not reflect the true sale prices of the aircraft. Much like the automotive industry, any number of discounts, rebates or other sales incentives may apply to a business aircraft purchase. This data is held strictly in confidence by the manufacturers and by most customers, so it is unlikely that true sales price data will ever become available.

Operating costs have not been available in the historical record for the business aviation industry. Some estimates for current airplanes are available from recent publications by *Business and Commercial Aviation*. Since a thorough historical comparison was desired in this research, it was felt that fuel consumption served as an adequate proxy for variable operating costs. It would be better, for models that focused solely on current product offerings, to use the variable and fixed operating cost data now becoming available for these products. The model developer will probably want to construct a uniform method for estimating annual flight hours for the aircraft so that the variable and fixed costs can be combined into a single operating cost figure of merit. The Federal Aviation Administration and the National Business Aviation Association both publish data on average annual flight hours for business aircraft.

8.2.1.4 Value of Options

This author has been asked several times by industry representatives if options could be priced using the RVI method. Options may include more sophisticated avionics systems, cabin entertainment or communications systems, higher quality interior furnishings, and other features that do not detract from the value of the product but may enhance the value. The RVI may unequivocally represent such options, as was discussed in Chapter 4. The absolute value of such options (in terms of dollars) may be reverse-engineered using market sales data as part of the Revealed Value calculation, though such an analysis has not been conducted for this study. Manufacturers appear to struggle with how to price options for customers, which may represent substantial profit margin for the manufacturer, and are looking for more quantifiable methods for doing so.

8.2.2 Theoretical Considerations

Some areas for further research should focus on the theory underlying the RVI method, including the assumptions made for demand estimation, the static nature of the model, correlations among attributes, and alternative methods for setting the attribute exponential weighting factor magnitudes.

8.2.2.1 Effects of Competition on Demand

An estimate of how competing products affect the demand for a product was presented in Chapter 4 – following Cook – in terms of the value/price relationships of those competing products. Two equations were noted in Chapter 4, with one being based on a linear demand assumption and the other based on the logit model for consumer choice. When contacted regarding the development of these estimates, Professor Cook indicated that both equations had been written "by inspection" and were not developed through derivations based on fundamental principles.

Though the estimates work well when tested with a limited set of sample data, their origin prevents their true limitations from being known. A more firm theoretical foundation for the mathematical effect of competing products on product demand would be desirable.

8.2.2.2 Linearized Demand

The value/price/demand relationship developed in Chapter 4 is based on a linearized form of the demand equation. This is a common simplification in many economic and marketing studies, as using the non-linear demand equation can become burdensome for all but a few of the more fundamental questions of interest. The assumption, however, is technically only valid for demand and prices near the median for the market segment under consideration.

In the implementation of the business aviation RVI model, it appears that all of the products under study remain far from the two ends of the linear demand equation, In other words, the Revealed Value of the products are far larger than the list prices, and the list prices are significantly greater than zero. However, there are some instances where products appear to overwhelmingly dominate a market in volume of shipments, and where other products drastically under perform the market average. In these cases the linear demand assumption might be violated by using products that are not near the segment demand average. It is at least of academic interest to know the impact on the RVI results of not using a non-linear demand equation. Unless the impacts are significant, the practical interest is likely negligible.

8.2.2.3 Incorporating Dynamics

The RVI method, as documented in this study, is a static representation of a dynamic system. Any product market, such as the business airplane market, is by nature dynamic and continuously changing. The business airplane market is measured, in some metrics, on a quarterly basis (shipments) and on an annual basis for other metrics (performance characteristics, list prices). The static RVI model may adequately represent such a long time constant market in a quasi-dynamic fashion by use of multiple RV=VI best fits over time. However, the time constants for other markets are not as long (e.g., the computer industry) and may require a true dynamic representation. There may also be opportunities for new ways to fit the part-worths value approach to empirical market data through use of a dynamic model.

The manner in which an RVI-like dynamic method may be developed is uncertain, though making the attribute weighting factors time-dependent is one approach. As attributes arise and drop out of the equation, the dynamics may be represented by weighting factors that vary from zero to positive numbers over time. The analysis in Chapter 6 shows that this is, in effect, what has already been done with the static RVI method to make it a quasi-dynamic simulation.

An interesting application of a dynamic model would be to incorporate feedback loops of competitive responses (potential and actual) to changes in the value of a product portfolio over time. In other words, a manufacturer could possibly use game theory to study the potential competitive responses to the introduction of a new product and game counter responses. A Monte Carlo type approach to uncertainties in the competitive environment could be employed.

8.2.2.4 Effects of Multicollinearity

A fair amount of time was spent ensuring that the attributes used in the RVI method were relatively uncorrelated. A "high" degree of correlation was assumed to be implied by *r*-values of 0.85 and above, based on heuristics published in the academic research literature. However, the true effects of having correlated attributes on the final RVI results are unknown, as is the actual threshold for how correlated attributes may be. A more thorough exploration of the theoretical mathematics may present an answer, as may an extensive exercising of the RVI method using carefully controlled input data. For the moment the heuristic of avoiding *r*-values above 0.85 is followed, but if it could be relaxed then some of the combined attributes might be returned to their more fundamental representations (e.g., range, passenger capacity). If the heuristic needs to be tightened (i.e., *r*-values lower than 0.85 need to be avoided) then some of the existing attributes will need to be revised to preserve the explanatory power of the method.

8.2.2.5 Alternative Methods for Setting the Weighting Factors

In this study the attribute exponential weighting factors are set by finding an optimal best fit between the market Revealed Value and the part-worth Value Index for the portfolio of products under consideration. In Chapter 4 three alternative methods for estimating the weighting factors were introduced: setting the factors based on the length of time, or percentage of total time, that the attribute was experienced by the product user; intuitively setting the factors based on subjective inputs from experienced product managers; and treating the factors parametrically by determining the sensitivity of the RVI results to changes in the weighting factors.

Each of these methods has its strengths. The RV=VI best fit method results in a set of factors based on the empirical ability of products to be differentiated on the attributes. Some attributes that may be important, but upon which the product is not differentiable, may have zero-value weighting factors resulting from this method. The intuitive estimation method, though not based in empirical evidence, would presumably capture all important attributes regardless of their differentiability in the market. The consumer experience method may be the least useful approach to setting the weighting factor magnitudes since it is difficult to determine how long certain attributes are experienced by the user. Since attributes like airplane range and fuel economy are experienced throughout a flight, should those weighting factors automatically be set to unity? If enterprise-related attributes, such as customer support level, were introduced it would also become difficult to set the factors based on consumer experience. The method would also limit all weighting factor magnitudes to 1.0 or less, presuming that a percent of total experience scheme is used (see Chapter 4 for details).

A combination of all the methods, with parametric studies for those attributes with uncertain weighting factor values, is probably the best approach. A study in which the RVI results were compared using the RV=VI best fit method and the intuitive estimation method would be of interest to determine the sources of differences between the two. Development of rapid methods for the intuitive estimation technique would be useful for those attributes that are novel or new to the market and cannot be estimated using the best fit method.

8.2.3 Linking the Method to Enterprise Profit

In this development of the RVI method, price has been treated as an independent variable for proposed new products when determining the value/price point for the product. Existing products, of course, are linked to price via the Revealed Value calculation, but when working with new products pricing strategy is limited to assessing the price of nearby competing airplanes on the RVI versus price chart. Figure 122 shows an example of how RVI placement may imply possible prices for the new product.

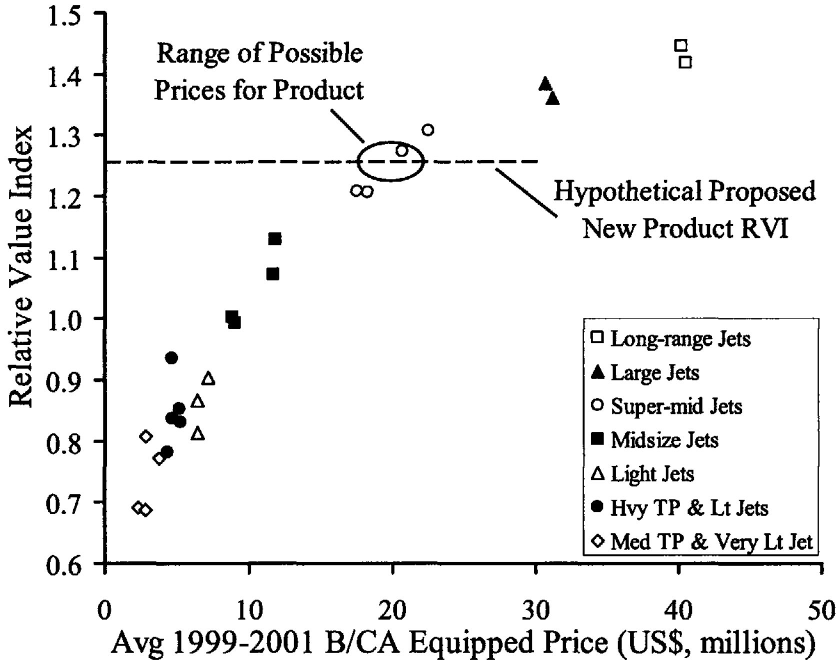


Figure 122: RVI Placement Implies Pricing Strategy

A major step in increasing the utility of the RVI method would be to link the method to enterprise profits such that the RVI rating directly determined a range of possible prices via estimated costs, desired profit margins, desired payback periods, etcetera. Note that this would, in effect, be the reverse of "value pricing" discussed in Chapters 3 and 6, but both methods could be used in a complementary fashion to evaluate permissible costs and prices.

The Relative Value Index is based on a part-worths build-up of attributes, all of which imply not only a customer value in the product but also an approximate cost of producing and developing that product. Detailed design methods such as those in Roskam (1990) enable engineers to form rough estimates of costs based on airplane attributes such as speed, range and size, all of which have been used in the RVI approach in this study for value assessment.

The value and costs estimates then set upper and lower bounds on the possible prices the market and manufacturer (to cover costs) will bear (Figure 123). If the minimum market price exceeds the maximum market price, then the product is not feasible and must be redesigned for a lower cost/higher value combination. Otherwise, a target price may be determined based on a desired profit margin.

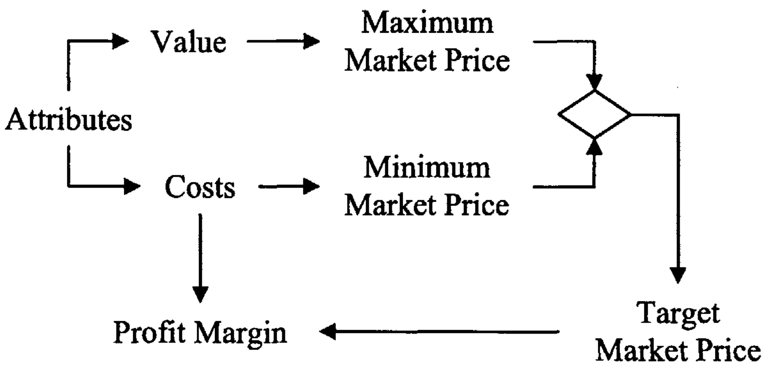


Figure 123: Linking the RVI Method to Costs and Profit

A link to costs such as that shown in Figure 123 also enables an optimization approach to product design. Currently, the value/price trend of existing products must be assumed to be near the Pareto optimal front for the industry (Figure 124). Were costs to be linked to value, then the true Pareto optimal front could be determined based on the costs associated with the value attributes. Profit margin might need to be treated parametrically in such an analysis since costs would determine only the minimum market price for the product. Note that the Pareto front in Figure 124 maximizes price for a given value, and thus represents the manufacturer's optimal front. Consumers, of course, would seek the maximum value for a given price.

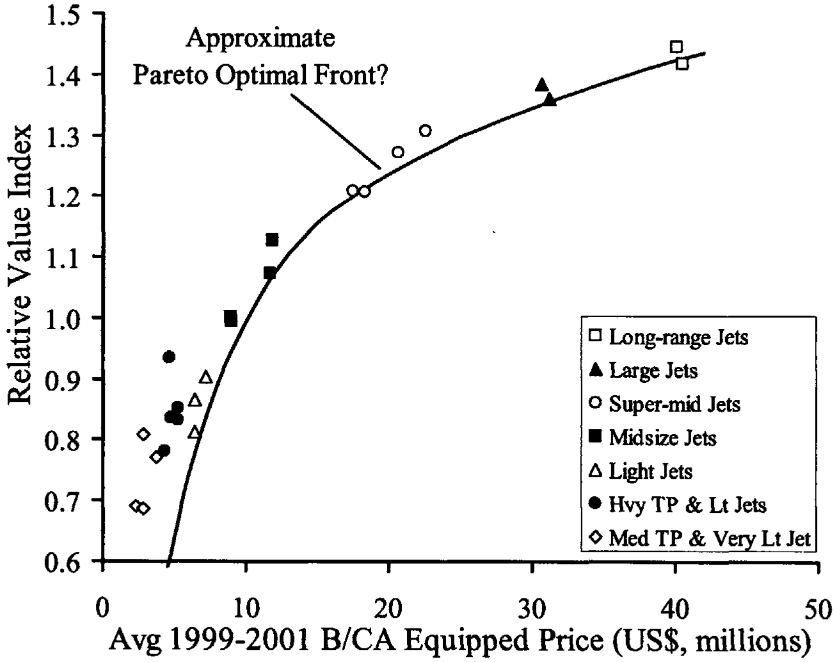


Figure 124: Assumed Approximate Pareto Optimal Front for Manufacturers

8.2.4 Other Product Value to the Enterprise

In addition to linking the RVI method to enterprise profit, there exists other enterprise-related value inherent in a product that the RVI approach does not consider. As currently structured, the RVI method focuses on the value customers derive from a product; speed, fuel efficiency, and such attributes all benefit the customer. This customer focus is key in determining the primary enterprise-related value: profit. The more beneficial a product is to customers, the more likely the product is to enjoy greater sales and, thus, the enterprise is to enjoy greater profits (this assumes a reasonable margin on the product price).

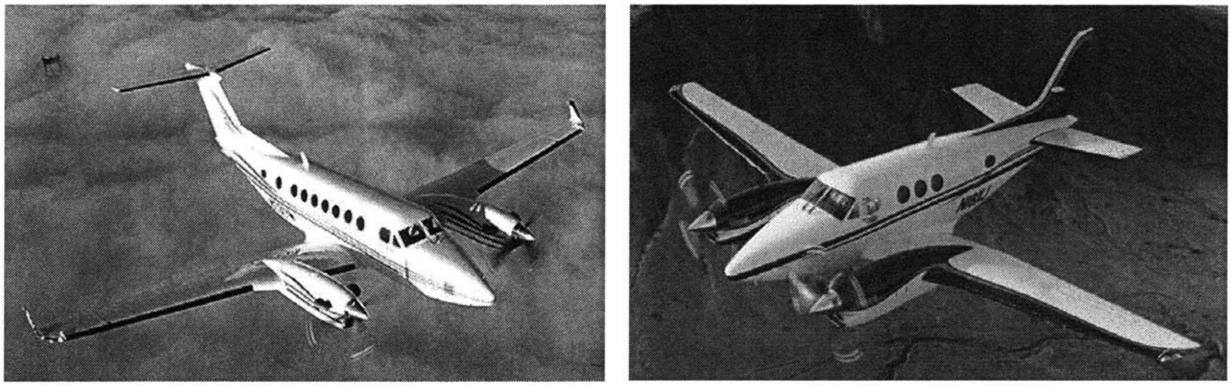
When considering whether to go forward with a development project, managers must also consider factors other than only the customer benefit inherent in a product. The flexibility of the product to changes in the market environment may be important if market conditions are uncertain or known to rapidly change over time. It is also important to consider the likelihood that a product might establish a foundation for a new product family (or might extend an existing product family), called "product platforms" in the design literature. Each of these considerations will be briefly discussed in this section.

8.2.4.1 Product Flexibility

Flexibility is, in essence, the innate ability of a system or product to support new functions and to perform these at some finite range of operating conditions and capacity levels during later stages of its lifecycle [Banerjee (2004)]. It is "the property of a system that allows it to respond to changes in its initial objectives and requirements – both in terms of capabilities and attributes – occurring after the system has been fielded" [Saleh, Hastings, and Newman (September 2002)]. Flexibility is commonly confused with other terms such as robustness and agility, which indicate the product's ability to cope with uncertainties in external inputs, or the ability to be modified to cope with wholly unanticipated operating conditions or functional requirements.

Flexibility is generally recognized as a desirable property for products or systems. However, the value model in no way rewards products that possess designed-in or accidental flexibility. As an example, the Beechcraft King Air series of aircraft, first designed in the early 1960s as the King Air 90, has since gone through over a dozen incarnations and today is still produced in three different versions: the King Air C90B, B200 and 350 series aircraft

(Figure 125), of which hundreds are produced annually. Though the complete explanation is unknown for why this series of business and utility aircraft, all based on the same original airframe design, has been one of the most successful aircraft ever introduced, one attributable aspect is the inherent flexibility of the structural design. The structure of the original airframe was strong enough to allow heavier engines to be mounted on the wings, for larger fuselages to be designed and mounted on the same wing fittings, and for the structure as a whole to endure higher aerodynamic loads as faster versions of the airframe were introduced. There is an inherent penalty at the outset for designing a structure as rugged and modular as that of the King Air, though 40+ years after the initial design it is difficult to quantify that cost. The added value to the manufacturer has been reduced tooling costs for later aircraft in the series that can be built from much of the same tooling, and the savings in not having to design brand new "clean sheet" aircraft to fulfill the dozens of roles the basic King Air airframe has successfully met. Revenues from the approximately 5,300 King Air series aircraft sold since the King Air 90's introduction in 1964 have unarguably given Beechcraft, and then Raytheon Aircraft, the opportunity to design and manufacture dozens of other products over the decades.



(a) King Air 350 (b) King Air C90B

Figure 125: Beechcraft King Air Series Aircraft

It would be desirable to have the RVI model recognize the potential added value of flexibility so that it could be weighed against the costs of building in such flexibility. Though it would be difficult to anticipate the resounding success of aircraft such as the King Air series, some method for forecasting the value of flexibility, even in a parametric sense, could prove useful to designers and product managers.

Though this discussion is not meant to be all-inclusive, several dimensions of flexibility should be recognized by the RVI model, including growth capability of a design (e.g., the airframe structure allows for increased aerodynamic loads due to faster aircraft versions, higher takeoff weight versions of the aircraft) and modularity (interfaces are designed such that functional modules may be updated with minimum impact on the rest of the product; e.g., the engines can be upgraded with new types without redesigning wing structure). The outcome of such designed-in flexibility would be the capability, or option, of operating with different functional, capacity, or performance specifications. As an example, flexibility in growth (e.g., airframe structure) presents the option for carrying more payload (capacity) or installing more powerful engines to fly faster (performance). Flexibility in modularity may allow for different avionics packages to be installed so that the aircraft can serve as a Navy Search and Rescue aircraft (functional).

One proposed way of addressing flexibility would be through a real options approach, which is convenient for analyzing the impacts of uncertainties. An option is a right, but not an obligation, to take some action now, or in the future for a pre-determined price. The real options approach recognizes that uncertainties in investment choices exist over time, and provides a framework within which to assess potential upside and downside risks associated with uncertainty. The concept of real options can be used to calculate the call value (or, in our terminology, the value) of the option.[*] A number of references introduce decision analysis and the real options approach to valuing uncertainty, including de Neufville (1990) and Trigeorgis (1996). A financial treatment of the subject may be found in Hull (1993).

The value framework proposed in this research makes cost and value comparisons possible through use of common metrics such as dollars. The difficulty in using a real options approach would be in defining a time horizon over which to evaluate the value of the flexibility option. Shorter time horizons would tend to make flexibility appear cost ineffective, but longer time horizons would present greater levels of uncertainty in terms of future user needs and external environments (economic conditions, regulatory environment, etc.). Certainly it would have been difficult in 1960 to predict that the King Air series would still be a major profit component of the future manufacturers' product portfolio 45 years later.

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[*] Real options can also be puts (not just calls) if the option is on downsizing, i.e., reducing the RVI of a particular product.

8.2.4.2 Product Families

In a similar manner as product flexibility, the potential for a new product to establish a product family or extend an existing family is not directly valued by the RVI method in its current form. Product platforms, upon which families with similar components and features are based, are an important element in product portfolio development strategy [Meyer and Utterback (Spring 1993), Meyer, Tertzakian, and Utterback (January 1997), Meyer and Lehnerd (1997), Ulrich and Eppinger (2000), Simpson, Maier and Mistree (2001)].

Cessna has had great success leveraging its 1971 introduction of the Citation I (Citation 500 at the time) into a world famous business jet product family (Figure 126). By 2002 eleven distinctly different models had been based on the original platform, and yet more have since been introduced (Citation CJ3 and XLS).

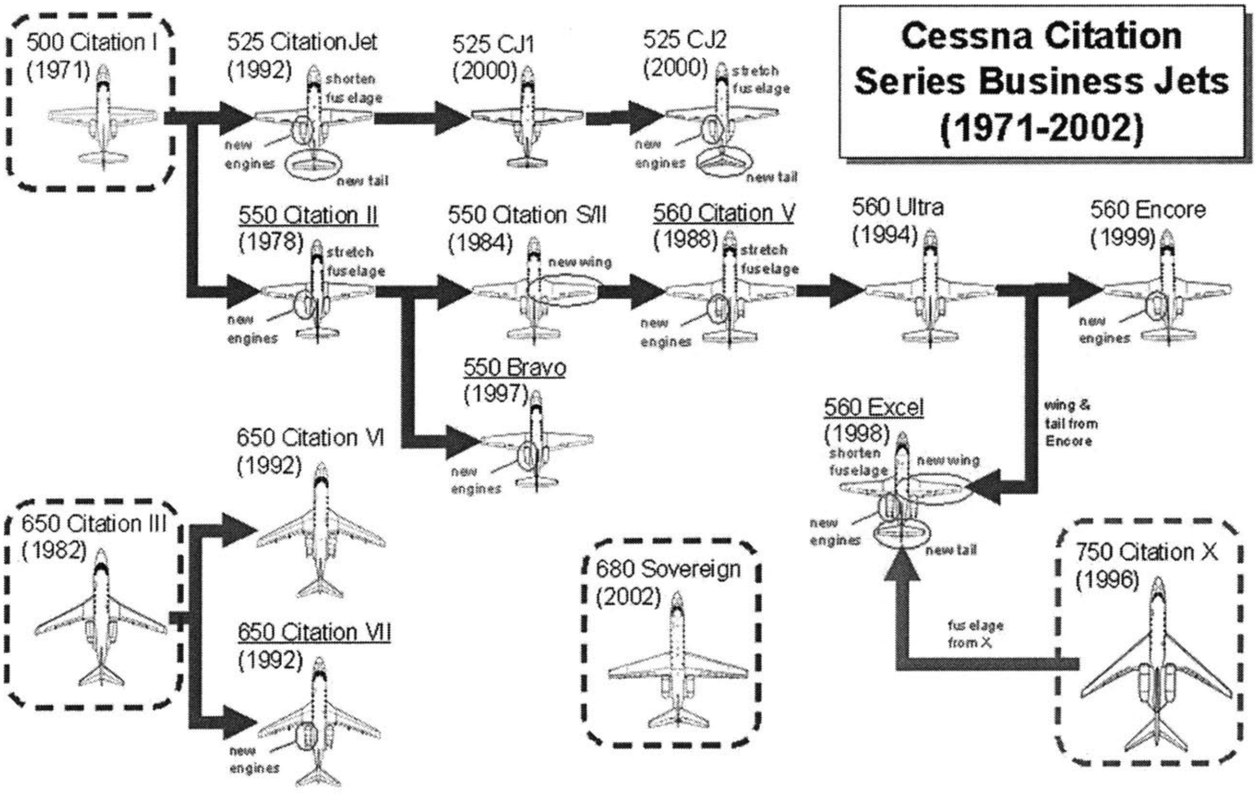

Figure 126: Cessna Citation Product Family

Successful product platforms certainly incorporate characteristics of flexibility, as discussed in the previous section. The RVI model does not currently value the Citation I in 1970 any differently than had the aircraft never led to the successful Citation family. From Cessna's point of view, the value of the Citation I has exceeded its obvious direct contribution to profits from sales. The Citation platform has enabled Cessna to design derivative airplanes at a fraction of the cost of clean-sheet designs and in a fraction of the time. When the RVI method is modified to consider enterprise-related values, the potential for establishing a product family needs to be addressed. An effort at deterministic valuation of platforms is made by de Weck, Suh and Chang (2003). However, since the actual outcome of efforts to position a new product as a family platform is unknown, a stochastic approach will likely be necessary to valuing the product. Real options theory may provide a method by which the potential value of products may be assessed when considering the possibility of future family derivatives. Steps in this direction have recently been documented by Gonzalez-Zugasti, Otto and Baker (2001). Since a real options approach can be complex, John Little's criteria for decision-making models should be kept in mind as the RVI method is modified (Chapter 7).

8.2.5 Impacts of the Used Aircraft Market

In this study, only new products have been considered as directly competing in the selected market segments. In reality, used markets exist in many industries that often compete directly with the new markets. The business airplane industry is no exception, though some marketing managers contend that the used market is wholly separate from the new market due to differences such as warranty packages and maintenance costs (the issue appears to remain a point of debate among industry experts). It would be of interest to investigate how the existence of used product markets influence the prices of new products as well as demand. For a given product value, is the associated demand and/or price depressed due to the existence of a used market? If so, how is the linear demand equation affected, and how should the effect of competing used aircraft be incorporated into the Revealed Value equation?

8.2.6 Large-Scale Engineering Systems

This study has been focused at the product-level of engineering systems and the product's value to consumers. As noted above, extension of the method to the product's value to an enterprise is also possible. A focus on smaller-scale engineering systems, such as the value contribution of subcomponents (e.g., hydraulic actuation systems vs. electrical actuation systems) to the whole-product value, is clearly possible as well.

Perhaps not so obvious is the potential for extending the RVI method to the analysis of large-scale engineering systems and their value to society. Taguchi's original loss function approach treated losses of quality to society due to inferior products. With Taguchi's methods composing the base framework of the Relative Value Index approach, it is possible to extend the product-focus of the RVI method to larger engineering systems.

For example, aircraft are one component in the larger air transportation system that includes supporting systems such as maintenance facilities, air terminals, and the air traffic management system. One might ask what is the value to society of having an air traffic management system (air corridors, traffic controllers, etc.) as opposed to a free-flight system or uncontrolled air space?* The primary value delivering process, transportation, has also not been directly addressed in this study; for example, what is the value of a business aircraft when it can land at an airport near the traveler's final destination, but when ground transportation for that traveler (e.g., taxi, rental car) is not available to complete the final few miles of the journey? The impact of the consumables on society (e.g., fuel, oil) and resultant products (e.g., engine emissions) have also not been studied using the RVI approach. Aircraft and their associated large-scale engineering systems have value to society beyond simply the immediate passenger transportation role, and the RVI methodology appears flexible enough to be used in studying such societal impacts.

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* Much of the air space over the African continent is uncontrolled, presenting unique problems and hazards not found elsewhere in the world. This might serve as a starting point for a study of the value of controlled air space. By analogy, what is the value to society of the United States' interstate highway system?

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APPENDIX A: BUSINESS AIRCRAFT CHARACTERISTICS

This appendix contains a complete list of all aircraft characteristics data used for analysis in this research.

Chapter 2 contains a detailed discussion of the sources used to compile the information listed in this appendix. Most performance and geometric data comes from *Business & Commercial Aviation* (B/CA) or *Aviation International News* (AIN) of various years. The tables in this appendix indicate for each aircraft model the year of B/CA or AIN from which the data predominantly originates. Deviations from this source are noted in the tables on a case-by-case basis. All data on wing area comes from *Jane's All the Worlds Aircraft.*

Note the existence of "derived parameters" in the table. These parameters are directly used in the calculations made in this study and are based on the component data also listed in the table (e.g., cabin volume is based on the cabin length, width and height listed in the tables). The derived parameters are listed for the convenience of those wishing to replicate the calculations in this study.

Best efforts have been made to ensure that the data is consistent across aircraft models as well across years for which the data was listed in B/CA. For example, numerous versions of the Raytheon King Air have been produced so data for fuselage lengths, passenger capacities, cruise ranges, etc. were checked to make sure that changes in the data across the aircraft models were consistent with how the models actually differed; i.e., fuselage stretches, more powerful engines, etc. Additionally, data for the same aircraft may change from year-to-year in B/CA due to reporting errors, typographical errors, or the accumulation of more information by the manufacturer about the aircraft. Information year-to-year was scrutinized to evaluate what changes were made in the data for any given aircraft and for what reason, and that data felt to be most correct was incorporated into the tables.

"N/A" for an item indicates that the data was not available from the consulted sources for that aircraft model.

Notes for the aircraft that indicate "B/CA" and a year refer to the *Business & Commercial Aviation* Purchase Planning Handbook of that year.

