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The ASAC Air Carrier Investment Model (Third Generation)

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The ASAC Air Carrier Investment Model (Third Generation)

SUMMARY

To meet its objective of assisting the U.S. aviation industry with the technological challenges of the future, National Aeronautics and Space Administration (NASA) must identify research areas that have the greatest potential for improving the operation of the air transportation system. Therefore, NASA seeks to develop the ability to evaluate the potential impact of various advanced technologies. By thoroughly understanding the economic impact of advanced aviation technologies and by evaluating how these new technologies would be used within the integrated aviation system, NASA aims to balance its aeronautical research program and help speed the introduction of high-leverage technologies. To meet these objectives, NASA is building the Aviation System Analysis Capability (ASAC).

NASA envisions the ASAC primarily as a process for understanding and evaluating the impact of advanced aviation technologies on the U.S. economy. ASAC consists of a diverse collection of models, databases, analysts, and other individuals from the public and private sectors brought together to work on issues of common interest to organizations within the aviation community. ASAC also will be a resource available to the aviation community to perform analyses; provide information; and assist scientists, engineers, analysts, and program managers in their daily work.

The ASAC differs from previous NASA modeling efforts in that the economic behavior of buyers and sellers in the air transportation and aviation industries is central to its conception. To link the economics of flight with the technology of flight, ASAC requires a parametrically based model that links airline operations and investments in aircraft with aircraft characteristics. This model also must provide a mechanism for incorporating air travel demand and profitability factors into the airlines' investment decisions. Finally, the model must be flexible and capable of being incorporated into a wide-ranging suite of economic and technical models that are envisioned for ASAC.

This report describes a third-generation Air Carrier Investment Model (ACIM) that meets these requirements. Earlier generations of ACIM incorporated econometric results from the supply and demand curves faced by U.S.-scheduled passenger air carriers, as well as detailed information about their 1995 fleets, to project revenue passenger-miles flown, numbers and types of aircraft in the fleet, and changes in airline and aircraft manufacturing employment under a variety of

user-defined scenarios. The third-generation model expands upon this approach in four dimensions. First, the scope of the econometric results is expanded with the inclusion of modules for the geographic regions of Europe and Asia Pacific. Second, using concepts from activity based costing (ABC), an alternate approach is developed to estimate U.S.-scheduled air carrier supply by examining operating costs in several functional cost categories. Third, a market share predictor module is developed to link U.S. aircraft manufacturing market share to changes in the relative performance of U.S. aircraft versus foreign aircraft. Fourth, an Input-Output Module is developed to project the impact of U.S. aircraft production on employment in the airframe manufacturing and related industries.

INTRODUCTION

NASA's Role in Promoting Aviation Technology

The United States has long been the world's leader in aviation technology for civil and military aircraft. During the past several decades, U.S. firms have transformed this position of technological leadership into a thriving industry with large domestic and international sales of aircraft and related products.

Despite its historic record of success, the difficult business environment of the recent past has stimulated concerns about whether the U.S. aeronautics industry will maintain its worldwide leadership position. Increased competition, both technological and financial, from European and other non-U.S. aircraft manufacturers has reduced the global market share of U.S. producers of large civil transport aircraft and cut the number of U.S. airframe manufacturers to only one.

The primary role of NASA in supporting civil aviation is to develop technologies that improve the overall performance of the integrated air transportation system, making air travel safer and more efficient, while contributing to the economic welfare of the United States. NASA conducts much of the basic and early applied research that creates the advanced technology introduced into the air transportation system. Through its technology research program, NASA aims to maintain and improve the leadership role in aviation technology and air transportation held by the United States for the past half century.

The principal NASA program supporting subsonic transportation is the Advanced Subsonic Technology (AST) program. In cooperation with the Federal Aviation Administration and the U.S. aeronautics industry, the goal of the AST program is to develop high-payoff technologies that support the development of a safe, environmentally acceptable, and highly productive global air transportation system. NASA measures the long-term success of its AST program by how well it contributes to an increased market share for U.S. civil aircraft and aircraft component producers and to the increased effectiveness and capacity of the national air transportation system.

NASA's Research Objective

To meet its objective of assisting the U.S. aviation industry with the technological challenges of the future, NASA must identify research areas that have the greatest potential for improving the operation of the air transportation system. Therefore, NASA seeks to develop the ability to evaluate the potential impact of various advanced technologies. By thoroughly understanding the economic impact of advanced aviation technologies and by evaluating how those new technologies would be used within the integrated aviation system, NASA aims to balance its aeronautical research program and help speed the introduction of high-leverage technologies. To meet these objectives, NASA is building an Aviation System Analysis Capability (ASAC).

Goal of the ASAC Project: Identifying and Evaluating Promising Technologies

The principal goal of ASAC is to develop credible evaluations of the economic and technological impact of advanced aviation technologies on the integrated aviation system. These evaluations would be used to assist NASA program managers to select the most beneficial mix of technologies for NASA to invest in, both in broad areas, such as propulsion or navigation systems, and in more specific projects within the broader categories. Generally, engineering analyses of this kind require multidisciplinary expertise, possibly using several models of different components and technologies, giving consideration to multiple alternatives and outcomes.

Airline Economics and Investment Behavior Drive the ASAC

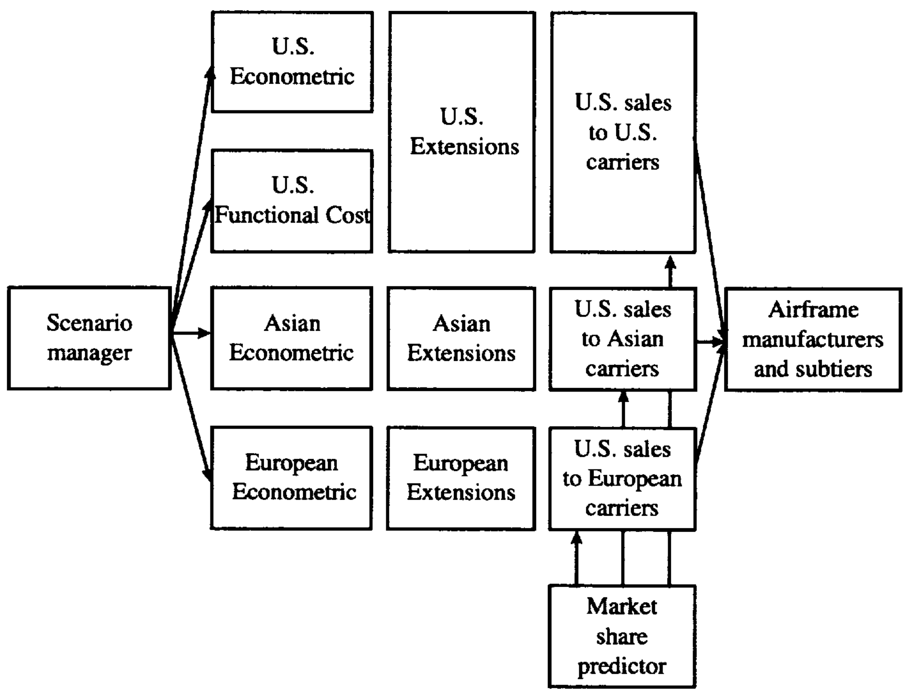
The ASAC differs from previous NASA modeling efforts in that the economic behavior of buyers and sellers in the air transportation and aviation industries is central to its conception. To link the economics of flight with the technology of flight, ASAC requires a parametrically based model that links airline operations and investments in aircraft with aircraft characteristics. That model also must provide a mechanism for incorporating air travel demand and profitability factors into the airlines' investment decisions. Finally, the model must be flexible and capable of being incorporated into a wide-ranging suite of economic and technical models that are envisioned for ASAC. The remainder of this report describes a third-generation ACIM, developed by Logistics Management Institute (LMI), that meets these requirements.

Overview of the Air Carrier Investment Model

In creating the ACIM, we had some specific goals in mind. A primary objective was to generate high-level estimates from broad industry-wide supply and demand factors. We envisioned being able to forecast the demand for air travel under a variety of user-defined scenarios. From these air travel demand forecasts, we then could estimate the derived demand for the factors of production, the most important being the number of aircraft in the fleets of passenger air carriers. We could also gauge the financial health of the airline industry as expressed in its operating profit margins.

Toward those goals, the third-generation Air Carrier Investment Model consists of several modules designed to operate in an integrated fashion, but have the flexibility to operate in isolation. The modules include the U.S. Econometric Module; the U.S. Functional Cost Module; the Asian and European Econometric Modules; the Asian, European, and U.S. Extension Modules; the Market Share Predictor Module; and the Input-Output Module. The interaction of the modules is summarized in Figure 1.

Figure 1. ACIM Modules



The scenario manager is a preliminary interface module in which the user identifies the ACIM modules to be run. The U.S. Econometric Module refers to the second generation ACIM,[1] which utilizes econometric results for industry demand and supply functions to generate aggregate projections for revenue

[1] The U.S. Econometric Module was previously developed by LMI and is documented in a NASA Contractor's Report, *The ASAC Air Carrier Investment Model (Second Generation), April 1997.*

passenger miles (RPMs) flown;[2] airline employment; number of aircraft in the fleet; and airline operating costs, revenues, and operating profit margins.

The U.S. Functional Cost Module (FCM) generates the same set of outputs, but utilizes an alternate approach based upon concepts from ABC to explicitly calculate cost functions for different classes of airlines. Costs are computed for six functional cost categories consisting of fuel, flight personnel labor, maintenance, flight equipment capital, ground property and equipment, and other indirect costs. The computational approach of the FCM is based on the interaction of a productivity ratio, such as available seat miles (ASMs)[3] per gallon of fuel, with the corresponding unit price, such as fuel price per gallon.

The Asian and European Econometric Modules apply the approach of the U.S. Econometric Module to the geographic regions of Asia-Pacific and Europe. Econometric estimates of air carrier supply functions are combined with demand parameters to project time series for the same set of outputs as in the U.S. modules. The largest passenger carriers in each region are used to formulate the baseline.

The Extension Modules map the high-level projections of the econometric and Functional Modules into a finer level of detail. This enables an appraisal of the persons to whom the economic benefits of investment in new technology accrue. This appraisal is accomplished by a series of six analytical modules that are dynamically linked to the Econometric and Functional Modules, but are accessible as a stand-alone model. The Extension Modules project several calculations including a retirement schedule for the year-end 1995 fleet, results of the retrofit versus replace analysis for existing Stage 2 aircraft, and expected seat sizes for new Stage 3 aircraft purchased to replace retiring aircraft and meet new growth.[4]

The Market Share Module projects, for each geographic region, the proportion of these Stage 3 aircraft purchases that will be sold by U.S. manufacturers in each of eight seat-size categories. The approach is based on econometric results regarding the determinants of U.S. market share in each geographic region. A subset of the determinants is designed to capture the relative advantages of U.S. manufactured

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[2] One revenue passenger (person receiving air transportation from the air carrier for which remuneration is received by the air carrier) transported one statute mile.

[3] One available seat of capacity transported one statute mile.

[4] The 1977 amendment to Part 36 of the Federal Aviation Regulations established noise designations for civil turbojet and transport category aircraft as Stage 1, Stage 2, or Stage 3. Aircraft that could not meet the original noise standards, issued in 1969, were designated as Stage 1. Examples of Stage 1 aircraft include the Boeing 707, 720, and early 727 and 737 models, the Douglas DC-8 and early DC-9 models, and the BAC 1-11. Aircraft that met the 1969 standards were designated as Stage 2. Examples of Stage 2 aircraft include the Boeing 747, Douglas DC-10, and Lockheed L-1011 models along with later versions of the 727, 737, and DC-9 models produced after 1974. Aircraft that meet the more stringent noise standards adopted in 1977 are designated Stage 3. Stage 3 models include the Boeing 757, 767 and 777, Douglas MD-80, and Fokker F-100 models.

aircraft over foreign aircraft and includes measures of acquisition cost per capacity and fuel efficiency.

The Input-Output Module calculates the impact of aircraft sales on employment in the airframe manufacturing industry and its related subtiers. The approach is a standard five-sector input-output model and includes the sectors of airframes, aircraft engines, avionics, aircraft equipment not elsewhere classified, and a residual sector termed "all others."

The remainder of this report describes the derivation and use of each of these ACIM modules.

DERIVATION OF THE ACIM FUNCTIONAL COST MODULE

Introduction

The Functional Cost Module of the ACIM is designed to complement the U.S. Econometric Module as an alternate approach to evaluating the impact of new technologies on the integrated aviation community. Whereas the U.S. Econometric Module is based on econometric estimates of air carrier supply functions, the FCM uses an activity based cost approach to explicitly calculate cost functions for different classes of airlines. The U.S. Econometric Module is a top-down aggregate model in which the econometric estimates, which have been derived at the industry level, are applied to individual air carriers. The FCM, however, utilizes an entirely bottom-up approach in which airline costs are computed at the carrier level and aggregated to obtain industry costs. Thus, an important feature of the FCM is that productivity ratios, cost parameters, and even demand assumptions may differ among air carriers.

The first step in creating this module was to statistically distinguish classes of airlines. The goal was to achieve a high degree of accuracy, but still have enough data points to maintain statistical validity. To accomplish this goal, we performed a clustering analysis procedure using 1995 annual U.S. Department of Transportation (DOT) Form 41 traffic and financial operating data for 26 Group II and III air carriers.[5] The result was the identification of five statistically distinct air carrier groups.

To estimate the demand for air travel, we identified 85 key U.S. airports at which flights originate and terminate. Subsequently, we collected 10 years of annual traffic and pricing information from U.S. DOT Origin and Destination data for all

[5] DOT classifies air carriers on the basis of total operating revenues. The largest carriers, having annual revenues in excess of $1 billion, are classified as Group III carriers. The next largest carriers, having revenues between $100 million and $1 billion, are classified as Group II carriers. The smallest carriers, having revenues less than $100 million are classified as Group I carriers.

26 carriers and identified a set of factors that influence a carrier's traffic. These observations were then used to developed an econometric model of demand for passenger service at the city-pair level of aggregation.

Applying concepts from activity based costing to the Form 41 traffic and financial operating data, we next constructed cost functions for each of the individual carriers or carrier groups. The cost functions are based upon six functional cost categories with flight equipment capital costs modeled in an especially detailed manner. This functional cost approach provides a high degree of accuracy in estimating air carrier costs.

