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The ASAC Air Carrier Investment Model

(Second Generation)

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SUMMARY

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 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 an 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, data bases, 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 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 second-generation Air Carrier Investment Model that meets these requirements. The enhanced model incorporates econometric results from the

supply and demand curves faced by U.S.-scheduled passenger air carriers. It uses detailed information about their fleets in 1995 to make predictions about future aircraft purchases. It enables analysts with the ability 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.

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 two.

The primary role of the National Aeronautics and Space Administration (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 then 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 second-generation Air Carrier Investment Model, developed by LMI, that meets these requirements.

ECONOMIC AND STATISTICAL DERIVATION OF THE BASIC ASAC AIR CARRIER INVESTMENT MODEL

Introduction

In creating the ASAC Air Carrier Investment Model (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 U.S. passenger air carriers. We could also gauge the financial health of the airline industry as expressed in its operating profit margins.

To create the model, we first identified 85 key U.S. airports from which flights originate; then we developed airport-level demand models for passenger service provided by major air carriers. Furthermore, we linked the air carrier-specific demand schedules to an analysis of the carriers' technologies via their cost functions expressed in terms of the prices of the major inputs—labor, fuel, materials, and flight equipment. Flight equipment was modeled in an especially detailed way by incorporating some key operating characteristics of aircraft.[1]

From the cost functions, we generated derived demand schedules for the factors of production, in particular aircraft fleets. The derived demand schedules are functions of the price of the factor of production, prices of other factors, parameters that describe the aircraft and the network used by a carrier, and the level of passenger service supplied.

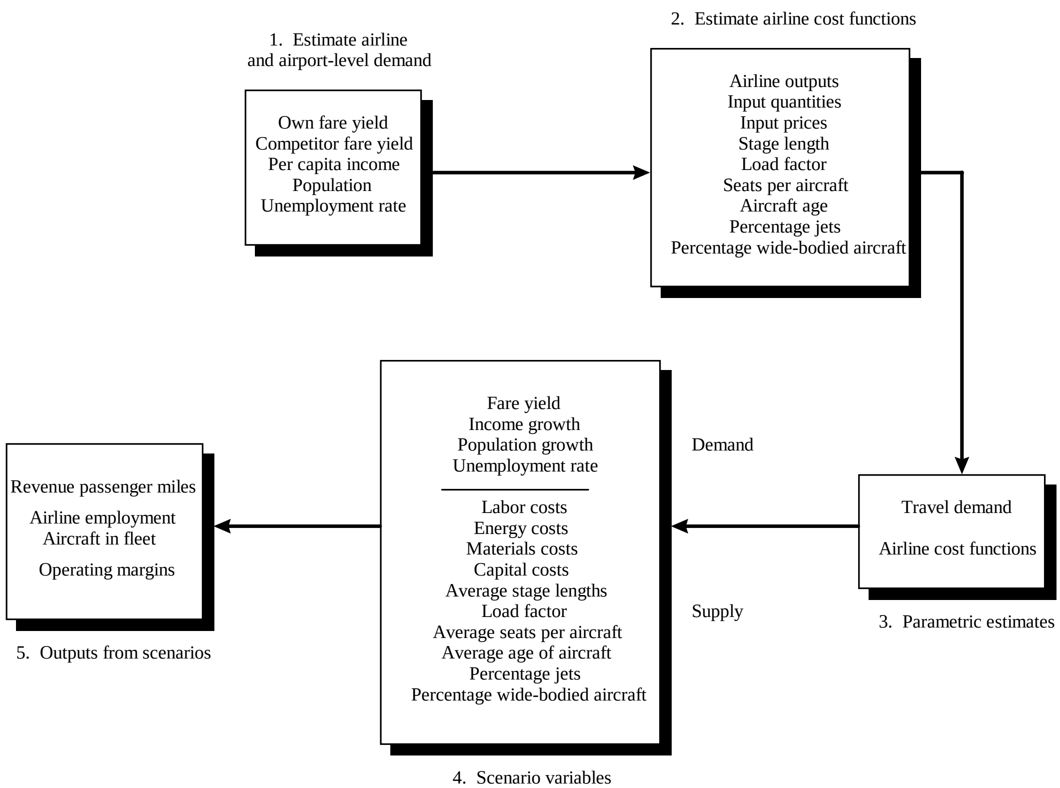
Because it is so capital-intensive, the airline industry must earn an operating profit margin of between 4 and 6 percent if it is going to maintain and expand its aircraft fleet. Accordingly, we added an operating profit margin constraint to the model. When this option is activated, passenger fare yields are adjusted up or down to ensure that the target operating profit margins are met.