The following abbreviations are used in the tables in this appendix:

JAWA = *Jane's All the Worlds Aircraft*
MTOW = maximum takeoff weight
BOW = basic operating weight
MFW = maximum fuel weight
ESHP = equivalent shaft horsepower
TOFL = runway takeoff field length
ROC = rate of climb

		Aircraft Manufacturer & Model			
		Adam Aircraft Adam 700	Aerospatiale (SOCATA) TBM-700	Aerospatiale Corvette SN-601	Airbus ACJ Corporate Jet
Data Source		AIN Oct 2003	B/CA May 1992	B/CA April 1975	B/CA May 2003
Wing Area (sq ft)		N/A	193.8	236.8	1,319.7
Passengers in Executive Config.		4	5	7	50 †
Cabin Dimensions (ft)	Length	13.6 *	15.0	18.9	78.0
	Height	4.3 *	4.1	5.0	7.4
	Width (max)	4.5 *	4.0	5.1	12.2
Weights (lbs)	MTOW	N/A	6,579	13,890	166,450
	BOW	N/A	4,055	9,092	97,653
	Useful Load	N/A	2,524	4,798	68,797
	MFW	N/A	1,887	4,188	62,671
Engine	Number	2	2	2	2
	Model	Wms FJ33-4A	P&W PT6A-64	P&W JT15D-4	IAE V2527M-A5
	Type	fan	prop	fan	fan
	Thrust (lb st.) or ESHP each	1,200	700	2300	26,500
Speeds (ktas)	High Speed Cruise	340	300	428	469
	Long Range Cruise	289 †	237	350	447
	M_{MO}	0.65	N/A	0.70	0.82
TOFL (ft)		2,950	2,136	4,050	6,200
Certified Ceiling (ft)		41,000	30,000	42,000	41,000
Range (nm)	Seats-Full	1,100	967	1,005	5,085 *
	Tanks-Full	1,320 †	1,467	1,297	5,085
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	25 / 37000
	Maximum ROC (fpm)	N/A	1,847	3,100	N/A
Fuel Flow (lbs/hr)	High-Speed	825 †	364	1,540	5,800
	Long-Range	587 †	236	897	4,565
Derived Parameters	Cabin Volume (cu ft)	263.2	246.0	482.0	7041.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.508	0.199	0.366	0.204
	Cabin Volume per Passenger (cu ft/pax)	65.8	49.2	68.9	140.8
	Available Seat-Miles (pax-nm)	4,400	4,835	7,035	254,250
Notes on Aircraft		*jet powered version of turboprop A500*		*look at 77-78 Janes for details* *production ceased after 40th aircraft*	
Notes on Data		** based on A500* *† estimates based on data for CJ1/2*			** estimated w/ 45 min reserve* *† estimate*

		Aircraft Manufacturer & Model			
		Allison Super Convair	Boeing BBJ1 (737-700-IGW)	Boeing BBJ2 (737-800)	Bombardier Challenger 300
Data Source		B/CA April 1960	B/CA May 2003	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		N/A	1,345.5	1,345.5	522.0
Passengers in Executive Config.		20 *	50 *	50 *	8
Cabin Dimen-sions (ft)	Length	N/A	79.2	98.3	23.7
	Height	N/A	7.1	7.1	6.1
	Width (max)	N/A	11.6	11.6	7.2
Weights (lbs)	MTOW	53,200	171,000	174,200	37,500
	BOW	31,500	94,570	100,315	22,350
	Useful Load	21,700	76,430	73,885	15,150
	MFW	11,418	71,657	69,968	13,599
Engine	Number	2	2	2	2
	Model	Allison 501-D13D	CFM56-7B27	CFM56-7B27	Honeywell AS907
	Type	prop	fan	fan	fan
	Thrust (lb st.) or ESHP each	3,750	27,300	27,300	6,501
Speeds (ktas)	High Speed Cruise	300	470	470	470
	Long Range Cruise	300	448	454	459
	M_{MO}	N/A	0.82	0.82	0.83
TOFL (ft)		2,370	5,888	6,832	4,950
Certified Ceiling (ft)		33,200	41,000	41,000	45,000
Range (nm)	Seats-Full	1,181	5,973 †	5,466 †	3,067 *
	Tanks-Full	1,181	6,023	5,602	3,067
Climb Perfor-mance	Time to Climb (min / altitude)	N/A	28 / 37000	29 / 37000	17 / 37000
	Maximum ROC (fpm)	2,230	N/A	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	2,046	5,648	5,846	1,848
	Long-Range	2,046	4,717	4,995	1,610
Derived Para-meters	Cabin Volume (cu ft)	2800.0 *	6522.9	8096.0	1040.9
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.341	0.211	0.220	0.438
	Cabin Volume per Passenger (cu ft/pax)	140.0	130.5	161.9	130.1
	Available Seat-Miles (pax-nm)	23,620	298,662	273,303	24,536
Notes on Aircraft			*-700 fuselage + -800 wing & landing gear*	*-800 in executive configuration*	*originally "BD-100 Continental"*
Notes on Data		** estimate*	** estimate* *† estimated w/ 45 min reserve*	** estimate* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Bombardier Global 5000	Bombardier Global Express (BD-700)	Bombardier (Canadair) Challenger 600	Bombardier (Canadair) Challenger 601
Data Source		B/CA May 2003	B/CA May 2003	B/CA April 1981	B/CA April 1982
Wing Area (sq ft)		1,022.0	1,022.0	520.0	520.0
Passengers in Executive Config.		13	15 *	9	9
Cabin Dimensions (ft)	Length	37.0	44.0	28.3	28.3
	Height	6.3	6.3	6.1	6.1
	Width (max)	8.2	8.2	8.2	8.2
Weights (lbs)	MTOW	87,700	95,000	40,400	41,650
	BOW	50,350	50,300	22,675	23,875
	Useful Load	37,350	44,700	17,725	17,775
	MFW	35,733	43,170	16,725	16,725
Engine	Number	2	2	2	2
	Model	RR BR710A2-20	RR BR710A2-20	ALF 502L	GE CF34-1A
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	14,750	14,750	7,500	8,650
Speeds (ktas)	High Speed Cruise	499	499	443	432
	Long Range Cruise	488	459	425	402
	M_{MO}	0.89	0.89	0.85	0.85
TOFL (ft)		5,000	5,820	6,510	5,600
Certified Ceiling (ft)		51,000	51,000	45,000	45,000
Range (nm)	Seats-Full	4,740 *	6,390 †	3,639 *	3,600
	Tanks-Full	4,740	6,390	3,838	3,815
Climb Performance	Time to Climb (min / altitude)	18 / 37000	20 / 37000	N/A	N/A
	Maximum ROC (fpm)	N/A	N/A	3,600	4,400
Fuel Flow (lbs/hr)	High-Speed	3,700	3,710	1,910	1,750
	Long-Range	3,120	2,760	1,710	1,558
Derived Parameters	Cabin Volume (cu ft)	1911.4	2273.0	1415.6	1415.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.492	0.401	0.447	0.431
	Cabin Volume per Passenger (cu ft/pax)	147.0	151.5	157.3	157.3
	Available Seat-Miles (pax-nm)	61,620	95,850	32,753	32,400
Notes on Aircraft		*shortened Global Express*		*originally LearStar 600 by Bill Lear. First Canadair biz jet.*	*GE engines mounted on -600 airframe*
Notes on Data		** estimated w/ 45 min reserve*	** BCA October '99 indicates 15 pax interior contrary to BCA '03 13 pax.* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	

		Aircraft Manufacturer & Model			
		Bombardier (Canadair) Challenger 601-3A	Bombardier (Canadair) Challenger 601-3R	Bombardier (Canadair) Challenger 604 (CL-600-2B16)	Bombardier (Learjet) Lear 23
Data Source		B/CA May 1989	B/CA May 1990	B/CA May 2003	B/CA April 1965
Wing Area (sq ft)		520.0	520.0	520.0	231.07
Passengers in Executive Config.		9	9	9	5 *
Cabin Dimensions (ft)	Length	28.3	28.3	25.5	9.0 †
	Height	6.1	6.1	6.1	4.3
	Width (max)	8.2	8.2	8.2	4.9
Weights (lbs)	MTOW	43,100	44,600	48,200	12,500
	BOW	24,685	25,650	27,100	6,745
	Useful Load	18,415	18,950	21,100	5,755
	MFW	16,422	17,628	19,850	5,465
Engine	Number	2	2	2	2
	Model	GE CF34-3A	GE CF34-3A	GE CF34-3B	GE CJ610-4
	Type	fan	fan	fan	jet
	Thrust (lb st.) or ESHP each	8,729	8,650	8,729	2,850
Speeds (ktas)	High Speed Cruise	459	459	468	458
	Long Range Cruise	424	424	436	441
	M_{MO}	0.85	0.85	0.85	0.82
TOFL (ft)		5,400	5,875	5,840	4,400
Certified Ceiling (ft)		41,000	41,000	41,000	45,000
Range (nm)	Seats-Full	2,522	3,374 *	3,973 *	1,333 ††
	Tanks-Full	3,284	3,478	3,973	1,582
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	21 / 37000	N/A
	Maximum ROC (fpm)	4,443	4,259	N/A	6,800
Fuel Flow (lbs/hr)	High-Speed	1,890	2,100	2,366	1,478
	Long-Range	1,670	1,815	1,894	1,261
Derived Parameters	Cabin Volume (cu ft)	1415.6	1415.6	1275.5	189.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.438	0.476	0.483	0.572
	Cabin Volume per Passenger (cu ft/pax)	157.3	157.3	141.7	37.9
	Available Seat-Miles (pax-nm)	22,698	30,363	35,757	6,666
Notes on Aircraft		*-601 upgrade. New engines, glass cockpit*	*extended range -601 (listed as -601AER orig.)*	*improved 601*	
Notes on Data			** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** based on Air Int'l article, July '03* *† B/CA April '70* *†† estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 24	Bombardier (Learjet) Lear 24B/D	Bombardier (Learjet) Lear 24E	Bombardier (Learjet) Lear 24F
Data Source		B/CA April 1967	B/CA April 1969	B/CA April 1977	B/CA April 1977
Wing Area (sq ft)		231.77	231.77	231.77	231.77
Passengers in Executive Config.		5 *	5 *	5 *	5 *
Cabin Dimen-sions (ft)	Length	9.0 †	9.0 †	9.0	9.0
	Height	4.3	4.3	4.3	4.3
	Width (max)	4.9	4.9	4.9	4.9
Weights (lbs)	MTOW	13,000	13,500	12,900	13,500
	BOW	7,090	7,327	7,678	7,790
	Useful Load	5,910	6,173	5,222	5,710
	MFW	5,590	5,504	4,791	5,628
Engine	Number	2	2	2	2
	Model	GE CJ610-4	GE CJ610-6	GE CJ610-6	GE CJ610-6
	Type	jet	jet	jet	jet
	Thrust (lb st.) or ESHP each	2,850	2,950	2,950	2,950
Speeds (ktas)	High Speed Cruise	441	464	464	464
	Long Range Cruise	431	418	418	418
	M_{MO}	0.82	0.82	0.82	0.82
TOFL (ft)		3,100	3,917	3,000	3,300
Certified Ceiling (ft)		41,000	45,000	45,000	45,000
Range (nm)	Seats-Full	1,331 ††	1,231 ††	1,026	1,142
	Tanks-Full	1,561	1,330	1,125	1,366
Climb Perfor-mance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	6,300	6,300	7,220	7,100
Fuel Flow (lbs/hr)	High-Speed	1,500 **	1,780 **	1,465	1,460
	Long-Range	1,279 **	1,400 **	1,140	1,155
Derived Para-meters	Cabin Volume (cu ft)	189.6	189.6	189.6	189.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.594	0.670	0.545	0.553
	Cabin Volume per Passenger (cu ft/pax)	37.9	37.9	37.9	37.9
	Available Seat-Miles (pax-nm)	6,657	6,155	5,130	5,710
Notes on Aircraft		*derivative of 23 - upgraded engines, bird-proof windshield*	*derivative of 24, upgraded engines & IGW & intro anti-icing equipment. 24D is minor refinement of 24B*		
Notes on Data		** based on Air Int'l article, July '03* *† B/CA April '70* *†† estimated w/ 45 min reserve* *** based on Lear 23 values*	** based on Air Int'l article, July '03* *† B/CA April '70* *†† estimated w/ 45 min reserve* *** B/CA April '74*	** based on Air Int'l article, July '03*	** based on Air Int'l article, July '03*

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 25/25B	Bombardier (Learjet) Lear 25C	Bombardier (Learjet) Lear 25D	Bombardier (Learjet) Lear 25G
Data Source		B/CA April 1969	B/CA April 1970	B/CA April 1977	B/CA April 1983
Wing Area (sq ft)		231.77	231.77	231.77	246.8
Passengers in Executive Config.		8	8	7	7
Cabin Dimen-sions (ft)	Length	12.1 *	12.1 *	12.1	12.1
	Height	4.5	4.5	4.5	4.3
	Width (max)	4.9	4.9	4.9	4.9
Weights (lbs)	MTOW	15,000	15,000	15,000	16,300
	BOW	7,775	7,775	8,297	8,720
	Useful Load	7,225	7,225	6,703	7,580
	MFW	6,032	8,250	6,098	6,594
Engine	Number	2	2	2	2
	Model	GE CJ610-6	GE CJ610-6	GE CJ610-6	GE CJ610-8A
	Type	jet	jet	jet	jet
	Thrust (lb st.) or ESHP each	2,950	2,950	2,950	2,950
Speeds (ktas)	High Speed Cruise	464 †	463	464	465
	Long Range Cruise	418 †	418	418 †	428
	M_{MO}	0.81	0.82	0.82	0.81
TOFL (ft)		5,186	5,186	3,940	5,150
Certified Ceiling (ft)		45,000	45,000	45,000	51,000
Range (nm)	Seats-Full	1,194 ††	1,194 ††	1,293	1,561
	Tanks-Full	1,303	1,897	1,343	1,961
Climb Perfor-mance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	5,600	5,600	6,300	5,720
Fuel Flow (lbs/hr)	High-Speed	1,960 †	1,960 †	1,595	1,600
	Long-Range	1,560 †	1,560 †	1,260	1,337
Derived Para-meters	Cabin Volume (cu ft)	266.8	266.8	266.8	254.9
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.467	0.467	0.431	0.446
	Cabin Volume per Passenger (cu ft/pax)	33.4	33.4	38.1	36.4
	Available Seat-Miles (pax-nm)	9,550	9,550	9,051	10,927
Notes on Aircraft		*stretched 24 w/ single point refueling. 25B is refinement of 25.*	*longer range verion of 25B - added fuselage fuel tank.*		*-25D w/ wing glove, tip tank fin cuff & aerodynamic improvements*
Notes on Data		** B/CA April '70* *† B/CA April '74* *†† estimated w/ 45 min reserves*	** B/CA April '70* *† B/CA April '74* *†† estimated w/ 45 min reserves*		

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 28	Bombardier (Learjet) Lear 29	Bombardier (Learjet) Lear 31	Bombardier (Learjet) Lear 31A
Data Source		B/CA April 1980	B/CA April 1980	B/CA May 1989	B/CA May 1992
Wing Area (sq ft)		264.5	264.5	264.5	264.5
Passengers in Executive Config.		8	6	7 *	7 *
Cabin Dimensions (ft)	Length	12.1	9.9	12.9	13.5
	Height	4.3	4.3	4.3	4.4
	Width (max)	4.9	4.9	4.9	4.9
Weights (lbs)	MTOW	15,000	15,000	15,500	16,500
	BOW	8,690	8,650	10,257	10,761
	Useful Load	6,310	6,350	5,243	5,739
	MFW	4,684	5,373	4,166	4,124
Engine	Number	2	2	2	2
	Model	GE CJ610-8A	GE CJ610-8A	Honeywell TFE 731-2-3B	Honeywell TFE 731-2-3B
	Type	jet	jet	fan	fan
	Thrust (lb st.) or ESHP each	2,950	2,950	3,500	3,500
Speeds (ktas)	High Speed Cruise	428	428	445	458
	Long Range Cruise	405	405	423	424
	M_{MO}	0.82	0.82	0.78	0.81
TOFL (ft)		2,998	2,998	2,970	3,280
Certified Ceiling (ft)		51,000	51,000	51,000	51,000
Range (nm)	Seats-Full	1,094	1,266	718	1,290 †
	Tanks-Full	1,250	1,483	1,202	1,290
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	N/A	N/A	5,480	5,100
Fuel Flow (lbs/hr)	High-Speed	1,291	1,291	954	1,121
	Long-Range	1,147	1,147	784	803
Derived Parameters	Cabin Volume (cu ft)	254.9	208.6	271.8	291.1
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.354	0.472	0.265	0.271
	Cabin Volume per Passenger (cu ft/pax)	31.9	34.8	38.8	41.6
	Available Seat-Miles (pax-nm)	8,752	7,596	5,026	9,030
Notes on Aircraft		*-25D w/ increased wing span*	*-25D w/ increased wing span*	*Lear 35A/36A fuselage/cabin & engines + 55 wing*	*improved 31*
Notes on Data				** based on B/CA April '92 article*	** based on B/CA April '92 article* *† estimated w/ 45 min reserves*

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 35	Bombardier (Learjet) Lear 35A	Bombardier (Learjet) Lear 36	Bombardier (Learjet) Lear 36A
Data Source		B/CA April 1975	B/CA April 1977	B/CA April 1975	B/CA April 1977
Wing Area (sq ft)		253.3	253.3	253.3	253.3
Passengers in Executive Config.		7 *	7 *	5	5
Cabin Dimensions (ft)	Length	13.2	13.2	11.0	11.0
	Height	4.3	4.3	4.3	4.3
	Width (max)	4.9	4.9	4.9	4.9
Weights (lbs)	MTOW	17,000	17,000	17,000	18,000
	BOW	9,298	9,613	9,258	9,657
	Useful Load	7,702	7,387	7,742	8,343
	MFW	6,171	6,238	7,432	7,437
Engine	Number	2	2	2	2
	Model	Honeywell TFE 731-2	Honeywell TFE 731-2B	Honeywell TFE 731-2	Honeywell TFE 731-2B
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	3,500	3,500	3,500	3,500
Speeds (ktas)	High Speed Cruise	464	464	464	464
	Long Range Cruise	418	418	418	418
	M_{MO}	0.83	0.83	0.83	0.83
TOFL (ft)		5,600	4,200	5,600	4,785
Certified Ceiling (ft)		42,500	45,000	42,500	45,000
Range (nm)	Seats-Full	2,215	2,289	2,625	2,738
	Tanks-Full	2,215	2,289	2,836	2,738
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	5,100	4,900	5,100	4,525
Fuel Flow (lbs/hr)	High-Speed	1,235	1,205	1,195	1,260
	Long-Range	950	940	920	965
Derived Parameters	Cabin Volume (cu ft)	278.1	278.1	231.8	231.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.325	0.321	0.440	0.462
	Cabin Volume per Passenger (cu ft/pax)	39.7	39.7	46.4	46.4
	Available Seat-Miles (pax-nm)	15,505	16,023	13,125	13,690
Notes on Aircraft			*improved 35*		*improved 36*
Notes on Data		** based on B/CA April'92 article*	** based on B/CA April'92 article*		

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 40	Bombardier (Learjet) Lear 45	Bombardier (Learjet) Lear 45XR	Bombardier (Learjet) Lear 55
Data Source		B/CA May 2003	B/CA May 2003	B/CA May 2003	B/CA April 1982
Wing Area (sq ft)		311.6	311.6	311.6	264.5
Passengers in Executive Config.		6	8	8	8
Cabin Dimensions (ft)	Length	17.7	19.8	19.8	13.7
	Height	4.9	4.9	4.9	5.7
	Width (max)	5.1	5.1	5.1	5.9
Weights (lbs)	MTOW	20,350	20,500	21,500	19,500
	BOW	13,428	13,729	13,729	12,600
	Useful Load	6,922	6,771	7,771	6,900
	MFW	5,375	6,062	6,062	6,707
Engine	Number	2	2	2	2
	Model	Honeywell TFE 731-20AR	Honeywell TFE 731-20AR	Honeywell TFE 731-20BR	Honeywell TFE 731-3A-2B
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	3,500	3,500	3,500	3,700
Speeds (ktas)	High Speed Cruise	457	456	456	438
	Long Range Cruise	430	420	420	401
	M_{MO}	0.81	0.81	0.81	0.81
TOFL (ft)		4,285	4,350	5,060	5,480
Certified Ceiling (ft)		51,000	51,000	51,000	51,000
Range (nm)	Seats-Full	1,516	1,885 *	1,885	2,311
	Tanks-Full	1,516	1,885	1,885	2,531
Climb Performance	Time to Climb (min / altitude)	15 / 37000	15 / 37000	16 / 37000	N/A
	Maximum ROC (fpm)	N/A	N/A	N/A	4,380
Fuel Flow (lbs/hr)	High-Speed	1,230	1,230	1,230	1,183
	Long-Range	936	935	935	1,012
Derived Parameters	Cabin Volume (cu ft)	442.3	494.8	494.8	460.7
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.363	0.278	0.278	0.315
	Cabin Volume per Passenger (cu ft/pax)	73.7	61.9	61.9	57.6
	Available Seat-Miles (pax-nm)	9,096	15,080	15,080	18,488
Notes on Aircraft		*31A replacement.* *Short version of -45*		*45 upgrade*	
Notes on Data			** estimated w/ 45 min reserves*		

		Aircraft Manufacturer & Model			
		Bombardier (Learjet) Lear 60	British Aerospace Hawker HS-125-400	British Aerospace Hawker HS-125-600	British Aerospace Hawker HS-125-700
Data Source		B/CA May 2003	B/CA April 1967	B/CA April 1973	B/CA April 1979
Wing Area (sq ft)		264.5	353.0	353.0	353.0
Passengers in Executive Config.		6	6	8	8
Cabin Dimensions (ft)	Length	15.8	19.3	21.3	21.3
	Height	5.7	5.9	5.6	5.8
	Width (max)	5.9	5.7	5.9	5.9
Weights (lbs)	MTOW	23,500	21,700	25,000	24,800
	BOW	14,746	11,400	13,488	13,800
	Useful Load	8,754	10,300	11,512	11,000
	MFW	7,910	8,118	9,487	9,450
Engine	Number	2	2	2	2
	Model	P&W PW305A	RR Bristol Viper 522	RR Bristol Viper 601	Honeywell TFE 731-3R-1
	Type	fan	jet	jet	fan
	Thrust (lb st.) or ESHP each	4,600	3,360	3,750	3,700
Speeds (ktas)	High Speed Cruise	453	435	447 *	427
	Long Range Cruise	422	350	402 *	390
	M_{MO}	0.81	0.76	0.78	0.78
TOFL (ft)		5,450	3,450	6,500	6,250
Certified Ceiling (ft)		51,000	41,000	41,000	41,000
Range (nm)	Seats-Full	2,289 *	1,563 *	1,909 †	2,300
	Tanks-Full	2,289	1,563	1,909	2,300
Climb Performance	Time to Climb (min / altitude)	13 / 37000	N/A	N/A	N/A
	Maximum ROC (fpm)	N/A	4,000	4,500	N/A
Fuel Flow (lbs/hr)	High-Speed	1,362	1,850 †	2,050 *	1,700
	Long-Range	1,113	1,557	1,725 *	1,350
Derived Parameters	Cabin Volume (cu ft)	531.4	649.1	703.8	728.9
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.440	0.741	0.536	0.433
	Cabin Volume per Passenger (cu ft/pax)	88.6	108.2	88.0	91.1
	Available Seat-Miles (pax-nm)	13,734	9,376	15,275	18,400
Notes on Aircraft			*delivery figures incl. HS-125 Srs 1 thru Srs 3B-RA*	*faster -400 w/fuselage extension.*	*improved -600*
Notes on Data		** estimated w/ 45 min reserves*	** estimated w/ 45 min reserves* *† B/CA '71*	** B/CA '74* *† estimated w/ 45 min reserves*	

		Aircraft Manufacturer & Model			
		British Aerospace Hawker HS-125-800	British Aerospace Hawker HS-125-1000	Cessna 208 Caravan I	Cessna 208B Grand Caravan IB
Data Source		B/CA April 1985	B/CA May 1992	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		374.0	374.0	279.4	279.4
Passengers in Executive Config.		8	8	4 *	6 *
Cabin Dimensions (ft)	Length	21.3	24.4	12.7	16.7
	Height	5.8	5.8	4.5	4.5
	Width (max)	6.0	6.0	5.3	5.3
Weights (lbs)	MTOW	27,400	31,000	8,000	8,750
	BOW	15,500	17,600	4,824	5,077
	Useful Load	11,900	13,400	3,176	3,673
	MFW	10,000	11,440	2,224	2,224
Engine	Number	2	2	1	1
	Model	Honeywell TFE 731-5R-1H	P&W PW305	P&W PT6A-114A	P&W PT6A-114A
	Type	fan	fan	prop	prop
	Thrust (lb st.) or ESHP each	4,300	5,225	675	675
Speeds (ktas)	High Speed Cruise	432	452	186	182
	Long Range Cruise	401	402	154	154
	M_{MO}	0.80	0.80	N/A	N/A
TOFL (ft)		5,600	6,000	2,053	2,420
Certified Ceiling (ft)		41,000	43,000	25,000	25,000
Range (nm)	Seats-Full	2,901	3,095 *	571	787
	Tanks-Full	3,059	3,095	866	834
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	9 / 10000	12 / 10000
	Maximum ROC (fpm)	3,500	3,577	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	1,927	1,700	379	379
	Long-Range	1,283	1,142	276	291
Derived Parameters	Cabin Volume (cu ft)	741.2	849.1	302.9	398.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.400	0.355	0.448	0.315
	Cabin Volume per Passenger (cu ft/pax)	92.7	106.1	75.7	66.4
	Available Seat-Miles (pax-nm)	23,208	24,760	2,284	4,722
Notes on Aircraft		*sold to Raytheon in 1993*	*sold to Raytheon in 1993*		
Notes on Data			** estimated w/ 45 min reserves*	** single club in exec. configuration*	** club and a half in exec. configuration*

		Aircraft Manufacturer & Model			
		Cessna 406 Caravan II	Cessna 425 Corsair/Conquest I	Cessna 441 Conquest II	Cessna Mustang
Data Source		B/CA April 1986	B/CA April 1981	B/CA April 1978	AIN Oct 2003 & JAWA 03/04
Wing Area (sq ft)		253.0	224.98	253.6	N/A
Passengers in Executive Config.		6 *	4	6	4
Cabin Dimensions (ft)	Length	13.3	10.6	14.0	11.0 *
	Height	4.3	4.3	4.3	4.5
	Width (max)	4.7	4.6	4.6	4.6
Weights (lbs)	MTOW	9,360	8,200	9,850	N/A
	BOW	5,823	5,400	6,285	5,150
	Useful Load	3,537	2,800	3,565	N/A
	MFW	3,183	2,459	3,183	2,580
Engine	Number	2	2	2	2
	Model	P&W PT6A-112	P&W PT6A-112	Honeywell TPE 331-8-401S	P&W 615F
	Type	prop	prop	prop	fan
	Thrust (lb st.) or ESHP each	500	450	636	1,350
Speeds (ktas)	High Speed Cruise	236	264	293	340
	Long Range Cruise	181	258	230	289 †
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,537	2,345	3,065	3,120 ††
Certified Ceiling (ft)		30,000	34,700	33,000	41,000
Range (nm)	Seats-Full	782	753	1,232	1,066 †
	Tanks-Full	971	1,251	1,896	1,300
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	/
	Maximum ROC (fpm)	1,851	2,027	2,425	N/A
Fuel Flow (lbs/hr)	High-Speed	609	536	510	825 †
	Long-Range	397	406	444	587 †
Derived Parameters	Cabin Volume (cu ft)	268.8	209.7	276.9	226.9
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.366	0.393	0.322	0.508
	Cabin Volume per Passenger (cu ft/pax)	44.8	52.4	46.2	56.7
	Available Seat-Miles (pax-nm)	4,692	3,012	7,392	4,264
Notes on Aircraft		*joint development w/ Reims Aviation in France*	*based on -421 piston airframe*		
Notes on Data		** club and a half in exec. configuration*			** estimate based on CJ1 cabin* *† based on CJ1 comparison* *†† Cessna.com*