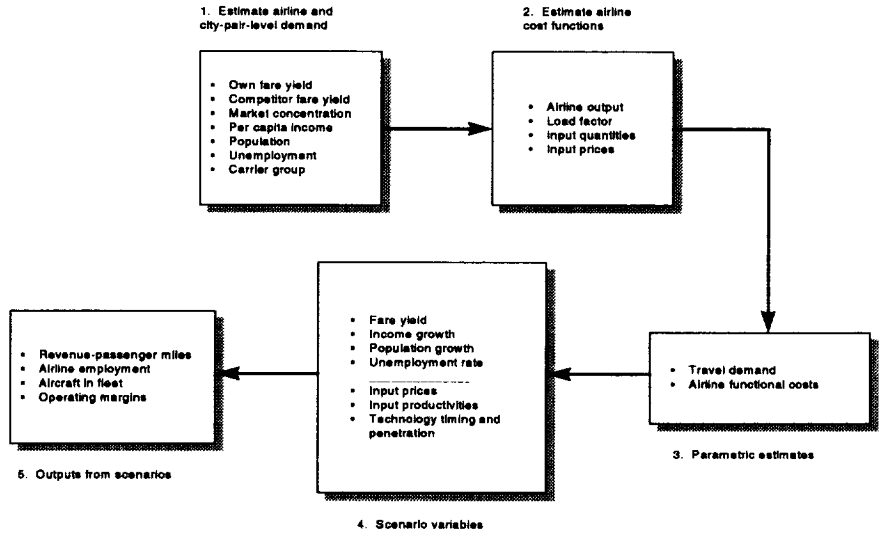
We then linked the carrier-specific demand models to the cost functions to determine an industry equilibrium. From the cost functions, we generated derived demand schedules for the factors of production, in particular aircraft fleets. The derived demand schedules are a function of the level of passenger service supplied, the airline load factor, and various aircraft productivity measures such as seats per aircraft.

Because it is so capital-intensive, the airline industry must earn positive operating profits in order to maintain and expand its aircraft fleet. Accordingly, we added a profit margin constraint to the model. When this option is activated, passenger fare yields are adjusted up or down to ensure that the target profit margins are met.

Overview of the Functional Cost Module

As shown in Figure 2, the Functional Cost Module starts with the factors affecting the demand for scheduled passenger air travel at the airline and city-pair level. It then examines historical data on airline costs and the resulting industry supply curve. The objective of the demand analysis is to obtain parametric estimates for the air travel demand, while the objective of the cost analysis is to obtain estimates of airline costs by functional cost category. These parametric estimates can then be combined with user-specified values of key supply and demand variables to generate industry-level forecasts of rates per minute of (RPM)'s flown, airline employment, number of aircraft in the fleet, and operating profit margins under various scenarios.

Figure 2. Schematic of the ACIM Functional Cost Module



Grouping Airlines

Our first analytic task was to determine if we could statistically distinguish classes of airlines based upon their traffic and financial operating data. We started by comparing 1995 quarterly Form 41 operating data from two airlines (American and United), which we presumed would be fairly similar, with data from another airline (Southwest), which we presumed would be entirely different. The goal was to identify a wide variety of statistics that expressed the differences and similarities among the three airlines. To do so, we constructed statistics designed to describe the carriers' network, aircraft fleet, cost structure, revenue structure, service structure, and underlying productivity. From this set of statistics, we selected a smaller subset of measures that clearly tended to capture the important similarities and differences among the carriers.

Next, we formulated this subset of measures for 26 Group II and III passenger air carriers using annual observations from calendar year 1995. To further reduce the dimension of the clustering problem, we reduced the set of defining statistics to 14 measures. The selection of the final set of measures was based upon two criteria. First, using numerous scatter plots of the data, preference was given to statistics that clearly tended to segment the carriers into groups. Second, preference was given to statistics that are explicit parameters of the cost calculations. The second criterion is important since we subsequently model the smaller air carriers by group. This approach amounts to replacing individual carrier parameters with the group mean. The final subset of measures is presented in Table 1.

Table 1. Group Defining Measures

Category	Measure	Source
Network statistics	Cities served	DOT O&D
	Average stage length	DOT Form 41
	Hub-Spoke[a]	DOT O&D
Fleet statistics	Average seats per aircraft	DOT Form 41
	ASM per block hour	DOT Form 41
Productivity statistics	ASM per employee	DOT From 41
	ASM per gallon fuel	DOT Form 41
	Block hours per aircraft per day	DOT Form 41
Cost statistics	Operating costs per ASM	DOT Form 41
	Flight personnel labor rate	DOT Form 41
	Maintenance costs per block hour	DOT Form 41
	Flight equipment capital costs per aircraft	DOT Form 41
Revenue statistics	Passenger yield	DOT Form 41
Service statistics	Percentage scheduled service	DOT Form 41

Note: O&D = Origin and Destination Data

[a]The variable Hub-Spoke measures the degree to which a carrier's network of flights follows a hub and spoke configuration. Given the number of cities served, Hub-Spoke is computed by comparing the actual number of flight segments flown to the minimum number of flight segments required to serve the network (all cities served through a single hub) and the maximum number of flight segments possible (all cities served through point-to-point service).

Next we performed a formal cluster analysis procedure on the set of 14 defining statistics for all 26 carriers. Specifically, we employed a *k-means* procedure that selects the best statistical division of the data by minimizing the sum of the Euclidean distances between observations and the associated group mean. Subsequently, the appropriate number of groups (k) to select is determined through iteration by tracking several diagnostic statistics. Because the procedure gives equal weight to each of the 14 variables, no variable is singularly important in the determination of the carrier groups.

The cluster analysis resulted in the selection of five groups of air carriers and the identification of two outliers. The results of the cluster analysis are presented in Table 2. No significance is implied in the attached group names.

Table 2. Cluster Analysis Results

Carrier group	Member carriers	
Majors	American Airlines	Trans World Airlines
	Continental Airlines	United Air Lines
	Delta Air Lines	U.S. Airways
	Northwest Airlines	
Nationals	Alaska Airlines	Midwest Express Airlines
	America West Airlines	Reno Air
	Carnival Air Lines	Southwest Airlines
	Kiwi International	
Regionals	Air Wisconsin	Horizon Air
	Atlantic Southeast Airlines	Mesa Airlines
	Business Express	Trans States Airlines
Shuttles	Aloha Airlines	U.S. Airways Shuttle
Nonscheduled	Continental Micronesia	Hawaiian Airlines
Outliers	American Trans Air	Tower Air

Air Travel Demand

Our second task was to develop a model of demand for an airline's passenger service. The approach taken was to model air travel demand at the city-pair level of aggregation. This approach is rooted in the assumption that market competition between carriers is best characterized at this level. The approach offers the additional advantage of providing many observations with which to estimate the parameters of the model. However, special econometric techniques are required to manage a data set that includes both a time dimension and a cross-sectional dimension. We chose to employ a *fixed-effect* model to account for the cross-sectional variation in the data.[6] Thus, our estimates are based upon changes in demand over time holding the cross-sectional variation constant.

For a particular route originating at city i and terminating at city j, carrier k will generate a certain level of passenger traffic. The U.S. DOT's Origin and Destination data record a 1 in 10 sample of all tickets. From these, the RPM service originating at time t on route i, j for carrier k was constructed.

Demand for a carrier's service between city pairs is driven by the carrier's passenger fare yield (measured by the average ticket price for travel between the cities divided by the nonstop mileage distance), the average yield of the carrier's competition on the route, the size and economic prosperity of the cities, the carriers

[6] See Hsiao (1986) for a comprehensive treatment of fixed-effect models.

market share for service between the cities, and the degree of market concentration (measured by the Hirschman-Herfindahl Index).[7] We modeled the economic characteristics of the Standard Metropolitan Statistical Area (SMSA) surrounding the 85 airports in the study in terms of the area's population, per capita income, and unemployment rate. The period under consideration was from the first calendar quarter of 1985 through the last calendar quarter of 1994. This approach yields a data set with nearly 2 million observations.

The demand function, in equation form, is

$$q^{k}_{t,i,j} = D^{k}_{t,i,j}(p^{k}_{t,i,j}, p^{c}_{t,i,j}, x_{t,i,j}), \quad \text{[Eq. 1]}$$

where $q^{k}_{t,i,j}$ is the scheduled demand (in RPMs) originating at time *t* for travel between city *i* and city *j* on carrier *k*. $p^{k}_{t,i,j}$ is the average yield for service originating at time *t* for travel between city *i* and city *j* on carrier *k*. $p^{c}_{t,i,j}$ is the average yield for the other carriers generating traffic at time *t* between city *i* and city *j*. $x_{t,i,j}$ are the other demand characteristics at time *t* for city pair *i, j*. These include population and income measures and market competition characteristics. In addition, conventional treatments for firm and city-pair fixed effects were used. These effects capture those important characteristics of a particular city pair that are not easily measured, such as tourism effects. We used a log specification for Equation 1 so that the regression coefficients may be interpreted as elasticities.

Table 3 shows the demand variable estimates that were incorporated into the model. We allowed the own-price elasticity to vary depending upon the carrier's group. In a few city-pair markets, a carrier faced no competition. These observations were treated separately with regard to the own price elasticity since they contained no information regarding a competitor's yield. However, since carriers rarely faced no competition, the number of observations with which to estimate the own-price elasticity was too small for statistical significance. All of the other variables were found to be statistically significant at the 95 percent level of confidence.[8] The overall fit of the model is quite good with a multiple coefficient of determination (adjusted R-square) of 91.6 percent.

[7] The Hirschman-Herfindahl Index is computed by the sum of the square of each carrier's market share for the given city-pair market. Thus, the Index ranges from zero (infinite number of small competitors) to one (a monopoly).

[8] The partial regression coefficients show the effects of changes in the independent variables (e.g., own fares and competitors' fares) on the dependent variable (i.e., total demand for an air carrier's passenger service). The t-ratios show the degree to which the partial regression coefficients are statistically different from zero. For degrees of freedom over 30, a t-ratio of 1.96 provides 95 percent confidence that the partial regression coefficient is not zero.

Table 3. Demand Variables

Variable	Name	Coefficient	T-ratio
Per capita income	LNPCI	2.0690	111.76
Population	LNPOP	0.2316	41.51
Unemployment rate	LNUNRATE	-0.2150	-43.63
Market share	LNMSHARE	1.1101	2183.60
Herfindahl index	LNHINDEX	0.1629	50.07
Competitors yield	LNYLDOT	0.1422	31.85
Own yield (major)	LNYLDOWxMAJOR	-1.1483	-473.76
Own yield (national)	LNYLDOWxNATIONAL	-1.0881	-139.78
Own yield (regional)	LNYLDOWxREGIONAL	-1.3856	-51.40
Own yield (shuttle)	LNYLDOWxSHUTTLE	-0.9526	-15.99
Own yield (nonscheduled)	LNYLDOWxNONSCHEDULED	-0.6395	-8.65
Own yield (no competition)	LNYLDOW1	-0.0082	-0.31

Note: Estimates of carrier and route variables are not reported.

Because of the log-log specification, the estimated coefficients may be interpreted as elasticities. For example, the coefficient of 2.069 on LNPCI implies that a 1 percent change in per capita income will generate a 2.069 percent change in demand. The other coefficients have similar interpretations.

Air Travel Supply

The second major component of the Functional Cost Module is designed to capture the costs of providing air travel services. The approach taken is to explicitly calculate costs in six functional cost categories using concepts from activity based costing. Within each functional cost category, total costs are a function of output, underlying productivity, and per-unit input prices. The cost analysis was based on observations from DOT Form 41 data in conjunction with detailed aircraft fleet inventories from AvSoft's ACAS Fleet Information System.[9] The cost data follow the 26 U.S. passenger air carriers with annual observations from 1985 through 1995. Appendix A provides details on the allocation of operating costs to functional cost categories.

The immense size of the major carriers relative to the rest of the industry significantly increases the risk of inaccuracy inherent in using the group mean to populate the parameters of the cost function. Therefore, we determined that a more accurate estimate of carrier costs would result from calculating functional costs at the individual airline level for the seven major carriers plus Southwest Airlines. The remaining airlines, however, are modeled by carrier group with the exception of the identified outliers, which are omitted.

[9] AvSoft Information Systems, Warwickshire England.

Within each functional cost category, operating costs per ASM are determined by the interaction of a productivity parameter and a unit price for the corresponding input. In the fuel cost category, for example, the fuel costs per ASM are calculated as the ratio of fuel price per gallon (unit price) to the ASM per gallon of fuel (productivity parameter). In some cases, the productivity parameter may itself depend upon the interaction of other underlying productivity ratios. For example, ASM per gallon of fuel is actually determined as the product of ASM per block hour and block hours per gallon of fuel. One advantage of modeling productivity in this way is that per unit costs are not dependent upon an arbitrary choice of a cost driver. Equation 2 details the fuel cost formulation while Appendix A provides detailed documentation on all of the individual cost calculations.

$$\frac{\text{Fuel costs}}{\text{ASM}} = \frac{\text{Fuel price/gallon}}{(\text{ASM/block hour})/(\text{Gallons/block hour})}. \qquad \text{[Eq. 2]}$$

Total costs within a functional category are then determined by the product of the cost per ASM and the number of ASMs flown. Some cost categories contain more than one cost element. Maintenance costs, for example, are comprised of both labor and materials components. In such cases, the total category costs are determined as the sum across all individual cost components. In the case of the indirect cost category, some elements, such as landing fees, are enumerated explicitly. Others, however, are grouped under a residual element termed "other indirect costs."

Flight equipment capital costs were computed in an especially detailed manner. We began with the 1995 inventory of aircraft for each carrier from the AvSoft fleet data. This inventory of aircraft provides detailed information on the age of each aircraft in the carrier's inventory. Using aircraft model-specific resale price information from Airclaims' *International Aircraft Price Guide*, we estimated the value of each aircraft as a function of its age. Summing over all the aircraft in a carrier's inventory gives a measure of the total value of the flight equipment.

Next we applied depreciation and cost of capital charges to the value of the flight equipment. The parameter for depreciation charges is 3.3 percent, which results from the standard straight-line approach with a useful life of 30 years and no residual value. The parameter for cost of capital charges is 10.3 percent, which was estimated separately. Thus, the flight equipment capital costs were calculated as 13.6 percent of the carrier's aircraft inventory value. We applied the same methodology to construct ground property and equipment capital costs. Starting with the value of ground property and equipment from a carrier's balance sheet, we applied the same depreciation and cost of capital charges (13.6 percent) to estimate the contribution of ground property and equipment toward total costs.