[1]Acting under subcontract to LMI, Professor Robin Sickles of Rice University and Professor David Good of Indiana University generated the data sets and performed an econometric study of major U.S. passenger airlines. They were assisted by Anthony Postert, a Ph.D. student at Rice University. See the bibliography for a listing of previously published studies by Sickles and Good.

Overview of the Basic Air Carrier Investment Model

As shown in Figure 1, the basic Air Carrier Investment Model starts with the factors affecting the demand for scheduled passenger air travel at the airline and airport levels. It then examines the determinants of airline cost functions and the resulting industry supply curve. The objective of both analyses is to obtain parametric estimates for the air travel demand and airline cost functions. These parametric estimates can then be combined with user-specified values of key supply and demand variables to generate industry-level forecasts of revenue passenger-miles (RPMs) flown,[2] airline employment, number of aircraft in the fleet, and operating margins under various scenarios.

Figure 1. Schematic of the Basic Air Carrier Investment Model



[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.

Air Travel Demand

Our first analytical task was to develop a model of demand for an airline's passenger service. From a particular airport at origin *i*, carrier *j* will generate a certain level of passenger traffic. The U.S. Department of Transportation's (DOT's) Origin and Destination data record a sample of all tickets; from these, the RPM service originating at a particular airport for a particular carrier was constructed. Demand for a carrier's service is driven by the carrier's passenger fare yield (measured by the average ticket price for flights originating at airport *i* divided by the average number of RPMs flown), its competitors' yields, and the size and economic prosperity of the market. 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 1979 through the last calendar quarter of 1992.

The demand function, in equation form, is

$$q_{t,i,j} = D_{t,i,j}(p_{t,i,j}, p_{t,i,c}, x_{t,i}), \qquad \text{[Eq. 1]}$$

where $q_{t,i,j}$ is the scheduled demand (in RPMs) originating at time *t* from airport *i* for carrier *j*; $p_{t,i,j}$ is the average yield for service originating at time *t* from airport *i* for carrier *j*; and $p_{t,i,c}$ is the average yield for the other carriers generating traffic at time *t* from airport *i*. The $x_{t,i}$ are the other demand characteristics at time *t* for airport *i*. Conventional treatments for firm and airport fixed effects were used. These effects capture those important characteristics of a particular city that are not easily measured, such as tourism effects. We used a log-log specification for Equation 1, so that the regression coefficients may be interpreted as elasticities.

Total demand for an air carrier's passenger service was then constructed by summing the airport-specific demand equations. In terms of Equation 1, the total demand for a carrier's service is given by

$$q_{t,j} = \sum_{i=1}^{ap} q_{t,i,j} \qquad \text{[Eq. 2]}$$

where *ap* is the number of airports (85).

Table 1 shows the demand variables that were incorporated into the model. All of the explanatory variables were found to be statistically significant at the 95 percent level of confidence.[3]

Table 1. Demand Variables

Variable	Name	Coefficient	T-ratio
Own fares	LNAVEOWN	–1.165	–46.00
Competitors' fares	LNAVEOTHER	0.095	1.83
Per capita income	LNPCI	1.334	8.33
Population	LNPOP	1.228	10.64
Unemployment rate	LNUNRATE	–0.121	–4.63

Note: Estimates of firm and airport variables are not reported.