		Aircraft Manufacturer & Model			
		Cessna 500 Citation	Cessna 500/501 Citation I	Cessna 525 CitationJet	Cessna 525 CJ1
Data Source		B/CA April 1972	B/CA April 1977	B/CA May 1993	B/CA May 2003
Wing Area (sq ft)		260.0	260.0	240.0	240.0
Passengers in Executive Config.		4	4	4	4
Cabin Dimensions (ft)	Length	12.7 *	12.7 *	10.9	11.0
	Height	4.9	4.9	4.8	4.8
	Width (max)	4.3	4.3	4.9	4.8
Weights (lbs)	MTOW	10,850	11,850	10,400	10,600
	BOW	6,750	7,293	6,535	6,870
	Useful Load	4,100	4,557	3,865	3,730
	MFW	3,538	3,780	3,220	3,220
Engine	Number	2	2	2	2
	Model	P&W JT15D-1	P&W JT15D-1A	Wms RR FJ44-1A	Wms RR FJ44-1A
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	2,200	2,200	1,900	1,900
Speeds (ktas)	High Speed Cruise	350	338	381	377
	Long Range Cruise	275 †	319	311	329
	M_{MO}	0.70	0.705	0.70	0.71
TOFL (ft)		3,035 *	2,930	3,080	3,280
Certified Ceiling (ft)		35,000	41,000	41,000	41,000
Range (nm)	Seats-Full	1,136 ††	1,278	1,185 *	1,023 *
	Tanks-Full	1,233	1,313	1,288	1,248
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	26 / 37000
	Maximum ROC (fpm)	3,100	2,680	3,311	N/A
Fuel Flow (lbs/hr)	High-Speed	1,148 †	757	829	825
	Long-Range	676 †	690	515	587
Derived Parameters	Cabin Volume (cu ft)	267.6	267.6	256.4	253.4
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.615	0.541	0.414	0.446
	Cabin Volume per Passenger (cu ft/pax)	66.9	66.9	64.1	63.4
	Available Seat-Miles (pax-nm)	4,545	5,112	4,740	4,093
Notes on Aircraft		*originally called "Fanjet 500"*	*wingspan increase, range increase over 500 Citation. 501 is single-pilot version*	*replaced Citation I*	*replaced CitationJet. CJ1 is identical w/ higher ramp weights & new avionics*
Notes on Data		**from B/CA '79* *† from B/CA '74* *†† estimated w/ 45 min reserve*	**from B/CA '79*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Cessna 525 CJ2	Cessna 525 CJ3	Cessna 550 Citation Bravo	Cessna 550 Citation II
Data Source		B/CA May 2003	B/CA May 2003	B/CA May 2003	B/CA April 1979
Wing Area (sq ft)		264.0	294.1	322.9	260.0
Passengers in Executive Config.		6	6	7	7
Cabin Dimensions (ft)	Length	13.8	15.7	15.7	16.2
	Height	4.8	4.8	4.7	4.9
	Width (max)	4.8	4.8	4.8	4.3
Weights (lbs)	MTOW	12,375	13,870	14,800	13,300
	BOW	7,840	8,660	9,380	7,815
	Useful Load	4,535	5,210	5,420	5,485
	MFW	3,930	4,710	4,824	4,971
Engine	Number	2	2	2	2
	Model	Wms RR FJ44-2C	Wms RR FJ44-3A	P&W PW530A	P&W JT15D-4
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	2,400	2,780	2,887	2,500
Speeds (ktas)	High Speed Cruise	407	413	400	356
	Long Range Cruise	352	349	344	322
	M_{MO}	0.72	0.72	0.70	0.705
TOFL (ft)		3,420	3,450	3,600	2,990
Certified Ceiling (ft)		45,000	45,000	45,000	43,000
Range (nm)	Seats-Full	1,287 *	1,526 *	1,404 *	1,483
	Tanks-Full	1,550	1,715	1,614	1,852
Climb Performance	Time to Climb (min / altitude)	17 / 37000	16 / 37000	19 / 37000	N/A
	Maximum ROC (fpm)	N/A	N/A	N/A	3,370
Fuel Flow (lbs/hr)	High-Speed	1,070	1,216	1,136	804
	Long-Range	596	614	606	652
Derived Parameters	Cabin Volume (cu ft)	318.0	361.7	354.2	341.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.282	0.293	0.252	0.289
	Cabin Volume per Passenger (cu ft/pax)	53.0	60.3	50.6	48.8
	Available Seat-Miles (pax-nm)	7,719	9,158	9,829	10,381
Notes on Aircraft		*stretched CJ1, increase wing span, swept H-tail, new avionics & engines.*	*stretched CJ2, Bravo replacement*	*replaced Citation II*	*stretched fuselage (42 inches) and slightly increased span Citation I*
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	

		Aircraft Manufacturer & Model			
		Cessna 550 Citation S/II	Cessna 700 Citation III	Cessna 560 Citation Encore	Cessna 560 Citation Ultra
Data Source		B/CA April 1985	B/CA April 1983	B/CA May 2003	B/CA May 1995
Wing Area (sq ft)		342.6	312.0	322.3	342.6
Passengers in Executive Config.		7	7	7	8
Cabin Dimensions (ft)	Length	16.0	18.7	17.3	17.8
	Height	4.8	5.8	4.7	4.8
	Width (max)	4.9	5.7	4.8	4.9
Weights (lbs)	MTOW	14,700	20,000	16,630	16,300
	BOW	8,756	12,111	10,520	9,820
	Useful Load	5,944	7,889	6,110	6,480
	MFW	5,777	7,410	5,400	5,771
Engine	Number	2	2	2	2
	Model	P&W JT15D-4B	Honeywell TFE 731-3B-100	P&W 535A	P&W JT15D-5D
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	2,500	3,650	3,400	3,045
Speeds (ktas)	High Speed Cruise	401	450	426	428
	Long Range Cruise	319	413	376	364
	M_{MO}	0.718	0.835	0.755	0.755
TOFL (ft)		3,240	4,350	3,490	3,180
Certified Ceiling (ft)		43,000	51,000	45,000	45,000
Range (nm)	Seats-Full	1,724	2,271	1,501 *	1,580 *
	Tanks-Full	2,303	2,824	1,668	1,736
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	13 / 37000	N/A
	Maximum ROC (fpm)	3,000	4,140	N/A	4,230
Fuel Flow (lbs/hr)	High-Speed	1,190	1,281	1,335	1,449
	Long-Range	704	1,005	804	813
Derived Parameters	Cabin Volume (cu ft)	376.3	618.2	390.3	418.7
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.315	0.348	0.305	0.279
	Cabin Volume per Passenger (cu ft/pax)	53.8	88.3	55.8	52.3
	Available Seat-Miles (pax-nm)	12,068	15,897	10,508	12,638
Notes on Aircraft				*Citation Ultra upgrade (increased wing span, new engines)*	*Citation V upgrade*
Notes on Data				** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Cessna 560 Citation V	Cessna 560XL Citation Excel	Cessna 650 Citation VI	Cessna 650 Citation VII
Data Source		B/CA May 1989	B/CA May 2003	B/CA May 1993	B/CA May 1993
Wing Area (sq ft)		342.6	369.7	312.0	312.0
Passengers in Executive Config.		8	8	6	6
Cabin Dimensions (ft)	Length	17.8	18.7	18.7	18.7
	Height	4.8	5.7	5.8	5.8
	Width (max)	4.9	5.6	5.7	5.7
Weights (lbs)	MTOW	15,900	20,000	22,000	22,450
	BOW	9,400	12,740	13,668	14,053
	Useful Load	6,500	7,260	8,332	8,397
	MFW	5,771	6,740	7,329	7,197
Engine	Number	2	2	2	2
	Model	P&W JT15D-5A	P&W 545A	Honeywell TFE 731-3B-100	Honeywell TFE 731-4R-2S
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	2,900	3,804	3,650	4,100
Speeds (ktas)	High Speed Cruise	427	423	463	470
	Long Range Cruise	350	366	404	417
	M_{MO}	0.75	0.75	0.835	0.835
TOFL (ft)		3,160	3,590	5,030	4,690
Certified Ceiling (ft)		45,000	45,000	51,000	51,000
Range (nm)	Seats-Full	1,257	1,482 *	1,795 *	1,736 *
	Tanks-Full	1,753	1,704	1,851	1,771
Climb Performance	Time to Climb (min / altitude)	N/A	14 / 37000	N/A	N/A
	Maximum ROC (fpm)	3,684	N/A	3,699	4,442
Fuel Flow (lbs/hr)	High-Speed	1,526	1,351	1,475	1,581
	Long-Range	740	905	1,060	1,120
Derived Parameters	Cabin Volume (cu ft)	418.7	596.9	618.2	618.2
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.264	0.309	0.437	0.448
	Cabin Volume per Passenger (cu ft/pax)	52.3	74.6	103.0	103.0
	Available Seat-Miles (pax-nm)	10,056	11,860	10,773	10,413
Notes on Aircraft		*stretched S-II*	*Citation X fuselage (shortened) + Ultra/Encore wing & tail*	*Citation III airframe, new engines*	*upgraded Citation VI*
Notes on Data			** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Cessna 680 Citation Sovereign	Cessna 750 Citation X	Dassault Falcon 10	Dassault Falcon 100
Data Source		B/CA May 2003	B/CA May 2003	B/CA April 1974	B/CA April 1983
Wing Area (sq ft)		516.0	527.0	259.0	259.4
Passengers in Executive Config.		9	8	7	7
Cabin Dimensions (ft)	Length	24.2	23.5	16.4	12.8
	Height	5.7	5.7	4.9	4.7
	Width (max)	5.6	5.6	4.7	4.8
Weights (lbs)	MTOW	30,000	36,100	18,300	18,740
	BOW	17,800	22,100	10,875	11,325
	Useful Load	12,200	14,000	7,425	7,415
	MFW	10,770	12,931	5,910	5,910
Engine	Number	2	2	2	2
	Model	P&W PW306C	RR AE3007C1	Honeywell TFE-731-2	Honeywell TFE 731-2-1C
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	5,686	6,764	3,230	3,230
Speeds (ktas)	High Speed Cruise	437	505	481	454
	Long Range Cruise	370	470	426	431
	M_{MO}	0.80	0.92	0.87	0.87
TOFL (ft)		3,694	5,140	5,100	4,500
Certified Ceiling (ft)		47,000	51,000	45,000	45,000
Range (nm)	Seats-Full	2,502 *	3,009 *	1,842	1,913
	Tanks-Full	2,527	3,070	1,842	2,040
Climb Performance	Time to Climb (min / altitude)	14 / 37000	18 / 37000	N/A	N/A
	Maximum ROC (fpm)	N/A	N/A	4,000	4,600
Fuel Flow (lbs/hr)	High-Speed	1,715	1,992	975	1,200
	Long-Range	1,122	1,529	655	1,080
Derived Parameters	Cabin Volume (cu ft)	772.5	750.1	377.7	288.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.337	0.407	0.220	0.358
	Cabin Volume per Passenger (cu ft/pax)	85.8	93.8	54.0	41.3
	Available Seat-Miles (pax-nm)	22,516	24,069	12,894	13,391
Notes on Aircraft				*shortened Falcon 20*	*complemented -10 model (not direct replacement). Increased MTOW. -10 deliveries from s/n 202 are -100*
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*		

		Aircraft Manufacturer & Model			
		Dassault Falcon 20	Dassault Falcon 200	Dassault Falcon 50	Dassault Falcon 50EX
Data Source		B/CA April 1967	B/CA April 1983	B/CA April 1979	B/CA May 1997
Wing Area (sq ft)		440.0	440.0	504.1	504.1
Passengers in Executive Config.		8	8	9	9
Cabin Dimensions (ft)	Length	23.2	23.8	23.5	23.5
	Height	6.2	5.7	5.9	5.9
	Width (max)	5.8	6.1	6.1	6.1
Weights (lbs)	MTOW	26,455	30,650	38,800	39,700
	BOW	15,500	18,513	20,255	21,900
	Useful Load	10,955	12,137	18,545	17,800
	MFW	8,296	10,623	15,633	15,520
Engine	Number	2	2	3	3
	Model	GE CF700-2C	ATF3-6A-4C	Honeywell TFE 731-3-1C	Honeywell TFE 731-40
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	4,125	5,200	3,700	3,700
Speeds (ktas)	High Speed Cruise	460	429	457	457
	Long Range Cruise	400	417	410	430
	M_{MO}	0.85	0.865	0.86	0.86
TOFL (ft)		5,650	4,650	4,900	4,890
Certified Ceiling (ft)		42,000	42,000	45,000	49,000
Range (nm)	Seats-Full	1,762 *	2,603	3,500	3,191 *
	Tanks-Full	1,782 *	2,757	3,750	3,191
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	17 / 37000
	Maximum ROC (fpm)	5,000	3,250	3,526	N/A
Fuel Flow (lbs/hr)	High-Speed	1,520 *	1,484	2,068	1,885
	Long-Range	955 *	1,418	1,661	1,529
Derived Parameters	Cabin Volume (cu ft)	834.3	827.5	845.8	845.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.298	0.425	0.450	0.395
	Cabin Volume per Passenger (cu ft/pax)	104.3	103.4	94.0	94.0
	Available Seat-Miles (pax-nm)	14,096	20,824	31,500	28,719
Notes on Aircraft		*first business jet for Dassault*	*replaced -20. New engines, larger fuel tank. Introduced in '81 as Falcon 20H*	*first Falcon tri-jet*	
Notes on Data		** B/CA '74*			** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Dassault Falcon 900	Dassault Falcon 900B	Dassault Falcon 900C	Dassault Falcon 900EX
Data Source		B/CA May 1987	B/CA May 1992	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		527.4	527.4	527.4	527.4
Passengers in Executive Config.		12	12	12	12
Cabin Dimensions (ft)	Length	33.2	33.2	33.2	33.2
	Height	6.2	6.2	6.2	6.2
	Width (max)	7.7	7.7	7.7	7.7
Weights (lbs)	MTOW	45,500	45,500	45,500	48,300
	BOW	23,400	24,660	25,106	26,029
	Useful Load	22,100	20,840	20,394	22,271
	MFW	19,000	19,165	19,165	21,000
Engine	Number	3	3	3	3
	Model	Honeywell TFE 731-5A	Honeywell TFE 731-5BR-1C	Honeywell TFE 731-5BR-1C	Honeywell TFE 731-60
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	4,500	4,750	4,750	5,000
Speeds (ktas)	High Speed Cruise	479	488	474	474
	Long Range Cruise	428	430	426	436
	M_{MO}	0.87	0.87	0.87	0.87
TOFL (ft)		5,300	4,930	4,932	5,213
Certified Ceiling (ft)		51,000	51,000	51,000	51,000
Range (nm)	Seats-Full	4,285 *	3,730 *	3,637 *	4,228 *
	Tanks-Full	4,285	3,845	3,869	4,404
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	21 / 37000	18 / 37000
	Maximum ROC (fpm)	3,500	4,000	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	2,625	2,490	2,384	2,268
	Long-Range	1,742	1,630	1,783	1,809
Derived Parameters	Cabin Volume (cu ft)	1585.0	1585.0	1585.0	1585.0
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.339	0.316	0.349	0.346
	Cabin Volume per Passenger (cu ft/pax)	132.1	132.1	132.1	132.1
	Available Seat-Miles (pax-nm)	51,420	44,756	43,642	50,734
Notes on Aircraft			*re-engined 900*		*long-range 900B*
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Dassault Falcon 2000	Dassault Falcon 2000EX	Eclipse Aviation Eclipse 500	Fairchild F-27
Data Source		B/CA May 2003	B/CA May 2004	AIN Oct 2003	B/CA April 1964
Wing Area (sq ft)		527.6	527.6	N/A	754.0
Passengers in Executive Config.		10 *	8 *	4	10
Cabin Dimensions (ft)	Length	26.3	26.3	12.3	40.6
	Height	6.2	6.2	4.2	6.7
	Width (max)	7.7	7.7	4.7	8.4
Weights (lbs)	MTOW	35,800	41,300	5,640	42,000
	BOW	22,750	24,000	3,590	25,500
	Useful Load	13,050	17,300	2,050	16,500
	MFW	12,154	16,660	1,540	12,540
Engine	Number	2	2	2	2
	Model	CFE738-1B	P&W PW308C	P&W 610F	RR Dart 7 Mk 529-7E
	Type	fan	fan	fan	prop
	Thrust (lb st.) or ESHP each	5,918	7,000	900	2,185
Speeds (ktas)	High Speed Cruise	479	482	375	261
	Long Range Cruise	417	421	319 *	228
	M_{MO}	0.87	0.86	0.64	N/A
TOFL (ft)		5,436	5,375	3,100 †	2,730
Certified Ceiling (ft)		47,000	47,000	41,000	28,800
Range (nm)	Seats-Full	2,916 †	3,603 †	1,050 *	2,611 *
	Tanks-Full	3,038	3,753	1,280	2,611
Climb Performance	Time to Climb (min / altitude)	19 / 37000	16 / 37000	N/A	N/A
	Maximum ROC (fpm)	N/A	N/A	N/A	1,690
Fuel Flow (lbs/hr)	High-Speed	2,018	2,351	825 *	1,496
	Long-Range	1,311	1,484	587 *	1,026
Derived Parameters	Cabin Volume (cu ft)	1255.6	1255.6	239.8	2285.0
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.314	0.441	0.460	0.451
	Cabin Volume per Passenger (cu ft/pax)	125.6	156.9	60.0	228.5
	Available Seat-Miles (pax-nm)	29,165	28,823	4,198	26,111
Notes on Aircraft			*extended range 2000*		*airliner heavy turboprop*
Notes on Data		** B/CA April '98* *† estimated w/ 45 min reserve*	** B/CA April '98* *† estimated w/ 45 min reserve*	** based on CJ1 comparison* *† based on Cessna Mustang compare.*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Fairchild FH 227	Fairchild Merlin II (SA-26T)	Fairchild Merlin III	Fairchild Merlin IIIA
Data Source		B/CA April 1965	B/CA April 1967	B/CA April 1971	B/CA April 1975
Wing Area (sq ft)		754.0	279.7	277.5	277.5
Passengers in Executive Config.		14 *	6	8	8
Cabin Dimensions (ft)	Length	53.4	10.6	10.6	10.6
	Height	6.7	5.2	5.2	5.2
	Width (max)	8.4	4.9	4.8	4.8
Weights (lbs)	MTOW	43,500	9,300	12,500	12,500
	BOW	27,000	6,000	7,500	7,875
	Useful Load	16,500	3,300	5,000	4,625
	MFW	9,002	2,548	4,277	4,342
Engine	Number	2	2	2	2
	Model	RR Dart 7 Mk 532-7	P&W PT6A-20	Honeywell TPE 331	Honeywell TPE 331-3U-303G
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	2,250	579	840	840
Speeds (ktas)	High Speed Cruise	261 †	235	274	276
	Long Range Cruise	228	217	250	220
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,980	2,300	2,300	2,150
Certified Ceiling (ft)		25,000	30,000	28,900	28,000
Range (nm)	Seats-Full	1,429 ††	1,165 *	1,154 *	1,161
	Tanks-Full	1,429	1,448	1,847 *	2,254
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,300	1,950	2,530	1,032
Fuel Flow (lbs/hr)	High-Speed	1,280	422	700 *	642
	Long-Range	1,280	343	500 *	458
Derived Parameters	Cabin Volume (cu ft)	3005.4	270.1	264.6	264.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.402	0.264	0.250	0.260
	Cabin Volume per Passenger (cu ft/pax)	214.7	45.0	33.1	33.1
	Available Seat-Miles (pax-nm)	20,007	6,990	9,232	9,288
Notes on Aircraft		*stretched and engine upgrade from F-27*	*listed under Swearingen in some sources*	*listed under Swearingen in some sources*	
Notes on Data		** estimated as +4 over F27 per B/CA '65* *† based on F27* *†† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** B/CA '74*	

		Aircraft Manufacturer & Model			
		Fairchild Merlin IIIB	Fairchild Merlin IIIC	Fairchild Merlin IV	Galaxy Aerospace (IAI) 1121B Commodore Jet
Data Source		B/CA April 1979	B/CA April 1982	B/CA April 1971	B/CA April 1969
Wing Area (sq ft)		277.5	277.5	277.5	303.3
Passengers in Executive Config.		8	8	12	7
Cabin Dimensions (ft)	Length	10.6	10.6	25.4	18.2
	Height	5.2	5.2	5.2	4.8
	Width (max)	4.8	4.8	4.8	4.9
Weights (lbs)	MTOW	12,500	12,500	12,500	18,500
	BOW	8,230	8,213	8,300	10,700
	Useful Load	4,270	4,287	4,200	7,800
	MFW	4,342	4,342	3,630	7,194
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-3U-303G	Honeywell TPE 331-10U	Honeywell TPE 331	GE CJ610-5
	Type	prop	prop	prop	jet
	Thrust (lb st.) or ESHP each	900	900	840	2,950
Speeds (ktas)	High Speed Cruise	300	303	260	445
	Long Range Cruise	256	271	247	410
	M_{MO}	N/A	N/A	N/A	0.76
TOFL (ft)		3,000 *	2,400	2,385	3,600
Certified Ceiling (ft)		31,400	31,000	27,000	45,000
Range (nm)	Seats-Full	1,393	1,300	623 *	1,835 *
	Tanks-Full	2,278	2,312	1,445	2,101
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,782	2,800	2,400	5,000
Fuel Flow (lbs/hr)	High-Speed	746	710	675 †	1,550 †
	Long-Range	577	437	550 †	1,225
Derived Parameters	Cabin Volume (cu ft)	264.6	264.6	634.0	428.1
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.282	0.202	0.186	0.427
	Cabin Volume per Passenger (cu ft/pax)	33.1	33.1	52.8	61.2
	Available Seat-Miles (pax-nm)	11,144	10,400	7,477	12,848
Notes on Aircraft			*listed under Swearingen in some sources*	*listed under Swearingen in some sources. Corporate version of Metro.*	*formerly Rockwell 1121 Jet Commander. 1121B model upgraded w/ engines and MTOW.*
Notes on Data		** B/CA '80*		** estimated w/ 45 min reserve* *† B/CA '74*	** estimated w/ 45 min reserve* *† B/CA '74*

		Aircraft Manufacturer & Model			
		Galaxy Aerospace (IAI) 1123 Westwind	Galaxy Aerospace (IAI) 1124 Westwind 1	Galaxy Aerospace (IAI) 1124A Westwind 2	Galaxy Aerospace (IAI) 1125 Astra SP
Data Source		B/CA April 1974	B/CA April 1977	B/CA April 1983	B/CA May 1986
Wing Area (sq ft)		308.26	308.26	308.26	316.6
Passengers in Executive Config.		8	8	8	7
Cabin Dimensions (ft)	Length	20.0	15.3	13.0	17.1
	Height	4.8	4.8	4.9	5.6
	Width (max)	4.9	4.9	4.8	4.8
Weights (lbs)	MTOW	20,700	22,850	23,500	23,500
	BOW	11,600	12,786	13,250	12,800
	Useful Load	9,100	10,064	10,250	10,700
	MFW	8,710	8,710	9,580	9,365
Engine	Number	2	2	2	2
	Model	GE CJ610-9	Honeywell TFE 731-3-1G	Honeywell TFE 731-3-1G	Honeywell TFE 731-3A-2B
	Type	jet	fan	fan	fan
	Thrust (lb st.) or ESHP each	3,100	3,700	3,700	3,700
Speeds (ktas)	High Speed Cruise	448	424	413	465 *
	Long Range Cruise	396	384	402	406 *
	M_{MO}	0.765	0.77	0.80	0.855
TOFL (ft)		6,400	4,950	5,150	5,250
Certified Ceiling (ft)		45,000	45,000	45,000	45,000
Range (nm)	Seats-Full	1,450	2,493	2,535	1,983 *
	Tanks-Full	1,780	2,493	2,875	2,688 *
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	4,040	4,000	3,500	4,500
Fuel Flow (lbs/hr)	High-Speed	2,910	1,498	1,275	1,474
	Long-Range	1,650	1,145	1,215	1,070
Derived Parameters	Cabin Volume (cu ft)	470.4	359.9	305.8	459.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.521	0.373	0.378	0.376
	Cabin Volume per Passenger (cu ft/pax)	58.8	45.0	38.2	65.7
	Available Seat-Miles (pax-nm)	11,600	19,944	20,280	13,881
Notes on Aircraft		*upgraded 1121 for production in Israel (fuselage stretch by 22 inches)*	*upgraded 1123*	*upgraded 1124. More cabin headroom, winglets, more range*	
Notes on Data					** B/CA '89*

		Aircraft Manufacturer & Model			
		Galaxy Aerospace (IAI) 1125 Astra SPX	Galaxy Aerospace (IAI) 1126 Galaxy	Gulfstream (Grumman) Gulfstream 840	Gulfstream (Grumman) Gulfstream 900
Data Source		B/CA May 1997	B/CA May 2003	B/CA April 1982	B/CA April 1982
Wing Area (sq ft)		316.6	369.0	279.37	279.37
Passengers in Executive Config.		7	10	7	7
Cabin Dimensions (ft)	Length	17.1	24.4	9.5	12.4
	Height	5.6	6.3	4.5	4.8
	Width (max)	4.8	7.2	4.1	4.1
Weights (lbs)	MTOW	24,650	35,450	10,325	10,700
	BOW	13,700	20,000	6,948	7,315
	Useful Load	10,950	15,450	3,377	3,385
	MFW	9,365	15,000	3,176	3,176
Engine	Number	2	2	2	2
	Model	Honeywell TFE 731-40R-200G	P&W PW306A	Honeywell TPE 331-5-254K	Honeywell TPE 331-5
	Type	fan	fan	prop	prop
	Thrust (lb st.) or ESHP each	4,250	6,040	718	748
Speeds (ktas)	High Speed Cruise	468	470	284	282
	Long Range Cruise	430	430	237	249
	M_{MO}	0.87	0.85	N/A	N/A
TOFL (ft)		5,395	6,083	1,833	1,937
Certified Ceiling (ft)		45,000	45,000	31,000	31,000
Range (nm)	Seats-Full	2,197	3,123 *	1,035	1,109
	Tanks-Full	2,849	3,432	1,775	1,950
Climb Performance	Time to Climb (min / altitude)	18 / 37000	19 / 37000	N/A	N/A
	Maximum ROC (fpm)	N/A	N/A	2,824	2,779
Fuel Flow (lbs/hr)	High-Speed	1,429	2,020	556	538
	Long-Range	1,063	1,536	352	348
Derived Parameters	Cabin Volume (cu ft)	459.6	1106.8	175.3	244.0
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.353	0.357	0.212	0.200
	Cabin Volume per Passenger (cu ft/pax)	65.7	110.7	25.0	34.9
	Available Seat-Miles (pax-nm)	15,379	31,231	7,245	7,763
Notes on Aircraft		*SPX upgraded version cert. Jan 1996*	*upgraded Astra SP (same wing, new fuselage)*	*formerly Aero Cmdr 840*	*formerly Aero Cmdr 900*
Notes on Data			** estimate w/ 45 min reserve*		

		Aircraft Manufacturer & Model			
		Gulfstream (Grumman) Gulfstream 980	Gulfstream (Grumman) Gulfstream 1000	Gulfstream (Grumman) Gulfstream G-159	Gulfstream (Grumman) Gulfstream G-II
Data Source		B/CA April 1982	B/CA April 1982	B/CA April 1967	B/CA April 1967
Wing Area (sq ft)		279.37	279.37	610.3	793.5
Passengers in Executive Config.		7	7	12 *	12 *
Cabin Dimensions (ft)	Length	9.5	12.4	32.5	34.0
	Height	4.5	4.8	6.1	6.1
	Width (max)	4.1	4.1	7.3	7.3
Weights (lbs)	MTOW	10,325	11,200	36,000	56,500
	BOW	7,036	7,519	21,479	32,900
	Useful Load	3,289	3,681	14,521	23,600
	MFW	3,176	3,176	10,230	21,021
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-10	Honeywell TPE 331-10	RR Dart 7 Mk 529-8X	RR Spey Mk 511-8
	Type	prop	prop	prop	fan
	Thrust (lb st.) or ESHP each	733	820	2,210	11,400
Speeds (ktas)	High Speed Cruise	302	301	305	512 †
	Long Range Cruise	298	253	305	422 †
	M_{MO}	N/A	N/A	N/A	0.85
TOFL (ft)		1,854	2,131	4,725	4,400
Certified Ceiling (ft)		31,000	35,000	30,000	44,250
Range (nm)	Seats-Full	898	1,365	2,135 †	3,150 †
	Tanks-Full	1,634	2,042	2,135	3,400 †
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,777	2,802	1,900	4,800
Fuel Flow (lbs/hr)	High-Speed	641	646	1,320	7,111 †
	Long-Range	509	332	1,320	3,296 †
Derived Parameters	Cabin Volume (cu ft)	175.3	244.0	1447.2	1514.0
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.244	0.187	0.361	0.651
	Cabin Volume per Passenger (cu ft/pax)	25.0	34.9	120.6	126.2
	Available Seat-Miles (pax-nm)	6,286	9,555	25,620	37,800
Notes on Aircraft		*formerly Aero Cmdr 980*	*formerly Aero Cmdr 1000*		*first business jet for Grumman Gulfstream.*
Notes on Data				** based on accommodations for GII – same cabin* *† estimate w/ 45 min reserve*	** based on info in Mead, Copp, and Strakosch (June 80)* *† B/CA '74*