The advantage of this approach is that the resulting measure of capital cost includes the opportunity cost of the carrier's investment in equipment whereas using only depreciation charges taken directly from the Form 41 reports does not.

Thus, we take an economic approach to determining the costs of capital as opposed to a less desirable accounting approach.

With the exception of the capital costs, the baseline productivity and unit price parameters of the model are derived directly from the carrier-specific Form 41 observations. In the case of the smaller airlines, which are modeled by carrier group, the productivity and price parameters are determined by computing the weighted average across all carriers in the group.

Integrating Air Travel Demand with Airline Costs

General Approach

The joint model of supply and demand for commercial passenger air service specified in our study and the inferences about factor demands that are imbedded in our functional cost categories enable us to simulate the effects of emerging technologies. We can also forecast the growth in total system demand for passenger service and for factor inputs such as the number of aircraft in the fleet.

We follow several general steps when evaluating scenarios: first, we predict the change in RPMs on the basis of changes in the explanatory variables and the demand equation estimates. Next, we estimate airline revenues on the basis of forecast RPM growth and hypothesized changes in ticket prices. Then, we estimate changes in airline operating costs on the basis of forecast RPM growth, changes in load factor, changes in underlying productivity, and changes in input prices. We predict the aircraft inventory from the required ASMs and the underlying productivity of each carrier's aircraft. Similarly, we project total air carrier employment on the basis of block hours (for flight personnel), required ASM (for nonflight personnel), and the underlying productivity of each carrier's employees. Finally, to validate our baseline model, we compare forecasts from the Functional Cost Module with predicted changes in RPMs, aircraft fleet, and operating margins from other published forecasts.

Forecasting Changes in Travel Demand

To predict changes in travel demand, the model starts with actual airline output for calendar year 1995 and changes it over time based on the estimated demand function coefficients and predicted changes in the explanatory variables. The equation for predicting annual changes in demand is

$$\% \Delta RPM = \sum_{i=1}^{4} \beta_i \; \% \Delta x_i , \qquad \text{[Eq. 3]}$$

where the β_i are the coefficients estimated from the econometric model and the x_i are the explanatory variables: income, population, unemployment, and fare yield.

The percentage change approach for forecasting changes in demand is derived from the log-log specification of the econometric model.

The annual percentage change in per capita income, population, and unemployment are parameters entered directly by the user. Per capita income growth is not directly input into the model. Instead, the user provides estimates of both the long-run annual growth rates in gross domestic product and population. The model then calculates the annual change in per capita income and uses it to generate the demand forecast.

Fare variables are treated in one of two possible ways. First, the user can specify the rates of change in the fare yield exogenously. Alternatively, the user can allow changes in fare yield to be endogenously determined through the interaction of demand and supply. This is accomplished by selecting profit rate constraints for each of the four 5-year intervals in the forecast period. Under this mode of operation, the model varies the fare yield to satisfy the profit rate constraints.

For purposes of forecasting fares and for calculating industry travel demand, the own-fare and other-fare changes are assumed to be identical. Therefore, the overall price effect is the sum of the two coefficients. The net effect shows that air passenger travel is sensitive to price changes—but not unusually so. The FCM predicts that, for major carriers, a 10 percent reduction in fares will increase RPMs by 10.061 percent. This implies that after holding other factors constant—such as population and income—changes in air fares will have virtually no effect on total revenues collected by the industry.

The econometric estimates of the demand function are based on quarterly traffic volume for each airline and city pair in the sample. While it is possible to build the demand forecasts up from this highly detailed level, it would be time-consuming and probably add more inaccuracy to the final estimate. Instead, we use the actual RPM data for the domestic and international routes of the carriers specified by the study as the starting point, and grow demand at the rate indicated by Equation 3. Since each of the carrier groups has its own price elasticity of demand, output is not constrained to grow at the same rate for each airline. Thus, our model projects a gradual departure from the current industry market share structure.

Forecasting Changes in Airline Costs

To predict changes in airline costs, the FCM begins with actual airline cost, productivity and output parameters for calendar year 1995. Thus, with the exception of capital costs, the baseline 1995 numbers are identical to the carriers reported Form 41 observations. For subsequent years of the forecast, the parameters of the model change according to user-supplied assumptions regarding productivity growth and changes in input prices. To the extent that changes in productivity and input prices follow predictable trends, the cost calculations will remain accurate throughout the forecast period.

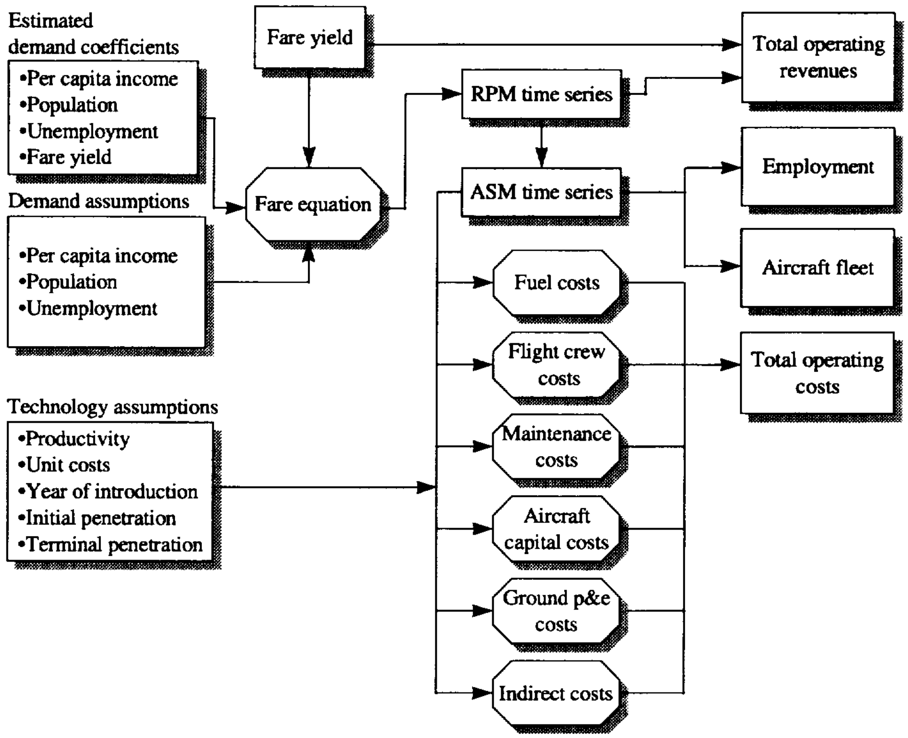
Deriving Industry Equilibrium

The flow of data within the FCM begins with the econometric estimates of air travel demand. The coefficients from the demand estimates together with user-supplied (or baseline) assumptions regarding annual demand variable changes determine a time series of RPMs flown by each of the individual carriers and carrier groups. Combining the RPM time series with the fare yield projections, the model obtains a revenue series. Then, for each carrier, the RPM series is supplemented with carrier-specific load factor observations to produce a time series of required ASM. The cost calculations in each functional category are subsequently computed on the basis of the ASM series according to the formulas presented in Appendix A.

Once the operating costs have been calculated for each functional cost category, the model aggregates across the carriers to obtain industry costs, revenues, and operating profit margins. If the user has indicated that fare yield changes are to be endogenously determined, the FCM then compares the projected operating profit margins with the target operating profit margins and adjusts the fare yield changes to satisfy the profit constraint. Figure 3 summarizes this process.

In selecting the operating profit rate constraint, we must consider the fact that the opportunity costs of flight equipment and ground property and equipment capital have been addressed previously in the formulation of the capital cost estimates. That is, the profit measured by the functional cost module is equal to the standard definition of operating profit less the opportunity cost of flight equipment and ground property and equipment capital. We call the profits measured by the FCM *adjusted operating profits*. To evaluate the impact of the opportunity costs on the profit rate, we compared the adjusted operating profits measured by the FCM with the actual accounting profits reported by the carriers. Industry wide, the discrepancy was equal to 2.25 percent and was of a similar magnitude for each of the carriers. Since it is generally accepted that the industry must earn an operating profit of approximately 5 percent in order to finance expansion, we selected an adjusted operating profit rate constraint of 3 percent for the default target value.

Figure 3. FCM Data Flow



Note: p&e = property and equipment

Aircraft Fleets and Airline Employment

Estimating the aircraft fleet required to meet the forecasted travel demand is a similarly straightforward calculation. The number of aircraft is a function of the ASM series and two aircraft productivity measures as shown by Equation 4 where an aircraft year is defined as one aircraft in service for 1 year.

$$\textit{Number of aircraft} = \frac{ASM}{(ASM/\text{block hour})(\text{Block hours/aircraft year})}. \qquad \text{[Eq. 4]}$$

Changes in either of the aircraft productivity ratios will impact the number of aircraft in the fleet. For example, if the average size of aircraft is increasing, all else being constant, the ratio of ASM to block hours will increase and less aircraft will be required to service a given level of demand. The calculations are performed at the individual carrier level and aggregated to obtain the industry fleet.

In estimating air carrier employment, we made a distinction between flight personnel and nonflight personnel. Our reasoning was that the level of flight personnel employment was most directly influenced by the number of block hours flown, whereas the level of nonflight personnel employment was most directly influenced by the ASM flown. The calculations are given by Equations 5 and 6.

$$\textit{Flight personnel employment} = \frac{ASM}{(ASM/block\ hour)(Block\ hours/employee)}. \quad \text{[Eq. 5]}$$

$$\textit{Nonflight personnel employment} = \frac{ASM}{(ASM/employee)}. \quad \text{[Eq. 6]}$$

Details regarding the default assumptions and the baseline forecast are provided in Appendix B.

DERIVATION OF THE ACIM ASIAN AND EUROPEAN ECONOMETRIC MODULES

The Asian and European Econometric Modules are designed to extend the modeling approach of the U.S. Econometric Module to the geographic regions of Asia-Pacific and Europe. This section describes the economic and statistical derivation of these modules.

Air Travel Demand

Attempts to perform an econometric study of demand and supply determinants for air travel in Asia and Europe were unsuccessful, most likely due to the lower quality of European airline data. Consequently, we fell back on published income and yield elasticities from Boeing's 1993 *Current Market Outlook* (page 2.4) to construct a simple two-explanatory-variable model of demand for air travel in Asia and Europe. These independent variables and their estimated elasticities with respect to changes in revenue-passenger miles (the dependent variable) are shown in Table 4.

Table 4. Independent Demand Variables

Variable	Elasticity
Fare yield	-0.6
National income	1.7

Air Travel Supply

SUPPLY DATA SET

Acting under subcontract to LMI, Robin Sickles from Rice University and David Good from Indiana University constructed a supply data set.[10] The primary sources for their cost data were the International Civil Aviation Organization's (ICAO's) *Digest of Statistics for Commercial Air Carriers* and the *Penn World Table* (Summers and Heston, 1994). There were frequent instances where these sources

[10] *A Model of World Aircraft Demand.* A.K. Postert served as a research assistant for this study.

were not complete. Consequently, cost data were supplemented from other sources such as the International Air Transport Association's (IATA's) *World Air Transport Statistics* and Federal Express Aviation Service's *Commercial Jet Fleets*. Using these multiple sources, Sickles and Good constructed a data set that included four factors of production: labor, energy, materials, and flight equipment capital. The data set also included two aggregate airline outputs, two network traits, and four aircraft attributes.

Inconsistencies in the definition of labor categories, differences in aggregation, and missing data required that the labor index be constructed from a single aggregate category. The labor index uses the number of employees at mid-year as the measure of quantity. Labor prices were calculated by dividing expenditures by this quantity.

Unlike the U.S. Form 41 data, there are no independent, carrier-specific measures of either prices or quantities for aircraft fuel. This shortcoming is particularly problematic since fuel prices vary widely around the world, primarily as the result of tax differences. However, ICAO does compile annual information about jet fuel prices within each of its 12 regions. Sickles and Good used this information as a price measure in cents/liter. Fuel quantities were estimated by dividing fuel expenditures by these regional prices.

The materials index is based on financial data from ICAO. It is total operating expenses minus the amounts spent on aircraft rentals, depreciation, fuel, and labor. Because the cost data are in different currencies, Sickles and Good needed to put these amounts in common terms. Simply using exchange rates does not adequately make expenditures comparable across countries since exchange rates are heavily influenced by the narrower sets of goods that are imported and exported and by financial flows. Instead, Sickles and Good used purchasing power parities.

Because of the importance of flight equipment capital, Sickles and Good described this input in considerable detail. They used an inventory of aircraft fleets provided by ICAO to determine the number of aircraft in over 80 separate aircraft types. For each aircraft type, they constructed a user price, roughly comparable to an annual rental price. Total aircraft capital expenses are the sum of these user prices, weighted by the number of aircraft in a carrier's fleet in each category.

Sickles and Good considered several alternatives in constructing user prices. They rejected the traditional approach of basing cost on reported balance sheet account values since this is not responsive to changing demands for different types of aircraft at different points in time. For example, following deregulation in the United States, the demand for small aircraft increased dramatically (along with their selling price) while wide-bodied aircraft had a dramatic decrease in price. The valuation of individual aircraft types was based on the average of Avmark's January and July subjective valuations of each type of aircraft for every year. These valuations reflect recent sales and perceptions of changing market conditions for aircraft in half-time condition.

The primary liability of this approach is that it does not capture benefits (for example, reduced maintenance costs) from newer rather than older aircraft within a particular type. This approach also poses some problems for aircraft that are not widely traded or for aircraft that are not jets. For aircraft not widely traded, Sickles and Good used the most comparable aircraft traded to estimate a market value.

For the Concorde, Sickles and Good used the Boeing 747-200. While the 747 is a much larger aircraft, because of the Concorde's speed, the revenue-generating capability of these two aircraft are roughly comparable.

Soviet-manufactured equipment also posed some problems. Most airlines do not consider this equipment very desirable and its market values tend to be fairly low. Sickles and Good valued Soviet equipment as equivalent to the *oldest* Western equipment of a comparable size. For example, they valued the Tupelov Tu-154 the same as the Boeing B727-100 and the Tu-134 the same as a BAC-111. They valued the Ilyushin Il-62 the same as a Douglas DC-8-10.