Air Travel Supply

The second major component of our econometric study explains total carrier costs in terms of output quantities, factor prices, aircraft attributes, and network traits.[4] The cost analysis was based mainly on observations from the Department of Transportation (DOT) Form 41 data (discussed in more detail in Appendix A). The cost data follow 17 U.S. passenger air carriers with quarterly observations between the beginning of 1970 and the end of 1994. These firms were the largest U.S. air carriers (or their descendents) that were operating at the time of deregulation. This provides nearly total coverage of scheduled air traffic in 1970, to more than 85 percent of the scheduled passenger air traffic by 1994. From the DOT Form 41 data, we generated a separate set of demand equations for each of the carrier's factors of production based on standard economic assumptions concerning the cost-minimizing behavior of a carrier. In turn, these demand equations permit examinations of the impact of factor price and factor productivity changes, fleet and network configurations, and aircraft operating characteristics.

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[3]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.

[4]Because of some double-counting of labor costs, the supply coefficients published in Wingrove et al., 1996, were wrong and had to be reestimated. Additional years were also included in the data set. The revised values are shown in this report.

Scheduled RPM traffic for carrier *j* at time *t* was constructed as the sum of originating traffic supplied by the carrier for all airports from which it offered flights. This was the first of the two outputs considered in the cost function below. The second was the level of nonscheduled RPM service. The two generic output categories at time *t* for carrier *j* are designated $y_{t,j,1}$ and $y_{t,j,2}$ for scheduled and nonscheduled RPM demand, respectively. The factors of production are labor, energy, materials, and capital. Factor prices are labeled *w*. In the model, capital refers to aircraft fleets only. Capital other than aircraft, such as ground structures and ground equipment, is included in the materials category. Omitting the time and firm subscripts, the transcendental logarithmic (translog) cost function is given by

$$\begin{aligned}\ln C = \alpha_0 + \textstyle\sum_{i=1}^{2} \alpha_i \ln y_i + \sum_{i \le j}^{2} \sum_{j=1}^{2} \alpha_{ij} \ln y_i \ln y_j + \\ \textstyle\sum_{i=1}^{4} \beta_i \ln w_i + \sum_{p \le q}^{4} \sum_{q=1}^{4} \beta_{pq} \ln w_p \ln w_q + \\ \textstyle\sum_{i=1}^{4} \rho_i \ \textit{aircraft attributes}_i \ln w_{capital} + \sum_{i=1}^{2} \lambda_i \ \textit{network traits}_i\end{aligned} \qquad \text{[Eq. 3]}$$

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

$$M_i = \beta_i + \sum_{j=1}^{4} \beta_{ij} \ \ln w_j \qquad \text{[Eq. 4]}$$

The cost share for capital is

$$M_{capital} = \beta_{capital} + \sum_{j=1}^{4} \beta_{capital,j} \ \ln w_j + \sum_{j=1}^{4} \rho_j \ \textit{aircraft attributes}_j \qquad \text{[Eq. 5]}$$

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

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

Summary statistics based on the translog cost equation and its associated share equations are provided by the Morishima and Allen-Uzawa substitution elasticities.[5] Several measures of returns to scale can also be obtained from the parameter estimates.

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.

In an engineering sense, transportation industries tend to be characterized by increasing returns to equipment size. 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 (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 has accentuated this liability by virtually eliminating monopolies in domestic high-density air travel markets. On the other hand, deregulation has increased 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.

Two attributes of the carrier's network are also included in the model: 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 de-

[5]The Morishima and Allen-Uzawa substitution elasticities are measures of the degree to which the various factors of production may substitute for one another, holding factor prices and the level of production constant.

mand 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. Inflight service levels also decline since the number of flight attendants is not generally adjusted upward as the passenger load factor increases.

Estimates of the long-run cost function and summary statistics for various elasticities are provided in Table 2.