		Aircraft Manufacturer & Model			
		Gulfstream (Grumman) Gulfstream G-II/TT	Gulfstream (Grumman) Gulfstream G-III	Gulfstream (Grumman) Gulfstream G-IV	Gulfstream (Grumman) Gulfstream G-IV-SP
Data Source		B/CA April 1978	B/CA April 1981	B/CA April 1988	B/CA May 1993
Wing Area (sq ft)		793.5	934.6	950.4	950.4
Passengers in Executive Config.		12 *	14 *	14	14
Cabin Dimensions (ft)	Length	34.0	36.0	45.1	45.1
	Height	6.1	6.1	6.1	6.1
	Width (max)	7.3	7.3	7.3	7.3
Weights (lbs)	MTOW	65,500	68,200	73,200	75,000
	BOW	37,186	38,100	42,500	42,884
	Useful Load	28,314	30,100	30,700	32,116
	MFW	26,800	27,900	29,500	29,280
Engine	Number	2	2	2	2
	Model	RR Spey Mk 511-8	RR Spey Mk 511-8	RR Tay Mk 610-8	RR Tay Mk 611-8
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	11,400	11,400	12,420	13,850
Speeds (ktas)	High Speed Cruise	501	459	488	480
	Long Range Cruise	430	445	442	459
	M_{MO}	0.85	0.85	0.88	0.88
TOFL (ft)		5,800	5,850	5,280	5,450
Certified Ceiling (ft)		43,000	45,000	45,000	45,000
Range (nm)	Seats-Full	3,306	4,120 †	4,131	4,033 *
	Tanks-Full	3,361	4,217	4,495	4,033
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	4,800	3,800	3,920	4,122
Fuel Flow (lbs/hr)	High-Speed	6,469	2,843	3,470	3,429
	Long-Range	2,983	2,728	2,300	2,713
Derived Parameters	Cabin Volume (cu ft)	1514.0	1603.1	2008.3	2008.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.578	0.438	0.372	0.422
	Cabin Volume per Passenger (cu ft/pax)	126.2	114.5	143.5	143.5
	Available Seat-Miles (pax-nm)	39,672	57,673	57,834	56,462
Notes on Aircraft		*extended range GII w/ tip tanks*	*stretched fuselage GIII and new wing*		*G-IV upgrade (higher weight & new avionics)*
Notes on Data		** based on info in Mead, Copp, and Strakosch (June 80)*	** based on info in Mead, Copp, and Strakosch (June 80)* *† estimated w/ 45 min*		** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Gulfstream (Grumman) Gulfstream G-V	Gulfstream (Grumman) Gulfstream G100	Gulfstream (Grumman) Gulfstream G200	Gulfstream (Grumman) Gulfstream G300
Data Source		B/CA May 2003	B/CA May 2003	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		1,137.0	316.6	369.0	950.4
Passengers in Executive Config.		15 *	7	10	14
Cabin Dimensions (ft)	Length	40.6	17.1	24.4	37.0
	Height	6.2	5.6	6.3	6.2
	Width (max)	7.3	4.8	7.2	7.3
Weights (lbs)	MTOW	85,100	24,650	35,450	72,000
	BOW	47,800	14,635	20,000	43,000
	Useful Load	37,300	10,015	15,450	29,000
	MFW	34,939	9,365	15,000	26,701
Engine	Number	2	2	2	2
	Model	RR BR700-710C4-11	Honeywell TFE 731-40R-200G	P&W PW306A	RR Tay Mk 611-8
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	15,385	4,250	6,040	13,850
Speeds (ktas)	High Speed Cruise	488	470	470	476
	Long Range Cruise	459	430	430	459
	M_{MO}	0.885	0.875	0.85	0.88
TOFL (ft)		5,150	5,395	6,083	5,100
Certified Ceiling (ft)		51,000	45,000	45,000	45,000
Range (nm)	Seats-Full	5,691 †	2,595 *	3,123 *	3,491 *
	Tanks-Full	5,748	2,790	3,432	3,526
Climb Performance	Time to Climb (min / altitude)	16 / 37000	16 / 37000	19 / 37000	16 / 37000
	Maximum ROC (fpm)	N/A	N/A	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	2,922	1,432	2,020	3,257
	Long-Range	2,416	1,144	1,536	2,658
Derived Parameters	Cabin Volume (cu ft)	1837.6	459.6	1106.8	1674.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.351	0.380	0.357	0.414
	Cabin Volume per Passenger (cu ft/pax)	122.5	65.7	110.7	119.6
	Available Seat-Miles (pax-nm)	85,358	18,163	31,231	48,870
Notes on Aircraft		*new engines, fuselage stretch, wingspan increase over GIV*			*shorter-range, less option-laden version of the G400*
Notes on Data		** based on info in B/CA March '97 article* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Gulfstream (Grumman) Gulfstream G400	Gulfstream (Grumman) Gulfstream G450	Gulfstream (Grumman) Gulfstream G500	Gulfstream (Grumman) Gulfstream G550
Data Source		B/CA May 2003	B/CA May 2004	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		950.4	N/A	1,137.0	1,137.0
Passengers in Executive Config.		14	14	16	16
Cabin Dimensions (ft)	Length	37.0	37.0	40.6	40.6
	Height	6.2	6.2	6.2	6.2
	Width (max)	7.3	7.3	7.3	7.3
Weights (lbs)	MTOW	74,600	73,900	85,100	91,000
	BOW	43,900	43,000	47,800	48,300
	Useful Load	30,700	30,900	37,300	42,700
	MFW	29,281	29,500	34,939	40,994
Engine	Number	2	2	2	2
	Model	RR Tay Mk 611-8	RR Tay Mk 611-8C	RR BR700-710C4-11	RR BR700-710C4-11
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	13,850	13,850	15,385	15,385
Speeds (ktas)	High Speed Cruise	476	476	488	488
	Long Range Cruise	459	459	459	459
	M_{MO}	0.88	0.88	0.885	0.885
TOFL (ft)		5,450	5,450	5,150	5,910
Certified Ceiling (ft)		45,000	45,000	51,000	51,000
Range (nm)	Seats-Full	3,857 *	4,165	5,691 *	6,458 *
	Tanks-Full	3,976	4,294	5,748	6,658
Climb Performance	Time to Climb (min / altitude)	17 / 37000	16 / 37000	16 / 37000	18 / 37000
	Maximum ROC (fpm)	N/A	N/A	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	3,293	3,060	2,922	3,040
	Long-Range	2,774	2,585	2,416	2,512
Derived Parameters	Cabin Volume (cu ft)	1674.6	1674.6	1837.6	1837.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.432	0.402	0.329	0.342
	Cabin Volume per Passenger (cu ft/pax)	119.6	119.6	114.8	114.8
	Available Seat-Miles (pax-nm)	53,994	58,313	91,048	103,332
Notes on Aircraft		*formerly GIV-SP*	*integrating G500 cockpit with G400 fuselage/wing/tail. Replace G400*	*shorter-range, less option-laden version of the G550*	*originally GV-SP (increased weight GV)*
Notes on Data		** estimated w/ 45 min reserve*		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Handley Page Dart Herald	Lockheed 1329 Jetstar 6	Lockheed 1329 Jetstar 8	Lockheed 1329-25 Jetstar II
Data Source		B/CA April 1960	B/CA April 1963	B/CA April 1967	B/CA April 1977
Wing Area (sq ft)		N/A	542.5	542.5	542.5
Passengers in Executive Config.		20 *	8	8	8
Cabin Dimensions (ft)	Length	54.0 *	28.2	28.2	28.2
	Height	6.2	6.2	6.2	6.2
	Width (max)	8.7	6.1	6.1	6.1
Weights (lbs)	MTOW	39,000	40,921	41,900	43,750
	BOW	25,700	18,740	22,074	24,178
	Useful Load	13,300	22,181	19,826	19,572
	MFW	7,128	17,312	17,556	17,822
Engine	Number	2	4	4	4
	Model	RR Dart R. Da. 7	P&W JT12A-6	P&W JT12A-8	Honeywell TFE 731-3
	Type	prop	jet	jet	fan
	Thrust (lb st.) or ESHP each	2,100	3,000	3,300	3,700
Speeds (ktas)	High Speed Cruise	239	478	444	464
	Long Range Cruise	239	430	416	425
	M_{MO}	N/A	0.82	0.82	0.82
TOFL (ft)		2,300	5,230	6,000 *	6,200
Certified Ceiling (ft)		30,000	43,000	38,000	43,000
Range (nm)	Seats-Full	1,086	2,395 *	2,200 †	2,690
	Tanks-Full	1,086	2,395	2,200	2,690
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	N/A	4,200	3,400	4,200
Fuel Flow (lbs/hr)	High-Speed	1,221	4,950	3,680	3,075 *
	Long-Range	1,221	2,739	2,907	2,300 *
Derived Parameters	Cabin Volume (cu ft)	2912.8	1066.5	1066.5	1066.5
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.256	0.796	0.874	0.676
	Cabin Volume per Passenger (cu ft/pax)	145.6	133.3	133.3	133.3
	Available Seat-Miles (pax-nm)	21,710	19,156	17,601	21,520
Notes on Aircraft		*airliner heavy turboprop*	*response to USAF UCX RFP, first purpose-built business jet.*	*more powerful engines than -6*	*engine upgrade of Jetstar 8*
Notes on Data		** B/CA '64*	** estimated w/ 45 min reserve*	** B/CA '69* *† estimated w/ 45 min reserve*	** B/CA '75*

		Aircraft Manufacturer & Model			
		Messerschmitt HFB-320 Hansa Jet	Mitsubishi MU-2D	Mitsubishi MU-2F	Mitsubishi MU-2J
Data Source		B/CA April 1967	B/CA April 1967	B/CA April 1969	B/CA April 1972
Wing Area (sq ft)		324.4	178.0	178.0	178.0
Passengers in Executive Config.		7	5	5	8
Cabin Dimensions (ft)	Length	15.0	11.0	11.0	20.6
	Height	6.3	4.9	4.9	4.9
	Width (max)	5.9	4.3	4.3	4.3
Weights (lbs)	MTOW	18,740	8,930	9,920	10,800
	BOW	11,025	5,340	5,790	6,880
	Useful Load	7,715	3,590	4,130	3,920
	MFW	6,950	1,947	2,416	2,452
Engine	Number	2	2	2	2
	Model	GE CJ610-1	Honeywell TPE 331	Honeywell TPE 331	Honeywell TPE 331-6-251M
	Type	jet	prop	prop	prop
	Thrust (lb st.) or ESHP each	2,850	605	705	665
Speeds (ktas)	High Speed Cruise	445	269	298	300
	Long Range Cruise	394	237	298	300
	M_{MO}	0.76	N/A	N/A	N/A
TOFL (ft)		5,500 *	1,500	1,700	1,890
Certified Ceiling (ft)		38,000	26,500	30,400	30,800
Range (nm)	Seats-Full	940 †	1,049 *	1,690 *	1,269 *
	Tanks-Full	1,064	1,049	1,690	1,354
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	4,080	2,220	2,875	2,590
Fuel Flow (lbs/hr)	High-Speed	2,550	376	376	695 †
	Long-Range	2,015	376	376	466 †
Derived Parameters	Cabin Volume (cu ft)	557.6	231.8	231.8	434.0
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.730	0.317	0.252	0.194
	Cabin Volume per Passenger (cu ft/pax)	79.7	46.4	46.4	54.3
	Available Seat-Miles (pax-nm)	6,577	5,244	8,450	10,148
Notes on Aircraft		*forward-sweep wing*		*commercial version of -2D, new engines*	*stretched version of -2F*
Notes on Data		** B/CA '72* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve* *† B/CA '74*

		Aircraft Manufacturer & Model			
		Mitsubishi MU-2K	Mitsubishi MU-2L	Mitsubishi MU-2M	Mitsubishi MU-2N
Data Source		B/CA April 1974	B/CA April 1975	B/CA April 1975	B/CA April 1978
Wing Area (sq ft)		178.0	178.0	178.0	178.0
Passengers in Executive Config.		5	8	5	8
Cabin Dimensions (ft)	Length	11.0	15.5	11.0	12.0
	Height	4.9	4.8	4.9	4.3
	Width (max)	4.3	4.3	4.3	4.9
Weights (lbs)	MTOW	9,920	11,575	10,470	11,575
	BOW	7,129	8,055	7,330	8,238
	Useful Load	2,791	3,520	3,140	3,337
	MFW	2,452	2,452	2,452	2,439
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-6-251M	Honeywell TPE 331-6-251M	Honeywell TPE 331-6-251M	Honeywell TPE 331-5-252M
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	665	776	724	776
Speeds (ktas)	High Speed Cruise	308	280	304	281
	Long Range Cruise	244	230	240	248
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		1,700	2,700	1,800	4,200
Certified Ceiling (ft)		25,000	25,000	28,000	25,000
Range (nm)	Seats-Full	616	909	1,145	881
	Tanks-Full	1,238	1,072	1,320	1,019
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,600	2,200	2,325	2,200
Fuel Flow (lbs/hr)	High-Speed	648	682	642	722
	Long-Range	432	479	444	518
Derived Parameters	Cabin Volume (cu ft)	231.8	319.9	231.8	252.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.354	0.260	0.370	0.261
	Cabin Volume per Passenger (cu ft/pax)	46.4	40.0	46.4	31.6
	Available Seat-Miles (pax-nm)	3,080	7,272	5,725	7,048
Notes on Aircraft		*-2F version w/new engines*	*similar to -2J w/ increased MTOW*	*similar to -2K w/ increased MTOW*	
Notes on Data					

		Aircraft Manufacturer & Model			
		Mitsubishi MU-2P	Mitsubishi MU-2B-40 (Solitare)	Mitsubishi MU-2B-60 (Marquise)	Mitsubishi Diamond I (MU-300)
Data Source		B/CA April 1978	B/CA April 1979	B/CA April 1979	B/CA April 1982
Wing Area (sq ft)		178.0	178.0	178.0	241.4
Passengers in Executive Config.		5	6	7	7
Cabin Dimensions (ft)	Length	7.3	8.0	15.9	15.7
	Height	4.3	4.3	4.3	4.8
	Width (max)	4.9	4.9	4.9	4.9
Weights (lbs)	MTOW	10,470	10,470	11,575	14,430
	BOW	7,532	7,478	8,157	9,515
	Useful Load	2,938	2,992	3,418	4,915
	MFW	2,439	2,700	2,700	4,255
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-5-252M	Honeywell TPE 331-10U	Honeywell TPE 331-10-501M	P&W JT15D-4
	Type	prop	prop	prop	fan
	Thrust (lb st.) or ESHP each	724	665	715	2,500
Speeds (ktas)	High Speed Cruise	310	313	296	425
	Long Range Cruise	240	258	257	369
	M_{MO}	N/A	N/A	N/A	0.785
TOFL (ft)		3,650	2,750	3,300	4,050
Certified Ceiling (ft)		28,000	31,000	29,400	41,000
Range (nm)	Seats-Full	1,035	1,050	1,119	1,224
	Tanks-Full	1,222	1,480	1,340	1,615
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,325	2,350	2,200	3,100
Fuel Flow (lbs/hr)	High-Speed	596	656	662	1,159
	Long-Range	440	610	538	833
Derived Parameters	Cabin Volume (cu ft)	153.8	168.6	335.0	369.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.367	0.394	0.299	0.322
	Cabin Volume per Passenger (cu ft/pax)	30.8	28.1	47.9	52.8
	Available Seat-Miles (pax-nm)	5,175	6,300	7,833	8,568
Notes on Aircraft			*similar to -2P w/ new engines and increased fuel capcity*	*similar to -2N w/ new engines and increased fuel capcity*	*sold to Raytheon in 1985*
Notes on Data					

		Aircraft Manufacturer & Model			
		Mitsubishi Diamond IA	Mitsubishi Diamond II	Piaggio P-180	Piaggio PD 808 Vespajet
Data Source		B/CA April 1984	B/CA April 1985	B/CA May 2003	B/CA April 1969
Wing Area (sq ft)		241.4	241.4	172.2	225.0
Passengers in Executive Config.		7	7	7	7
Cabin Dimensions (ft)	Length	15.7	15.7	14.1	20.0
	Height	4.8	4.8	5.8	4.7
	Width (max)	4.9	4.9	6.1	5.4
Weights (lbs)	MTOW	14,630	15,780	11,550	18,000
	BOW	9,640	9,925	7,670	10,745
	Useful Load	4,990	5,855	3,880	7,255
	MFW	4,260	4,904	2,802	6,508
Engine	Number	2	2	2	2
	Model	P&W JT15D-4D	P&W JT15D-5	P&W PT6A-66	RR Bristol Viper 526
	Type	fan	fan	prop	jet
	Thrust (lb st.) or ESHP each	2,500	2,900	850	3,360
Speeds (ktas)	High Speed Cruise	422	446	392	385
	Long Range Cruise	375	394	311	370
	M_{MO}	0.785	0.79	N/A	0.75
TOFL (ft)		3,940	3,950	2,850	3,350
Certified Ceiling (ft)		41,000	41,000	41,000	45,000
Range (nm)	Seats-Full	1,220	1,593	1,418 *	951 *
	Tanks-Full	1,594	1,873	1,575	1,087
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	9 / 25000	N/A
	Maximum ROC (fpm)	3,050	3,960 *	N/A	5,100
Fuel Flow (lbs/hr)	High-Speed	1,156	1,298	781	2,100
	Long-Range	870	890	387	1,764
Derived Parameters	Cabin Volume (cu ft)	369.3	369.3	498.9	507.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.331	0.323	0.178	0.681
	Cabin Volume per Passenger (cu ft/pax)	52.8	52.8	71.3	72.5
	Available Seat-Miles (pax-nm)	8,540	11,151	9,923	6,654
Notes on Aircraft		*new engines, increased MTOW for -I*	*new engines for -I. Sold to Raytheon in 1985. Almost immediately became Beechjet 400*		*29 aircraft produced; no deliveries on record to US*
Notes on Data			** based on Beechjet 400*	** estimate*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Pilatus PC-12	New Piper PA-31T-501T Cheyenne I	New Piper PA-31T-501T Cheyenne IA	New Piper PA-31T-620 Cheyenne II
Data Source		B/CA May 2003	B/CA April 1979	B/CA April 1984	B/CA April 1974
Wing Area (sq ft)		277.8	229.0	229.0	229.0
Passengers in Executive Config.		6	6 *	6 *	6 *
Cabin Dimensions (ft)	Length	16.9	8.0 *	8.0 *	8.0 *
	Height	4.8	4.3	4.3	4.3
	Width (max)	5.0	4.2	4.2	4.2
Weights (lbs)	MTOW	9,920	8,700	8,700	9,000
	BOW	6,295	5,783	5,555	5,813
	Useful Load	3,625	2,917	3,145	3,187
	MFW	2,704	2,559	2,452	2,559
Engine	Number	1	2	2	2
	Model	P&W PT6A-67B	P&W PT6A-11	P&W PT6A-11	P&W PT6A-28
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	1,200	500	500	620
Speeds (ktas)	High Speed Cruise	270	249	261	278
	Long Range Cruise	202	189	249	195
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,300	2,986	2,490	2,000
Certified Ceiling (ft)		30,000	28,200	29,000	29,000
Range (nm)	Seats-Full	1,416	1,077	951	934
	Tanks-Full	1,833	1,331	1,199	1,238
Climb Performance	Time to Climb (min / altitude)	24 / 25000	N/A	N/A	N/A
	Maximum ROC (fpm)	N/A	1,750	1,750	2,800
Fuel Flow (lbs/hr)	High-Speed	453	566	549	688
	Long-Range	226	364	412	370
Derived Parameters	Cabin Volume (cu ft)	405.6	144.5	144.5	144.5
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.186	0.321	0.276	0.316
	Cabin Volume per Passenger (cu ft/pax)	67.6	24.1	24.1	24.1
	Available Seat-Miles (pax-nm)	8,496	6,462	5,706	5,604
Notes on Aircraft			*low cost version of Cheyenne II*	*minor improvements of Cheyenne I*	*originally known as "Cheyenne." Renamed upon intro. of Cheyenne I*
Notes on Data			** aligned w/ B/CA '82 information*	** aligned w/ B/CA '82 information*	** aligned w/ B/CA '82 information*

		Aircraft Manufacturer & Model			
		New Piper PA-31T2-620 Cheyenne II-XL	New Piper PA-42-7 Cheyenne III	New Piper PA-42-720 Cheyenne IIIA	New Piper PA-42-1000 Cheyenne IV (400)
Data Source		B/CA April 1982	B/CA April 1983	B/CA April 1984	B/CA April 1985
Wing Area (sq ft)		229.0	293.0	293.0	293.0
Passengers in Executive Config.		7 *	8 *	8	8
Cabin Dimensions (ft)	Length	10.0 *	14.9 *	17.6	17.7
	Height	4.3	4.3	4.4	4.7
	Width (max)	4.2	4.2	4.3	4.3
Weights (lbs)	MTOW	9,474	11,200	11,200	12,050
	BOW	5,926	7,184	7,154	7,856
	Useful Load	3,548	4,016	4,046	4,194
	MFW	2,559	3,873	3,752	3,819
Engine	Number	2	2	2	2
	Model	P&W PT6A-135	P&W PT6A-41	P&W PT6A-61	Honeywell TPE 331-14-801
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	620	720	720	1,000
Speeds (ktas)	High Speed Cruise	277	291	313	351
	Long Range Cruise	255	281	300	334
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,940	3,230	2,280	2,230
Certified Ceiling (ft)		31,000	33,000	35,000	41,000
Range (nm)	Seats-Full	1,062	1,075	1,128	1,182
	Tanks-Full	1,070	1,814	1,857	1,842
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	1,750	2,920	2,380	3,242
Fuel Flow (lbs/hr)	High-Speed	700	768	760	940
	Long-Range	424	536	535	620
Derived Parameters	Cabin Volume (cu ft)	180.6	269.1	333.0	357.7
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.238	0.238	0.223	0.232
	Cabin Volume per Passenger (cu ft/pax)	25.8	33.6	41.6	44.7
	Available Seat-Miles (pax-nm)	7,434	8,600	9,024	9,456
Notes on Aircraft		*Cheyenne II w/ fuselage stretch*	*fuselage stretch, increased wingspan, T-tail version of Cheyenne II*	*minor improvements of Cheyenne III*	*upgraded Cheyenne III*
Notes on Data		** aligned w/ B/CA '82 information*	** aligned w/ B/CA '82 information*		

		Aircraft Manufacturer & Model			
		New Piper PA-46-500TP Meridian	Raytheon Aircraft King Air 90/A90	Raytheon Aircraft King Air B90	Raytheon Aircraft King Air C90
Data Source		B/CA May 2003	B/CA April 1967	B/CA April 1969	B/CA April 1971
Wing Area (sq ft)		183.0	279.74	293.94	293.94
Passengers in Executive Config.		4	4	4	4
Cabin Dimensions (ft)	Length	12.3	12.9 *	12.9	12.9
	Height	3.9	4.8	4.8	4.8
	Width (max)	4.1	4.5	4.5	4.5
Weights (lbs)	MTOW	5,092	9,300	9,650	9,650
	BOW	3,594	5,680	5,685	5,526
	Useful Load	1,498	3,620	3,965	4,124
	MFW	1,139	2,534	2,534	2,534
Engine	Number	1	2	2	2
	Model	P&W PT6A-42A	P&W PT6A-20	P&W PT6A-20	P&W PT6A-20
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	500	500	550	550
Speeds (ktas)	High Speed Cruise	257	219	220	217
	Long Range Cruise	178	179	220	217
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,438	1,420	1,200	1,340
Certified Ceiling (ft)		30,000	27,000	27,200	25,600
Range (nm)	Seats-Full	470	1,344 †	1,176 *	1,292 *
	Tanks-Full	960	1,344	1,176	1,292
Climb Performance	Time to Climb (min / altitude)	19 / 25000	N/A	N/A	N/A
	Maximum ROC (fpm)	N/A	1,900	2,000	2,000
Fuel Flow (lbs/hr)	High-Speed	242	396	416 †	540 †
	Long-Range	135	307	416 †	378
Derived Parameters	Cabin Volume (cu ft)	196.7	278.6	278.6	278.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.190	0.429	0.473	0.435
	Cabin Volume per Passenger (cu ft/pax)	49.2	69.7	69.7	69.7
	Available Seat-Miles (pax-nm)	1,880	5,376	4,704	5,169
Notes on Aircraft			*turbine powered 80/88 Queen Air*		*less expensive model 90*
Notes on Data			** B/CA '69* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve* *† B/CA '70*	** estimated w/ 45 min reserve* *† B/CA '74*

		Aircraft Manufacturer & Model			
		Raytheon Aircraft King Air C90B	Raytheon Aircraft King Air E90	Raytheon Aircraft King Air F90	Raytheon Aircraft King Air A100
Data Source		B/CA May 1994	B/CA April 1974	B/CA April 1980	B/CA April 1970
Wing Area (sq ft)		293.94	293.94	279.7	279.7
Passengers in Executive Config.		4	4	4	6
Cabin Dimensions (ft)	Length	12.9	12.9	12.7	16.7 *
	Height	4.8	4.8	4.8	4.8
	Width (max)	4.5	4.5	4.5	4.5
Weights (lbs)	MTOW	10,100	10,100	10,950	10,600
	BOW	6,875	6,634	7,190	6,372
	Useful Load	3,225	3,466	3,760	4,228
	MFW	2,573	3,176	3,149	2,468
Engine	Number	2	2	2	2
	Model	P&W PT6A-21	P&W PT6A-28	P&W PT6A-135	P&W PT6A-28
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	550	550	750	680
Speeds (ktas)	High Speed Cruise	247	248	267	239
	Long Range Cruise	194	196	211	226
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,710	2,024	2,875	1,729
Certified Ceiling (ft)		30,000	27,600	29,802	25,900
Range (nm)	Seats-Full	953 *	969	1,246	1,059 †
	Tanks-Full	1,176	1,513	1,537	1,059
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	/	N/A
	Maximum ROC (fpm)	2,003	1,870	2,380	2,200
Fuel Flow (lbs/hr)	High-Speed	592	672	750	716 ††
	Long-Range	316	392	368	454 ††
Derived Parameters	Cabin Volume (cu ft)	278.6	278.6	274.3	360.7
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.407	0.500	0.436	0.335
	Cabin Volume per Passenger (cu ft/pax)	69.7	69.7	68.6	60.1
	Available Seat-Miles (pax-nm)	3,810	3,876	4,984	6,356
Notes on Aircraft		*upgraded interior & cockpit, new propellers*	*more powerful engines*	*C90 fuselage, A100 wing, B200 tail*	*longer fuselage, more powerful engines, reduced wing span*
Notes on Data		** estimated w/ 45 min reserve*			** same as -200* *† estimated w/ 45 min reserve* *†† B/CA '74*

		Aircraft Manufacturer & Model			
		Raytheon Aircraft King Air B100	Raytheon Aircraft King Air 200	Raytheon Aircraft King Air B200	Raytheon Aircraft King Air 300
Data Source		B/CA April 1976	B/CA April 1974	B/CA April 1985	B/CA April 1985
Wing Area (sq ft)		279.7	303.0	303.0	303.0
Passengers in Executive Config.		6	6	6	6
Cabin Dimensions (ft)	Length	16.7 *	16.7 *	16.7 *	16.7 *
	Height	4.8	4.8	4.8	4.8
	Width (max)	4.5	4.5	4.5	4.5
Weights (lbs)	MTOW	11,800	12,500	12,500	14,000
	BOW	7,824	8,355	8,181	8,838
	Useful Load	3,976	4,145	4,319	5,162
	MFW	3,149	3,645	3,645	3,611
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-6-252B	P&W PT6A-41	P&W PT6A-42	P&W PT6A-60A
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	715	850	850	1,050
Speeds (ktas)	High Speed Cruise	267	286	291	316
	Long Range Cruise	226	209	280	300
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,700	3,200	3,300	2,208
Certified Ceiling (ft)		29,100	31,000	35,000	35,000
Range (nm)	Seats-Full	1,135	1,003	1,212	1,546
	Tanks-Full	1,386	1,453	1,653	1,761
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,140	2,450	2,450	2,844
Fuel Flow (lbs/hr)	High-Speed	634	876	700 †	800
	Long-Range	494	470	540 †	612
Derived Parameters	Cabin Volume (cu ft)	360.7	360.7	360.7	360.7
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.364	0.375	0.321	0.340
	Cabin Volume per Passenger (cu ft/pax)	60.1	60.1	60.1	60.1
	Available Seat-Miles (pax-nm)	6,810	6,018	7,272	9,276
Notes on Aircraft		*new engines*	*increased wing span, more powerful engines, IGW, T-tail*	*replaced 200 model. New engines, increased MZFW*	*aerodynamic clean up of B200, new engines, increased MTOW*
Notes on Data		* *same as -200*	* *B/CA 2003*	* *B/CA 2003* † *B/CA '74*	* *B/CA 2003*