Avmark also provides some limited information about turboprop aircraft. Sickles and Good divided turboprop aircraft into six categories (YS-11, Lockheed Electra, Lockheed Hercules, Fairchild F-227, Fokker 27, and Saab 340) and allocated types other than these to the six categories based on age and size (for example, they allocated the Fokker 50 into the Saab 340 category since they are both relatively new design commuter aircraft). They allocated the HS-748 to the YS-11 category since they are both 1960s design 50-passenger aircraft. They had a final residual category for aircraft that could not conveniently be categorized this way. Some carriers, Swissair, for example, operate a small fleet of single-engine aircraft. Others operate one or two helicopters. Sickles and Good valued single-engine piston aircraft at $100,000 and helicopters at $400,000.

Because aircraft are valued in half-time condition, Sickles and Good assumed that their remaining useful life was 14 years and used a "one and a half declining balance" method to estimate economic depreciation. An alternative to this method is to construct the depreciation portion by viewing an aircraft as an economic asset. Under this approach, the depreciation cost of holding and using the aircraft would be the difference in market value at the end of the year compared to the beginning of the year. Sickles and Good ultimately rejected this approach because it led to several instances where the capital price fluctuated dramatically during periods in which the price for a particular aircraft was depressed due to random events (such as the DC-10 grounding in 1979, or the bankruptcy of a carrier leading to lots of a particular aircraft flooding the market).

They considered several alternatives for constructing the interest portion of the rental price: local versus U.S. real interest rates. They rejected the approach that used country-specific interest rates because it was not possible to find comparable interest and inflation rates across different countries. In some cases (e.g., Pakistan), real interest rates always were negative and nominal rates did not change over the entire sample period. Under the assumption that marginal decisions about fleet size were based on the international leasing market, and that the leasing market was dominated by U.S. carriers and U.S. prices, they used U.S. interest rates based on Moody's Baa rate for 6-month commercial paper.

The Sickles and Good supply data provided for two separate categories of airline output: scheduled passenger output and nonscheduled and incidental output. Scheduled passenger output is measured in revenue-tonne kilometers. This is calculated under the reporting convention that a passenger, along with checked baggage, constitutes 200 pounds in weight. The nonscheduled output measure combines charter, mail, and cargo operations. Charter passenger traffic again assumes 200 pounds per passenger. Incidental output includes revenues that are attributable to airline-related activities but that are not the physical transport of passengers or cargo. An example would be maintenance performed for other airlines. For some carriers, incidental output can be a significant component of revenue (and user of resources). For others, incidental output is virtually nil. For the scheduled and nonscheduled outputs, both quantity and price data were available. For incidental output, the country's purchasing power parity was used as a deflator to construct a quantity measure.

Two traits of the carrier's network also were included in the supply data set: average stage length and passenger-load factor. Stage length enables us to account for different ratios of costs due to ground-based resources compared with costs attributable to the actual stage length flown. Shorter flights use a higher proportion of ground-based systems per passenger-mile of output than do longer flights. Also, shorter flights tend to be more circuitously routed by air traffic control and spend a lower fraction of time at an efficient altitude than longer flights. Passenger load factor can be viewed as a control for capacity utilization and macroeconomic demand shocks. Many transportation studies also interpret it as a proxy for service quality. As load factors increase and the network becomes less resilient, the number and length of passenger flight delays generally increase as do the number of lost bags and ticketed passengers who are bumped. In-flight service levels also decline since the number of flight attendants is not generally adjusted upward as the passenger-load factor increases.

Aircraft attributes are modeled from various characteristics of the aircraft fleet. A major component of airline productivity growth is measured by changes in these attributes over time. For example, all other things being equal, newer aircraft types are expected to be more productive than older types. The most significant contribution to productivity growth in the 1960s was the introduction of jet equipment. While this innovation was widely adopted, it was not universal for carriers throughout the data sample. Newer wing designs, improved avionics, and more fuel-efficient propulsion technologies also make flight equipment more productive. Once an aircraft design is certified, a large portion of the technological innovation becomes fixed for its productive life.

Sickles and Good measured two characteristics of the aircraft in each airline's fleet: average number of seats per aircraft and average technological age. Average equipment size was measured with the highest density seating configuration listed in *Jane's All the World's Aircraft* for each aircraft type. This assumption was necessary for consistency. Over time, the number of seats for a particular aircraft type has increased by decreasing seat pitch. Even within a particular carrier's fleet, the number of seats varied, sometimes significantly. Furthermore, for aircraft used in combination service, the actual number of seats would seriously understate the aircraft's true capacity and revenue-generating capability. Since the purpose was to consistently describe the bulk transport capability of the fleet, Sickles and Good used the single maximum value regardless of the actual seating configuration. The fleet average was weighted by the average number of aircraft of each type assigned into service. Data on these characteristics were collected for individual aircraft types from *Jane's All the World's Aircraft* (1945 to 1996 editions).

In an engineering sense, transportation industries tend to be characterized by increasing returns to equipment size. For example, a relatively large aircraft, such as the Boeing 747, will have substantially lower operating costs per ASM then a relatively small aircraft such as the Boeing 737. Fixed costs for fuel, pilots, terminal facilities, and even landing slots can be spread over more passengers. However, large aircraft size is not without potential diseconomies. As equipment size increases, it becomes more difficult to fine-tune air traffic scheduled capacity on a particular route. Because airline capacity (reflected by available seat-miles) is concentrated into fewer and fewer departures, quality of service also declines (i.e., the probability decreases that a flight is offered at the time a passenger desires it most). This raises particular difficulties in competitive markets where an airline's capacity must be adjusted in response to the behavior of rival carriers. Deregulation tends to accentuate this liability by eliminating monopolies in high-density air travel markets. On the other hand, deregulation also increases the total volume of traffic through more vigorous fare competition, somewhat attenuating this liability. In any event, the operating economies of increased equipment size must be traded off against limited flexibility.

Sickles and Good used the average time (measured in years) since "first flight" of aircraft designs as a measure of the technological age of the fleet under the assumption that technological innovation in an aircraft does not change significantly after the design is first flown. While it would have been desirable to use the certification date of equipment (as in the U.S. data set), not all equipment types flown worldwide are FAA-certified. This measure of technological age does not fully capture the deterioration in capital and increased maintenance costs caused by use. However, it does capture retrofitting older designs with major innovations, if those innovations were significant enough to lead to a new aircraft designation. For example, a Convair 580 is a retrofitted Convair 240 with new turboprop engines and wing modifications and a DC-8-72 is a retrofit of a previous version with new engines.

The final two aircraft attributes were the percentages of the airline's fleet in two categories: jets, and a subset, wide-bodied jets (defined as having two aisles in the main cabin). To the extent that jet aircraft are not 100 percent of the total, it indicates the presence of turbo-prop, piston, or rotary-wing aircraft in a carrier's fleet. The percentage of aircraft other than jets provides a measure of aircraft speed. This type of aircraft flies at approximately one third the speed of jet equipment. Consequently, providing service in these types of equipment requires proportionately more flight crew resources than with jets. Conversely, as more wide-bodied aircraft are used, resources for flight crews, passenger and aircraft handlers, and landing slots do not increase proportionately.

ESTIMATING AIR TRAVEL SUPPLY

To analyze the cost data, we used a transcendental logarithmic (translog) functional form for our supply equation. This is the most widely used of the flexible functional forms (Greene, 1993). We imposed homotheticity in the cost function. We also imposed symmetry on the cross-price derivatives. In our specification, the factors of production are labor, energy, materials, and capital. Factor prices are labeled *w*. Capital refers to aircraft fleets only. Capital other than aircraft, such as ground structures and ground equipment, is included in the materials category. The two generic output categories at time *t* for carrier *j* are designated $y_{t,j,1}$ and $y_{t,j,2}$ for scheduled output and nonscheduled, cargo, and incidental output, respectively. Omitting the time and firm subscripts, the transcendental logarithmic (translog) cost function is given by

$$\begin{aligned} lnC = \alpha_0 &+ \sum_{i=1}^{4} \beta_i lnw_i + \sum_{p\leq q}^{4} \sum_{q=1}^{4} \beta_{pq} lnw_p lnw_q \\ &+ \sum_{i=1}^{2} \alpha_i lny_i + \sum_{i\leq j}^{2} \sum_{j=1}^{2} \alpha_{ij} lny_i lny_j + \\ &\sum_{i=1}^{2} \lambda_i \; network\ traits_i + \sum_{i=1}^{4} \rho_i \; aircraft\ attributes_i lnw_{capital}. \end{aligned} \quad \text{[Eq. 7]}$$

Cost shares for labor, energy, and materials are given by

$$M_i = \beta_i + \sum_{j=1}^{4} \beta_{ij} \; lnw_j \quad \text{[Eq. 8]}$$

The cost share for capital is

$$M_{capital} = \beta_{capital} + \sum_{j=1}^{4} \beta_{capital,j} \ln w_j + \sum_{j=1}^{4} \rho_j \textit{ aircraft attributes}_j . \qquad \text{[Eq. 9]}$$

The translog cost equation can be viewed roughly as a second-order approximation of the cost function dual to a generic production function. Symmetry and linear homogeneity in input prices are imposed on the cost function by the restrictions

$$\alpha_{ij} = \alpha_{ji}, \forall i, j; \beta_{ij} = \beta_{ji}, \forall i, j; \Sigma_i \beta_i = 1; \Sigma_j \beta_{ij} = 0; \textit{and } \Sigma_j \rho_j = 0$$

Before we did any estimation, we normalized the data so that all the variables were set to unity at the data median. We evaluated the cost function through iterated, seemingly unrelated regression (ITSUR) estimation. This procedure produced coefficient estimates that were deemed reasonable when stage length was excluded from the model.[11] The fitted function is concave in prices at the mean of the data as required and is concave at 99 percent of the data points. Also, the fit of the model is quite good, with a system weighted R-square value of 96.7 percent. Estimates of the long-run cost function are provided in Table 5.

Integrating Air Travel Demand with Air Travel Supply

The ACIM Asian and European econometric modules integrate the supply and demand models discussed above. The general approach is identical to the approach employed by the U.S. Econometric Module, which is documented in a previous LMI report. A brief summary of that approach is given below.

[11] When stage length was included as an explanatory variable, it had a positive sign (0.137056) and was statistically significant (T-ratio equal to 3.061). However, we found that stage length and the output variables were highly correlated. Therefore, we chose to exclude stage length because it had a counterintuitive sign and created multicollinearity.

Table 5. Supply Variables

Variable	Name	Coefficient	T-ratio
Labor price	LNLP	0.286	N/A
Labor price squared	LNLP^2	0.009	1.27
Labor × energy	LNLPEP	-0.011	-2.43
Labor × materials	LNLPMP	0.005	0.80
Labor × capital	LNLPKP	-0.004	-1.10
Energy price	LNEP	0.202	N/A
Energy price squared	LNEP^2	0.037	7.77
Energy × materials	LNEPMP	-0.006	-1.11
Energy × capital	LNEPKP	-0.020	-6.72
Materials price	LNMP	0.429	N/A
Materials price squared	LNMP^2	0.012	1.28
Materials × capital	LNMPKP	-0.011	-3.34
Capital price	LNKP	0.083	N/A
Capital price squared	LNKP^2	0.035	11.69
Scheduled output	LNSQ	0.923	33.82
Scheduled output squared	LNSQ^2	0.081	1.94
Nonscheduled/incidental output	LNNQ	0.018	2.82
Nonscheduled/incidental output squared	LNNQ^2	0.011	2.35
Scheduled × nonscheduled/incidental output	LNSQNQ	-0.034	-3.21
Load factor	LNLF	-0.579	-5.16
Average seats per aircraft	XLNAS	0.006	1.15
Average age of aircraft	XLNAA	0.020	4.34
Percentage jets[a]	XXPJ	-0.014	-6.05
Percentage wide-bodied aircraft[a]	XXPWB	-0.012	-2.48

Note: Estimates of firm and quarterly dummy variables are not reported.
[a]All other variables are expressed as natural logarithms.

Forecasting Travel Demand

The modules first project air travel demand forward from the 1995 baseline level for each of the geographic regions based upon assumptions regarding the change in fare yield and the growth in income. Specifically, the equation for predicting annual changes in demand is

$$\%\Delta RPM = \sum_{i=1}^{2} \beta_i \ \%\Delta x_i \,, \qquad \text{[Eq. 10]}$$

where the β_i are the coefficients estimated from the econometric model and the x_i are the explanatory variables: income and fare yield.

Forecasting Travel Supply

Equation 7 describes the airline cost equation estimated for the model. As shown, total costs are a function of airline outputs, factor costs, and aircraft and airline network attributes. Using the supply parameter estimates shown in Table 5, Equation 7 can easily be used to produce a time series of predicted changes in airline costs. Using the log-log structure of the equation to our advantage, the following forecast equation is derived.

$$\%\Delta TC = \sum_{i=1}^{2} \alpha_i \, \%\Delta\, y_i + \sum_{i \le j}^{2} \alpha_{ij} \, \%\Delta\, y_i \, \%\Delta\, y_j + \sum_{i=1}^{4} \beta_i \, \%\Delta\, w_i$$

$$+ \sum_{p \le q}^{4} \sum_{q=1}^{4} \beta_{pq} \, \%\Delta\, w_p \, \%\Delta\, w_q + \sum_{i=1}^{4} \rho_i \, \%\Delta\, aircraft\ attributes_i \, \%\Delta\, w_{aircraft}$$

$$+ \lambda_i \, \%\Delta\, load\,factor,$$

[Eq. 11]

where %Δ indicates annual percentage change in the variable.

In Equation 11, *factor costs*, *aircraft attributes*, and *network traits* are user-defined variables in the basic ASAC Air Carrier Investment Model. For labor and capital, changes in factor costs are net of price and productivity effects. Scheduled and nonscheduled output changes are estimated directly in the demand model forecasting component and then input into the cost functions. Therefore, changes in output cannot be made directly by the user.

As with the demand forecasts, total costs are projected forward from the baseline defined by the reported data. The model changes the costs at the rates predicted by Equation 11, given output forecasts, factor cost changes, and changes in aircraft and network characteristics.

Aircraft Fleets

Estimating the gross aircraft fleet required to meet the forecast travel demand is a somewhat more involved process. Four factors enter into the forecast of aircraft fleets:

- The changes in total airline costs
- The estimated share of aircraft costs in total costs
- The forecast change in average aircraft price
- The forecast change in average aircraft size.

