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MIT

The Impact of Changing Technology on the Demand for Air Transportation

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DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

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This report reviews a series of interrelated research tasks conducted between December 1975 and November 1977 by an MIT research team under the sponsorship of the National Aeronautics and Space Administration - Ames Research Center (Grant No. NSG-2129). The tasks were carried out under the general title of "The Impact of Changing Technology on the Demand for Air Transportation" with Professor Nawal K. Taneja of MIT as Principal Investigator. Senior members of the research team consisted of Professor Robert W. Simpson, Dr. James T. Kneafsey and Dr. Steven E. Eriksen. In addition, several graduate students and members of the Flight Transportation Laboratory participated during different stages of the research program.

The initial purpose of this research grant was to develop demand models for air transportation that are sensitive to the impact of changing technology. In order to satisfy this requirement, the models not only had to be responsive to potential changes in technology, but also to changing economic, social, and political factors as well. While these models were developed to conform with past history, they also went beyond simple projections of historical trends, carefully incorporating the important basic variables that explain these trends. In addition to anticipating the wide differences in the factors influencing the demand for long haul and short haul air travel, the models were designed to clearly distinguish among the unique features of these markets.

The initial proposal was submitted with research to be carried out in three phases. The first phase focused on the development of the relationship between past and current aviation technology and current aviation demand and was completed according to plan. The second phase was to investigate the relationship between future aviation technology and future aviation demand, while the final phase was to produce projections of fleet requirements.

However, the scope of the second and third phases changed in light of the results of the first phase and the NASA-Ames in-house research project entitled, "Development of a Methodology for Assessing the Benefits of Aeronautical R & T". The objective of this NASA work was to provide an in-house capability to evaluate the potential benefits/costs for using advanced technology in air transportation. In-depth discussions between the research team and the Ames technical monitors during Autumn 1976 had narrowed the scope of the second phase in order to integrate more effectively the research at MIT with the projects being carried out in-house at the Ames Research Center.

In conducting the tasks under the NASA grant during the past two years, the MIT research team has investigated several economic and technological issues that bear directly on the interrelationships between aviation technology and future aviation demand. While some of these investigations are more elaborate extensions of prior work, others represent exploratory efforts in demand modeling and the economics of technological change. It is hoped that these research results will extend the frontiers of econometric model applications as well as enhance the understanding of the principal determinants of air transportation demand, aircraft technology and their interactions.*

*The research project was carried out under the technical monitorship of Mr. Louis Williams and Mr. Mark Waters of NASA Ames Research Center.

2. TECHNICAL BACKGROUND

2.1 Overall Objectives of the Research Program

The ultimate objective in the research program was the projection of passenger and cargo traffic growth for the air transport industry with clear distinctions for the short haul, intermediate haul and long haul market as well as for passenger and cargo. It is anticipated that these traffic growth projections and the models used to evaluate the technological impacts of plausible future scenarios can be implemented in the overall technology and cost-benefit evaluation models under development at NASA. In order that this research prove beneficial to NASA, this report reviews the highlights and principal findings of completed model applications.

During the progress of the MIT research, the scope of the effort has expanded from that originally contemplated. Based on consultations with industry and NASA representatives, the MIT research team concluded during the initial year that the research program should involve several linkages between macroeconomic events and air transport factors, some of which ultimately involved a more intensified modeling effort. In light of the changed scope of the research program the total modeling process was labeled, "An Integrated Air Transport Model", and its generalized format is presented in Figure 1. The interactive process shown in this figure is described below and is particularly important in light of the current research into the methodologies for performing cost-benefit studies of advanced aeronautical technology that is being performed in the Research Aircraft Technology Office at NASA Ames Research Center.