		Aircraft Manufacturer & Model			
		Raytheon Aircraft King Air 350	Raytheon Aircraft Starship 2000	Raytheon Aircraft Starship 2000A	Raytheon Aircraft Premier I 390
Data Source		B/CA May 1991	B/CA May 1990	B/CA May 1993	B/CA May 2003
Wing Area (sq ft)		310.0	280.9	280.9	247.0
Passengers in Executive Config.		8	8	6	6
Cabin Dimen-sions (ft)	Length	19.5	21.1	21.1	11.2
	Height	4.8	5.5	5.5	5.4
	Width (max)	4.5	5.5	5.5	5.5
Weights (lbs)	MTOW	15,000	14,400	14,900	12,500
	BOW	9,251	10,365	10,329	8,470
	Useful Load	5,749	4,035	4,571	4,030
	MFW	3,611	3,550	3,786	3,670
Engine	Number	2	2	2	2
	Model	P&W PT6A-60A	P&W PT6A-67A	P&W PT6A-67A	Wms RR FJ44-2A
	Type	prop	prop	prop	fan
	Thrust (lb st.) or ESHP each	1,050	1,200	1,200	2,300
Speeds (ktas)	High Speed Cruise	311	335	335	451
	Long Range Cruise	230	266	283	369
	M_{MO}	N/A	N/A	N/A	0.80
TOFL (ft)		3,737	4,300	3,854 *	3,792
Certified Ceiling (ft)		35,000	41,000	41,000	41,000
Range (nm)	Seats-Full	1,524	990 *	1,340 †	1,153 *
	Tanks-Full	1,524	1,286	1,457	1,460
Climb Perfor-mance	Time to Climb (min / altitude)	N/A	N/A	N/A	17 / 37000
	Maximum ROC (fpm)	2,731	3,225	2,748	N/A
Fuel Flow (lbs/hr)	High-Speed	772	990	998	1,203
	Long-Range	380	494	526	662
Derived Para-meters	Cabin Volume (cu ft)	421.2	638.3	638.3	332.6
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.207	0.232	0.310	0.299
	Cabin Volume per Passenger (cu ft/pax)	52.7	79.8	106.4	55.4
	Available Seat-Miles (pax-nm)	12,192	7,922	8,043	6,920
Notes on Aircraft		*replaced 300 model*		*IGW -2000, removed 2 pax*	
Notes on Data			** estimated w/ 45 min reserve*	** B/CA March '93 article* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Raytheon Aircraft Beechjet 400	Raytheon Aircraft Beechjet 400A	Raytheon Aircraft Hawker 400XP	Raytheon Aircraft Hawker 800XP
Data Source		B/CA April 1986	B/CA May 2003	B/CA May 2003	B/CA May 2003
Wing Area (sq ft)		241.4	241.4	241.4	374.0
Passengers in Executive Config.		7	7	7	8
Cabin Dimensions (ft)	Length	15.6	15.5	15.5	21.3
	Height	4.8	4.8	4.8	5.7
	Width (max)	4.9	4.9	4.9	6.0
Weights (lbs)	MTOW	15,780	16,300	16,300	28,000
	BOW	9,975	10,950	10,950	16,245
	Useful Load	5,805	5,350	5,350	11,755
	MFW	4,904	4,912	4,912	10,000
Engine	Number	2	2	2	2
	Model	P&W JT15D-5	P&W JT15D-5	P&W JT15D-5	Honeywell TFE 731-5BR
	Type	fan	fan	fan	fan
	Thrust (lb st.) or ESHP each	2,900	2,965	2,965	4,660
Speeds (ktas)	High Speed Cruise	447	450	450	447
	Long Range Cruise	388	414	414	402
	M_{MO}	0.785	0.78	0.78	0.80
TOFL (ft)		3,950	3,906	3,906	5,032
Certified Ceiling (ft)		41,000	45,000	45,000	41,000
Range (nm)	Seats-Full	1,766 *	1,200 *	1,200 *	2,407 *
	Tanks-Full	1,999	1,428	1,428	2,407
Climb Performance	Time to Climb (min / altitude)	N/A	18 / 37000	18 / 37000	20 / 37000
	Maximum ROC (fpm)	3,960	N/A	N/A	N/A
Fuel Flow (lbs/hr)	High-Speed	1,211	1,255	1,255	1,824
	Long-Range	831	938	938	1,214
Derived Parameters	Cabin Volume (cu ft)	366.9	364.6	364.6	728.5
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.306	0.324	0.324	0.377
	Cabin Volume per Passenger (cu ft/pax)	52.4	52.1	52.1	91.1
	Available Seat-Miles (pax-nm)	12,360	8,397	8,397	19,256
Notes on Aircraft		*formerly MHI Diamond II. Sold to Raytheon from MHI in 1985*	*originally Beechjet 400. larger cabin, higher ceiling, new avionics.*	*formerly Beechjet 400A.*	*sold to Raytheon from BAe in 1993. Rebranded 800XP in 1995*
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Raytheon Aircraft Hawker 1000	Raytheon Aircraft Hawker Horizon	Rockwell Aero Commander AE-680T Turbo Commander	Rockwell Aero Commander AE-680V Turbo II Commander
Data Source		B/CA May 1992	B/CA May 2003	B/CA April 1965	B/CA April 1969
Wing Area (sq ft)		374.0	531.0	242.5	242.5
Passengers in Executive Config.		8	8	10	10
Cabin Dimensions (ft)	Length	24.4	25.0	14.5	14.5
	Height	5.8	6.0	4.6	4.6
	Width (max)	6.0	6.5	4.3	4.3
Weights (lbs)	MTOW	31,000	37,500	8,500	9,450
	BOW	17,600	21,555	5,100	5,833
	Useful Load	13,400	15,945	3,400	3,617
	MFW	11,440	14,300	1,861	1,894
Engine	Number	2	2	2	2
	Model	P&W PW305	P&W PW308A	Honeywell TPE 331	Honeywell TPE 331
	Type	fan	fan	prop	prop
	Thrust (lb st.) or ESHP each	5,225	6,900	575	575
Speeds (ktas)	High Speed Cruise	452	470	247	250
	Long Range Cruise	402	430	234 *	248
	M_{MO}	0.80	0.84	N/A	N/A
TOFL (ft)		6,000	5,088	2,000	1,975
Certified Ceiling (ft)		43,000	45,000	30,000	26,500
Range (nm)	Seats-Full	3,095 *	3,294 *	577 †	735 *
	Tanks-Full	3,095	3,294	824	892
Climb Performance	Time to Climb (min / altitude)	N/A	13 / 37000	N/A	N/A
	Maximum ROC (fpm)	3,577	N/A	2,000	2,025
Fuel Flow (lbs/hr)	High-Speed	1,700	1,823	455	455
	Long-Range	1,142	1,501	436 *	436
Derived Parameters	Cabin Volume (cu ft)	849.1	975.0	286.8	286.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.355	0.436	0.186	0.176
	Cabin Volume per Passenger (cu ft/pax)	106.1	121.9	28.7	28.7
	Available Seat-Miles (pax-nm)	24,760	26,352	5,766	7,346
Notes on Aircraft		*sold to Raytheon from BAe in 1993.*			
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*	** based on B/CA '67* *† estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*

		Aircraft Manufacturer & Model			
		Rockwell Aero Commander AE-681 Hawk Commander	Rockwell Aero Commander AE-690 /A Turbo Commander	Rockwell Aero Commander AE-690B Turbo Commander	Rockwell Aero Commander AE-840 (RI 840)
Data Source		B/CA April 1970	B/CA April 1972	B/CA April 1977	B/CA April 1982
Wing Area (sq ft)		242.5	266.0	266.0	279.37
Passengers in Executive Config.		7	7	6	7
Cabin Dimensions (ft)	Length	14.5	14.3	9.5	9.5
	Height	4.6	4.5	4.5	4.5
	Width (max)	4.3	4.0	4.0	4.1
Weights (lbs)	MTOW	9,450	9,900	10,325	10,325
	BOW	5,647	5,850	7,238	6,948
	Useful Load	3,803	4,050	3,087	3,377
	MFW	1,894	2,157	2,573	3,176
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331	Honeywell TPE 331-5-251K	Honeywell TPE 331-5-251K	Honeywell TPE 331-5-254K
	Type	prop	prop	prop	prop
	Thrust (lb st.) or ESHP each	575	575	718	718
Speeds (ktas)	High Speed Cruise	290	280	283	284
	Long Range Cruise	271	241	220	237
	M_{MO}	N/A	N/A	N/A	N/A
TOFL (ft)		2,016	2,001	2,280	1,833
Certified Ceiling (ft)		25,600	25,000	31,000	31,000
Range (nm)	Seats-Full	975 *	1,201 *	889	1,035
	Tanks-Full	975	1,201	1,284	1,775
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,007	3,003	2,830	2,824
Fuel Flow (lbs/hr)	High-Speed	455	594	588	556
	Long-Range	436	376	424	352
Derived Parameters	Cabin Volume (cu ft)	286.8	257.4	171.0	175.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.230	0.223	0.321	0.212
	Cabin Volume per Passenger (cu ft/pax)	41.0	36.8	28.5	25.0
	Available Seat-Miles (pax-nm)	6,826	8,407	5,334	7,245
Notes on Aircraft					*sold to Gulfstream*
Notes on Data		** estimated w/ 45 min reserve*	** estimated w/ 45 min reserve*		

		Aircraft Manufacturer & Model			
		Rockwell Aero Commander AE-980 (RI 980)	Rockwell Aero Commander AE-1121 Jet Commander	Rockwell North American NA-40 Sabreliner	Rockwell North American NA-40A Sabre Commander
Data Source		B/CA April 1982	B/CA April 1967	B/CA April 1967	B/CA April 1972
Wing Area (sq ft)		279.37	303.3	342.55	342.05
Passengers in Executive Config.		7	7	6	6
Cabin Dimensions (ft)	Length	12.4	18.2 *	21.4	21.2
	Height	4.8	4.8	5.6 *	5.6 *
	Width (max)	4.1	4.9	5.2 *	5.2 *
Weights (lbs)	MTOW	10,325	16,800	18,650	19,035
	BOW	7,036	9,560	9,895 †	10,390
	Useful Load	3,289	7,240	8,755	8,645
	MFW	3,176	6,112	7,016	7,016
Engine	Number	2	2	2	2
	Model	Honeywell TPE 331-5	GE CJ610-1	P&W JT12A-8A	P&W JT12A-8
	Type	prop	jet	jet	jet
	Thrust (lb st.) or ESHP each	748	2,850	3,300	3,300
Speeds (ktas)	High Speed Cruise	302	455	485	482
	Long Range Cruise	298	437	424	407 †
	M_{MO}	N/A	0.765	0.85	0.81
TOFL (ft)		1,854	3,200	4,275	4,500
Certified Ceiling (ft)		31,000	45,000	45,000	45,000
Range (nm)	Seats-Full	898	1,882 †	1,700 ††	1,700 †
	Tanks-Full	1,634	1,985	1,700 ††	1,750
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	2,777	5,000	4,700	4,900
Fuel Flow (lbs/hr)	High-Speed	641	1,462	2,770	2,855 †
	Long-Range	509	1,155	1,128 **	1,163 †
Derived Parameters	Cabin Volume (cu ft)	244.0	428.1	623.2	617.3
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.244	0.378	0.444	0.476
	Cabin Volume per Passenger (cu ft/pax)	34.9	61.2	103.9	102.9
	Available Seat-Miles (pax-nm)	6,286	13,173	10,200	10,200
Notes on Aircraft		*sold to Gulfstream*	*first business jet for Aero Commander*	*designed to meet USAF UTX RFP - First biz jet for North American.*	*wing from 75, fuselage & engines from 40. Reduced price version of 40.*
Notes on Data			** based on BCA '69 entry under IAI Commodore Jet (MTOW and engine mods).* *† estimated w/ 45 min reserve*	** consistent across -40 and -60 series.* *† mis-stated in B/CA '67* *†† Based on similar data from BCA 1974* ***based on -40A.*	** made to be consistent across -40 and -60 series. Data from 1969-70 JAWA* *† B/CA '74*

		Aircraft Manufacturer & Model			
		Rockwell North American NA-60 Sabreliner	Rockwell North American NA-65 Sabreliner	Rockwell North American NA-75 Sabreliner	Rockwell North American NA-75A Sabreliner
Data Source		B/CA April 1969	B/CA April 1981	B/CA April 1972	B/CA April 1974
Wing Area (sq ft)		342.55	380.0	342.05	342.05
Passengers in Executive Config.		8	8	8	8
Cabin Dimensions (ft)	Length	25.0	19.0	24.6	19.0
	Height	5.6 *	5.6 *	6.0 *	6.0 *
	Width (max)	5.2 *	5.2 *	5.2 *	5.2 *
Weights (lbs)	MTOW	20,273	23,800	21,200	22,800
	BOW	11,140	14,100	11,940	13,650
	Useful Load	9,133	9,700	9,260	9,150
	MFW	7,016	8,684	7,260	7,377
Engine	Number	2	2	2	2
	Model	P&W JT12A-8	Honeywell TFE 731-3R-1D	P&W JT12A-8	GE CF700-2D2
	Type	jet	fan	jet	fan
	Thrust (lb st.) or ESHP each	3,300	3,700	3,300	4,315
Speeds (ktas)	High Speed Cruise	482 †	441	482	446 †
	Long Range Cruise	430	420	407 †	422 †
	M_{MO}	0.81	0.83	0.81	0.80
TOFL (ft)		5,050 ††	5,300	5,780	4,825
Certified Ceiling (ft)		45,000	45,000	45,000	45,000
Range (nm)	Seats-Full	1,770 †	2,677 †	1,700 ††	1,260 †
	Tanks-Full	1,770 †	2,893	1,700 ††	1,260 †
Climb Performance	Time to Climb (min / altitude)	N/A	N/A	N/A	N/A
	Maximum ROC (fpm)	4,660	3,450	4,000	4,500
Fuel Flow (lbs/hr)	High-Speed	2,805 †	1,223	1,520	2,140 †
	Long-Range	1,125 †	1,137	1,163	1,686 †
Derived Parameters	Cabin Volume (cu ft)	728.0	553.3	767.5	592.8
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.327	0.338	0.357	0.499
	Cabin Volume per Passenger (cu ft/pax)	91.0	69.2	95.9	74.1
	Available Seat-Miles (pax-nm)	14,160	21,417	13,600	10,080
Notes on Aircraft		*stretched version of NA-40*	*re-engined -60A, which was in turn a mod of the -60*	*upgraded Series 60. Exact changes unknown, but BCA 4/72 implies mostly cabin changes.*	*upgraded -75 w/ higher thrust engines*
Notes on Data		** made to be consistent across -40 and -60 series. Data from 1969-70 JAWA* *† B/CA '74* *†† B/CA '73*	** made to be consistent across -40 and -60 series. Data from 1969-70 JAWA* *† estimate w/ 45 min reserve*	** data made to be consistent for both -70 series. Data from 1978-79 Janes* *† based on BCA 1974 entry for Sabreliner 40A* *†† B/CA '74*	** data made to be consistent for both -70 series. Data from 1978-79 Janes* *† B/CA '75*

		Aircraft Manufacturer & Model	
		Swearingen SJ30-2	Vickers Viscount 810
Data Source		B/CA May 2003	B/CA April 1960
Wing Area (sq ft)		190.7	N/A
Passengers in Executive Config.		4	24 *
Cabin Dimensions (ft)	Length	12.5	N/A
	Height	4.3	N/A
	Width (max)	4.7	N/A
Weights (lbs)	MTOW	13,500	72,500
	BOW	8,200	41,620
	Useful Load	5,300	30,880
	MFW	4,950	19,133
Engine	Number	2	4
	Model	Wms RR FJ44-2A	RR Dart Mk 525
	Type	fan	prop
	Thrust (lb st.) or ESHP each	2,300	1,990
Speeds (ktas)	High Speed Cruise	459	317
	Long Range Cruise	447	317
	M_{MO}	0.83	N/A
TOFL (ft)		3,993	6,160
Certified Ceiling (ft)		49,000	30,000
Range (nm)	Seats-Full	2,431 *	1,910
	Tanks-Full	2,614	1,910
Climb Performance	Time to Climb (min / altitude)	16 / 37000	N/A
	Maximum ROC (fpm)	N/A	1,240
Fuel Flow (lbs/hr)	High-Speed	732	2,409
	Long-Range	682	2,409
Derived Parameters	Cabin Volume (cu ft)	252.6	2800.0 †
	Fuel Consumption per Passenger Seat Mile (lb/nm/pax)	0.381	0.317
	Cabin Volume per Passenger (cu ft/pax)	63.2	116.7
	Available Seat-Miles (pax-nm)	9,724	45,852
Notes on Aircraft			
Notes on Data		** estimated w/ 45 min reserve*	** estimate* *† quoted in Jane's 1960/61*

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APPENDIX B: BUSINESS AIRCRAFT SHIPMENTS DATA

This appendix contains a complete list of the worldwide business airplane shipments data used for analysis in this research. According to the General Aviation Manufacturers Association, "A shipment occurs when a general aviation airplane is shipped from its production facility to a customer located anywhere in the world."

Global business airplane annual unit shipments data is taken from three primary sources, depending on the level of detail available and the years the source was published: *Aviation Week & Space Technology* "Forecast & Inventory" issues (March of 1960-1965), *Weekly of Business Aviation* (various issues, 1966-2000), and GAMA's General Aviation Airplane Shipment Report (2001 onwards). There is some overlap in the years each of these sources was published, so shipments data was corroborated among sources and made to be consistent to the greatest extent possible.

Aircraft are listed in alphabetical order by last or most recent manufacturer. For example, all Learjet aircraft are listed under Bombardier, all Dornier and Swearingen aircraft are listed under Fairchild, etcetera.

All shipments, unless noted in the tables, are for customers in the civilian market, exclusive of airline shipments.

As previously noted, in 2002 Gulfstream Aerospace stopped reporting detailed shipments data for its aircraft, instead choosing to report only grand totals for the company as a whole.

"N/A" indicates that shipments data was not available from the consulted sources for that year. "Total Shipments" in the tables reflects total known shipments of that aircraft model.

No deliveries are on record for the following recently, or not-yet certified aircraft; they are therefore not listed in the tables in this appendix:

Adam Aircraft Adam 700
Bombardier Global 5000
Bombardier Lear 40
Bombardier Lear 45XR
Cessna Mustang
Cessna 525 CJ3
Cessna 680 Citation Sovereign
Eclipse Aviation Eclipse 500
Raytheon Hawker Horizon
Sino Swearingen SJ30-2

Detailed delivery information is not available for the following certified aircraft (available information may be for the manufacturer's total product line and not broken out by model, may include airline shipments, or may not be available on a year-by-year basis); the aircraft are therefore not listed in the tables in this appendix:

Aerospatiale Corvette SN-601
Allison Super Convair
Gulfstream G300
Gulfstream G400
Gulfstream G450
Gulfstream G500
Gulfstream G550
Handley Page Dart Herald
Piaggio PD 808 Vespajet
Vickers Viscount 810

	Aircraft Manufacturer & Model						
Year	Aero-spatiale (SOCATA) TBM-700	Airbus ACJ Corporate Jet	Boeing BBJ1 (737-700-IGW)	Boeing BBJ2 (737-800)	Bombardier Challenger 300	Bombardier Global Express (BD-700)	Bombardier (Canadair) Challenger 600
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983							13
1984							4
1985							
1986							
1987							
1988							
1989							
1990	2						
1991	23						
1992	30						
1993	14						
1994	13						
1995	1						
1996							
1997							
1998			7			3	
1999	21		29			32	
2000	14	6	14			35	
2001	33	4	11	5		30	
2002	34	2	9	2		17	
2003	34	N/A	4	3	1	14	
Total	219	12	74	10	1	131	17

	Aircraft Manufacturer & Model						
Year	Bombardier (Canadair) Challenger 601	Bombardier (Canadair) Challenger 601-3A	Bombardier (Canadair) Challenger 601-3R	Bombardier (Canadair) Challenger 604 (CL-600-2B16)	Bombardier (Learjet) Lear 23	Bombardier (Learjet) Lear 24	Bombardier (Learjet) Lear 24B/D
1960							
1961							
1962							
1963							
1964					3 **		
1965					80 ***		
1966					19	32	
1967					3	30	
1968						25	
1969							34
1970					** *Av. Wk*		19
1971					*& Space*		12
1972					*Tech.*		16
1973					*Mar. 15, '65*		21
1974							22
1975					*** *Av. Wk*		18
1976					*& Space*		12
1977					*Tech.*		
1978					*Mar. 7, '66*		
1979							
1980							
1981							
1982							
1983	14						
1984	17						
1985	9						
1986	7 *	10 *					
1987	2 *	19 *					
1988		22					
1989		20					
1990	* *based on*	28					
1991	*info in*	18					
1992	*"Biz Jets"*	22					
1993	*by Phillips*	10	10				
1994	*(p. 129)*		25				
1995		* *based on*	24				
1996		*info in*	5	27			
1997		*"Biz Jets"*		34			
1998		*by Phillips*		36			
1999		*(p. 129)*		42			
2000				38			
2001				41			
2002				31			
2003				24			
Total	49	149	64	273	105	87	154

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 24E	Bombardier (Learjet) Lear 24F	Bombardier (Learjet) Lear 25/25B	Bombardier (Learjet) Lear 25C	Bombardier (Learjet) Lear 25D	Bombardier (Learjet) Lear 25G	Bombardier (Learjet) Lear 28
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967			1				
1968			16				
1969			27				
1970			12 *	4 *			
1971			7	4			
1972			14	9			
1973			38	7			
1974			35	5			
1975			14				
1976	7	2	6		4		
1977	8	9		* *estimate*	20		
1978	1	1			29		
1979		1	* *estimate*		33		5
1980					29		
1981					25		
1982					7		
1983					6		
1984					3		
1985					3	4	
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	16	13	170	29	159	4	5

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 29	Bombardier (Learjet) Lear 31	Bombardier (Learjet) Lear 31A	Bombardier (Learjet) Lear 35	Bombardier (Learjet) Lear 35A	Bombardier (Learjet) Lear 36	Bombardier (Learjet) Lear 36A
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974				3		1	
1975				34		13	
1976				27	21	2	4
1977					55		13
1978					64		7
1979	1				64		3
1980	1				88		2
1981	1				93		4
1982					39		
1983	1				12		2
1984					12		2
1985					8		1
1986					11		2
1987					12		
1988		5			15		1
1989		7			9		3
1990		13			7		1
1991		7	9		7		
1992			19		4		
1993			18		3		1
1994			14				
1995			19				
1996			13				
1997			21				
1998			22				
1999			24				
2000			28				
2001			17				
2002			9				
2003			2				
Total	4	32	215	64	524	16	46

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 45	Bombardier (Learjet) Lear 55	Bombardier (Learjet) Lear 60	British Aerospace Hawker HS-125-400	British Aerospace Hawker HS-125-600	British Aerospace Hawker HS-125-700	British Aerospace Hawker HS-125-800
1960							
1961							
1962							
1963							
1964				3 *			
1965				20 **			
1966				65			
1967				20			
1968				37			
1969				32			
1970				32			
1971				20			
1972				16	3		
1973				9	20		
1974					16		
1975				** based on*	11		
1976				*info in*	10		
1977				*"Biz Jets"*		25	
1978				*by Phillips*		35	
1979						26	
1980				*** Av. Wk*		37	
1981		15		*& Space*		34	
1982		53		*Tech.*		28	
1983		24		*Mar. 7, '66*		19	
1984		16				8	15
1985		7					25
1986		7					25
1987		4					31
1988		2					30
1989		6					32
1990		4					24
1991		2					14
1992							12
1993			16				
1994			22				
1995			24				
1996			23				
1997			24				
1998	7		32				
1999	43		32				
2000	71		35				
2001	63		29				
2002	33		18				
2003	17		12				
Total	234	140	267	254	60	212	208

	Aircraft Manufacturer & Model						
Year	British Aerospace Hawker HS-125-1000	Cessna 208 Caravan I	Cessna 208B Grand Caravan IB	Cessna 406 Caravan II	Cessna 425 Corsair/ Conquest I	Cessna 441 Conquest II	Cessna 500 Citation
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							1
1972							51
1973							81
1974							85
1975							69
1976							54
1977						4	29 *
1978						69	
1979						42	
1980					7	77	** based on info in "Biz Jets" by Phillips (p. 81)*
1981					100	65	
1982					38	39	
1983					34	24	
1984					18	11	
1985		63			8	13	
1986		54		2	16	9	
1987		77		11	6	7	
1988		90		9			
1989		89		12			
1990		66		4			
1991	10	62		2			
1992	18	41					
1993		13					
1994		51					
1995		6					
1996		13					
1997		14					
1998		22					
1999		20					
2000		16					
2001		19	56				
2002		14	66				
2003		8	49				
Total	28	738	171	40	227	360	370

	Aircraft Manufacturer & Model						
Year	Cessna 500/501 Citation I	Cessna 525 CitationJet	Cessna 525 CJ1	Cessna 525 CJ2	Cessna 550 Citation Bravo	Cessna 550 Citation II	Cessna 550 Citation S/II
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977	48 *						
1978	49					38	
1979	61					79	
1980	43					102	
1981	67					129	
1982	27					97	
1983	12					32	
1984	9					42	
1985	6					62	
1986						40	
1987						14	22
1988						28	19
1989						32	1
1990	** based on*					30	
1991	*info in*					34	
1992	*"Biz Jets"*					22	
1993	*by Phillips*	34				14	
1994	*(p. 81)*	49				9	
1995		42					
1996		44					
1997		63			28		
1998		64			34		
1999		59			36		
2000			56	8	54		
2001			61	41	48		
2002			30	86	41		
2003			22	56	31		
Total	322	355	169	191	272	804	42

	Aircraft Manufacturer & Model						
Year	Cessna 700 Citation III	Cessna 560 Citation Encore	Cessna 560 Citation Ultra	Cessna 560 Citation V	Cessna 560XL Citation Excel	Cessna 650 Citation VI	Cessna 650 Citation VII
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983	18						
1984	50						
1985	28						
1986	21						
1987	26						
1988	15						
1989	16			33			
1990	15			56			
1991	12			62		4	
1992	1			51		10	15
1993				44		13	11
1994				39		10	14
1995				56		1	14
1996			52				19
1997			47				8
1998			41		15		11
1999			32		39		14
2000		6			79		12
2001		37			85		
2002		36			81		
2003		21			48		
Total	202	100	172	341	347	38	118

	Aircraft Manufacturer & Model						
Year	Cessna 750 Citation X	Dassault Falcon 10	Dassault Falcon 100	Dassault Falcon 20	Dassault Falcon 200	Dassault Falcon 50	Dassault Falcon 50EX
1960							
1961							
1962							
1963							
1964							
1965				14 **			
1966				46			
1967				56			
1968				43			
1969				26			
1970				20 ***			
1971				18			
1972				30			
1973				24			
1974				21			
1975		35		23			
1976		24		16			
1977		19		18			
1978		23		22			
1979		20		21		5	
1980		22		16		24	
1981		16		24		42	
1982		10		7		49	
1983			1 *	4	8	12	
1984			1	1	10	13	
1985			1	1	9	12	
1986			3	1	4	14	
1987			5	2	4	8	
1988			6	1		9	
1989			4	2		12	
1990			3		2	12	
1991						12	
1992						6	
1993						7	
1994						7	
1995			** based on*	*** Av. Wk*		8	
1996	7		*info in*	*& Space*		1	
1997	28		*“Biz Jets”*	*Tech.*			10
1998	30		*by Phillips*	*Mar. 7, ‘66*			13
1999	36		*(p. 171)*				11
2000	37			**** Av. Wk*			18
2001	34			*& Space*			13
2002	31			*Tech.*			10
2003	18			*Mar. 9, ‘70*			8
Total	221	169	24	457	37	253	83

	Aircraft Manufacturer & Model						
Year	Dassault Falcon 900	Dassault Falcon 900B	Dassault Falcon 900C	Dassault Falcon 900EX	Dassault Falcon 2000	Dassault Falcon 2000EX	Fairchild F-27
1960							13 **
1961							9 **
1962							7 **
1963							6 **
1964							3 ***
1965							3 †
1966							1 ††
1967							5 ††
1968							N/A
1969							
1970							*** from*
1971							*F-27*
1972							*Friendship*
1973							*Assoc. &*
1974							*incl. airline*
1975							*shipments.*
1976							
1977							
1978							
1979							
1980							**** Av. Wk*
1981							*& Space*
1982							*Tech.*
1983							*Mar. 15, '65*
1984							*†Mar. 7, '66*
1985							*†† Mar. 6, '67*
1986	3						
1987	30						
1988	27						
1989	14						
1990	16						
1991		14 *					
1992		13 *					
1993		8 *					
1994		18					
1995		10			10		
1996		8		3	21		
1997		7		16	18		
1998		5		15	14		
1999		8		16	34		
2000		** may incl.*	6	23	26		
2001		*some -900*	6	21	35		
2002		*shipments.*	4	17	35		
2003			3	10	12	16	
Total	90	91	19	121	205	16	65

	Aircraft Manufacturer & Model						
Year	Fairchild FH 227	Fairchild Merlin II (SA-26T)	Fairchild Merlin III	Fairchild Merlin IIIA	Fairchild Merlin IIIB	Fairchild Merlin IIIC	Fairchild Merlin IV
1960							
1961							
1962							
1963							
1964							
1965							
1966	26 *	5					
1967	38	25					
1968	4	39					
1969	N/A	59					
1970	N/A	19	8				1
1971	N/A		11				3
1972	N/A	1	10				2
1973	N/A		16				8
1974			7				6
1975	**from*			7			12
1976	*F-27*			14			6
1977	*Friendship*			12			4
1978	*Assoc. &*				13		6
1979	*incl. airline*				24		4
1980	*shipments.*				33		1
1981					7	20	11
1982						4	15
1983						6	0
1984						2	3
1985						4	1
1986						1	0
1987							1
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	68	148	52	33	77	37	84

	Aircraft Manufacturer & Model						
Year	Galaxy Aerospace (IAI) 1121B Commodore Jet	Galaxy Aerospace (IAI) 1123 Westwind	Galaxy Aerospace (IAI) 1124 Westwind 1	Galaxy Aerospace (IAI) 1124A Westwind 2	Galaxy Aerospace (IAI) 1125 Astra SP	Galaxy Aerospace (IAI) 1125 Astra SPX	Galaxy Aerospace (IAI) 1126 Galaxy
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967	21						
1968	21						
1969	14						
1970	7						
1971	4						
1972	9	2					
1973		16					
1974		12					
1975		7					
1976		2	16				
1977			23				
1978			18				
1979			31				
1980			35				
1981			39				
1982			18				
1983			7	14			
1984			4	12			
1985			5	8	1		
1986			2	7	7		
1987			4		1		
1988			1		8		
1989					11		
1990					9		
1991					11		
1992					6		
1993					8		
1994					6		
1995					5		
1996					2	7	
1997						6	
1998						14	
1999						9	1
2000						11	6
2001						4	12
2002							
2003							
Total	76	39	203	41	75	51	19

	Aircraft Manufacturer & Model						
Year	Gulfstream (Grumman) Gulfstream 840	Gulfstream (Grumman) Gulfstream 900	Gulfstream (Grumman) Gulfstream 980	Gulfstream (Grumman) Gulfstream 1000	Gulfstream (Grumman) Gulfstream G-159 (G-I)	Gulfstream (Grumman) Gulfstream G-II	Gulfstream (Grumman) Gulfstream G-II/TT
1960					36		
1961					21 *		
1962					21 *		
1963					21 *		
1964					27 **		
1965					18[†]		
1966					13		
1967					9		
1968					10	42	
1969					2	37	
1970						20	
1971					* *estimate*	12	
1972						15	
1973						19	
1974						15	
1975					** *Av. Wk*	18	
1976					*& Space*	20	
1977					*Tech.*	4	15[††]
1978					*Mar. 15, '65*		17
1979					[†]*Mar. 7, '66*		22
1980							
1981	47		33	22			[††] *based in,*
1982	7	11	1	27			*information*
1983	6	16		13			*in B/CA*
1984	2	6		4			*May 1981*
1985	1	8		29			*(p. 55)*
1986				2			
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	63	41	34	97	206	202	54