Changes in total airline costs were discussed in the previous section. Referring to Equation 9, the aircraft share of total costs is a function of factor costs and aircraft attributes. As with the cost and demand forecasts, we update the capital share. equation through the forecast period as a function of the rates of change in the factor cost and aircraft attribute parameters. The equation for changes in the capital cost share is

$$\Delta\ Aircraft\ cost\ share = \beta_{aircraft} + \sum_{i=1}^{4} \beta_{aircraft,j} \%\Delta w_j + \sum_{j=1}^{4} \rho_j \%\Delta\, aircraft\ attributes_j. \qquad \text{[Eq. 12]}$$

The resulting capital share time-series predicts the fraction of total costs that will be spent on aircraft investments. By multiplying this share estimate by total costs, we obtain a time-series of capital investments in aircraft.

The final pieces of information needed to calculate the number of planes in the aircraft fleet are the predicted levels of average aircraft price and average aircraft size. The rate of growth in aircraft size is measured by the average number of seats. The product of average aircraft price (holding size constant) and average size is divided into the aircraft investment to get the estimated number of planes in each airline's fleet. In equation form, the formula is

$$Number\ of\ aircraft = \frac{(capital\ share \times total\ cost)}{(aircraft\ price \times average\ size)}. \qquad \text{[Eq. 13]}$$

The required fleets for all the airlines are then summed to get the industry estimate.

Extensions to the Basic ACIM

Introduction

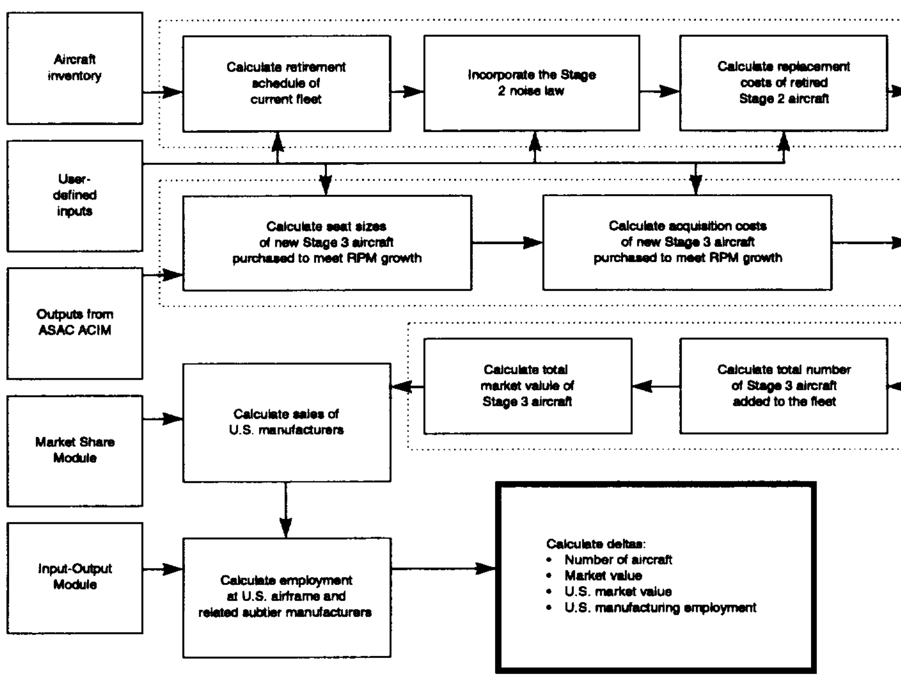
This section describes a series of analytic modules that map the high-level estimates of the basic ACIM into a finer level of detail. This mapping enables an appraisal of to whom the economic benefits of investment in new aircraft technology accrue. The appraisal is accomplished by three sets of analytic modules that are dynamically linked to the basic ACIM but are also accessible as standalone models. The first set of analytic modules determines the number and allocation of aircraft required to satisfy replacement demand and meet new traffic growth. The second projects the U.S. manufacturers' market share for these new aircraft. The third determines the number of work years of employment at U.S. airframe, engine, and related equipment manufacturers generated by the aircraft sales. The end result is that any change in aircraft aviation technology can be translated to benefits accruing to any or all of the following parties:

- The flying public, in the form of lower ticket prices and/or expanded service
- U.S. airframe, engine, and related subtier manufacturers, in the form of increased volume of aircraft production
- U.S. passenger air carriers, in the form of jobs and increased traffic.

The first set of analytic models that determine the size and composition of the aircraft fleet was previously developed by LMI for the U.S. Econometric Module. We refer to this collection of models as the ACIM Extensions. This section describes our adaptation of the original ACIM Extensions for use with the Asian and European Econometric Modules. Subsequent sections detail the development of the Market Share Module and the Input-Output Module, which function in a highly integrated fashion with the ACIM Extensions but are not referred to under that title.

Figure 4 shows a schematic of the ACIM Extensions and the Market Share and Airframe Manufacturers Modules. The Extensions start with several outputs from the basic ACIM, data from the aircraft inventory database and a set of user-defined specifications or scenarios. There are two tracks of analysis regarding the aircraft fleet requirements: the first, a static analysis whose results compute the aircraft requirements due to replacement demand, and the second, a dynamic analysis whose results compute the aircraft requirements due to new traffic growth. The results of these two analyses then are combined to estimate the total aircraft requirements.

Figure 4. Schematic of the ACIM Extensions



The Market Share Module projects the U.S. aircraft manufacturers' market share for each region of the World and for each seat-size category. U.S. market share is a function of the relative performance of U.S. aircraft versus foreign aircraft as measured by fuel efficiency and acquisition cost per capacity. The impact of new aircraft designs is also a factor. Applying the projected U.S. market share to the total aircraft requirements by seat-size category yields the total U.S. airframe manufacturer production.

The Input-Output Module calculates the impact of the projected aircraft sales on employment in the airframe manufacturing industry and its related subtiers. The approach is a standard five-sector, Input-Output Model and includes the sectors of aircraft, aircraft engines, avionics, aircraft equipment not elsewhere classified, and a residual sector termed all others.

Adapting the ACIM Extensions to Europe and Asia

The first task in adapting the original ACIM Extensions to the European and Asian fleets was to modify the parameters governing the retirement of older Stage 2 aircraft. Two observations underlie this modification. First, it is well documented that European and Asian carriers tend to retire aircraft at an earlier age than U.S. carriers.[12] Second, European and Asian carriers are choosing to replace most of their Stage 2 aircraft in lieu of retrofitting them with new engines or hushkits. Several explanations have been offered for these phenomenon including that foreign carriers historically have had greater access to capital than U.S. carriers by virtue of their close relationship with state governments.

We incorporate these tendencies through modification of the aircraft retirement assumptions for the European and Asian aircraft fleets. The original ACIM Extensions assign a retirement age to each aircraft according to the aircraft type and the year of first delivery.[13] The baseline retirement age assumptions for the U.S. fleet are 25 years and 28 years, respectively, for narrow body and wide body aircraft produced prior to 1980 (incorporation of the new noise regulations)—and 28 years and 31 years, respectively, for narrow body and wide body aircraft produced after 1980. According to Airbus Industrie's *Global Market Forecast, 1997–2016*, however, European air carriers have tended to retire aircraft an average of 3 years earlier than U.S. carriers while Asian-Pacific carriers have tended to retire aircraft an average of 4 years earlier than U.S. carriers. This result is in spite of the fact that foreign carriers generally have a higher proportion of wide-body aircraft than U.S. carriers. Thus, we modify the Extensions Module by subtracting 3 years from the useful life of aircraft in the European fleet and 4 years for aircraft in the Asian-Pacific fleet (as compared with aircraft in the U.S. fleet). The modifications are summarized by Table 6.

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[12] See, for example, the Airbus Industrie *Global Market Forecast, 1997–2016.*

[13] In the ACIM Extensions, retirement denotes withdrawal from revenue-passenger service.

Table 6. Aircraft Retirement Age Assumptions

Aircraft type	U.S fleet (years)	Asia-Pacific fleet (years)	European fleet (years)
Narrow body (pre-1980)	25	21	22
Wide body (pre-1980)	28	24	25
Narrow body (post-1980)	28	24	25
Wide body (post -1980)	31	27	28

The ACIM Extensions Module also performs an analysis of the impact of noise regulations on the replacement of Stage 2 aircraft. Carriers have two options to satisfy the requirement that all aircraft be Stage 3-compliant by the year 2000 (2002 for Europe). The first option is to replace existing Stage 2 aircraft with new Stage 3 aircraft. Alternatively, carriers can modify existing Stage 2 aircraft by replacing the engines or by installing a hushkit to reduce the noise impact. The Extensions Module estimates the net economic benefits of retrofitting existing Stage 2 aircraft relative to replacing the aircraft entirely. A primary determinant of the net benefit of retrofitting is the useful life remaining before the aircraft is expected to be retired. All else equal, younger Stage 2 aircraft are more likely to be retrofitted than older Stage 2 aircraft because the former have a greater number of productive years remaining to offset the costs of retrofit. Thus, the reduction in the average retirement age parameters for the Asian and European fleet has the effect of reducing the proportion of existing Stage 2 aircraft that are retrofitted, which is consistent with our initial observations on foreign carriers.

DERIVATION OF THE MARKET SHARE MODULE

Acting under subcontract to LMI, Abel Fernandez of Old Dominion University performed a study of market share in the airframe manufacturers' industry.[14] The underlying objective of that study was to determine the factors affecting the market share for U.S.-manufactured aircraft in each seat-size category and region of the world.

Market Share Database

The first task was to gather historical data on airframe orders at the major airframe manufacturers. The study objectives required a comprehensive database that detailed not only the number of aircraft ordered by year, but also the geographic location of the customer. The primary source of data for this study was provided by AvSoft's ACAS Fleet Information System. These data were supplemented with, and subsequently validated by, a variety of sources including the *World Jet Inventory*, *Airline Monitor*, *Morgan Stanley Equity Research*, *Jane's All the World's Aircraft*, and *Speednews*. The result is a database containing 3,869

[14] *Market Share Study: Commercial Aircraft Industry—Phase 1: Historical Market Share Analysis.* Sudhanva Paranjape served as a research assistant for this study.

purchase transactions representing 19,302 aircraft over the period 1970 through 1996.

Fernandez segmented the data according to eight seat-size categories and four regions of the world. The categories are consistent with the standard Boeing seat-size category definitions presented in Table 7. The geographic regions of the world are U.S., Europe, Asia-Pacific, and the rest of the world. Details regarding the member states of each geographic region are provided in Appendix D.

Table 7. Seat-Size Categories

Aircraft type	Seating capacity
1	< 50
2	50–69
3	70–90
4	91–120
5	121–170
6	171–240
7	241–350
8	>350

Because each aircraft model can support a variety of seating configurations, it is possible for the seating capacity to vary considerably. To address this possibility, we gathered seating configuration data for each aircraft model from the AvSoft fleet data. We computed the average seats per aircraft for each equipment type by region of World to allow for the possibility of differences in configuration. With the exception of the A330 in Europe and the 767-300 in Asia, the average number of seats per aircraft was consistent with the standard configuration definition of seat-size category. Therefore, to obtain consistency with the actual use of the aircraft, we allowed the allocation of seat-size category for the A330 and the 767-300 to depend upon the world region. Details regarding the allocation of each equipment type are provided in Appendix E.

The study objectives required Fernandez to compute the market share of U.S. manufacturers on the basis of order value. To satisfy this requirement, Fernandez matched the database of unit orders to aircraft specific estimates of acquisition costs from a variety of sources including the *Airline Monitor*, Avmark's *Commercial Aircraft Transaction Data Base*, Airclaims' *International Aircraft Price Guide*, and *Morgan Stanley Equity Research*. Combining the unit orders data with the acquisition cost data yields estimates of the dollar value of orders for each equipment type. Because the unit orders data tended to fluctuate dramatically from year to year, Fernandez employed a centered moving average (CMA) technique to filter the value data. The formula for this procedure is given by

$$CMA_t = \frac{(y_{t-1} + 2y_t + y_{t+1})}{4}, \qquad \text{[Eq. 14]}$$

where CMA_t is the centered moving average for observation t, and y_t is the dollar value of orders at time t. Essentially this procedure will smooth some of the year-to-year fluctuations in the value data. Finally, Fernandez divided the sum of U.S. manufacturer CMA value orders by the world CMA total to obtain a measure of U.S. market share.

An Econometric Model of U.S. Market Share

The next objective of our study was to identify the key factors that affect U.S. market share. We selected a set of explanatory variables including

- the relative fuel efficiency of U.S. aircraft versus foreign aircraft,
- the relative acquisition costs per capacity of U.S. aircraft versus foreign aircraft,
- the introduction of new U.S. aircraft models, and
- the introduction of new foreign aircraft models.

Data regarding the fuel-efficiency measure was obtained through operational equipment-level reports from the ASAC Quick Response System (QRS). Our measure of fuel efficiency is the inverse of gallons of fuel per 1,000 ASM. Data regarding the cost-per-capacity measure was obtained from *Jane's All the World's Aircraft*. Our measure of cost per capacity is the ratio of the total acquisition cost to the product of range and seating capacity. For these performance measures, we computed the average parameter value for both U.S.- and foreign-manufactured equipment separately for each seat-size category. Finally, we computed the ratio of the U.S. parameter value to the foreign parameter value. In addition, we constructed a set of dummy variables that capture the impact of new aircraft introduction by a given manufacturer in a given seat-size category. The result is a data set containing the centered moving average U.S. market share, and a set of explanatory variables for each seat-size category and region of the world.

Next, we estimated an econometric model of U.S. market share using the data set described above. We employed a log-log specification so that the coefficients on the performance measures may be interpreted as elasticities. We included time as an explanatory variable to capture the gradual erosion of U.S. market share over the sample period, and we employed standard econometric techniques to account for region- and type-specific fixed effects. The results are summarized in Table 8.

Table 8. Market Share Variables

Variable	Name	Coefficient	T-ratio
Time	TIME	-0.02478	-5.948
Fuel efficiency (U.S. relative to foreign)	LNEFFCY	0.50862	1.908
Cost per capacity (U.S relative to foreign)	LNCSTCAP	-0.12798	-0.702
New foreign model	NEWF	-0.15829	-2.471
New U.S. model	NEWU	0.03653	0.615

Note: Estimates of seat-size category and region variables are not reported.