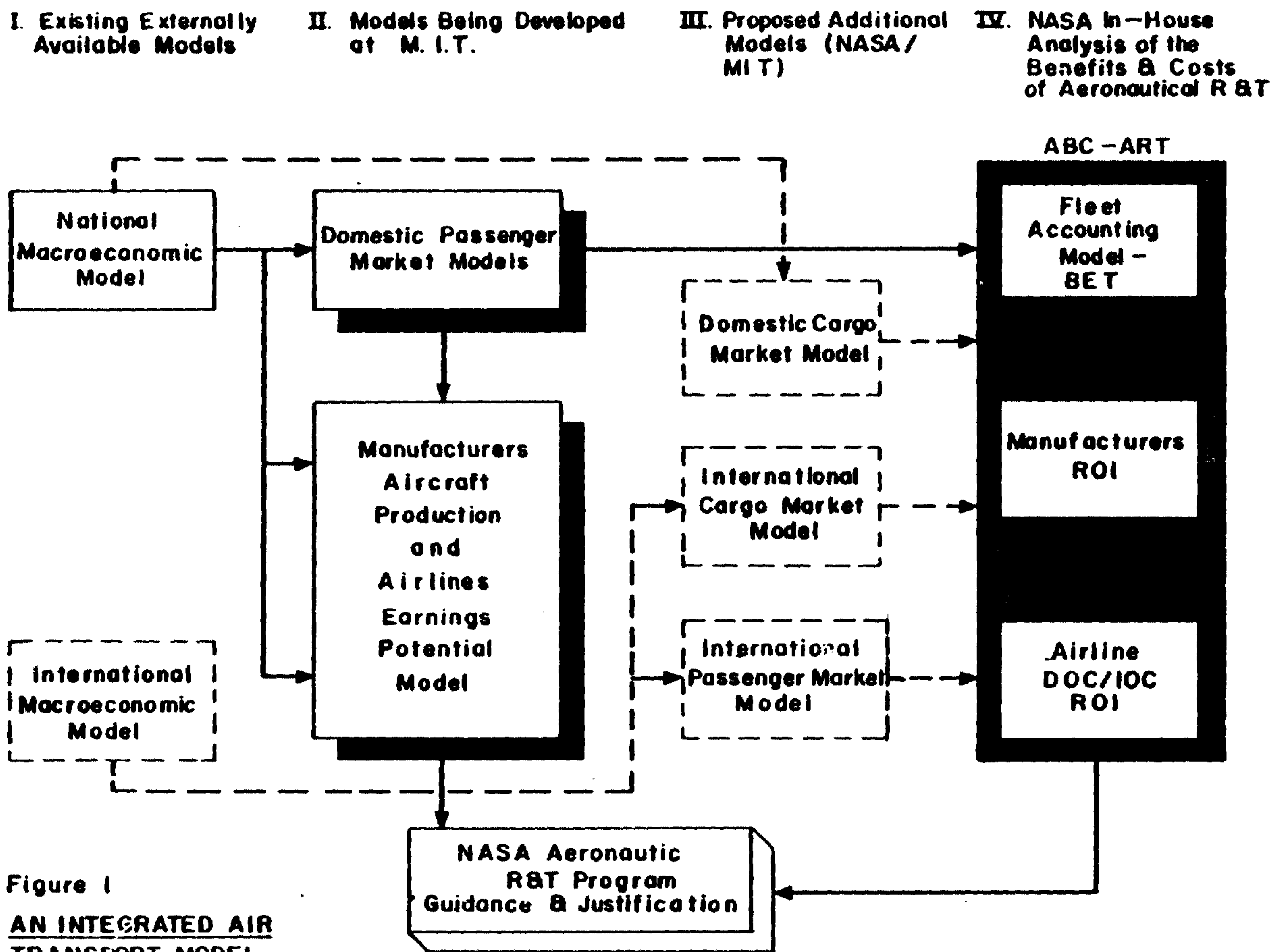

Figure I

AN INTEGRATED AIR TRANSPORT MODEL

A desirable feature of an integrated approach is that the sensitivities of key variables can be determined very clearly. The integrated model allows for the examination of the impact on air transport demand resulting from a change in technology and vice versa. The driving force in the whole integrated air transport modeling process is a national macroeconomic model (domestic). Relatively little effort was devoted to developing this model, except to the extent that a modified version of a commercially available,* large macromodel was considered for future research programs. The model also allows the estimation of the effects on either air transport demand or technology resulting from higher or lower estimates of GNP, population, or inflation. In addition, the model can be used to estimate how high GNP must be for a sufficient growth in passenger demand to occur that would warrant launching a "new" technology aircraft, for adequate airline profitability so that the airlines would purchase it, and for sufficient attraction for the manufacturers to promote and construct it. In summary, the integrated modeling approach should represent the most comprehensive attempt presently available to analyze the appropriate interactions between demand and technological characteristics in the air transport industry.