	Aircraft Manufacturer & Model						
Year	Gulfstream (Grumman) Gulfstream G-III	Gulfstream (Grumman) Gulfstream G-IV	Gulfstream (Grumman) Gulfstream G-IV-SP	Gulfstream (Grumman) Gulfstream G-V	Gulfstream (Grumman) Gulfstream G100	Gulfstream (Grumman) Gulfstream G200	Lockheed 1329 Jetstar 6
1960							
1961							16 *
1962							21 *
1963							8 *
1964							6 **
1965							17 †
1966							24
1967							5 *
1968							
1969							
1970							** based on*
1971							*info in*
1972							*"Biz Jets"*
1973							*by Phillips*
1974							
1975							*** Av. Wk*
1976							*& Space*
1977							*Tech.*
1978							*Mar. 15, '65*
1979							*†Mar. 7, '66*
1980	20						
1981	26						
1982	36						
1983	33						
1984	38						
1985	15						
1986	14	8					
1987	4	26					
1988	2	49					
1989		40					
1990		34					
1991		29					
1992		25					
1993		26					
1994		22					
1995		26					
1996		24		3			
1997			22	29			
1998			32	29			
1999			39	31			
2000			37	34			
2001			36	35	1	12	
2002			N/A	N/A	N/A	N/A	
2003					N/A	N/A	
Total	188	309	166	161	1	12	97

	Aircraft Manufacturer & Model						
Year	Lockheed 1329 Jetstar 8	Lockheed 1329-25 Jetstar II	Messerschmitt HFB-320 Hansa Jet	Mitsubishi MU-2D	Mitsubishi MU-2F	Mitsubishi MU-2J	Mitsubishi MU-2K
1960							
1961							
1962							
1963							
1964							
1965							
1966				7 **			
1967	15 *			14 **			
1968	19		14	44 **	N/A		
1969	12		6	12 †	32 †		
1970	8		10	††	41 ††		
1971	6		2	††	39 ††		
1972	13		6	††	64 ††		
1973	7		12	3	1	39	28
1974					8	38	25
1975	** based on*			*** manuf.*	2	9	11
1976	*info in*			*by Mooney*	2	8	4
1977	*"Biz Jets"*	17		*in U.S.*		1	
1978	*by Phillips*	7					
1979	*(p. 142)*	8					
1980		4		*† Av. Wk*	*†† cannot*		
1981				*& Space*	*separate*		
1982				*Tech.*	*-D and –F*		
1983				*Mar. 9, '70*	*shipments*		
1984					*these years*		
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	80	36	50	80	189	95	68

	Aircraft Manufacturer & Model						
Year	Mitsubishi MU-2L	Mitsubishi MU-2M	Mitsubishi MU-2N	Mitsubishi MU-2P	Mitsubishi MU-2B-40 (Solitare)	Mitsubishi MU-2B-60 (Marquise)	Mitsubishi Diamond I (MU-300)
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974		1					
1975	10	9					
1976	10	10					
1977	14	8	13	8			
1978			24	22		4	
1979			2	8	26	28	
1980	1				11	43	
1981					14	29	
1982					4	17	22
1983						7	36
1984						3	
1985					1	5	
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	35	28	39	38	56	136	58

	Aircraft Manufacturer & Model						
Year	Mitsubishi Diamond IA	Mitsubishi Diamond II	Piaggio P-180	Pilatus PC-12	New Piper PA-31T-501T Cheyenne I	New Piper PA-31T-501T Cheyenne IA	New Piper PA-31T-620 Cheyenne II
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							13
1975							49
1976							54
1977							70
1978					16		97
1979					60		99
1980					65		85
1981					37		40
1982					13		9
1983					6	5	7
1984	12					6	2
1985	12	6			1	2	
1986						4	
1987						1	
1988							
1989							
1990			1				
1991			6				
1992			7				
1993			7				
1994			1	6			
1995			0	25			
1996				36			
1997				5			
1998				51			
1999				55			
2000			6	69			
2001			12	70			
2002			14	45			
2003			12	61			
Total	24	6	66	423	198	18	525

	Aircraft Manufacturer & Model						
Year	New Piper PA-31T2-620 Cheyenne II-XL	New Piper PA-42-7 Cheyenne III	New Piper PA-42-720 Cheyenne IIIA	New Piper PA-42-1000 Cheyenne IV (400)	New Piper PA-46-500TP Meridian	Raytheon Aircraft King Air 90/A90	Raytheon Aircraft King Air B90
1960							
1961							
1962							
1963							
1964						9 *	
1965						84 **	
1966						114	
1967						119	
1968							98
1969							60
1970						** Av. Wk*	6
1971						*& Space*	
1972						*Tech.*	
1973						*Mar. 15, '65*	
1974						***Mar. 7, '66*	
1975							
1976							
1977							
1978							
1979							
1980		13					
1981	35	46					
1982	22	19					
1983	12	10	5				
1984	5	1	15	8			
1985		1	6	21			
1986		1	9	6			
1987	3		12	5			
1988			2	5			
1989			1	4			
1990			9	2			
1991			3	1			
1992			1				
1993			1				
1994							
1995							
1996							
1997							
1998							
1999							
2000					18		
2001					98		
2002					25		
2003					24		
Total	77	91	64	52	165	326	164

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft King Air C90	Raytheon Aircraft King Air C90B	Raytheon Aircraft King Air E90	Raytheon Aircraft King Air F90	Raytheon Aircraft King Air A100	Raytheon Aircraft King Air B100	Raytheon Aircraft King Air 200
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969					21		
1970					50		
1971	35				25		
1972	27		33		42		
1973	46		53		41		
1974	32		39		22		28
1975	30		37		15		76
1976	33		46		8	18	105
1977	43		53		8	15	113
1978	64		50		2	23	115
1979	64		17	14	9	24	166
1980	59		15	81		24	189
1981	68		3	63		20	
1982	37			27		7	
1983	15			19		4	
1984	30			15		5	
1985	25			4			
1986	17			5			
1987	20			1			
1988	30						
1989	38						
1990	35						
1991	31						
1992	28						
1993	32						
1994		35					
1995		40					
1996		42					
1997		38					
1998		34					
1999		41					
2000		46					
2001		41					
2002		21					
2003		18					
Total	839	356	346	229	243	140	792

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft King Air B200	Raytheon Aircraft King Air 300	Raytheon Aircraft King Air 350	Raytheon Aircraft Starship 2000	Raytheon Aircraft Starship 2000A	Raytheon Aircraft Premier I 390	Raytheon Aircraft Beechjet 400
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981	238						
1982	114						
1983	81						
1984	34	24					
1985	31	42					
1986	30	27					11
1987	32	37					14
1988	27	53					21
1989	32	33					10
1990	41	10	35	11			8
1991	26	5	35	7			
1992	31	4	25	4			
1993	37	2	15	N/A	N/A		
1994	23	5	24		3		
1995	28		15		13		
1996	35		24		8		
1997	43		27				
1998	45		36				
1999	44		42				
2000	59		46				
2001	46		32			18	
2002	26		24			29	
2003	38		24			29	
Total	1,141	242	404	22	24	76	64

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft Beechjet 400A	Raytheon Aircraft Hawker 400XP	Raytheon Aircraft Hawker 800XP	Raytheon Aircraft Hawker 1000	Rockwell Aero Cmdr AE-680T Turbo Commander	Rockwell Aero Cmdr AE-680V Turbo II Commander	Rockwell Aero Cmdr AE-681 Hawk Commander
1960							
1961							
1962							
1963							
1964							
1965					3		
1966					31		
1967					20	20	
1968						39	
1969						27	17
1970						2	17
1971							22
1972							16
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991	20						
1992	24						
1993	18		17	12			
1994	22		16	5			
1995	30		26	8			
1996	26		20	4			
1997	37		35				
1998	49		40				
1999	48		55				
2000	51		67				
2001	25		55				
2002	19		46				
2003		24	47				
Total	369	24	424	29	54	88	72

	Aircraft Manufacturer & Model						
Year	Rockwell Aero Cmdr AE-690 /A Turbo Commander	Rockwell Aero Cmdr AE-690B Turbo Commander	Rockwell Aero Cmdr AE-840 (RI 840)	Rockwell Aero Cmdr AE-980 (RI 980)	Rockwell Aero Cmdr AE-1121 Jet Commander	Rockwell North American NA-40 Sabreliner	Rockwell N. Amer. NA-40A Sabre Commander
1960							
1961							
1962							
1963						3 †	
1964						19 †	
1965					32	27	
1966					50	31 †	
1967						20 *	
1968						7 **	
1969						6 *	
1970						3 *	
1971	1						
1972	46						10
1973	68						23
1974	87						7
1975	74						
1976	49	16				1	
1977		84					
1978		61					
1979		59	13				
1980			43	51		** estimate.*	
1981						*Difficult*	
1982						*to separate*	
1983						*-40 and -60*	
1984						*shipments.*	
1985						*** B/CA*	
1986						*April '69*	
1987							
1988							
1989							
1990						*† based on*	
1991						*info in*	
1992						*"Biz Jets"*	
1993						*by Phillips*	
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
Total	325	220	56	51	82	117	40

	Aircraft Manufacturer & Model			
Year	Rockwell North American NA-60 Sabreliner	Rockwell North American NA-65 Sabreliner	Rockwell North American NA-75 Sabreliner	Rockwell North American NA-75A Sabreliner
1960				
1961				
1962				
1963				
1964				
1965				
1966				
1967	9 *			
1968	18 **			
1969	27 *			
1970	9 *			
1971	9			
1972	3		6	
1973	2		1	
1974	17			18
1975	0			19
1976	14			13
1977	14			12
1978	12			12
1979	4	6		5
1980		41		
1981		37		
1982		2		
1983		1		
1984				
1985	** estimate.*			
1986	*Difficult*			
1987	*to separate*			
1988	*-40 and -60*			
1989	*shipments.*			
1990	*** B/CA*			
1991	*April '69*			
1992				
1993				
1994				
1995				
1996				
1997				
1998				
1999				
2000				
2001				
2002				
2003				
Total	138	87	7	79

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APPENDIX C: BUSINESS AIRCRAFT PRICE DATA

This appendix contains a complete listing of all pricing data used in the analyses for this research. All pricing data is derived from *Business & Commercial Aviation* of the appropriate years with only a few exceptions as noted in the tables.

Prices are in United States dollars for the year listed (not corrected for inflation).

Aircraft are listed in alphabetical order by last or most recent manufacturer. For example, all Learjet aircraft are listed under Bombardier, all Dornier and Swearingen aircraft are listed under Fairchild, etcetera.

Prices are "list" from 1960 through 1973 and reflect information provided to B/CA by the manufacturers. For this 13 year period the prices reflect varying levels of installed options and equipment onboard the airplanes, depending on how the manufacturer chose to advertise its products. Direct price comparison between products in this period should be performed with care, and it would be best to consult original period publications for any information on how aircraft were equipped. No single method of converting the "list" prices from this time period is possible, but the prices in the database are believed to be useful for direct comparison between contemporary aircraft.

Price data from 1974 and after is "equipped." This price reflects the "computed retail price with at least the level of equipment specified in the B/CA Required Equipment List." The B/CA Required Equipment List is available in every Purchase Planning Handbook after 1973 and represents that level of equipment, from avionics to air conditioning and ice protection, necessary to safely conduct flight operations typical for most business aviation missions. The list varies depending on the aircraft type.

Because a price is listed for a particular year does not indicate that the aircraft is in production. Aircraft are marketed, and thus have listed prices, years before full-scale production begins.

"N/A" indicates that price data was not available from the consulted sources for that year.

Some price data for very new aircraft (e.g., Adam 700, Cessna Mustang, Eclipse 500) is from the "Emerging Aircraft" section of B/CA for the appropriate years.

	Aircraft Manufacturer & Model						
Year	Adam Aircraft Adam 700	Aerospatiale (SOCATA) TBM-700	Aerospatiale Corvette SN-601	Airbus ACJ Corporate Jet	Allison (GM div.) Super Convair	Boeing BBJ1 (737-700-IGW)	Boeing BBJ2 (737-800)
1960					1,100,000		
1961							
1962					*N/A*		
1963					*after 1960*		
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973			N/A				
1974			1,300,000				
1975			1,300,000				
1976			1,498,040				
1977			N/A				
1978			N/A				
1979			N/A				
1980			2,200,000				
1981			1,750,000				
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990		1,095,000					
1991		1,350,000					
1992		1,370,250					
1993		1,370,250					
1994		1,931,100					
1995		2,538,508					
1996		2,607,048					
1997		2,610,000					
1998		2,610,000					
1999		2,310,000		45,000,000		43,750,000	
2000		2,456,226		45,000,000		47,400,000	55,000,000
2001		2,310,000		45,000,000		47,500,000	59,500,000
2002		2,512,390		46,000,000		51,000,000	64,000,000
2003	1,995,000	2,660,340		47,000,000		52,000,000	65,000,000
2004	1,995,000	2,679,390		47,000,000		53,000,000	65,000,000

	Aircraft Manufacturer & Model						
Year	Bombardier Challenger 300	Bombardier Global 5000	Bombardier Global Express (BD-700)	Bombardier (Canadair) Challenger 600	Bombardier (Canadair) Challenger 601	Bombardier (Canadair) Challenger 601-3A	Bombardier (Canadair) Challenger 601-3R
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977				5,700,000			
1978				7,250,000			
1979				7,610,000			
1980				8,300,000			
1981				9,000,000			
1982				10,000,000	11,000,000		
1983				10,000,000	11,700,000		
1984				10,100,000	11,300,000		
1985					13,100,000		
1986					12,500,000		
1987						12,950,000	
1988						13,000,000	
1989						15,500,000	
1990						15,700,000	16,100,000
1991						15,700,000	16,100,000
1992						16,950,000	17,386,000
1993							18,200,000
1994							18,436,000
1995							18,700,000
1996							
1997			37,500,000				
1998			37,700,000				
1999			38,015,000				
2000			40,660,000				
2001			41,700,000				
2002	16,290,000		43,350,000				
2003	17,415,000	33,500,000	44,400,000				
2004	17,850,000	33,500,000	45,300,000				

	Aircraft Manufacturer & Model						
Year	Bombardier (Canadair) Challenger 604 (CL-600-2B16)	Bombardier (Learjet) Lear 23	Bombardier (Learjet) Lear 24	Bombardier (Learjet) Lear 24B/D	Bombardier (Learjet) Lear 24E	Bombardier (Learjet) Lear 24F	Bombardier (Learjet) Lear 25/25B
1960							
1961							
1962							
1963		489,000					
1964		500,000					
1965		595,000					
1966			649,000				
1967			649,000				795,000
1968			649,000				795,000
1969				762,200			868,270
1970				798,000			899,000
1971				798,735			896,145
1972				853,750			955,995
1973				863,000			966,765
1974				883,000			1,014,565
1975				1,027,700			1,164,200
1976					943,700	1,144,700	
1977					1,000,740	1,308,400	
1978					1,245,700	1,514,400	
1979						1,649,000	
1980						1,975,000	
1981							
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995	20,500,000						
1996	19,450,000						
1997	20,750,000						
1998	21,800,000						
1999	21,800,000						
2000	22,500,000						
2001	23,245,000						
2002	23,850,000						
2003	24,882,200						
2004	26,220,000						

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 25C	Bombardier (Learjet) Lear 25D	Bombardier (Learjet) Lear 25G	Bombardier (Learjet) Lear 28	Bombardier (Learjet) Lear 29	Bombardier (Learjet) Lear 31	Bombardier (Learjet) Lear 31A
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970	950,000						
1971	958,785						
1972	1,015,315						
1973	1,026,085						
1974	1,079,785						
1975	1,234,100						
1976		1,284,700					
1977		1,409,740					
1978		1,618,200		1,809,200	1,870,000		
1979		1,719,000		1,834,000	1,884,000		
1980		2,043,000		2,143,000	2,193,000		
1981		2,131,000		2,336,400	2,388,300		
1982		2,453,735	2,753,735	2,661,935	2,721,035		
1983		2,703,380	3,011,775				
1984		2,367,485	2,625,880				
1985		2,375,000	2,625,000				
1986		2,375,000	2,625,000				
1987							
1988						3,650,000	
1989						3,650,000	
1990						3,850,000	
1991							4,504,400
1992							4,666,000
1993							4,795,000
1994							5,263,500
1995							4,842,400
1996							5,480,000
1997							5,775,000
1998							6,100,000
1999							6,294,150
2000							6,419,600
2001							6,525,600
2002							6,604,700
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 35	Bombardier (Learjet) Lear 35A	Bombardier (Learjet) Lear 36	Bombardier (Learjet) Lear 36A	Bombardier (Learjet) Lear 40	Bombardier (Learjet) Lear 45	Bombardier (Learjet) Lear 45XR
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974	1,395,000		1,445,000				
1975	1,586,000		1,639,000				
1976		1,678,520		1,733,358			
1977		1,796,285		1,853,785			
1978		2,224,600		2,271,200			
1979		2,245,000		2,350,000			
1980		2,855,000		2,983,000			
1981		3,395,485		3,545,485			
1982		3,491,540		3,641,540			
1983		3,908,075		4,074,075			
1984		3,753,315		3,956,315			
1985		3,850,000		4,100,000			
1986		3,400,000		3,650,000			
1987		3,550,000		3,750,000			
1988		4,050,000		4,250,000			
1989		4,175,000		4,375,000			
1990		4,395,000		4,595,000			
1991		4,619,000		4,819,000			
1992		4,919,000		5,119,000			
1993		4,975,000		5,175,000			
1994		5,247,200					
1995		5,495,000					
1996						6,878,000	
1997						7,925,000	
1998						8,275,000	
1999						8,193,450	
2000						8,988,700	
2001						9,420,200	
2002						9,848,400	
2003					7,737,400	10,255,300	10,837,500
2004					7,800,000	10,250,000	10,850,000

	Aircraft Manufacturer & Model						
Year	Bombardier (Learjet) Lear 55	Bombardier (Learjet) Lear 60	British Aerospace Hawker HS-125-400	British Aerospace Hawker HS-125-600	British Aerospace Hawker HS-125-700	British Aerospace Hawker HS-125-800	British Aerospace Hawker HS-125-1000
1960							
1961							
1962							
1963			625,000				
1964			750,000				
1965			640,300				
1966			780,400				
1967			780,400				
1968			722,400				
1969			799,900				
1970			829,187				
1971			829,187				
1972			1,267,158				
1973			1,300,000	1,592,000			
1974				1,750,000			
1975				1,936,000			
1976				2,075,000			
1977					3,220,000		
1978	3,086,300				3,450,000		
1979	N/A				3,800,000		
1980	3,125,000				4,540,000		
1981	3,529,785				5,845,000		
1982	5,307,515				5,995,000		
1983	5,216,015				5,995,000		
1984	5,507,952				5,995,000	6,650,000	
1985	5,780,000					6,700,000	
1986	5,150,000					6,750,000	
1987	5,450,000					7,060,000	
1988	6,150,000					7,500,000	
1989	6,575,000					8,350,000	
1990	6,900,000					9,097,500	
1991		7,900,000				9,500,000	12,220,000
1992		8,295,000				9,950,000	12,900,000
1993		8,866,000				9,950,000	12,900,000
1994		9,100,200				9,950,000	12,995,000
1995		9,380,000					
1996		10,263,000					
1997		10,775,000					
1998		11,100,000					
1999		11,384,045					
2000		11,584,045					
2001		11,968,300					
2002		12,451,000					
2003		12,743,500					
2004		12,600,000					

	Aircraft Manufacturer & Model						
Year	Cessna 208 Caravan I	Cessna 208B Grand Caravan IB	Cessna 406 Caravan II	Cessna 425 Corsair/ Conquest I	Cessna 441 Conquest II	Cessna Mustang	Cessna 500 Citation
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							695,000
1972							695,000
1973							725,000
1974							731,095
1975							825,900
1976							917,880
1977					886,470		1,116,625
1978					886,050		
1979					950,685		
1980				887,615	1,104,995		
1981				914,329	1,174,470		
1982				1,010,920	1,434,195		
1983				1,116,990	1,684,025		
1984				1,221,960	1,859,980		
1985	631,380			1,230,415	1,855,010		
1986	733,075		1,194,750	1,316,544	1,855,010		
1987	733,075		1,234,750	1,316,544	1,855,010		
1988	768,500		1,395,000				
1989	914,206		1,526,737				
1990	942,406		1,641,737				
1991	951,200		1,641,737				
1992	951,200	1,060,300	1,641,737				
1993	996,300	1,099,800	1,641,737				
1994	1,124,000	1,233,000					
1995	1,124,000	1,233,000					
1996	1,311,380	1,493,260	2,391,269				
1997	1,243,300	1,330,370	2,510,832				
1998	1,360,000	1,364,250	2,111,150				
1999	1,398,135	1,410,720	2,110,075				
2000	1,443,199	1,456,635	2,107,555				
2001	1,484,505	1,507,135	2,200,000				
2002	1,485,906	1,596,270	2,500,000				
2003	1,575,640	1,607,090	2,600,000			2,295,000	
2004	1,634,635	1,665,445	2,600,000			2,295,000	

	Aircraft Manufacturer & Model						
Year	Cessna 500/501 Citation I	Cessna 525 CitationJet	Cessna 525 CJ1	Cessna 525 CJ2	Cessna 525 CJ3	Cessna 550 Citation Bravo	Cessna 550 Citation II
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							1,363,000
1978	1,333,400						1,658,400
1979	1,573,400						2,144,950
1980	1,696,048						2,387,375
1981	1,947,525						2,518,475
1982	1,980,025						2,561,675
1983	2,017,800						2,633,500
1984	2,192,400						N/A
1985	2,191,400						N/A
1986	1,815,600						2,478,100
1987							2,630,425
1988							3,028,074
1989							3,100,300
1990							3,300,000
1991		2,550,000					3,370,550
1992		2,600,000					3,467,000
1993		2,894,000					3,766,000
1994		3,103,000					3,936,000
1995		3,150,000				4,395,000	
1996		3,213,000				4,395,000	
1997		3,287,000				4,550,000	
1998		3,375,000				4,845,000	
1999			3,695,000	4,290,000		4,994,000	
2000			3,716,000	4,529,000		5,184,000	
2001			3,808,000	5,305,000		5,434,000	
2002			3,986,000	4,879,000		5,446,000	
2003			4,024,000	5,214,000	5,995,000	5,708,000	
2004			4,213,000	5,685,000	6,010,000	5,904,000	

	Aircraft Manufacturer & Model						
Year	Cessna 550 Citation S/II	Cessna 700 Citation III	Cessna 560 Citation Encore	Cessna 560 Citation Ultra	Cessna 560 Citation V	Cessna 560XL Citation Excel	Cessna 650 Citation VI
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978		3,100,000					
1979		N/A					
1980		4,237,925					
1981		4,298,400					
1982		5,579,886					
1983		6,120,036					
1984	2,868,050	5,803,725					
1985	2,960,500	5,956,545					
1986	3,273,100	6,374,025					
1987	3,475,375	6,183,200					
1988	3,808,023	6,727,583			3,840,525		
1989		7,295,000			4,321,900		
1990		7,900,000			4,600,000		
1991		8,050,375			4,582,950		7,230,000
1992					4,842,400		7,990,000
1993					5,133,000		7,889,000
1994					5,495,000		8,251,000
1995					5,795,000		
1996				5,988,000		6,775,000	
1997				6,063,000		7,200,000	
1998				6,465,000		7,574,000	
1999			6,928,000			8,545,000	
2000			7,159,000			8,795,000	
2001			7,304,000			9,732,000	
2002			7,559,000			9,451,000	
2003			7,576,000			10,154,000	
2004			7,888,000			10,136,000	

	Aircraft Manufacturer & Model						
Year	Cessna 650 Citation VII	Cessna 680 Citation Sovereign	Cessna 750 Citation X	Dassault Falcon 10	Dassault Falcon 100	Dassault Falcon 20	Dassault Falcon 200
1960							
1961							
1962							
1963							
1964						900,000	
1965						995,000	
1966						1,100,000	
1967						1,140,000	
1968						1,240,000	
1969						1,675,000	
1970						1,650,000	
1971						1,650,000	
1972						1,650,000	
1973				N/A		1,750,000	
1974				1,475,000		2,400,000	
1975				1,662,000		2,517,000	
1976				1,905,000		3,005,000	
1977				2,090,000		3,200,000	
1978				2,163,000		3,595,000	
1979				2,550,000		4,250,000	
1980				2,950,000		4,825,000	
1981				3,200,000		5,960,000	
1982					4,058,790	6,188,790	6,938,790
1983					4,058,790	6,188,790	8,850,000
1984					3,970,000	6,188,790	7,500,000
1985					4,350,000	5,450,000	7,450,000
1986					4,350,000		7,450,000
1987					4,350,000		7,450,000
1988					4,700,000		8,000,000
1989					4,700,000		
1990							
1991	8,800,000						
1992	8,950,000						
1993	9,403,000						
1994	9,931,000		15,996,000				
1995	10,160,000		15,295,000				
1996	9,950,000		15,295,000				
1997	10,641,000		15,384,000				
1998	10,974,000		16,350,000				
1999	11,638,000		16,505,000				
2000	11,414,000		17,372,000				
2001			18,615,000				
2002		13,270,000	18,995,000				
2003		13,523,000	19,394,000				
2004		13,404,000	19,261,000				

	Aircraft Manufacturer & Model						
Year	Dassault Falcon 50	Dassault Falcon 50EX	Dassault Falcon 900	Dassault Falcon 900B	Dassault Falcon 900C	Dassault Falcon 900EX	Dassault Falcon 2000
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977	5,750,000						
1978	6,232,700						
1979	7,550,000						
1980	8,400,000						
1981	8,750,000						
1982	9,394,960						
1983	10,850,000						
1984	10,950,000		13,500,000				
1985	10,950,000		13,500,000				
1986	11,450,000		13,500,000				
1987	12,000,000		13,500,000				
1988	13,200,000		17,500,000				
1989	12,750,000		20,450,000				
1990	12,950,000		20,850,000				
1991	14,650,000			22,350,000			
1992	14,750,000			22,500,000			
1993	14,750,000			23,425,000			15,765,000
1994	14,750,000			23,425,000			16,076,000
1995	14,750,000			23,950,000			16,900,000
1996		16,050,000		24,950,000		27,500,000	18,150,000
1997		16,575,000		25,400,000		28,510,000	18,920,000
1998		17,200,000		26,550,000		29,580,000	19,630,000
1999		17,780,000			26,930,000	30,430,000	20,160,000
2000		18,230,000			27,810,000	31,190,000	20,600,000
2001		18,800,000			28,650,000	31,900,000	21,130,000
2002		19,475,000			29,550,000	32,800,000	21,835,000
2003		20,070,000			30,400,000	34,250,000	22,550,000
2004		20,580,000			31,200,000	34,650,000	23,150,000

	Aircraft Manufacturer & Model						
Year	Dassault Falcon 2000EX	Eclipse Aviation Eclipse 500	Fairchild F-27	Fairchild FH 227	Fairchild Merlin II (SA-26T)	Fairchild Merlin III	Fairchild Merlin IIIA
1960			770,000				
1961			770,000				
1962			890,000				
1963			895,000				
1964			895,000				
1965			998,300	1,145,000	310,000		
1966			1,095,000	1,200,000	335,000		
1967			1,095,000	1,200,000	335,000		
1968				1,425,000	405,000		
1969				N/A	430,000		
1970				N/A	442,000		
1971				N/A	442,000	580,000	
1972				N/A		625,000	
1973				N/A		625,000	
1974						698,515	
1975							845,356
1976							1,027,400
1977							1,092,286
1978							1,147,000
1979							
1980							
1981							
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002	23,550,000						
2003	23,800,000	1,175,000					
2004	24,850,000	1,175,000					