The overall fit of the model was not exceptional, with a coefficient of determination (adjusted R-square) of 47.5 percent. However, this is not disturbing given the substantial fluctuations in the raw data. Therefore, we settled on the model as presented in Table 8.

Because of the log-log specification, the coefficients on fuel efficiency and cost per capacity are interpreted as elasticities. Thus, a 10 percent improvement in the relative fuel efficiency of U.S. aircraft will increase U.S. market share by 5.086 percent. Similarly, the introduction of a new foreign aircraft will decrease U.S. market share by 0.158 percent. According to the criteria of statistical significance, the main drivers of U.S. manufacturers market share are the relative fuel efficiency of U.S. aircraft and the timing of new model deliveries by foreign manufacturers.

Projecting U.S. Market Share

To project changes in market share forward, we begin with the centered moving average U.S. market share in each region for each seat-size category. We then take advantage of the log-log specification by incrementing percentage changes in market share as the sum of the percentage changes in the explanatory variables multiplied by the estimated coefficient. Specifically, the formula for incremental changes in market share is given by

$$\%\Delta y = \sum_{i=1}^{2} \alpha_i \%\Delta x_i + \sum_{j=1}^{2} \alpha_j z_j, \qquad \text{[Eq. 15]}$$

where $\%\Delta y$ is the percentage change in U.S. market share, α_i are the estimated coefficients, $\%\Delta x_i$ is the percentage change in the performance variables (i.e., fuel efficiency and cost per capacity), and the z_i are the dummy variables for new model introductions by U.S. and foreign manufacturers, respectively. The default values and baseline projection for U.S. market share are presented in Appendix F.

Derivation of the Airframe Manufacturers Module

To trace the impact of sales of U.S.-manufactured aircraft on the U.S. economy, we utilized a technique called input-output analysis.[15] Essentially, input-output analysis answers the question: "What level of output did each of *n* industries in an economy produce, in order to satisfy final demand for particular commodities." In our case, we are interested in the industries that provide goods or services required directly or indirectly in the production of aircraft. To do so, we constructed a simple five-sector model. Table 9 shows the composition of the sectors in our input-output model.

Table 9. Composition of Five-Sector Model

I-O industry number[a]	Name of sector	SIC industries included[b]
60.0100	Aircraft	3721
60.0200	Aircraft/Missile Engines	3724
60.0400	Aircraft/Missile Equipment, not elsewhere classified (NEC)	3728
56.05, 62.0101, 62.02	Avionics	3663, 3669, 3812, 3823, 3824, and 3829
N/A	All others	N/A

[a]From the *Benchmark Input-Output Accounts of the United States, 1987.*
[b]From the Standard Industrial Classification Manual, 1987.

Starting with data from Table 2B of the *Benchmark Input-Output Accounts*, a "use table for industries" was constructed (Table 10). To interpret the table, read down the column to see which sectors provide intermediate inputs to a particular industry of interest. For example, we see that engines contributed $4,637,900,000 or 11.8 percent to the production of aircraft in 1987. Value-added is defined as the difference between total output and total intermediate inputs. It reflects payments to workers, indirect business taxes paid to the government, and the return to capital invested in the industry.

Table 10. The Use Table for Industries (millions of dollars at producer's prices)

Sector	Aircraft ($)	Engines ($)	Equip NEC[a] ($)	Avionics ($)	All others ($)
Aircraft	24.8	0.0	94.8	0.0	68,508.7
Engines	4,637.9	3,583.2	309.7	0.0	0.0
Equipment, NEC	4,879.1	1,555.5	827.3	0.0	0.0
Avionics	2,950.6	76.2	3.3	932.0	156,201.9
All Others	11,229.9	7,032.8	5,415.0	24,588.1	3,309,336.2
Compensation of Employees	12,888.8	7,987.0	9,126.5	25,844.3	2,642,810.4

[15] For additional information, see the *Benchmark Input-Output Accounts of the United States, 1987.*

Table 10. The Use Table for Industries (millions of dollars at producer's prices)(Cont.)

Sector	Aircraft ($)	Engines ($)	Equip NEC[a] ($)	Avionics ($)	All others ($)
Indirect Business Taxes	260.4	238.4	114.7	844.9	363,527.6
Profit, Net Interest, Capital Consumption	2,564.7	3,307.5	3,019.5	9,770.6	1,490,523.7
Value Added	15,713.9	11,532.9	12,260.7	36,459.8	4,496,861.7
Total Output	39,436.2	23,780.6	18,910.8	61,979.9	8,030,908.5

[a]NEC=Not elsewhere classified.

After appropriate manipulation of these raw data, a Leontief inverse matrix was derived. Information from Table 4A of the *Benchmark Input-Output Accounts* was used to refine our estimates for I-O accounts 60.0100, 60.0200, and 60.0400. The modified Leontief inverse matrix is shown in Table 11. To interpret the table, read down a column. For example, the table shows that to deliver a dollar's worth of aircraft, the economy must produce slightly over a dollar's worth of aircraft.[16] This is true because aircraft are intermediate inputs to industries that are themselves inputs to the aircraft-producing sector. Working down the column, we also observe that 13.96 cents of aircraft engines, 13.91 cents of aircraft equipment NEC, 9.06 cents of avionics, and 75.84 cents of all other industries are required as intermediate inputs to produce a dollar's worth of aircraft for final demand.

Table 11. Modified Leontief Inverse Matrix (in dollars)

Sector	Aircraft	Engines	Equip NEC	Avionics	All others
Aircraft	1.0013	0.0059	0.0098	0.0060	0.0148
Engines	0.1396	1.1705	0.0490	0.0008	0.0021
Equipment, NEC	0.1391	0.0802	1.0713	0.0008	0.0021
Avionics	0.0906	0.0171	0.0115	1.0295	0.0354
All others	0.7584	0.7403	0.6237	0.6984	1.7340

The final step in our analysis was to scale Table 11 to reflect the shipments, value-added, and work-years that flow from $1,000,000 of aircraft purchases in the base year 1995. The results are shown in Table 12. To estimate the employment effects, we divided shipments within a sector by the shipments per worker in that particular industry, as derived from the *1992 Economic Census of Manufactures*.[17] The exception was the "All others" sector, which we estimated by dividing value-added

[16] The combined markup for wholesale/retail trade margins and transportation costs are 6.3 percent for this industry; so, we approximate purchasers' prices with producers' prices. (See Table E.1 of the *Benchmark Input-Output Accounts*.)

[17] The 1992 figures for shipments per worker were increased 17.93 percent for aircraft, aircraft engines, and aircraft equipment NEC, and by 12.90 percent for avionics. These increases reflect the combined effects of inflation and productivity gains for the period 1992 to 1995.

for that sector by gross domestic product (GDP) per worker for the U.S. economy.[18]

Table 12. Scaled Results (in dollars)

Sector	Final demand ($)	Shipments ($)	Value-added ($)	Work years
Aircraft	1,000,000	1,001,270	378,769	3.57
Engines	0	139,620	62,830	0.64
Equipment, NEC	0	139,110	80,244	0.99
Avionics	0	90,596	53,294	0.58
All others	0	758,354	424,863	7.33
Totals	1,000,000	2,128,950	1,000,000	13.10

CONCLUSIONS

To link the economics of flight with the technology of flight, NASA's ASAC requires a parametrically based model that links airline operations and investments in aircraft with aircraft characteristics. That model also must provide a mechanism for incorporating air travel demand and profitability factors into the airlines' investment decisions. Finally, the model must be flexible and capable of being incorporated into a wide-ranging suite of economic and technical models that are envisioned for ASAC.

The third-generation Air Carrier Investment Model meets all of these requirements. The enhanced model incorporates econometric results from the supply and demand curves faced by U.S., Asian, and European scheduled passenger air carriers. It incorporates cost data across six functional cost categories to project changes in operating costs for U.S. carriers. The enhanced model uses detailed information about the carriers' fleets in 1995 to make predictions about future aircraft purchases. It incorporates econometric results from a study of U.S. aircraft manufacturers to link changes in the relative productivity of U.S. aircraft with changes in U.S. market share. It incorporates results from input-output analysis to project the impact of U.S. aircraft sales on employment in the U.S. airframe manufacturing industry and its related activities. Thus, the enhanced model provides analysts with the ability to project revenue-passenger-miles flown, airline industry employment, airline operating profit margins, number and types of aircraft in the fleet, U.S. manufacturers' market share, and changes in aircraft manufacturing employment under various user-defined scenarios.

[18] 1995 GDP was $7,241 billion and 1995 employment was 124.9 million people. Therefore, GDP per worker was $57,974.

Bibliography

ACAS Fleet Information System. Rugby, England: AvSoft Information Systems, 1996.

Airline Monitor (various editions). Ponte Vedra Beach, Florida: ESG Aviation Services.

Commercial Aircraft Transaction Data Base. Missoula, Montana: Avmark Inc., 1997.

Commercial Jet Fleets (various editions). Memphis, Tennessee: Federal Express Aviation Services.

Cornwell, C., P. Schmidt, and R. C. Sickles. "Production Frontiers with Cross-Sectional and Time-Series Variation in Efficiency Levels." *Journal of Econometrics*, Vol. 46, pp. 185–200, 1990.

Current Market Outlook: World Market Demand and Airplane Supply Requirements (various editions). Seattle, Washington: Boeing Commercial Airplane Group.

Digest of Statistics for Commercial Air Carriers (various editions). Montreal, Canada: International Civil Aviation Organization.

Executive Office of the President. Office of Management and Budget. *Standard Industrial Classification Manual.* Washington, D.C., 1987.

FAA Aviation Forecasts (various editions). Washington, D.C., U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Policy and Plans.

Fernandez, Abel A. *Market Share Study: Commercial Aircraft Industry—Phase 1: Historical Market Share Analysis.* Unpublished Technical Report, Department of Engineering Management, Old Dominion University, June 1997.

Global Market Forecast 1997–2016: Confirming Very Large Demand. Blagnac, France: Airbus Industrie, March 1997.

Good, D., A.K. Postert, and R.C. Sickles. *A Model of World Aircraft Demand.* Unpublished Report. Department of Economics, Indiana University, June 1997.

Greene, W. H. *Econometric Analysis (Third Edition)*. Upper Saddle River, New Jersey. Prentice Hall, 1993.

Hsiao, Cheng. *Analysis of Panel Data*. New York, New York: Cambridge University Press, 1986.

Interavia Business and Technology. *Airline 500 CD-ROM*. Geneva, Switzerland: Pyramid Media Group, 1995.

International Aircraft Price Guide. London, England: Airclaims Ltd., Winter 1996.

Jane's All the World's Aircraft. Coulsdon, United Kingdom: Jane's Information Group Limited, various editions.

Morgan Stanley Equity Research. "The Upturn in the Commercial Aircraft Industry—Challenges for the Supplier Base." Presentation given at the Air Transport Research Council International Forum, Washington, D.C.: March 1996. Pierre A. Chao, Vice President.

Speednews: Turboprop Aircraft Orders and Deliveries. Los Angeles, California: Speednews Inc., December 1996.

Summers, R. and A. Heston. "The Penn World Table (Mark 5.0): An Expanded Set of International Comparisons, 1950–1988." *Quarterly Journal of Economics,* Vol. 106, pp. 327–368, 1991.

U.S. Department of Commerce. Bureau of the Census. *1992 Economic Census of Manufactures*. Contained in *1992 Economic Census CD-ROM Report Series, Disk 1H*. Washington, D.C.: May 1996.

U.S. Department of Commerce. Bureau of Economic Analysis. *Benchmark Input-Output Accounts of the United States, 1987*. Washington, D.C.: U.S. Government Printing Office, November 1994.

Wingrove, E. R. III, J. P. Johnson, R. C. Sickles, and D. H. Good. *ASAC Air Carrier Investment Model (Second Generation)*. NASA Contractor Report No. 201678, April 1997.

World Air Transport Statistics (various editions). Geneva, Switzerland: International Air Transport Association.

World Jet Inventory. Woodinville, Washington: Jet Information Services Inc., 1995.

Appendix A
Functional Costs

This appendix provides additional detail regarding two related aspects of the derivation of the Functional Cost Module: the allocation of operating costs to functional categories and the functional cost computational formula.

FUNCTIONAL COST CATEGORIES

Because we were interested in fully accounting for airline operating costs, we used DOT Form 41 Schedule P-6 (*Operating Expenses by Objective Groupings*), which is only filed by Group II and III carriers. Table A-1 lists the elements of this schedule.

Table A-1. Lines of Schedule P-6

Line number	Elements
3	Salaries and wages of general management personnel
4	Salaries and wages of flight personnel
5	Salaries and wages of maintenance personnel
6	Salaries and wages of aircraft and traffic-handling personnel
7	Salaries and wages of other airline personnel
10	Personnel expenses
11	Employee benefits and pensions
12	Payroll taxes
16	Aircraft fuel and oil (including fuel and oil taxes)
17	Maintenance materials
18	Passenger food
19	Other materials
22	Advertising and other promotion
23	Communications
24	Insurance
25	Outside flight equipment maintenance
26	Passenger traffic commissions
27	Cargo traffic commissions
28	Other services
30	Landing fees
31	Rentals
32	Depreciation
33	Amortization
34	Other
35	Transport-related expenses

While using Schedule P-6 creates some loss of precision because of aggregation, it has the virtue of full visibility of all reported costs. The scheme we used to allocate the various lines of Schedule P-6 to the appropriate functional cost categories is shown in Table A-2.

Table A-2. Cost Category Components (Reference Line From Schedule P-6)

Functional cost category	Cost elements
Fuel	16
Flight personnel labor	4[a]
Maintenance	5[a], 17, 25
Flight equipment capital	13.6% (flight equipment value)
Ground property and equipment	13.6% (ground property and equipment value)
Indirect costs	3[a], 6[a], 7[a], 18, 19, 22, 23, 24, 26, 27, 28, 30, 34, 35

[a]Plus an allocated share of lines 10, 11, and 12.

Because we construct flight equipment and ground property and equipment capital costs independently, we had no need for lines 31, 32, and 33 of Schedule P-6.