Nearly all airline passenger demand models in the past have been limited to single-equation specifications, with the result that many of the real world, interactive characteristics of the airline industry could not be adequately captured. Not until the development and implementation of a viable simultaneous and/or sequential equation system model can these more

* The leading prognosticating firms who were contacted include Chase Econometrics Associates, Inc., Data Resources, Inc., and Wharton Economic Forecasting Service, Inc.

comprehensive behavioral features be tested and verified. In fact, with the progress during the first phase of this research program, it became absolutely necessary to use a multi-equation system to measure the interactive impacts between changing technology and the demand for air transportation. Furthermore, the use of a simultaneous equation system approach allowed for the integration of macroeconomic events with both air passenger demand and ultimately the choice of aircraft technology by the airline firms. Such interactions and integrations have been incorporated into the research program and are portrayed in Figure 1. It should be noted that the product of the completed research includes only those models developed in column two of Figure 1. However, these models are considered to be the heart of the total integrated air transport model in that they are designed to reflect the actual behavior of the principal participants in air transport: the firms who operate aircraft and offer a service to the public, the manufacturers who design and build the aircraft, and the passengers who fly in them. While each of these participating groups has special needs and pursues different objectives, our general hypothesis is that there exists among these groups a complex set of interactions that can be modeled in such a way as to more effectively capture the dynamics of air transport economics than has heretofore been possible.

The completed research has focused on domestic passenger operations and thus has not covered cargo or international passenger activities. Since domestic airline operations cannot be totally isolated from international activities and passenger operations cannot be analyzed independent of cargo activities, it is clear that future research should be directed to the interactive inputs from cargo and international operations.

2.2 Model Output and Interrelationships

The structure of the integrated air transport model depicted in Figure 1 is intentionally separated into four columns to distinguish among: (1) existing and externally determined models (to the NASA/MIT research program) that can be used to drive the integrated systems: (2) models developed under the NASA/MIT grant; (3) future models that will be required to continue the research on an optimal path; and finally, (4) subsequent integration with the models of the Ames in-house research program.

Concerning the NASA studies labeled in column four as "Benefits and Costs of Aeronautical R & T", these models consider the benefits that would be derived through the introduction of new technology aircraft into the existing air transport fleet (for example, reduced energy consumption or reduced noise). The aircraft replacement sequence develops a market for the postulated new aircraft over time, and separate models evaluate the improved airline economics that may result and the prospect for the aircraft manufacturer(s) to sell the new aircraft at a price necessary to realize a successful production problem. If the airline economics are not significantly improved with the introduction of the new aircraft, then the market will be reduced and the profit picture of the manufacturer weakened.

These models are driven by an input of projected growth in air transport revenue passenger miles. Hence, the major link with NASA/MIT study program is through the passenger market model which develops passenger demand growth projections for short, medium and long range markets.* Also shown in Figure 1 is a model developed in this research program to address the purchase potential of the airlines and the production potential of the manufacturer. This combined model receives input from the National Macroeconomic Model and from the Market models in Figure 1. Distinction must be made between this model and those in the NASA cost-benefit analysis. In the NASA models, a single or series of new aircraft programs are addressed, and the relative economic merit to both the airline and manufacturer is assessed. In the NASA/MIT model, a broader evaluation of the U.S. airlines and aircraft manufacturers is made, based on the historical growth in air transportation and their own financial status. Recent concern over new aircraft development risk is well documented, and even though many factors might appear promising -- high projected growth, improved seat-mile costs and an apparent large market for the aircraft -- companies (airlines, manufacturers, and their financiers) may be reluctant to undertake a new airplane development because of the risk associated with the introduction of new technology. In some respects, this analysis reflects the bottom line for NASA in this project because, through their aeronautics program, the agency may be in a

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*It should be noted that a feed back loop form the NASA cost-benefit models to the market model is a distinct possibility, if not a requirement, with the prospect of deregulated airline fares. The airline cost model in the NASA model examines airline profitability with an assumed fare structure which could easily be modified. However, fare level is a major factor in the market model and a feedback loop would be necessary to readjust the projected growth.

unique position to reduce the risk of introducing new technology into air transportation.