	Aircraft Manufacturer & Model						
Year	Fairchild Merlin IIIB	Fairchild Merlin IIIC	Fairchild Merlin IV	Galaxy Aerospace (IAI) 1121B Commodore Jet	Galaxy Aerospace (IAI) 1123 Westwind	Galaxy Aerospace (IAI) 1124 Westwind 1	Galaxy Aerospace (IAI) 1124A Westwind 2
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968				595,000			
1969				650,000			
1970				650,000			
1971			645,000	650,000	980,000		
1972			700,000	785,000	998,000		
1973			700,000		1,050,000		
1974			751,640		1,180,000		
1975			934,036			1,749,500	
1976			1,114,500			1,789,500	
1977			1,190,186			2,002,000	
1978			1,254,700			2,327,400	
1979	1,419,590		1,481,395			2,480,000	
1980	1,475,605		1,527,965			2,765,000	3,147,500
1981		1,849,320	2,071,180			3,428,710	3,828,060
1982		1,994,665	2,363,325			3,695,500	4,349,000
1983		1,994,665	2,363,325			3,695,000	4,349,000
1984			2,663,325			3,695,000	4,349,000
1985			2,950,000			3,695,000	4,349,000
1986			3,285,000			3,695,000	4,339,490
1987			3,648,605			3,695,000	4,349,000
1988			3,923,605			3,695,000	4,349,000
1989			3,982,305				
1990			3,750,000				
1991			3,945,835				
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Galaxy Aerospace (IAI) 1125 Astra SP	Galaxy Aerospace (IAI) 1125 Astra SPX	Galaxy Aerospace (IAI) 1126 Galaxy	Gulfstream (Grumman) Gulfstream 840	Gulfstream (Grumman) Gulfstream 900	Gulfstream (Grumman) Gulfstream 980	Gulfstream (Grumman) Gulfstream 1000
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981				1,157,715		1,357,715	1,500,075
1982				1,218,355	1,418,355	1,460,855	1,610,855
1983				1,318,355	1,618,355	1,660,855	1,810,855
1984				1,416,000	1,777,750		1,877,500
1985	5,995,000			1,489,000	1,804,750		1,935,000
1986	5,495,000						
1987	4,995,000						
1988	5,460,000						
1989	5,882,250						
1990	6,437,125						
1991	7,140,593						
1992	7,537,200						
1993	7,660,000						
1994	8,351,000						
1995	8,752,000	9,967,000					
1996	8,752,000	9,967,000					
1997		10,869,000					
1998		11,750,000	16,900,000				
1999		11,925,000	17,525,000				
2000		12,100,000	18,050,000				
2001		12,350,000	18,750,000				
2002							
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Gulfstream (Grumman) Gulfstream G-159 (G-I)	Gulfstream (Grumman) Gulfstream G-II	Gulfstream (Grumman) Gulfstream G-II/TT	Gulfstream (Grumman) Gulfstream G-III	Gulfstream (Grumman) Gulfstream G-IV	Gulfstream (Grumman) Gulfstream G-IV-SP	Gulfstream (Grumman) Gulfstream G-V
1960	860,000						
1961	860,000						
1962	860,000						
1963	N/A						
1964	986,000 *						
1965	1,059,000 **	2,100,000					
1966	1,059,000	2,100,000					
1967	1,119,000	2,325,000					
1968	1,119,000	2,525,000					
1969		2,745,000					
1970	**based on*	2,900,000					
1971	*Aviation*	3,000,000					
1972	*Week &*	3,200,000					
1973	*Space Tech.*	3,204,000					
1974	*Mar. 16, '64*	4,350,000					
1975	***based on*	5,100,000					
1976	*Aviation*	5,500,000					
1977	*Week &*	5,900,000		7,400,000			
1978	*Space Tech.*		6,750,000	N/A			
1979	*Mar. 6, '67*		7,100,000	N/A			
1980				10,000,000			
1981				11,000,000			
1982				12,500,000			
1983				14,000,000			
1984				14,195,000	15,000,000		
1985				14,195,000	15,000,000		
1986				15,000,000	15,800,000		
1987					15,800,000		
1988					17,800,000		
1989					21,000,000		
1990					23,500,000		
1991					24,000,000		
1992					25,000,000		
1993						27,000,000	
1994						27,000,000	
1995						27,000,000	
1996						27,000,000	34,000,000
1997						28,000,000	35,000,000
1998						28,600,000	38,000,000
1999						29,500,000	39,500,000
2000						30,500,000	40,500,000
2001						32,075,000	41,450,000
2002						32,750,000	43,243,000
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Gulfstream (Grumman) Gulfstream G100	Gulfstream (Grumman) Gulfstream G200	Gulfstream (Grumman) Gulfstream G300	Gulfstream (Grumman) Gulfstream G400	Gulfstream (Grumman) Gulfstream G450	Gulfstream (Grumman) Gulfstream G500	Gulfstream (Grumman) Gulfstream G550
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
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1988							
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1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002	11,750,000	20,100,000					
2003	11,845,000	20,200,000	25,500,000	32,500,000	33,000,000	37,500,000	45,750,000
2004	11,850,000	20,800,000			33,500,000	38,000,000	45,750,000

	Aircraft Manufacturer & Model						
Year	Handley Page Dart Herald	Lockheed 1329 Jetstar 6	Lockheed 1329 Jetstar 8	Lockheed 1329-25 Jetstar II	Messer-schmitt HFB-320 Hansa Jet	Mitsubishi MU-2D	Mitsubishi MU-2F
1960	900,000 *	1,000,000					
1961	N/A	1,350,000					
1962	N/A	1,366,330					
1963		1,450,000					
1964	* *estimate*	1,450,000			567,500		
1965		1,492,200			600,000	350,000	
1966		1,492,000			700,000	260,000	
1967		1,590,000			700,000	348,000	
1968		1,650,000	1,650,000		700,000	311,000	
1969			1,650,000		840,000		368,850
1970			1,750,000		840,000		368,850
1971			1,750,000		890,000		368,850
1972			N/A		890,000		399,850
1973			1,750,000		890,000		
1974				3,500,000			
1975				4,550,000			
1976				5,035,000			
1977				5,195,000			
1978				5,255,000			
1979				5,900,000			
1980							
1981							
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Mitsubishi MU-2J	Mitsubishi MU-2K	Mitsubishi MU-2L	Mitsubishi MU-2M	Mitsubishi MU-2N	Mitsubishi MU-2P	Mitsubishi MU-2B-40 (Solitare)
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972	542,500						
1973	569,625	484,625					
1974	718,920	611,690					
1975			773,617	673,677			
1976			775,520	701,910			
1977					866,101	773,421	
1978					1,011,000	869,800	
1979							991,445
1980							1,145,000
1981							1,198,900
1982							1,372,435
1983							1,372,435
1984							1,372,435
1985							1,372,435
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

	Aircraft Manufacturer & Model						
Year	Mitsubishi MU-2B-60 (Marquise)	Mitsubishi Diamond I (MU-300)	Mitsubishi Diamond IA	Mitsubishi Diamond II	Piaggio P-180	Piaggio PD 808 Vespajet	Pilatus PC-12
1960							
1961							
1962							
1963						500,000	
1964						N/A	
1965						N/A	
1966						N/A	
1967						850,000	
1968						760,000	
1969						760,000	
1970						760,000	
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979	1,231,700						
1980	1,355,000	2,180,000					
1981	1,475,815	2,381,710					
1982	1,722,550	2,250,000					
1983	1,837,550	2,450,000					
1984	1,837,550		2,938,125	3,175,000			
1985	1,837,550		2,957,500	3,175,000			
1986							
1987							
1988					3,600,000		
1989					4,000,000		
1990					4,130,000		
1991					4,168,800		
1992					4,364,300		
1993					4,364,300		1,500,000
1994					4,680,000		2,040,720
1995					4,680,000		2,040,720
1996							2,315,900
1997							2,539,233
1998							2,565,378
1999							2,802,947
2000					4,595,000		2,826,877
2001					4,695,000		2,874,844
2002					4,695,000		2,944,247
2003					4,995,000		2,972,774
2004					5,495,000		2,979,439

	Aircraft Manufacturer & Model						
Year	New Piper PA-31T-501T Cheyenne I	New Piper PA-31T-501T Cheyenne IA	New Piper PA-31T-620 Cheyenne II	New Piper PA-31T2-620 Cheyenne II-XL	New Piper PA-42-7 Cheyenne III	New Piper PA-42-720 Cheyenne IIIA	New Piper PA-42-1000 Cheyenne IV (400)
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974			536,760				
1975			588,620				
1976			645,360				
1977			687,490				
1978	660,000		687,490		870,000		
1979	674,740		838,410				
1980	722,995		832,785		1,285,355		
1981	845,165		1,055,640	1,168,450	1,347,930		
1982	965,740		1,187,165	1,324,665	1,632,275		
1983	1,004,755		1,251,390	1,490,030	1,712,740		2,142,135
1984		1,123,480		1,537,930		1,943,755	2,153,223
1985		1,118,053		1,537,930		2,043,030	2,432,670
1986		1,118,053		1,537,930		2,043,030	2,432,670
1987						2,342,030	2,788,670
1988						2,342,030	2,788,670
1989						2,685,436	2,720,637
1990						2,790,660	2,861,090
1991						3,510,475	3,958,615
1992						4,037,046	4,552,407
1993						4,037,046	
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

	Aircraft Manufacturer & Model						
Year	New Piper PA-46-500TP Meridian	Raytheon Aircraft King Air 90/A90	Raytheon Aircraft King Air B90	Raytheon Aircraft King Air C90	Raytheon Aircraft King Air C90B	Raytheon Aircraft King Air E90	Raytheon Aircraft King Air F90
1960							
1961							
1962							
1963							
1964		300,000					
1965		320,000					
1966		407,500					
1967		420,000					
1968			442,000				
1969			465,000				
1970			465,000				
1971				399,500			
1972				460,150			
1973				429,500		518,750	
1974				511,199		603,929	
1975				579,523		665,278	
1976				593,730		740,020	
1977				609,923		791,847	
1978				664,080		839,000	
1979				763,900		957,020	
1980				796,135		1,014,170	1,150,000
1981				988,540		1,198,105	1,349,025
1982				1,046,880			1,412,695
1983				1,114,950			1,423,910
1984				1,321,370			1,721,420
1985				1,418,695			1,888,550
1986				1,474,585			1,888,550
1987				1,650,000			
1988				1,646,613			
1989				1,739,651			
1990				1,871,250			
1991				2,050,906			
1992					2,232,967		
1993					2,307,780		
1994					2,369,957		
1995					2,438,608		
1996					2,488,654		
1997					2,674,456		
1998					2,651,786		
1999	1,350,000				2,721,285		
2000	1,375,000				2,810,170		
2001	1,619,391				2,931,860		
2002	1,648,000				2,987,735		
2003	1,765,855				2,998,125		
2004	1,834,035				2,762,790		

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft King Air A100	Raytheon Aircraft King Air B100	Raytheon Aircraft King Air 200	Raytheon Aircraft King Air B200	Raytheon Aircraft King Air 300	Raytheon Aircraft King Air 350	Raytheon Aircraft Starship 2000
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970	565,000						
1971	605,000						
1972	644,500						
1973	644,500						
1974	712,573		811,660				
1975	803,890		877,111				
1976	860,970	885,940	1,014,320				
1977	880,697	920,992	1,062,802				
1978	914,100	955,520	1,148,250				
1979	1,045,100	1,076,990	1,320,235				
1980	1,106,413	1,151,628	1,395,018				
1981		1,367,493	1,655,380				
1982		1,502,584		1,785,070			
1983		1,491,131		1,955,659			
1984				2,047,600	2,528,080		
1985				2,209,936	2,534,710		
1986				2,385,170	2,696,510		
1987				2,493,746	2,849,523		
1988				2,797,533	3,020,433		4,260,000
1989				2,928,972	3,276,723		3,886,700
1990				3,115,153	3,640,000	4,025,493	3,911,196
1991				3,245,848		4,016,113	4,111,485
1992				3,450,953		4,232,836	
1993				3,675,087		4,413,097	
1994				3,714,475		4,527,241	
1995				3,714,475		4,557,720	
1996				3,757,804		4,559,870	
1997				3,870,709		4,697,875	
1998				3,999,640		4,921,375	
1999				4,110,410		5,070,410	
2000				4,285,370		5,260,330	
2001				4,481,230		5,499,720	
2002				4,578,855		5,606,960	
2003				4,843,415		5,838,460	
2004				4,997,320		5,832,660	

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft Starship 2000A	Raytheon Aircraft Premier I 390	Raytheon Aircraft Beechjet 400	Raytheon Aircraft Beechjet 400A	Raytheon Aircraft Hawker 400XP	Raytheon Aircraft Hawker 800XP	Raytheon Aircraft Hawker 1000
1960							
1961							
1962							
1963							
1964							
1965							
1966							
1967							
1968							
1969							
1970							
1971							
1972							
1973							
1974							
1975							
1976							
1977							
1978							
1979							
1980							
1981							
1982							
1983							
1984							
1985							
1986			3,500,000				
1987			3,697,975				
1988			3,909,444				
1989			4,118,122				
1990			4,731,157				
1991				5,008,916			
1992	4,399,521			5,309,451			
1993	4,937,000			5,362,889			
1994	4,327,900			5,773,723			
1995	4,300,000			5,761,994		9,950,000	12,695,000
1996				5,787,357		10,295,000	12,955,000
1997				5,775,662		10,545,000	
1998				5,919,130		10,845,000	
1999		4,526,000		6,216,780		11,595,000	
2000		4,858,000		6,332,840		11,895,000	
2001		5,258,015		6,607,290		12,053,240	
2002		5,473,025		6,648,475	6,648,475	12,490,000	
2003		5,594,085			6,648,675	12,982,755	
2004		5,668,175			6,748,950	13,193,306	

	Aircraft Manufacturer & Model						
Year	Raytheon Aircraft Hawker Horizon	Rockwell Aero Cmdr AE-680T Turbo Commander	Rockwell Aero Cmdr AE-680V Turbo II Commander	Rockwell Aero Cmdr AE-681 Hawk Commander	Rockwell Aero Cmdr AE-690 /A Turbo Commander	Rockwell Aero Cmdr AE-690B Turbo Commander	Rockwell Aero Cmdr AE-840 (RI 840)
1960							
1961							
1962							
1963							
1964							
1965		299,950					
1966		299,950					
1967		299,950					
1968			335,000				
1969			362,675				
1970				389,500			
1971				389,500			
1972					442,000		
1973					442,000		
1974					593,870		
1975					660,920		
1976					722,450		
1977						770,495	
1978						854,750	
1979						901,555	
1980							1,040,650
1981							
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002	17,288,000						
2003	18,038,000						
2004	18,453,000						

	Aircraft Manufacturer & Model						
Year	Rockwell Aero Cmdr AE-980 (RI 980)	Rockwell Aero Cmdr AE-1121 Jet Commander	Rockwell North American NA-40 Sabreliner	Rockwell N. Amer. NA-40A Sabre Commander	Rockwell North American NA-60 Sabreliner	Rockwell North American NA-65 Sabreliner	Rockwell North American NA-75 Sabreliner
1960							
1961							
1962							
1963		475,000	795,000				
1964		595,000	795,000				
1965		595,000	795,000				
1966		595,000	825,000				
1967		595,000	825,000				
1968			N/A		1,400,000 *		
1969			N/A		1,400,000 *		
1970			1,255,000		1,400,000		
1971					1,400,000		
1972				995,000	1,400,000		1,600,000
1973				1,145,000	1,496,000		
1974				1,435,000	1,671,500		
1975					1,725,300		
1976					1,878,000		
1977					1,990,500		
1978					2,290,000	3,300,000	
1979						3,448,000	
1980	1,204,810				** estimates*	4,880,000	
1981						5,100,000	
1982							
1983							
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							

	Aircraft Manufacturer & Model		
Year	Rockwell N. Amer. NA-75A Sabreliner	Swearingen SJ30-2	Vickers Viscount 810
1960			1,388,800
1961			1,515,000
1962			1,515,000
1963			
1964			
1965			
1966			
1967			
1968			
1969			
1970			
1971			
1972			
1973	1,800,000		
1974	2,195,000		
1975	2,222,700		
1976	2,406,450		
1977	2,550,800		
1978	2,933,400		
1979			
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992		2,595,000	
1993		2,932,000	
1994		3,012,000	
1995		3,080,000	
1996			
1997			
1998		3,800,000	
1999			
2000			
2001		4,869,041	
2002		5,169,041	
2003		5,495,855	
2004		5,495,855	

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APPENDIX D: METHOD FOR PRICE CONVERSIONS

To enable direct comparison of products over time, it is necessary to convert some product prices to a common baseline year. The conversion is performed via the Consumer Price Index, CPI.

To convert dollars of a year X to year Y dollars, divide the dollar amount from year X by the conversion factor (CF) for year Y and multiply by the CF for year X.

$$Dollars_{year\ Y} = \frac{CF_{year\ Y}}{CF_{year\ X}} \cdot Dollars_{year\ X}$$

The conversion factors used in this study are taken from Robert Sahr, Associate Professor, Political Science Department, Oregon State University. "Inflation Conversion Factors for Dollars 1665 to Estimated 2013" located online at (http://oregonstate.edu/dept/pol_sci/fac/sahr/sahr.htm)

All conversion factors are indexed to the year 2002 (CF_{2000}=1.000).

Year	CPI Conversion Factor	Year	CPI Conversion Factor
1960	0.165	1983	0.554
1961	0.166	1984	0.578
1962	0.168	1985	0.598
1963	0.170	1986	0.609
1964	0.172	1987	0.631
1965	0.175	1988	0.658
1966	0.180	1989	0.689
1967	0.186	1990	0.727
1968	0.193	1991	0.757
1969	0.204	1992	0.780
1970	0.216	1993	0.803
1971	0.225	1994	0.824
1972	0.232	1995	0.847
1973	0.247	1996	0.872
1974	0.274	1997	0.892
1975	0.299	1998	0.906
1976	0.316	1999	0.926
1977	0.337	2000	0.957
1978	0.362	2001	0.984
1979	0.404	2002	1.000
1980	0.458	2003	1.023
1981	0.505	2004	1.044
1982	0.536		

It may be technically more correct to use the Producer Price Index (PPI) for aircraft price conversions. The Bureau of Labor Statistics "PPI Program Spotlight" No. 98-3 (http://stats.bls.gov) explains the difference between the PPI and CPI conversion factors:

> While both the PPI and CPI measure price change over time for a fixed set of goods and services, the goods and services eligible for inclusion differ. The target set of goods and services included in the PPI is the entire marketed output of U.S. producers. The set includes both goods and services purchased by other producers as inputs to their operations or as capital investment, as well as goods and services purchased by consumers either directly from the producer or indirectly through a retailer. Since the PPI target is U.S. production, imports are excluded. In contrast, the target set of items included in the CPI is the set of goods and services purchased for personal consumption by urban U.S. households.

Unfortunately the publicly available PPI conversion data available from the Bureau of Labor Statistics does not extend farther back in time than the early 1970s, unlike the more complete set of CPI data available from Oregon State University. As shown in the figure below, the PPI and CPI closely track each other when both are indexed to a common year of 1985 (PPI data shown is for Transportation Equipment: Aircraft and Aircraft Equipment). The more complete set of CPI data was chosen for use in this study.

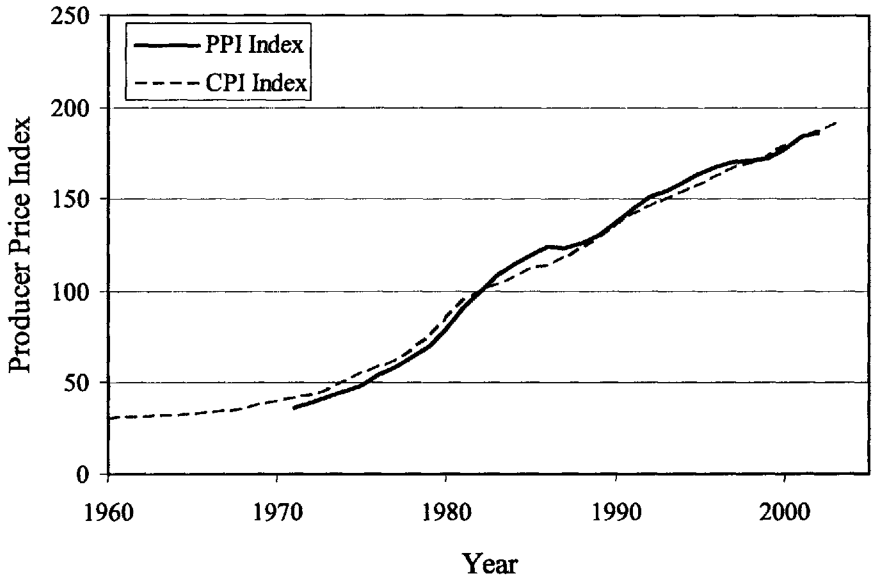


Figure D1: Comparison of CPI and PPI Data

APPENDIX E: SPORT UTILITY VEHICLE MODEL AND CHARACTERISTICS

In this appendix a Relative Value Index model is developed for the sport utility vehicle (SUV) segment of the automotive industry. The model is used to demonstrate the generalizability of the new approach for estimating attribute weighting factors based on empirical market date. Also listed in this appendix is the characteristics data used with the model, as it is available from AutoSite Pro. These characteristics are for the 2002 market and are listed exactly as available from the source. No units on the data were provided by the source, but some were assumed for the study in this appendix.

E1. Sport Utility Vehicle RVI Model

Data was obtained from AutoSite Pro for the 2002 market of sport utility vehicles. Parameters available for the analysis are listed in Table E1.

Table E1: SUV Parameters Available from AutoSite Pro, 2002 Market

- GM Segment
- EPA Class
- Cargo Volume (MFR)
- Displacement CC
- Horsepower
- Fuel Capacity
- Passenger Volume (MFR)
- Tow Capacity (Standard)
- Fuel Economy City
- Fuel Economy Highway
- Combined Fuel Economy
- Curb Weight MT
- Curb Weight AT
- Ground Clearance
- Height
- Length
- Track (Front)
- Track (Rear)
- Wheelbase
- Width
- Base Price MSRP
- Sales Volume
- Steering Diameter Left
- Steering Diameter Right
- Tire Width
- Tire Aspect Ratio
- Tire Wheel Diameter

Correlation coefficients for those parameters felt to be of the most importance to consumers are shown in Table E2. This initial set of attributes was selected, in part, from automotive review articles on SUVs that focused on these attributes in rating the vehicles [*Boston Globe* (January 31, 2004), (February 7, 2004) and (February 22, 2004)]. Unfortunately passenger volume was not available for most of the SUV models in this analysis. The parameter would have likely proven useful as a partial measure of passenger comfort had it been available.

Table E2: Preliminary SUV Attribute Correlation Coefficients

	Attribute			
	Cargo Volume (cu ft)	Towing Capacity (lbs)	Combined Fuel Economy (mpg)	Horsepower (hp)
Cargo Volume	1	0.10	0.14	0.22
Towing Capacity		1	0.81	0.85
Fuel Economy			1	0.72
Horsepower				1

The correlation coefficients show that vehicle horsepower is highly correlated with towing capacity and somewhat correlated to fuel economy. Neither result is surprising since greater engine power tends to permit greater loads to be towed and also requires higher rates of fuel consumption. Horsepower and vehicle weight were combined into a new attribute "power-to-weight ratio" that is known to be directly related to the important consumer attribute of acceleration performance.

$$\text{power - to - weight} = \frac{\text{horsepower}}{\text{curb weight AT}} \tag{E-1}$$

The fuel economy and towing capacity attributes are correlated to a greater degree than would be preferred, but a combined replacement variable could not be developed, so both parameters remain in the model. The correlations of the new attribute set are shown in Table E3.

Table E3: Final SUV Attribute Correlation Coefficients

	Attribute			
	Cargo Volume (cu ft)	Towing Capacity (lbs)	Fuel Economy (mpg)	Power-to-Weight (hp / lb)
Cargo Volume	1	0.10	0.14	0.21
Towing Capacity		1	0.81	0.35
Fuel Economy			1	0.18
Power-to-Weight				1

Bounds on the attribute set were developed based on intuition and estimates for the SUV segment.

Table E4: SUV Relative Value Index Model Attributes

			Attribute Bounds		
Attribute	Units	Type	Critical	Baseline	Ideal
Cargo Volume	cu. ft.	LIB	10 *(approx room for one bicycle)*	36 *(average for SUV market)*	45 *(approx room for medium desk)*
Towing Capacity	lbs	LIB	800 *(approx small trailer)*	3,780 *(average for SUV market)*	4000 *(approx large trailer)*
Fuel Economy	mpg	SIB	10 *(estimate)*	18.8 *(average for SUV market)*	45 *(approx for fuel efficient car)*
Power-to-Weight	hp/lb	LIB	0.03 *(estimate)*	0.05 *(estimate)*	0.06 *(estimate)*

Thirty-one standard SUV models were included in the data set to be evaluated (see §E2 for a listing), plus an additional 12 luxury SUV models were placed in a second segment to be simultaneously considered in the model. The results of the best fit, VI = RV, for the model are shown in Table E5. The routine obviously had a difficult time fitting the two value indices based on the R^2 value for the fit, and only the towing capacity and power-to-weight ratio parameters were leveraged for the fit.

Table E5: SUV 2002 Market Best Fit Weights and Sensitivities

Attribute	Weighting Factor	$\frac{\partial J}{\partial \gamma}$	$\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$
Cargo Volume	0.00	10,596	0.00
Towing Capacity	0.06	13,278	0.26
Fuel Economy	0.00	13,607	0.00
Power-to-Weight	0.03	2,242	0.02

$J = 3{,}098$, $R^2 = 0.39$, $F = 4.67$, $F_{.05} = 2.47$

The graph of Revealed Values and prices in Figure for the standard SUV models (SMLUT, MEDUT, LGEUTL) and the luxury models (MLXUTL, LLXUTL) does indicate a relationship between RV and manufacturer suggested retail prices, albeit considerably weaker than that in the business aviation industry. One important aspect of Figure E1 that is misleading, however, is that the MSRP is not necessarily the actual price at which the vehicle was sold. In fact, a recent plethora of discounting, rebates, and special financing offers almost guarantee that the vehicles were not sold at the MSRP listed in the data. The relationship shown in Figure E1 between RV and MSRP may, then, not truly exist.

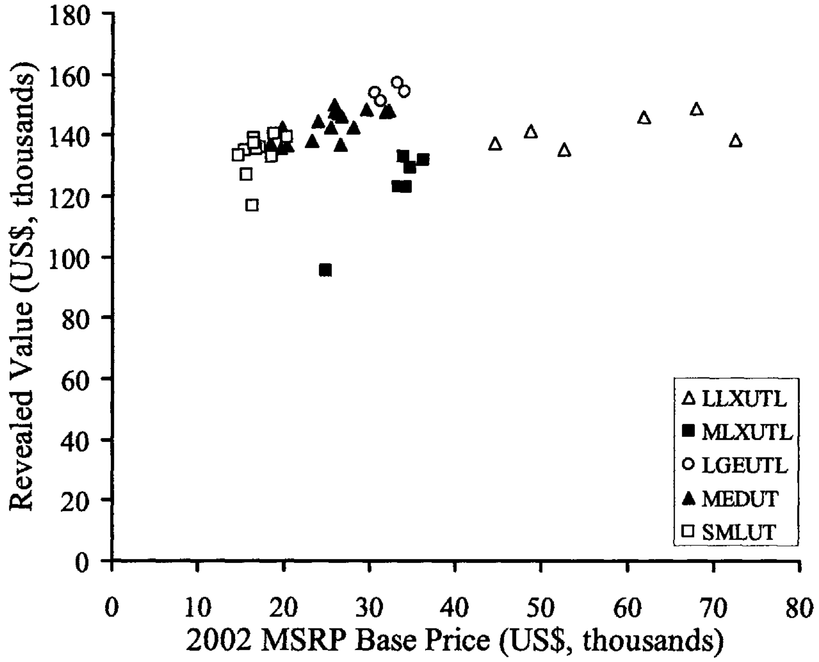
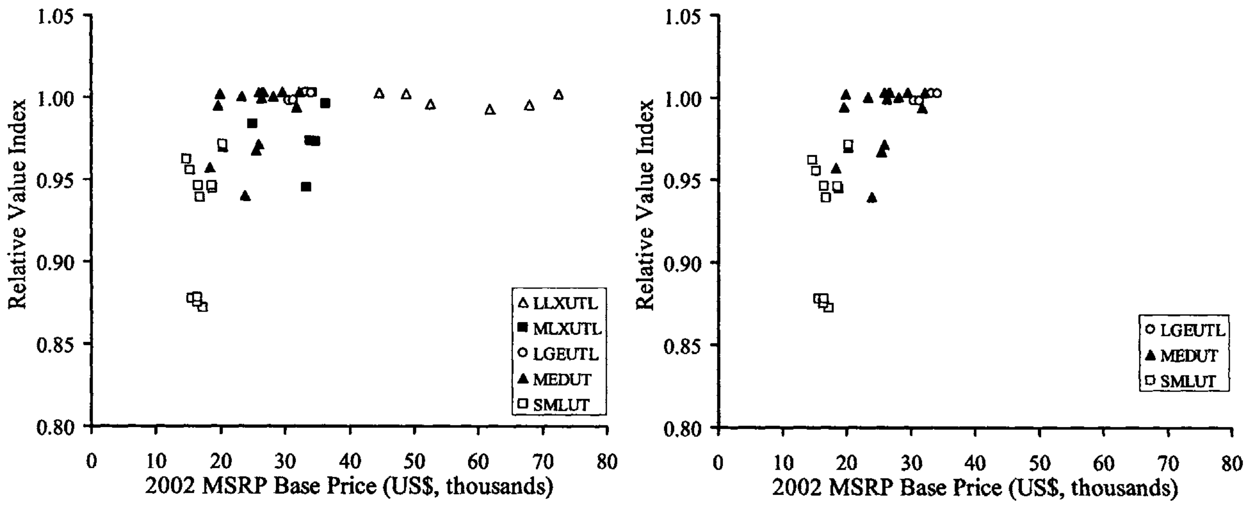


Figure E1: Revealed Value for SUVs in 2002 Market

The Revealed Value Index resulting from the attribute weights in Table E5 are shown in Figure E2, both with and without the luxury models included on the charts. Without the luxury vehicles a relationship between RVI and MSRP is clearer, although it does appear weak. This is consistent with the poor fit and only minor leveraging of the attributes used for the model.



(a) Including Luxury SUVs (b) Standard SUVs Only

Figure E2: Relative Value Index for SUV 2002 Market

The poor fit results in Table E5 would seem to indicate that all of the true parameters on which consumers are basing their purchase decisions have not been correctly identified for the RVI model. One parameter already identified is the passenger volume, which was not available for most of the models included in the study. Other factors may include comfort issues in the front cabin (seat width, etc.), standard appointments such as radios and air conditioning, and ride quality features such as cabin noise, vibration, and cornering. None of these parameters are currently available through the AutoSite Pro source. In the automotive market, which is not dominated by organizational buyers as is the business aviation industry, aesthetic features (so-called "styling") play an important role in purchases and are difficult to quantify. Some of the alternative marketing science methods documented in Chapter 3 (e.g., conjoint analysis) could be used to help quantify such parameters.

Another issue of significance to the purchase decision is the rebates, discounts, and financing terms available on particular models. These are very difficult to track but likely play a highly important role in the final purchase decision, particularly once an evoked set of models has been chosen that may be very similar in most other features. And it should be noted that factors such as safety and reliability have not been quantified in the AutoSite Pro data. Such factors might be gleaned from independent testing agencies such as *Consumer Reports*. Model designers would have to make certain assumptions regarding the ability and motivation of consumers to seek out such data before including it the model, however (i.e., just how many consumers research their vehicle purchases thoroughly enough to know the safety and reliability ratings).