Functional Cost Formulations

The equations for each functional cost category are given by equations A-1 through A-6 below.

$$Fuel\ costs = ASM \times \left(\frac{fuel\ price\ /\ gallon}{(ASM\ /\ block\ hour)\ /\ (gallons\ /\ block\ hour)} \right) \quad \text{[Eq. A-1]}$$

$$Flight\ personnel\ labor\ costs = ASM \times \left(\frac{flight\ personnel\ labor\ rate\ /\ block\ hour}{ASM\ /\ block\ hour} \right) \quad \text{[Eq. A-2]}$$

$$Maintenance\ costs = ASM \times \left(\frac{(labor\ rate + material\ rate)\ /\ block\ hour}{ASM\ /\ block\ hour} \right) \quad \text{[Eq. A-3]}$$

$$Flight\ equipment\ capital\ costs = ASM \times \left(\frac{(aircraft\ capital\ costs\ /\ aircraft\ day)}{(ASM\ /\ block\ hour) x (block\ hours\ /\ aircraft\ day)} \right) \quad \text{[Eq. A-4]}$$

$$Ground\ property\ and\ equipment\ costs = ASM \times \left(\frac{GP\&E\ costs}{ASM} \right) \quad \text{[Eq. A-5]}$$

$$Indirect\ costs = ASM \times \left(\frac{indirect\ costs}{ASM} \right) \quad \text{[Eq. A-6]}$$

Appendix B
Functional Cost Module Baseline

This appendix documents the default assumptions used to derive the baseline scenario of the U.S. Functional Cost Module.

DEFAULT VALUES

The Functional Cost Module baseline assumptions are drawn from a variety of sources including the 1996 and 1997 editions of the *FAA Aviation Forecasts*, the 1996 and 1997 editions of the Boeing *Current Market Outlook*, Form 41 historical data, and population projections of the U.S. Census Bureau. Table B-1 lists the default assumptions along with the source values and the corresponding values from the ACIM U.S. Econometric Module. All parameters represent compound annual rates of change.

Table B-1. Default Values

Baseline feature	FAA 1996	FAA 1997	Boeing 1996 (97)	Form 41 historic	FCM	ACIM
U.S. income	2.615	2.252	2.4 (2.3)		2.350	2.510
U.S. population					0.826	0.940
U.S. unemployment					0.000	0.000
Load factor (96–00)	0.242	0.845			0.845	
Load factor (01–15)	0.000	0.000			0.000	
Implied load factor (96–15)			0.196		0.209	0.200
Per gallon fuel prices	0.554	0.015			0.285	
Ground p&e* costs				-0.170	-0.170	
Traffic commissions				-2.200	-1.100	
Landing fees				0.760	0.760	
Other indirect costs				-1.230	-1.230	
Fuel gallons/block hour				-0.877 [b]	-0.877 [b]	
Seats/aircraft	0.805	1.116	(0.531) [a]		0.805	0.700
Aircraft miles/block hour				0.253 [b]	0.253 [b]	
Block hours/aircraft day				0.000	0.000	
Block hours/employee				0.283 [b]	0.283 [b]	
ASM/employee				1.518 [b]	0.506 [b]	
Flight crew labor rate				1.139 [b]	1.139 [b]	
Maintenance labor rate				-1.250 [b]	-1.250 [b]	
Maintenance material rate				-0.922 [b]	-0.922 [b]	
Flight equipment capital				-- [c]	0.000	

[a]Based upon worldwide analyses.

[b]The parameter varies by carrier group and the value for major carriers is reported.

[c]No information was available.

*Note: p&e = property and equipment.

BASELINE FORECAST

The default assumptions constitute the baseline scenario of the U.S. Functional Cost Module. The results derived from these assumptions are presented along with projections from other published forecasts in Table B-2. The FCM baseline compares quite favorably with the other forecasts.

Table B-2. Forecast Values

Forecast feature	FAA 1996	FAA 1997	Boeing 1993[a]	FCM	ACIM
Absolute 1995 RPMs (billions)	543.6	543.6	578.6	526.1	550.7
Absolute 2005 RPMs (billions)	834.1	876.1	888.5	850.3	855.6
Absolute 2015 RPMs (billions)			1358.4	1304.8	1287.8
RPM growth rates (%)	4.290	4.680	4.513	4.646	4.340
Total aircraft 1995	4100	4100	3890	3836	4179
Total aircraft 2005	5537	5871	5332	5309	5451
Fleet growth rates (%)	3.050	3.650	3.200	3.295	2.690
Fare yield change (%) (96-00)	-1.940	-1.970		-2.085	-1.370
Fare yield change (%) (01-10)	-0.948	-0.802		-1.042	-0.940

[a]The 1993 edition of Current Market Outlook was used since it is the last year in which U.S. carriers are treated separately.

Table B-3 shows the projected distribution of aircraft in 2015 by Seat-Size category.

Table B-3. Projected Distributed of Aircraft by Seat-Size in 2015

Seat size	Under 50	50–69	70–90	91–120	121–170	171–240	241–350	Over 350	Total
U.S. FCM aircraft	426	80	116	1,015	2,941	2,116	449	133	7,276

Appendix C
Asian and European Baseline

This appendix documents the methodology and default assumptions used to derive the baseline scenario of the Asian and European Econometric Modules.

Baseline Methodology

For the Asian and European modules of the ACIM, we had to establish the 1995 baseline. Unfortunately, Asian and European air carriers are not required to submit detailed cost and traffic data such as those required of U.S. airlines under Form 41. Consequently, we had to collect data from a variety of sources and estimate missing data elements, as will be described below.

We started with data from the 1996 edition of Airline 500. Airline 500 is a database produced by Interavia. The edition we used cited 1995 traffic data and the most recent financial data available. Specific data elements included revenue-passenger kilometers, operating revenues, operating expenses, and numbers of employees. We supplemented the Airline 500 traffic and financial data with ACAS fleet inventory data for 1995 from AvSoft Information Systems. Aircraft counts were split into jet and propeller/turbo-prop categories. Where gaps existed in the Airline 500 traffic and financial data, they were filled with 1995 IATA data and 1992 ICAO data (scaled appropriately).

The combination of these four data sources gave fairly complete coverage for the 25 Asian and European air carriers shown in Tables C-1 and C-2. These named carriers were the same ones used by Sickles and Good in their econometric study of airline cost functions.

Regional totals for RPMs flown were obtained from Appendix A to Boeing's 1996 *Current Market Outlook.* To obtain the RPMs flown by residual airlines, we subtracted the sum of RPMs flown for the named carriers from the Asian and European regional totals. Operating revenues and operating costs for the residual airlines were assumed to be a function of RPMs flown and were scaled in proportion to the regional subtotals. Numbers of aircraft operated by the residual airlines were obtained directly from the AvSoft fleet data.

For the 25 named carriers, number of workers was regressed against number of jet aircraft and number of propeller/turbo-prop aircraft. The multiple coefficient of determination (R Square) for the ordinary least squares (OLS) regression was 73.1 percent. The results are shown in Tables C1 through C-3. From these results, we estimated the numbers of workers employed by the residual airlines.

Table C-1. Asia-Pacific Carriers

Airline name	RPMs flown	Operating revenues ($)	Operating costs ($)	Work years	Total aircraft
Air India	5,678,315,295	821,954,790	783,177,330	18,067	28
Air New Zealand	9,818,120,000	1,769,524,000	1,594,145,000	7,404	35
Cathay Pacific	21,949,712,200	3,904,000,000	3,498,000,000	14,744	52
Garuda	12,273,011,655	1,698,900,000	1,721,000,000	14,589	52
Indian Airlines	4,312,285,461	622,982,034	615,032,167	22,600	73
Japan Airlines	39,185,198,777	11,633,325,000	11,744,101,000	20,679	121
Japan Asia Airways	1,604,454,800	512,627,932	505,217,706	923	5
Korean Air	18,404,510,241	3,878,000,000	3,531,000,000	16,515	83
Pakistan International Airlines	6,470,548,718	770,071,000	740,174,000	20,382	29
Philippine Airlines	8,688,317,240	1,339,924,851	1,214,476,397	13,750	46
Qantas Airways	30,149,531,365	3,472,200,966	3,562,651,155	26,600	92
Singapore Airlines	27,930,003,660	3,544,000,000	3,204,000,000	12,557	64
Thai International	16,810,734,200	2,983,506,000	2,585,697,000	21,906	73
Named Asian subtotal	203,274,743,612	36,951,016,574	35,298,671,755	210,716	755
Asian residual	148,559,256,388	27,004,906,991	25,797,324,027	301,201	1,744
Asian grand total	351,834,000,000	63,955,923,565	61,095,995,781	511,917	2,499

Table C-2. European Carriers

Airline name	RPMs flown	Operating revenues ($)	Operating costs ($)	Work years	Total aircraft
Air France	30,774,213,600	6,989,009,811	7,092,778,632	42,093	137
Alitalia	18,805,133,656	4,923,000,000	4,832,000,000	27,859	147
Austrian Airlines	3,053,150,097	908,331,000	920,255,000	3,862	32
British Airways	53,686,084,782	11,699,000,000	10,691,000,000	53,060	248
Finnair	5,710,278,868	1,538,000,000	1,321,000,000	9,586	37
Iberia	14,005,175,340	3,082,166,800	3,040,134,800	23,576	108
KLM, Royal Dutch	25,390,407,728	4,961,520,000	4,544,640,000	24,177	74
Lufthansa	38,279,482,800	9,774,578,000	9,527,528,000	33,240	199
Sabena	4,658,617,779	1,908,000,000	1,882,000,000	9,549	41
Scandinavian Airlines System	11,499,628,400	4,566,500,000	4,213,600,000	17,648	151
Swissair	12,257,115,000	3,452,500,000	3,412,500,000	17,733	65
TAP-Air Portugal	4,794,722,400	1,099,474,000	1,188,100,000	8,226	35
Named European subtotal	222,914,010,452	54,902,079,611	52,665,536,432	270,609	1,274
European residual	162,864,489,548	40,112,324,716	38,478,271,018	342,054	2,092
European grand total	385,778,500,000	95,014,404,327	91,143,807,450	612,663	3,366

Table C-3. Workforce Regression Results

Variable	Coefficient	Standard error	T-ratio
Intercept	5,499	2,178	2.52
Number of jets	174.12	24.09	7.23
Number of other aircraft	68.12	192.94	0.35

DEFAULT VALUES

Table C-4 shows the default values for the annual changes (from 1995 through 2015) of the key variables in the Asian and European modules of the ASAC ACIM.

Table C-4. Default Values

Variable	(%)
GDP growth, Asia	3.80
GDP growth, Europe	2.40
Labor price change, Asia	1.00
Labor price change, Europe	0.00
Labor productivity effect, Asia	1.60
Labor productivity effect, Europe	0.80
Fuel cost change	-1.60
Materials cost change	0.00
Capital price change	0.00
Capital productivity effect, Asia	0.46
Capital productivity effect, Europe	0.23
Change in load factor	0.20
Change in average seats per aircraft	0.70
Change in average age of aircraft	0.74
Change in proportion of jet aircraft[a]	0.00
Change in proportion of wide-bodied aircraft[a]	0.002275

Note: All economic values are measured in constant dollars. Therefore, the annual percentage changes are real rates of change.

[a]These variables are the projected annual changes in the proportions.

BASELINE FORECAST

When these baseline figures are inserted into the ASAC ACIM, the values of future travel and aircraft requirements, shown in Table C-5, are predicted for the period 1995 through 2015. These forecasts may be compared with those from Boeing.

Table C-5. Forecast Values

Variable	Boeing[a]	LMI
Asian revenue passenger-mile (RPM) growth	6.88	6.96
Asian RPMs (billions) in 2015	1,331.3	1,351.9
European RPM growth	4.46	4.56
European RPMs (billions) in 2015	923.9	941.4

[a]The Boeing figures are from the 1996 edition of the *Current Market Outlook*.

Table C-6 shows the projected distribution of aircraft in 2015 by seat-size category.

Table C-6. Projected Distribution of Aircraft by Seat-Size in 2015

Seat-size	Under 50	50–69	70-90	91-120	121-170	171-240	241-350	Over 350	Total
Asian aircraft	1,093	399	155	458	960	2896	873	583	7,418
European aircraft	883	495	205	725	1,324	2,201	384	278	6,497

Appendix D
Geographic Regions of the World

This appendix details the composition of the geographic regions of the world. The U.S. region consists exclusively of the 50 U.S. states. The members of the European region, which is composed of the subregions of Western Europe, Eastern Europe, and Southern Europe, are listed in Table D-1. Similarly the members of the Asia-Pacific region, which is composed of the subregions of Australasia, China, the Far East, Southeast Asia, and the Indian subcontinent, are listed in Table D-2. Countries not elsewhere identified are allocated to the rest of the World region. These include the regions of Central and South America, Canada and the Caribbean, the Middle East, and Africa. The members of the Commonwealth of Independent States (former Soviet Union) are not addressed in this study. The source of this classification is AvSoft's ACAS Fleet Information System.

Table D-1. European States

Albania	Germany	Netherlands
Austria	Greece	Norway
Belgium	Greenland	Poland
Bosnia Hercegovina	Hungary	Portugal
Bulgaria	Iceland	Romania
Croatia	Ireland	Slovakia
Cyprus	Italy	Slovenia
Czech Republic	Latvia	Spain
Denmark	Liechtenstein	Sweden
Estonia	Lithuania	Switzerland
Finland	Luxembourg	Turkey
France	Macedonia	United Kingdom
Gibraltar	Malta	Yugoslavia

Table D-2. Asia-Pacific States

Afghanistan	Kiribati	Papua New Guinea
Australia	Laos	Philippines
Bangladesh	Macau	Singapore
Bhutan	Malaysia	Solomon Islands
Brunei	Maldives	South Korea
Cambodia	Mariana Island	Sri Lanka
China	Marshall Islands	Taiwan
Cook Islands	Mongolia	Thailand
Fiji	Myanma	Tonga
French Polynesia	Nauru	Vanuatu
Hong Kong	Nepal	Vietnam
India	New Caledonia	Western Samoa
Indonesia	New Zealand	
Japan	Pakistan	

Appendix E

Aircraft Seat-Size Categories

This appendix details the allocation of aircraft models to seat-size categories. With the exception of the 767-300 in Asia and the A330 in Europe, aircraft seat-size categories correspond to the standard configuration definitions. Tables E-1 through E-8 list the aircraft models included in each of the eight seat-size categories.