The following sections of this report summarize the results of each model that provided the initial foundation for this integrated approach. Specifically, these models include: (a) the General Passenger Market Model; (b) the Short Haul Passenger Demand Model for Air Transportation; and (c) the Manufacturers' Model of Aircraft Production and Airlines Earnings Potential. Distinct volumes describing each of these models in detail have been prepared by the MIT research team and are available under separate cover. These volumes are the following:

Volume I -- Analysis of Long and Medium Haul Air Passenger Demand

Volume II -- Analysis of Short Haul Air Passenger Demand

Volume III -- An Economic Model of the Manufacturers Aircraft Production and Airlines Earnings Potential

3. SYNOPSES OF ACCOMPANYING RESEARCH REPORTS (VOLUMES I-III)

3.1 Analysis of Long and Medium Haul Air Passenger Demand (Volume I)

The goal of this model is to identify a set of mathematical relationships which will accurately indicate how the levels of origin-to-destination air passenger traffic between region pairs vary as functions of their determining factors. This set of relationships will not only predict future levels of demand between region pairs, but will also be sufficiently sensitive to measure the impact of decisions upon demand. In particular, the impact of decisions regarding individual causal attributes such as the level-of-service, technology, pricing, and regulatory factors can be assessed.

While most of the published air transportation econometric models are reasonably adequate for forecasting aggregate demand if the transportation system continues in the same direction, they are inadequate for planning and analysis purposes, such as determining the impact of route awards, fare changes, alterations in quality of service, frequency of service, and acquisition of new equipment. Since decisions regarding factors such as these will have different effects on different markets, a truly sensitive model must necessarily be microeconomic rather than macroeconomic. Therefore, a general passenger market model has been calibrated on sets of "region pairs" that are representative of the U.S. domestic system. The concept of "region pairs" rather than "city pairs" has been adopted to appropriately accommodate the fact that a major airport serves a greater surrounding area than merely the home city. Therefore, the included variables are descriptive of regional economics rather than focused on the central urban area.

One of the unique features of this model is its explicit inclusion of a composite proxy to measure level-of-service. Many existing models adopt a frequency variable (for example, number of daily departures) as such a measure. However, frequency alone does not consider the time of day distribution of these departures, nor does it consider the number of intermediate stops and/or connections, the speed of the aircraft, or expected delays due to congestion. A non-dimensional generalized trip time, scaled from zero to one, which accounts for all of these factors is developed and implemented as the level-of-service variable for the analysis of long and medium haul air passenger demand.

The selection of a region pair formulation rather than an aggregate model presents a statistical problem in that a mutual causality between demand and level-of-service exists. Therefore, in a single equation model with demand as the dependent variable, the level-of-service and the residual variable will be correlated, and the ordinary least squares estimation procedure is inappropriate. Furthermore, since the interrelationships between the variables in the air transportation marketplace are very complex, the standard linear or log-linear specifications may likewise be inappropriate. These problems are addressed in the long and medium haul passenger air travel models by specifying a multi-equation nonlinear system which is calibrated using estimation techniques that are substantially more sophisticated than ordinary least squares.

The model is essentially a two equation region pair econometric system in which air passenger demand and airline level-of-service are the endogenous variables. The objective of the model is to identify the causal relationship between each of these two variables and its determining factors, and to also identify the interaction of demand and level-of-service with each other.

The level-of-service is an index scaled from zero (no service offered) to one ("perfect" service). This measure is a function not only of the number of flights or seats that are scheduled in the market, but also whether these flights are direct or connecting, the number of intermediate stops, and how well the departure times match the time-of-day demand fluctuations. Empirical data on the time-of-day distribution is for most markets difficult to find since actual passenger flow is dependent upon imperfect scheduling. However, some markets with very frequent and regular service (such as the Boston-New York shuttle) have provided such data. A procedure for estimating time-of-day distribution of demand for any segment based upon these data and some behavioral assumptions have been developed.

Other explanatory variables included in the two equations are fare, socioeconomic activity, level of competition, and location within the route structure. These variables are defined in Volume I. The models were calibrated over a sample of 180 region pairs for six years between 1969 and 1974 inclusive.