One assumption made in the business aviation industry is that the market is nearly ideal; in other words, consumers are fully aware of all alternatives and all characteristics of the products, and that distribution networks exist to make all products available to all consumers. Although this is not an unrealistic assumption for the well-edcuated and motivated organizational buyers of the business aviation industry, it is not a realistic assumption for the automotive industry. Not all brands and models are available for purchase by all consumers, and it is unlikely that all consumers thoroughly study every alternative car, perhaps via *Consumer Reports* ratings and searches on the internet.

It was briefly considered that including the luxury vehicle data in the model might be affecting the goodness of the RVI model fit. A second fit with only the 31 standard SUV models was performed with the results listed in Table E6. Although the fit was somewhat better, the same attributes were again leveraged in the fit, and only to a slight extent.

Table E6: SUV 2002 Market Best Fit Weights and Sensitivities (Standard SUV Models Only)

Attribute	Weighting Factor	$\frac{\partial J}{\partial \gamma}$	$\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$
Cargo Volume	0.00	8,145	0.00
Towing Capacity	0.05	12,830	0.62
Fuel Economy	0.00	5,074	0.00
Power-to-Weight	0.04	1,892	0.07

$J = 1{,}130$, $R^2 = 0.47$, $F = 4.51$, $F_{.05} = 2.60$

The resulting Relative Value Indices for the standard SUV models are shown in Figure E3. The issue in the poor fit still appears to be poor identification and quantification of the proper attributes for the SUV purchase decision.

Despite the poor fit achieved for the SUV model, the RVI approach is still sound and has proven useful even in this analysis for identifying parameters that do not appear to support differentiation among SUV models in the 2002 market. For example, though fuel economy is claimed by many to be of importance in the purchase decision, the purchase behavior of SUV owners does not support that many consumers are making their buying decisions based on that factor. If they were, the data would indicate higher sales among the low MSRP models that tend to have higher fuel economies. The horsepower or engine size in the vehicle appears to be a more reliable indicator of purchase decisions. These parameters are directly related to the size of the SUV, so vehicle weight (or length and height) might be more reliable parameters for judging the market behavior.

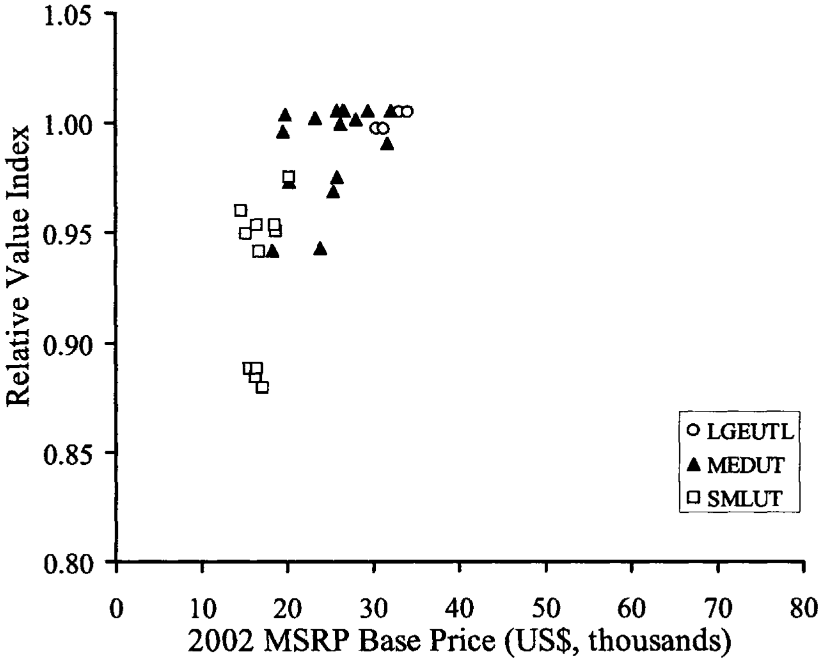


Figure E3: Relative Value Index for SUV 2002 Market (Standard SUV Models Only)

E2. Automobile Characteristics

Of the types and models of SUVs available from the source, only 31 standard SUV models (SMLUT, MEDUT, LGEUTL) and 12 luxury models (MLXUTL, LLXUTL) are listed in this appendix and used for the study. Thirteen additional models (10 standard, 3 luxury) were not used for the analysis due to a lack of data for key parameters. The terms "NA" and "NL" in the tables indicate missing data for those models and parameters.

The automobile models are listed in order corresponding to their GM segment: SMLUT, MEDUT, etc.

	Jeep Wrangler SE 2.5L I4 5M OD	Kia Sportage 2 Door 4X2 2.0L I4 4A OD	Suzuki Vitara Two-Door JLS 2.0L I4 5M OD	Honda CR-V 2WD LX 2.4L I4 4A OD	Hyundai Santa Fe GL 2.4L I4 5M OD	Chevrolet Tracker 2WD 4-Door Hardtop 2.0L I4 5M OD
GM Segment	SMLUT2	SMLUT2	SMLUT2	SMLUT4	SMLUT4	SMLUT4
EPA Class	SPURP4WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD
Cargo Volume (MFR)	55.2	13	12.1	33.5	30.5	20.2
Displacement CC	2464	1998	1999	2400	2351	1983
Horsepower	120	130	127	160	149	127
Fuel Capacity	19	15.8	14.8	15.3	17.2	16.9
Passenger Volume (MFR)	NL	88.1	93.4	106	100.7	83.5
Tow Capacity (Standard)	2000	2000	1000	1500	1000	1500
Fuel Economy City	18	18	23	23	21	23
Fuel Economy Highway	20	21	26	28	28	26
Combined Fuel Economy	19	19	24	25	24	24
Curb Weight MT	3110	NA	2679	NA	3494	2866
Curb Weight AT	3126	3108	2712	3201	3574	2906
Ground Clearance	8.5	7.9	7.2	8.1	7.4	7.2
Height	70.9	65	65	66.2	66	65.6
Length	155.4	156.4	152	178.6	177.2	162.6
Track (Front)	58	56.7	57.5	60.4	60.7	57.5
Track (Rear)	58	56.7	57.5	60.6	60.7	57.5
Wheelbase	93.4	92.9	86.6	103.1	103.1	97.6
Width	66.7	68.1	67.3	70.2	72.7	67.3
Base Price MSRP	15305	14645	15599	18800	17199	16790
Sales Volume	68830	52368	7907	118313	56017	52368
Steering Diameter Left	32.8	32.2	31.5	34.1	37.1	34.8
Steering Diameter Right	32.8	32.2	31.5	34.1	37.1	34.8
Tire Width	205	205	215	205	225	195
Tire Aspect Ratio	75	75	65	70	70	75
Tire Wheel Diameter	15	15	16	15	16	15

	Saturn VUE FWD 4 2.2L I4 5M OD	Subaru Forester L 2.5L H4 5M OD	Suzuki Grand Vitara JLS 2.5L V6 5M OD	Chrysler PT Cruiser Base 2.4L I4 5M OD	Toyota RAV4 4-Door 4X2 2.0L I4 5M OD	Chevrolet Blazer 2-Door 2WD LS 4.3L V6 5M OD
GM Segment	SMLUT4	SMLUT4	SMLUT4	SMLUT4	SMLUT4	MEDUT2
EPA Class	SPURP2WD	SPURP4WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD
Cargo Volume (MFR)	30.3	32	23.4	13.1	29.2	29.8
Displacement CC	2198	2457	2494	2429	1998	4300
Horsepower	143	165	165	150	148	190
Fuel Capacity	15.5	15.9	16.9	15	14.7	19
Passenger Volume (MFR)	99.8	94.3	NL	107	NL	NL
Tow Capacity (Standard)	1000	2000	1500	1000	1500	4200
Fuel Economy City	23	21	19	21	25	16
Fuel Economy Highway	28	27	22	29	31	22
Combined Fuel Economy	25	23	20	24	27	18
Curb Weight MT	3179	3140	3075	3108	2711	3502
Curb Weight AT	3236	3195	3075	3190	2777	3488
Ground Clearance	8	7.5	7	6	6.3	8.1
Height	66.5	65	67.3	63	65.7	65.2
Length	181.3	175.6	164.5	168.8	166.2	177.3
Track (Front)	61	58.1	59.1	58.3	59.3	55
Track (Rear)	61	57.7	59.1	58.2	59.1	54.6
Wheelbase	106.6	99.4	97.6	103	98	100.5
Width	71.5	68.3	70.1	67.1	68.3	67.8
Base Price MSRP	16325	20295	18599	16450	16525	19855
Sales Volume	393	55041	16030	144717	86208	149195
Steering Diameter Left	38	34.7	34.8	36.5	35.4	34.8
Steering Diameter Right	38	34.7	34.8	36.5	35.4	34.8
Tire Width	215	205	235	195	215	235
Tire Aspect Ratio	70	70	60	65	70	70
Tire Wheel Diameter	16	15	16	15	16	15

	Buick Rendezvous FWD CX 3.4L V6 4A OD	Chevrolet All New TrailBlazer LS 2WD 4.2L I6 4A OD	GMC Envoy SLE 2WD 4.2L I6 4A OD	Isuzu Axiom Base 2WD 3.5L V6 4A OD	Isuzu Trooper S 4X2 3.5L V6 4A OD	Isuzu Rodeo S 2WD 2.2L I4 5M OD
GM Segment	MEDUT4	MEDUT4	MEDUT4	MEDUT4	MEDUT4	MEDUT4
EPA Class	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD
Cargo Volume (MFR)	54.5	41	39.8	35.2	46.3	33
Displacement CC	3350	4195	4195	3494	3494	2198
Horsepower	185	270	270	230	215	130
Fuel Capacity	18	18.7	18.7	19.5	22.5	20
Passenger Volume (MFR)	109.3	83.3	83.3	NL	NL	NL
Tow Capacity (Standard)	2000	5400	5400	4500	5000	2500
Fuel Economy City	19	16	16	16	15	19
Fuel Economy Highway	26	22	22	20	19	23
Combined Fuel Economy	22	18	18	18	17	20
Curb Weight MT	NA	NA	NA	NA	NA	3709
Curb Weight AT	4024	4312	4312	3920	4238	3753
Ground Clearance	7	8	8	7.9	8.3	8.4
Height	68.9	74.5	71.9	67.2	72.2	69.2
Length	186.5	191.8	191.6	182.6	187.8	177.5
Track (Front)	62.7	63.1	63.1	59.6	59.6	59.6
Track (Rear)	63.8	62.1	62.1	59.8	59.8	59.8
Wheelbase	112.2	113	113	106.4	108.7	106.4
Width	73.6	74.6	74.7	70.7	72.2	70.4
Base Price MSRP	25520	25885	29575	26535	28105	18380
Sales Volume	31754	115103	51208	5851	15608	54807
Steering Diameter Left	37.4	36.4	36.4	38.4	38.1	38.4
Steering Diameter Right	37.4	36.4	36.4	38.4	38.1	38.4
Tire Width	215	245	245	235	245	225
Tire Aspect Ratio	70	70	65	65	70	75
Tire Wheel Diameter	16	16	17	17	16	16

	Oldsmobile Bravada 2-Wheel Drive W/O G80 & NW7 4.2L I6 4A OD	Pontiac Aztek Front-Wheel Drive 3.4L V6 4A OD	Suzuki XL-7 Standard 2WD 2.7L V6 5M OD	Jeep Grand Cherokee Laredo 2WD 4.0L I6 4A OD	Honda Passport 2WD LX 3.2L V6 5M OD	Mitsubishi Montero XLS 3.5L V6 4A OD
GM Segment	MEDUT4	MEDUT4	MEDUT4	MEDUT4	MEDUT4	MEDUT4
EPA Class	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP4WD
Cargo Volume (MFR)	39.8	45.4	43.3	39	33	42.1
Displacement CC	4195	3350	2726	3960	3165	3497
Horsepower	270	185	183	195	205	200
Fuel Capacity	18.7	18	16.9	20.5	19.5	23.8
Passenger Volume (MFR)	NL	105.1	NL	NL	97	104.6
Tow Capacity (Standard)	5700	2000	3000	2000	3500	5000
Fuel Economy City	16	19	18	15	17	15
Fuel Economy Highway	22	26	20	21	20	19
Combined Fuel Economy	18	22	19	17	18	17
Curb Weight MT	NA	NA	3549	NA	3816	NA
Curb Weight AT	4442	3779	3560	3786	3854	4600
Ground Clearance	8	7.2	7	8.3	8	8.7
Height	74.5	66.7	67.5	70.3	68.6	71.3
Length	191.8	182.1	183.6	181.6	184	189.2
Track (Front)	63.1	62.7	59.1	59.5	59.6	61.6
Track (Rear)	62.1	63.8	59.1	59.5	59.8	61.6
Wheelbase	113	108.3	110.2	105.9	106.4	109.7
Width	75.4	73.7	70.1	72.6	70.4	74
Base Price MSRP	32215	20295	19599	25865	23300	31787
Sales Volume	23867	27322	25096	223612	17448	24802
Steering Diameter Left	36.4	36.4	38.7	37.4	38.4	37.4
Steering Diameter Right	36.4	36.4	38.7	37.4	38.4	37.4
Tire Width	245	215	235	225	225	265
Tire Aspect Ratio	65	70	60	75	75	70
Tire Wheel Diameter	17	16	16	16	16	16

	Nissan Pathfinder SE 4X2 3.5L V6 4A OD	Toyota Highlander Sport Utility 4X2 2.4L I4 4A OD	Toyota 4Runner SR5 4X2 3.4L V6 4A OD	Chevrolet Tahoe 2WD LS 4.8L V8 4A OD	GMC Yukon 2WD 4.8L V8 4A OD	Ford Expedition XLT 4X2 4.6L V8 4A OD
GM Segment	MEDUT4	MEDUT4	MEDUT4	LGEUTL	LGEUTL	LGEUTL
EPA Class	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD	SPURP2WD
Cargo Volume (MFR)	38	38.5	44.6	63.6	63.6	20.5
Displacement CC	3498	2362	3378	4785	4807	4605
Horsepower	240	155	183	275	275	232
Fuel Capacity	21.1	19.8	18.5	26	26	26
Passenger Volume (MFR)	92.9	105.7	87.1	NL	NL	NL
Tow Capacity (Standard)	5000	1500	5000	5800	5700	5800
Fuel Economy City	16	22	17	15	15	15
Fuel Economy Highway	19	27	19	19	19	20
Combined Fuel Economy	17	24	18	16	16	17
Curb Weight MT	NA	NA	NA	NA	NA	NA
Curb Weight AT	3871	3485	3740	4811	4863	4909
Ground Clearance	8.3	6.9	9.8	8.4	8.4	7.5
Height	70.9	66.1	67.5	76.5	76.7	74.3
Length	182.7	184.4	183.3	196.9	198.9	204.6
Track (Front)	60.6	62.2	59.3	65	65	65.4
Track (Rear)	60.8	61.6	58.9	66	66	65.5
Wheelbase	106.3	106.9	105.3	116	116	119.1
Width	71.7	71.9	66.5	78.9	78.9	78.6
Base Price MSRP	26649	23880	26335	33204	34091	30555
Sales Volume	64515	86699	90250	202319	77254	178045
Steering Diameter Left	37.4	37.4	38.1	38.3	38.3	40.4
Steering Diameter Right	37.4	37.4	38.1	38.3	38.3	40.4
Tire Width	255	225	225	265	265	255
Tire Aspect Ratio	65	70	75	70	70	70
Tire Wheel Diameter	16	16	15	16	16	16

	Toyota Sequoia SR5 4X2 4.7L V8 4A OD	Mercedes-Benz M-Class ML320 3.2L V6 5A OD	Land Rover Discovery Series II SD 4.0L V8 4A OD	Land Rover Freelander S 2.5L V6 5A OD	Acura MDX Sport Utility 3.5L V6 5A OD
GM Segment	LGEUTL	MLXUTL	MLXUTL	MLXUTL	MLXUTL
EPA Class	SPURP2WD	SPURP4WD	SPURP4WD	SPURP4WD	SPURP4WD
Cargo Volume (MFR)	26.6	34.7	40.5	19.3	14.8
Displacement CC	4664	3199	3950	2497	3471
Horsepower	240	215	188	174	240
Fuel Capacity	26.1	22.6	24.6	15.8	19.2
Passenger Volume (MFR)	NL	NL	NL	NL	161.5
Tow Capacity (Standard)	6500	5000	1650	2500	2000
Fuel Economy City	14	15	13	17	17
Fuel Economy Highway	18	19	17	21	23
Combined Fuel Economy	16	17	15	18	19
Curb Weight MT	NA	NA	NA	NA	NA
Curb Weight AT	5070	4786	4576	3620	4374
Ground Clearance	10	8.7	8.2	7.2	8
Height	73.2	71.7	76.4	NL	68.7
Length	203.9	182.6	185.2	175	188.5
Track (Front)	65.9	60.4	60.6	60.4	66.3
Track (Rear)	66.1	60.4	61.4	60.8	66.5
Wheelbase	118.1	111	100	101	106.3
Width	76	72.4	74.4	71.1	77
Base Price MSRP	31265	36300	33350	24975	34700
Sales Volume	68574	45655	20104	1329	40950
Steering Diameter Left	42.3	39	39	38	38
Steering Diameter Right	42.3	39	39	38	38
Tire Width	245	255	255	215	235
Tire Aspect Ratio	70	60	65	65	65
Tire Wheel Diameter	16	17	16	16	17

	Infiniti QX4 4-Door Luxury SUV 4x2 3.5L V6 4A OD	Lexus RX 300 Front Wheel Drive 3.0L V6 4A OD	Mercedes-Benz G-Class G500 5.0L V8 5A OD	Land Rover Range Rover 4.6 HSE 4.6L V8 4A OD
GM Segment	MLXUTL	MLXUTL	LLXUTL	LLXUTL
EPA Class	SPURP2WD	WAGONMID	SPURP4WD	SPURP4WD
Cargo Volume (MFR)	38	39.8	45.2	31
Displacement CC	3498	2995	4966	4554
Horsepower	240	220	292	222
Fuel Capacity	21.1	19.8	25.4	24.6
Passenger Volume (MFR)	92.9	100.8	88.5	NL
Tow Capacity (Standard)	5000	2000	7000	6500
Fuel Economy City	15	19	12	12
Fuel Economy Highway	19	23	14	15
Combined Fuel Economy	17	20	13	13
Curb Weight MT	NA	NA	NA	NA
Curb Weight AT	4074	3715	5423	4960
Ground Clearance	8.3	7.7	8.3	8.4
Height	70.7	65.7	77.8	71.6
Length	183.1	180.1	185.6	185.5
Track (Front)	60.6	61.6	59.6	60.6
Track (Rear)	60.8	61	59.6	60.2
Wheelbase	106.3	103.1	112.2	108.1
Width	72.4	71.5	71.3	74.4
Base Price MSRP	34150	33955	72500	68000
Sales Volume	18735	77391	674	5771
Steering Diameter Left	37.4	41.3	43.5	39
Steering Diameter Right	37.4	41.3	43.5	39
Tire Width	245	225	265	255
Tire Aspect Ratio	70	70	60	55
Tire Wheel Diameter	16	16	18	18

	Lincoln Navigator 4X2 5.4L V8 4A OD	Lexus LX 470 Sport Utility 4.7L V8 4A OD	Toyota Land Cruiser 4X4 4.7L V8 4A OD	Cadillac Escalade 2WD 5.3L V8 4A OD
GM Segment	LLXUTL	LLXUTL	LLXUTL	LLXUTL
EPA Class	SPURP2WD	SPURP4WD	SPURP4WD	SPURP2WD
Cargo Volume (MFR)	19.6	19.1	20.8	16.3
Displacement CC	5408	4664	4664	5328
Horsepower	300	230	230	285
Fuel Capacity	30	25.4	25.4	26
Passenger Volume (MFR)	NL	NL	135.2	122.1
Tow Capacity (Standard)	8900	6500	6500	7400
Fuel Economy City	12	13	13	14
Fuel Economy Highway	17	16	16	18
Combined Fuel Economy	14	14	14	16
Curb Weight MT	NA	NA	NA	NA
Curb Weight AT	5424	5401	5115	5333
Ground Clearance	8.5	9.8	9.8	9.7
Height	75.2	72.8	73.2	76.5
Length	204.8	192.5	192.5	198.9
Track (Front)	65.4	63.8	63.8	65
Track (Rear)	65.5	63.6	63.6	66
Wheelbase	119	112.2	112.2	116
Width	79.8	76.4	76.4	78.9
Base Price MSRP	44590	61855	52595	48735
Sales Volume	31759	9355	7591	31270
Steering Diameter Left	40.4	39.7	39.7	39.5
Steering Diameter Right	40.4	39.7	39.7	39.5
Tire Width	275	275	275	265
Tire Aspect Ratio	60	70	70	70
Tire Wheel Diameter	17	16	16	17

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APPENDIX F: ATTRIBUTE EXPONENTIAL WEIGHTING FACTOR DATA

Listed in this appendix is the attribute exponential weighting factor data resulting from the Revealed Value and Value Index best fits for historical business aircraft markets. The markets under consideration reflect three-year averages (e.g., 1999 - 2001) for both price and shipments data.

The data listed in the tables of this appendix includes the following:

- Attribute exponential weighting factors resulting from the best fit analysis
- Best fit statistics
  - sum-squared error cost function, J
  - multiple coefficient of determination, R^2
  - ANOVA F test statistic
  - the rejection region at an 0.05 confidence level, $F_{0.05}$
- Attribute exponential weighting factor dimensional sensitivities, $\frac{\partial J}{\partial \gamma}$
- Attribute exponential weighting factor non-dimensional sensitivities, $\frac{\partial J}{\partial \gamma} \cdot \frac{\gamma}{J}$

	Attribute Exponential Weighting Factor								
Three-year average	Max. Speed	Field Length	Fuel Cons./ Seat Mile	Cabin Vol. per Pax	Avail. Seat-Miles	J	R^2	F	$F_{0.05}$
1965-67	0.23	0.00	0.00	0.05	0.04	0.31	0.99	691.63	2.62
1966-68	0.27	0.00	0.00	0.06	0.07	0.93	0.99	780.73	2.59
1967-69	0.47	0.00	0.00	0.06	0.17	1.31	0.99	452.45	2.60
1968-70	0.35	0.00	0.00	0.03	0.08	2.02	0.95	47.12	3.11
1969-71	0.15	0.06	0.03	0.02	0.00	0.73	0.96	49.62	3.48
1970-72	0.19	0.00	0.00	0.01	0.00	1.61	0.96	42.48	3.33
1971-73	0.08	0.00	0.00	0.00	0.00	2.37	0.92	36.02	2.90
1972-74	0.15	0.02	0.02	0.04	0.00	2.38	0.93	41.97	2.85
1973-75	0.18	0.38	0.01	0.07	0.00	1.20	0.95	62.97	2.90
1974-76	0.15	0.68	0.17	0.03	0.00	3.12	0.91	37.03	2.77
1975-77	0.00	0.33	0.08	0.00	0.00	6.10	0.97	142.41	2.66
1976-78	0.00	0.00	0.00	0.01	0.00	9.27	0.93	62.29	2.66
1977-79	0.11	0.53	0.00	0.00	0.04	10.15	0.94	65.21	2.74
1978-80	0.19	0.03	0.24	0.01	0.01	15.62	0.89	26.28	2.81
1979-81	0.17	0.00	0.29	0.04	0.05	16.45	0.97	137.97	2.71
1980-82	0.07	0.00	0.00	0.05	0.04	16.21	0.97	131.20	2.66
1981-83	0.00	0.00	0.00	0.04	0.07	17.64	0.96	104.19	2.66
1982-84	0.01	0.65	0.00	0.07	0.22	76.38	0.98	255.66	2.56
1983-85	0.00	0.49	0.00	0.08	0.27	92.61	0.98	274.10	2.55
1984-86	0.00	0.82	0.00	0.11	0.27	107.25	0.96	117.41	2.60
1985-87	0.59	0.27	0.08	0.29	0.08	66.99	0.99	526.20	2.71
1986-88	1.14	0.56	0.33	0.38	0.00	93.53	0.99	626.85	2.71
1987-89	0.69	0.00	0.32	0.69	0.12	30.91	1.00	617.83	2.90
1988-90	0.54	0.00	0.00	0.64	0.01	48.80	0.98	183.09	2.90
1989-91	0.00	0.00	0.00	0.31	0.06	130.04	0.96	83.27	2.77
1990-92	0.00	0.11	0.00	0.33	0.06	124.20	0.97	118.80	2.77
1991-93	0.00	0.00	0.00	0.38	0.15	72.53	0.98	152.18	3.11
1992-94	0.00	0.00	0.04	0.46	0.08	59.33	0.99	346.25	2.90
1993-95	0.86	0.00	0.00	0.70	0.43	72.87	0.99	223.57	3.03
1994-96	0.00	0.00	0.00	0.46	0.20	88.63	0.98	136.89	3.11
1995-97	0.36	0.00	0.00	0.68	0.39	82.72	0.99	144.87	3.20
1996-98	0.42	0.00	0.00	0.44	0.38	189.34	0.99	259.49	2.85
1997-99	0.49	0.00	0.00	0.43	0.42	282.12	0.98	183.80	2.85
1998-00	0.19	0.21	0.00	0.22	0.24	148.23	0.99	479.56	2.74
1999-01	0.25	0.00	0.00	0.23	0.15	141.89	0.99	512.54	2.74

	Attribute Exponential Weighting Factor Dimensional Sensitivity					Attribute Exponential Weighting Factor Non-Dimensional Sensitivity				
Three-year average	Max. Speed	Field Length	Fuel Cons./ Seat Mile	Cabin Vol. per Pax	Avail. Seat-Miles	Max. Speed	Field Length	Fuel Cons./ Seat Mile	Cabin Vol. per Pax	Avail. Seat-Miles
1965-67	0.22	0.28	0.79	0.60	0.42	0.168	0.000	0.000	0.097	0.055
1966-68	0.42	1.09	5.16	0.79	1.02	0.123	0.000	0.000	0.053	0.082
1967-69	0.34	1.11	4.07	1.15	1.56	0.122	0.000	0.000	0.051	0.204
1968-70	0.39	1.42	5.69	0.97	1.04	0.068	0.000	0.000	0.013	0.044
1969-71	0.15	0.00	1.64	1.76	1.66	0.031	0.000	0.066	0.037	0.000
1970-72	0.65	0.07	4.77	3.64	1.09	0.077	0.000	0.000	0.021	0.000
1971-73	0.71	0.10	4.55	2.95	7.19	0.024	0.000	0.000	0.000	0.000
1972-74	0.58	0.11	2.95	2.56	3.91	0.036	0.001	0.027	0.042	0.000
1973-75	0.81	0.06	0.38	3.51	2.31	0.124	0.020	0.004	0.205	0.000
1974-76	0.62	0.04	0.58	6.44	3.52	0.030	0.008	0.033	0.063	0.000
1975-77	4.94	0.00	0.97	15.45	7.51	0.000	0.000	0.012	0.011	0.000
1976-78	9.54	0.64	5.86	17.08	4.71	0.000	0.000	0.000	0.010	0.000
1977-79	1.06	0.10	5.11	29.91	4.22	0.012	0.005	0.000	0.000	0.018
1978-80	1.40	0.53	1.59	17.09	3.31	0.017	0.001	0.024	0.015	0.003
1979-81	2.40	3.83	3.17	35.22	8.97	0.025	0.000	0.056	0.094	0.030
1980-82	2.47	2.16	8.94	51.45	13.73	0.011	0.000	0.000	0.153	0.037
1981-83	3.42	4.41	9.69	71.78	17.76	0.000	0.000	0.000	0.168	0.075
1982-84	4.45	5.27	13.84	148.05	32.30	0.000	0.045	0.000	0.130	0.091
1983-85	32.75	0.51	12.65	151.20	39.51	0.000	0.003	0.000	0.131	0.114
1984-86	52.41	0.20	11.19	68.32	33.12	0.000	0.002	0.000	0.071	0.082
1985-87	3.17	3.76	3.39	20.47	74.01	0.028	0.015	0.004	0.089	0.083
1986-88	13.34	1.48	4.52	1.73	110.24	0.162	0.009	0.016	0.007	0.000
1987-89	1.87	6.27	0.71	12.19	62.17	0.042	0.000	0.007	0.271	0.246
1988-90	0.72	11.25	11.08	11.65	18.09	0.008	0.000	0.000	0.154	0.004
1989-91	51.99	1.89	25.44	26.40	23.76	0.000	0.000	0.000	0.063	0.010
1990-92	34.47	0.76	33.57	14.84	24.90	0.000	0.001	0.000	0.039	0.011
1991-93	18.70	18.59	25.62	4.46	24.48	0.000	0.000	0.000	0.023	0.049
1992-94	33.36	52.27	1.29	15.14	37.57	0.000	0.000	0.001	0.118	0.051
1993-95	1.08	39.11	48.00	8.60	31.19	0.013	0.000	0.000	0.083	0.185
1994-96	10.54	16.04	58.54	9.81	21.65	0.000	0.000	0.000	0.051	0.048
1995-97	0.85	37.03	74.66	5.75	25.88	0.004	0.000	0.000	0.048	0.122
1996-98	4.94	81.00	182.30	15.47	37.82	0.011	0.000	0.000	0.036	0.076
1997-99	2.35	96.93	185.07	23.43	32.43	0.004	0.000	0.000	0.036	0.048
1998-00	4.91	2.98	47.38	38.17	60.85	0.006	0.004	0.000	0.058	0.098
1999-01	10.75	36.06	62.60	43.58	54.42	0.019	0.000	0.000	0.071	0.058

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