Table E-1. Seat-Size Category 1

Manufacturer	Aircraft model	Regions	Seat-size category
ATR	ATR42	All	<50
BAE	J31	All	<50
BAE	J41	All	<50
Beech	Beech 99	All	<50
Beech	Beech 1900	All	<50
Beech	Beech Jet	All	<50
BRAD	DHC6	All	<50
BRAD	DHC8	All	<50
CASA	212	All	<50
CASA	235	All	<50
Domier	228	All	<50
Domier	328	All	<50
Embraer	110	All	<50
Embraer	120	All	<50
Embraer	145	All	<50
Fairchild	F-27	All	<50
Fairchild	SA226	All	<50
Fairchild	SA227	All	<50
Fokker	F-27	All	<50
Grumman	G159	All	<50
IPTN	212	All	<50
IPTN	235	All	<50
Saab	340	All	<50
Shorts	330	All	<50
Shorts	360	All	<50

Table E-2. Seat-Size Category 2

Manufacturer	Aircraft model	Region	Seat-size category
ATR	ATR72	All	50–69
BAE	748	All	50–69
BAE	ATP	All	50–69
BAE	Viscount	All	50–69
BRAD	CRJ	All	50–69
BRAD	DHC7	All	50–69
Convair	CV5	All	50–69
Convair	CV580	All	50–69
Convair	CV600	All	50–69
Fokker	F-50	All	50–69
NAMC	YS11	All	50–69
Saab	2000	All	50–69

Table E-3. Seat-Size Category 3

Manufacturer	Aircraft model	Region	Seat-size category
Fokker	F-28	All	70–90
BAE	146	All	70–90

Table E-4. Seat-Size Category 4

Manufacturer	Aircraft model	Region	Seat-size category
BAE	1-11	All	91–120
Boeing	737-100/200	All	91–120
Boeing	737-500	All	91–120
Boeing	737-600	All	91–120
British Aerospace	Concorde	All	91–120
Douglas	DC-9	All	91–120
Douglas	MD-95	All	91–120
Fokker	F-100	All	91–120

Table E-5. Seat-Size Category 5

Manufacturer	Aircraft model	Region	Seat-size category
Airbus	A319	All	121–170
Airbus	A320	All	121–170
Boeing	707	All	121–170
Boeing	720	All	121–170
Boeing	727-100/200	All	121–170
Boeing	737-300	All	121–170
Boeing	737-400	All	121–170
Boeing	737-700/800	All	121–170
Douglas	MD-80	All	121–170
Douglas	MD-90	All	121–170

Table E-6. Seat-Size Category 6

Manufacturer	Aircraft model	Region	Seat-size category
Airbus	A310	All	171–240
Airbus	A321	All	171–240
Boeing	757-200/300	All	171–240
Boeing	767-200	All	171–240
Boeing	767-300	U.S., Europe, ROW	171–240
Douglas	DC-8	All	171–240

Table E-7. Seat-Size Category 7

Manufacturer	Aircraft model	Region	Seat-size category
Airbus	A300	All	241–350
Airbus	A330	U.S., Asia, ROW	241–350
Airbus	A340	All	241–350
Boeing	777-200	All	241–350
Boeing	767-300	Asia	241–350
Douglas	DC-10	All	241–350
Douglas	MD-11	All	241–350
Lockheed	L-1011	All	241–350

Table E-8. Seat-Size Category 8

Manufacturer	Aircraft model	Region	Seat-size category
Airbus	A330	Europe	>350
Boeing	747	All	>350
Boeing	777-300	All	>350

Appendix F

Market Share Module Baseline

This appendix provides details on the default parameters of the Market Share Module and the resulting baseline forecast of U.S. aircraft manufacturers' market share.

Baseline Methodology and Default Values

We begin with the 1995 centered moving average market share for U.S. aircraft manufacturers in each seat-size category and for each region of the world. Because the projections are quite sensitive to these initial conditions, we further smooth the most recent market share observations by increasing the scope of the moving average from one to two periods in each direction. The resulting initial market shares for our projections are presented in the first lines of Tables F-2 through F-4.

As outlined in the report, the incremental change in U.S. market share from period to period is determined by the incremental change in the explanatory variables. Thus, to accurately project a baseline forecast, we require realistic assumptions regarding expected changes in these variables. In the case of new model introductions, we researched the strategic plans of the world's major aircraft manufacturers to determine projected delivery dates for new aircraft models. The source of this research was *Jane's All the World's Aircraft* and various publications of the respective manufacturers. Since the U.S. has not traditionally produced any aircraft models in seat categories 2 and 3, we assume no new model introductions in these categories. In addition, no information was available regarding model introductions for seat category 1.

Next, we determined the historical frequency of new model introductions in each seat-size category for both U.S and foreign manufacturers. The result was the computation of an average cycle time between new model introductions for each seat-size category. The results of this analysis are presented in Table F-1. The Market Share Module also provides an option to the user that enables the introduction of special aircraft models outside the normal cycle of new model introductions. However, this option is not activated for the baseline projections.

Table F-1. Default New Model Delivery Assumptions

Seat categories	1	2	3	4	5	6	7	8
New foreign model	—	—	—	2003	2002	2004	2002	2003
New U.S. model	—	—	—	1998	1997	1999	2000	1998
Foreign cycle (years)	—	—	—	9	11	10	8	10
U.S. cycle (years)	—	—	—	9	5	7	7	10

With the exception of seat category 8, the baseline forecast does not alter either of the performance ratio measures. Our rationale was that we lacked sufficient expertise to judge the likely impacts of the new model introductions upon the performance characteristics of the seat-size categories. However, we recognized that the projected delivery of the Airbus A3XX in 2003 would alter the category 8 performance measures to such a degree as to deserve special attention.[1] The baseline projections assume an impact of 5 percent on the category 8 fuel-efficiency ratio and an impact of 10 percent on the corresponding cost-per-capacity ratio in the year 2003.

When a U.S. or foreign manufacturer introduces a new model that incorporates a technological advancement, other manufacturers often respond with a model of their own to incorporate the advancement. The Market Share Module provides the user with two alternate approaches for including this technology diffusion impact. If the technological advancement is relatively minor and could be easily incorporated into existing models, the impact of the initial change in the performance ratio is likely to be mitigated relatively quickly. The Market Share Module addresses this possibility with a damping option that, when activated, gradually reverses the initial performance impact over a specified period of time. If, on the other hand, the technological advancement is substantial and would not easily be incorporated into existing models, the impact of the initial change is not likely to be mitigated until other manufacturers can develop completely new models. The Market Share Module addresses this possibility with an optional secondary impact on the performance measure after a specified period of time. Both the delay incorporating the new technology and the magnitude of the secondary impact can also be varied by the user.

In addition to the performance measure and new model delivery variables, a user may choose to activate the market share time-erosion switch. This option continues to erode U.S. manufacturers' market share over the course of the projections at a rate consistent with historical data. However, we strongly caution a user against activating this option since there is no reason to suppose that the U.S. market share will continue to be eroded.

[1] The Airbus A3XX will be the largest passenger aircraft in the World with seating capacity for 555 passengers in standard configuration and a range of approximately 8,000 nautical miles. Airbus projects substantial cost and performance improvements over the existing category 8 designs.

BASELINE FORECAST

The baseline projections that result from the default assumptions outlined above are summarized by Tables F-2 through F-4. Because of the sensitivity of the projections to the initial conditions, the Market Share Module enables users to vary the 1995 baseline U.S. market shares for all three regions.

Table F-2. Baseline U.S. Market Share Projections for the U.S. Region by Seat-Size Category (Percent)

Year	1	2	3	4	5	6	7	8
1995	23.31	0.00	0.00	87.59	67.42	84.59	57.37	100.00
1996	23.31	0.00	0.00	87.59	67.42	84.59	57.37	100.00
1997	23.31	0.00	0.00	87.59	67.44	84.59	57.37	100.00
1998	23.31	0.00	0.00	87.62	67.44	84.59	57.37	100.00
1999	23.31	0.00	0.00	87.62	67.44	84.62	57.37	100.00
2000	23.31	0.00	0.00	87.62	67.44	84.62	57.39	100.00
2001	23.31	0.00	0.00	87.62	67.44	84.62	57.39	100.00
2002	23.31	0.00	0.00	87.62	67.36	84.62	57.30	100.00
2003	23.31	0.00	0.00	87.48	67.36	84.62	57.30	96.02
2004	23.31	0.00	0.00	87.48	67.36	84.49	57.30	96.02
2005	23.31	0.00	0.00	87.48	67.36	84.49	57.30	96.02
2006	23.31	0.00	0.00	87.48	67.36	84.52	57.30	96.02
2007	23.31	0.00	0.00	87.51	67.38	84.52	57.23	96.02
2008	23.31	0.00	0.00	87.51	67.38	84.52	57.23	96.05
2009	23.31	0.00	0.00	87.51	67.38	84.52	57.23	96.05
2010	23.31	0.00	0.00	87.51	67.38	84.52	57.23	96.05
2011	23.31	0.00	0.00	87.51	67.38	84.52	57.23	96.05
2012	23.31	0.00	0.00	87.37	67.41	84.52	57.23	96.05
2013	23.31	0.00	0.00	87.37	67.30	84.55	57.23	95.90
2014	23.31	0.00	0.00	87.37	67.30	84.41	57.25	95.90
2015	23.31	0.00	0.00	87.37	67.30	84.41	57.25	95.90

Table F-3. Baseline U.S. Market Share Projections for the European Region by Seat-Size Category (Percent)

Year	1	2	3	4	5	6	7	8
1995	1.12	0.00	0.00	48.45	63.13	89.38	54.51	66.30
1996	1.12	0.00	0.00	48.45	63.13	89.38	54.51	66.30
1997	1.12	0.00	0.00	48.45	63.15	89.38	54.51	66.30
1998	1.12	0.00	0.00	48.47	63.15	89.38	54.51	66.32
1999	1.12	0.00	0.00	48.47	63.15	89.41	54.51	66.32
2000	1.12	0.00	0.00	48.47	63.15	89.41	54.53	66.32
2001	1.12	0.00	0.00	48.47	63.15	89.41	54.53	66.32
2002	1.12	0.00	0.00	48.47	63.08	89.41	54.44	66.32
2003	1.12	0.00	0.00	48.39	63.08	89.41	54.44	63.68
2004	1.12	0.00	0.00	48.39	63.08	89.27	54.44	63.68
2005	1.12	0.00	0.00	48.39	63.08	89.27	54.44	63.68
2006	1.12	0.00	0.00	48.39	63.08	89.30	54.44	63.68
2007	1.12	0.00	0.00	48.41	63.10	89.30	54.46	63.68
2008	1.12	0.00	0.00	48.41	63.10	89.30	54.46	63.71
2009	1.12	0.00	0.00	48.41	63.10	89.30	54.46	63.71
2010	1.12	0.00	0.00	48.41	63.10	89.30	54.38	63.71
2011	1.12	0.00	0.00	48.41	63.10	89.30	54.38	63.71
2012	1.12	0.00	0.00	48.33	63.12	89.30	54.38	63.71
2013	1.12	0.00	0.00	48.33	63.02	89.34	54.38	63.61
2014	1.12	0.00	0.00	48.33	63.02	89.20	54.40	63.61
2015	1.12	0.00	0.00	48.33	63.02	89.20	54.40	63.61

Table F-4. Baseline U.S. Market Share Projections for the Asia-Pacific Region by Seat-Size Category (Percent)

Year	1	2	3	4	5	6	7	8
1995	2.45	0.00	0.00	23.93	56.16	65.71	41.40	100.00
1996	2.45	0.00	0.00	23.93	56.16	65.71	41.40	100.00
1997	2.45	0.00	0.00	23.93	56.18	65.71	41.40	100.00
1998	2.45	0.00	0.00	23.94	56.18	65.71	41.40	100.00
1999	2.45	0.00	0.00	23.94	56.18	65.73	41.40	100.00
2000	2.45	0.00	0.00	23.94	56.18	65.73	41.41	100.00
2001	2.45	0.00	0.00	23.94	56.18	65.73	41.41	100.00
2002	2.45	0.00	0.00	23.94	56.12	65.73	41.35	100.00
2003	2.45	0.00	0.00	23.90	56.12	65.73	41.35	96.02
2004	2.45	0.00	0.00	23.90	56.12	65.62	41.35	96.02
2005	2.45	0.00	0.00	23.90	56.12	65.62	41.35	96.02
2006	2.45	0.00	0.00	23.90	56.12	65.65	41.35	96.02
2007	2.45	0.00	0.00	23.91	56.14	65.65	41.36	96.02
2008	2.45	0.00	0.00	23.91	56.14	65.65	41.36	96.05
2009	2.45	0.00	0.00	23.91	56.14	65.65	41.36	96.05
2010	2.45	0.00	0.00	23.91	56.14	65.65	41.30	96.05
2011	2.45	0.00	0.00	23.91	56.14	65.65	41.30	96.05
2012	2.45	0.00	0.00	23.87	56.16	65.65	41.30	96.05
2013	2.45	0.00	0.00	23.87	56.07	65.67	41.30	95.90
2014	2.45	0.00	0.00	23.87	56.07	65.67	41.31	95.90
2015	2.45	0.00	0.00	23.87	56.07	65.67	41.31	95.90

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To meet its objective of assisting the U.S. aviation industry with the technological challenges of the future, NASA must identify research areas that have the greatest potential for improving the operation of the air transportation system. To accomplish this, NASA is building an Aviation System Analysis Capability (ASAC). The ASAC differs from previous NASA modeling efforts in that the economic behavior of buyers and sellers in the air transportation and aviation industries is central to its conception. To link the economics of flight with the technology of flight, ASAC requires a parametrically based model with extensions that link airline operations and investments in aircraft with aircraft characteristics. This model also must provide a mechanism for incorporating air travel demand and profitability factors into the airlines' investment decisions. Finally, the model must be flexible and capable of being incorporated into a wide-ranging suite of economic and technical models that are envisioned for ASAC.

We describe a third-generation Air Carrier Investment Model that meets these requirements. Previous generations are enhanced by expanding the scope of the econometric approach to the geographic regions of Asia-Pacific and Europe, by developing activity based costing methods to estimate U.S. air carrier operating costs, by developing a market share module to project U.S. aircraft manufacturers' share of the world market, and by developing an input-output module to project the resulting employment impact in the U.S. aircraft manufacturing industry. The enhanced model enables analysts to project revenue passenger-miles flown, airline industry employment, airline operating profit margins, numbers and types of aircraft in the fleet, and changes in aircraft manufacturing employment under various user-defined scenarios.

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