A series of statistical tests was conducted to determine proper aggregation of subsets of the data. As was expected, the tests affirmed that the characteristics of long, medium, and short lengths of haul markets differ sufficiently to warrant separate analyses. Furthermore, within the length of haul strata, market characteristics across market size varied significantly.

Consequently, nine subsets of the total sample, categorized three ways by length of haul and three ways by market size, were analyzed separately.

As shown in Volume I, a series of models has been developed which may be used to forecast future passenger traffic in U.S. domestic air passenger markets. These models are sufficiently policy-sensitive so as to measure the impacts upon market demand due to changes in quality of service, fares, and technological factors. While the general structure of the models is sufficiently simple, the underlying derivations of the components of the model are sufficiently sophisticated so as to capture the important characteristics of this complex industry.

3.2 Analysis of Short Haul Air Passenger Demand (Volume II)

This analysis is designed to forecast short-haul air traffic in domestic markets. Some models like point-to-point time series forecast well but lack analytical powers, due to their inherent dependence on the selected city pair. Other models use extremely sophisticated structures in an attempt to model passenger behavior, but because of a lack of equally sophisticated data, cannot be trusted for forecasting. The models specified in Volume II use a simple structure, and equally simple and reliable data, but also include behavioral concepts normally found only in the more sophisticated specifications. These models therefore can yield both reliable forecasts and analyses on air travel in short-haul markets.

The models described in Volume II use a slightly modified formulation of level of service, since they are intentionally oriented toward short haul travel with service being offered by competing modes. These short haul demand models incorporate components of the level-of-service index within the impedance variable. For example, the level-of-service index includes an average service time which is used directly in the impedance variable which itself is a function of the average service time and the trip cost to the passenger. The short haul models use a single equation, log-linear specification calibrated on several explanatory terms. The first two terms describe city pair gravitational attraction and the service offered by the air mode. This is where most simple forecasting models stop. In our specification, however, intermodal competition and alternate destination attraction terms are included, thereby offering a finer explanation of passenger behavior.

Air impedance is made up of a combination of waiting time, travel time and fare. In turn, waiting time and travel time are combined and used in the computation of level-of-service. The average passenger waiting time decreases with distance for the air mode in short haul markets. The justification of this relationship between average air passenger waiting time and distance draws upon the functional relationships between waiting time and frequency, frequency and demand, and demand and distance for the air mode. An examination of passenger demand for air travel as a function of distance shows that air passenger demand actually increases with distance on the short haul segments. Finally, the models developed to predict demand for short haul air transportation are destination sensitive in that they describe the process by which cities generate and attract passengers. The generation-attraction process draws upon the attraction of the origin and destination cities alone and is combined with the gravitational attraction of the alternate destinations.

The calibration of the models is performed on cross-sectional data to describe differences between cities. The calibration yields a high coefficient of explained variation (R^2), with all of the usual assumptions in least squares regression analysis being validated. Thus, it appears that the models have good forecasting abilities as well as excellent analysis capabilities.

The initial testing of the models has suggested several inferences. First, fare at its present level is insignificant to the short haul air traveler (typically a business traveler), since travel time considerations dominate. Second, other modes must be considered in the short haul market; currently, for short haul, the major competition with commercial air transportation is the automobile. Finally, the model suggests that subsequent extensions could profitably benefit by investigating business and time related effects in more detail.

The outstanding feature of these short haul demand models is that extensions beyond the usual modal split models were investigated so that behavioral properties of the travelers could be included. Another feature of the short haul models is that their specification can be extended to the exclusively commuter markets, especially since the current models include commuter flights within the scheduled trunk short haul markets. Finally, these models are satisfying a vital and conceptual role in explaining more comprehensively the endemic characteristics of short haul air markets -- an area of analysis in which the long and medium haul passenger market models discussed in the previous section intentionally did not encompass.

The research results shown in Part 1 of Volume II have demonstrated successfully that short haul air travel demand models can, from a statistical point of view, successfully incorporate the effects of alternative destinations and modal splits, thereby providing a substantial improvement to gravity models for intercity demand markets. However, the research team felt strongly that the short haul models could be improved significantly by making the specification even more behavioral, that is, incorporating cause and effect logic. With this new goal, one of the previous short haul models was respecified with significant modifications to three components: trip destination, modal split, and trip cost.

The results of this modification are the following. First, the behavioral analysis suggested that it was more appropriate to add the populations of the cities as a proxy for trip consumption as opposed to the product form. Second, the behavioral analysis incorporated a more precise formulation of modal split which depended on the performance of the next best mode to air in terms of speed. Third, the behavioral analysis showed that consumption depended on total perceived cost, that is, the total travel time and the ticket price. Finally, the behavioral analysis suggested that the attractiveness of alternative destinations is proportional to their populations. Thus, the behavioral analysis led to the conclusion that there are four largely independent effects to model: (1) traffic generation for all trips; (2) split of trips to destination; (3) split of trips to the air mode; and (4) consumption versus price.

Part 2 of Volume II contains a mathematical specification of a short haul air travel demand model which contains most of the behavioral requirements described above. This model was calibrated using 1973 data for 33 city pairs. The empirical results appear to be encouraging and the formulation shows a good promise for this model to not only blend gracefully into the long haul but also intraurban air travel models.

The preliminary results from the behavioral model suggest that it is worthwhile to continue the investigation along the same lines. Two advantages of a behavioral formulation are that components of the model can be calibrated from very modest survey data and that any improvement of any component allows more meaningful calibration of all other components, even using the old data. A few specific improvements to the mathematical form of the model are suggested in Part 2 of Volume II.

3.3 An Economic Model of the Aircraft Manufacturers' Production and Airline Earnings Potential (Volume III)

The principal focus of this econometric model is to provide a behavioral explanation of the process of technological change in the U.S. aircraft manufacturing industry. The primary objectives are first, to indicate the key factors that determine aircraft manufacturer decisions on research and development, manufacturing, and promoting new aircraft technology, and second, to denote the main variables that influence commercial airlines in purchasing these aircraft. These factors were determined by examining historical data on the relationships between the manufacturer and airline economic situation, airline fleet composition, aircraft orders, perceived future of the industry, and decisions to launch new aircraft programs.

It is hoped that the results of this model will assist in quantifying the potential for the introduction of a new aircraft embodying advanced technology in the future. This model also encompasses the principal features that determine the choice of aircraft type by the airline purchasers along with the general proclivities of the aircraft manufacturers to produce and deliver new and derivative aircraft over varying periods of time. The model's output is especially valuable in ascertaining the economic and industry requirements for future deliveries, especially in view of recent estimates of the large financial resources to be dedicated to the purchase of new aircraft over the next decade.* These financial requirements are vast primarily because of the anticipated continuation of passenger growth over this period and have become widely noticed in view of recent domestic and foreign competition for new medium-size aircraft to be added to airlines' fleets during the 1980's.

The manufacturers' model is specified in three general interrelated steps: first, a T equation relating an aircraft technology production potential variable to a set of explanatory terms that reflect the purely economic characteristics of the airlines, manufacturers, and other external

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* See Air Transport Association, "The 60 Billion Dollar Question" (September 1976; and Civil Aeronautics Board, "Airline Equipment Needs and Financing Through 1985" (November 1976), pp. 13ff.

factors; second, an equation explaining variations in the airline fleet composition (this second equation is partially an aircraft replacement or retirement model); and third, an equation explaining variations in the earning potential of each trunk airline. Estimates of the dependent variables in the second and third equations are made and then recursively entered into the first equation to provide an overall forecast of the numbers of aircraft types required in the aggregate by each airline.

The second and third equations of the model describe the behavioral factors which influence the timing of the deliveries of new aircraft by the manufacturer to the airline purchaser. These two equations explain variations in the proportion of each airline's fleet accounted for by a newer aircraft type over time and, as such, can represent the potential demand for new aircraft types at given points in time.* This feature of the model can explain a substantial portion of the interfirm variation in each airline's rate of diffusion (that is, why some airlines adopt certain aircraft types more quickly than others).

In view of the substantial financial requirements for new aircraft types during the coming decade, this three-stage model attempts to provide an understanding of the relationship between key economic and technological indicators and manufacturer decisions to launch new aircraft development programs. While full consideration has been given in the model to both the risk and the substantial financing requirements involved in the development and delivery of new aircraft, it must be remembered that the forecasts are

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* No direct allowances are made for the estimates of the markets for new jet transport parts, equipment modifications or special manufacturer adoption programs.

highly aggregative. In order to refine any further application of the model results, special attention must be given to assessing the unique features of derivative aircraft from the perspective of the airlines' requirements in relation to the manufacturer potential for producing and delivering these aircraft.

Given that the production potential of the manufacturers and the earnings potential of the airlines are simultaneously determined, the next step in the integrated air transport model described above is to connect the estimates of the general passenger demand models described in Volumes I and II. This linkage can be accomplished in the future by aggregating the estimates of the region-pair market demand into an overall demand forecast and then by inserting this estimate into the T equation of this manufacturer-airline potential model. For the present analysis, the development of these models hopefully is a major step forward in the understanding and explanation of the significant interactions which occur in the causal nexus among air passenger demand, airline market characteristics, and aircraft manufacturer decisions. While the models should be refined further in future applications (especially in the extension to international passenger markets and to the air cargo arena), it is anticipated that their present results are highly suggestive and useful for a better quantitative understanding of the dynamics of the domestic airline industry.

4. DIRECTIONS FOR FUTURE RESEARCH

Based on the insights and understanding developed during the period of the sponsored research, we wish to offer several directions for future research for the consideration of potential sponsorship. These recommendations are intended to be helpful not only for researchers, but also for practitioners and government agencies whose missions are committed to both the extensions of the frontiers of the field and the practical uses of the research by the companies which comprise the field. Briefly, our recommendations for future research directives are the following:

(1) From the research described in Volumes I and II on air transportation demand models --

- o Research on the performance of these air travel demand models in relation to more aggregate demand forecasting approaches. One of the logical extensions of the present work is to aggregate the region-pair market demand forecasts into an overall national forecast and to corroborate these results with those of the more aggregate models.

- o Additional research on the time/cost tradeoff for air travelers. This research would provide valuable information for the analyses of markets in which two types of services -- one faster and more expensive and one slower and cheaper -- exist. This problem is especially relevant in the analysis of possible domestic supersonic transport service (as observed in Volume I, Section 3.1.5.2.)

o Research on the inclusion of an additional stratification -- a market distinction between business and pleasure trip purposes -- would be very insightful. While the problem is very difficult to analyze at the present time, the need for empirical evidence in this area is compelling.

o Additional research complementing the present studies on more sophisticated short haul air transportation demand models which are sensitive to the relative levels of the attributes of the competing modes.

(2) From the research conducted in Volume III, "An Economic Model of the Manufacturers' Aircraft Production and Airlines Earnings Potential", several directions for future research have arisen:

o Research on the factors influencing aircraft production and airline purchases by specific series of aircraft type. For example, to date, the research could only analyze B-727 aircraft, even though the B-727-200 series is technological and economically different from the B-727-100 series (although both aircraft types are still in most airlines' fleets).

o Extensions of the model to the international and supplemental passenger markets. Although the present genre of models applies only to the domestic fleet, natural extensions to encompass the international carriers should be quite valuable, especially from the perspectives of the aircraft manufacturers'.

- o Applications of the models as cross-checks on the efficiency of the current wave of ordering decisions for new aircraft by United, Eastern, and other carriers.

- o Research on the refinements of national and international macroeconomic models and their impacts on the air transportation demand models and <u>especially</u> on the manufacturer-airline potential model. After all, it is the set of macroeconomic conditions (both domestic and international) which will determine the uses of new aviation technology and airline demand in the future. At minimum, we can increase our understanding of the likely future economic scenarios and their impacts on air transportation demand and aviation technology by encouraging this type of economic research.

While the models developed and tested under the aegis of the NASA sponsorship during the past two years have been inspiring and illuminating to the research team, and hopefully practical and rewarding to subsequent users, substantial additional work needs to be performed in the future. The initial objective of the research grant was to develop demand models for air transportation that are sensitive to the impact of changing technology. We sincerely trust that this objective has been fulfilled. In a larger domain, the ultimate objective is the projection of passenger and cargo traffic growth in the air transport industry. It is anticipated that this larger objective can be expedited and completed through the implementation of the types of models developed and tested in this research project.