Table 2. Supply Variables

Variable	Name	Coefficient	T-ratio
Labor price	LNLP	0.376	N/A
Labor price squared	LNLP^2	– 0.017	– 1.06
Labor × energy	LNLPEP	– 0.011	– 2.43
Labor × materials	LNLPMP	0.047	3.60
Labor × capital	LNLPKP	– 0.019	– 2.84
Energy price	LNEP	0.206	N/A
Energy price squared	LNEP^2	0.119	35.63
Energy × materials	LNEPMP	– 0.106	– 30.60
Energy × capital	LNEPKP	– 0.002	– 0.91
Materials price	LNMP	0.297	N/A
Materials price squared	LNMP^2	0.099	7.91
Materials × capital	LNMPKP	– 0.039	– 6.73
Capital price	LNKP	0.121	N/A
Capital price squared	LNKP^2	0.060	12.13
Scheduled demand	LNSQ	0.844	62.62
Scheduled demand squared	LNSQ^2	– 0.090	– 2.88
Nonscheduled demand	LNNQ	0.098	7.99
Nonscheduled demand squared	LNNQ^2	– 0.122	– 2.76
Scheduled × nonscheduled demand	LNSQNQ	0.150	3.96
Stage length	LNSL	– 0.216	– 9.54
Load factor	LNLF	– 0.818	– 20.85
Average seats	XLNAS	0.027	5.08
Average age	XLNAA	– 0.009	– 1.59
Percentage jets[a]	XXPJ	0.002	1.61
Percentage wide-bodied aircraft[a]	XXPWB	– 0.020	– 12.36

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

USING THE MODEL

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 econometric results 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 economic forecasts 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 airline operating costs on the basis of forecasted RPM growth, changes in input prices, and changes in aircraft and network characteristics. We predict the aircraft inventory from airline operating costs, the capital share equation, and hypothesized changes in aircraft price and aircraft size. We follow a similar procedure to estimate airline employment. Finally, we compare forecasts from the second-generation ASAC Air Carrier Investment Model with predicted changes in RPMs, aircraft fleet, and operating margins from other published forecasts.

Forecasting Changes in Travel Demand, Airline Costs, and Aircraft Fleets

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

$$\%\Delta\, RPM = \sum_{i=1}^{5} \beta_i \,\%\Delta\, X_i \qquad \text{[Eq. 6]}$$

where the β_i are the coefficients estimated from the econometric model and the X_i are the explanatory variables. Due to the logarithmic structure of the statistical model, the coefficients are interpreted as elasticities. For example, the coefficient of 1.334 on per capita income means that a 1 percent increase in per capita income raises the demand for air travel by 1.334 percent.

The annual percentage change in per capita income, population, and unemployment are parameters entered by the user. The baseline model uses estimates of population growth published by the Bureau of Labor Statistics. Per capita income growth is not directly input into the model. Instead, the user provides estimates of 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. User-defined rates of change in fare yields can be input directly into the model, and their effects will be estimated immediately. The second mode of operation, as described later in the report, enables the user to set a series of profit rate constraints for each of the four, 5-year intervals in the forecast period. The user then instructs the model to vary the fare yields until the profit rate constraints are met.

The econometric estimates of the demand function are based on quarterly traffic volume for each airline and airport 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 U.S. scheduled passenger airlines as the starting point, and grow demand at the rate indicated by Equation 6. This imposes the constraint that output grows at the same rate for each airline. While obviously inaccurate, this is not a significant bias in the model since our goal at this time is to forecast industry-wide demand, costs, employment, and aircraft fleets. For long-run forecasts such as those generated by the model, it is immaterial whether the aggregate demand for air travel is satisfied by a particular carrier such as United Airlines or Delta Airlines.

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 model predicts that a 10 percent reduction in fares will increase RPMs by 10.7 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.

AIRLINE COSTS

Equation 3 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 2, Equation 3 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.

$$\%\Delta TC = \sum_{i=1}^{2} \alpha_i \; \%\Delta y_i + \sum_{i \le j}^{2} \alpha_{ij} \; \%\Delta y_i \; \%\Delta y_j + \sum_{i=1}^{4} \beta_i \; \%\Delta w_i \; + \sum_{p \le q}^{4} \sum_{q=1}^{4} \beta_{pq} \; \%\Delta w_p \; \%\Delta w_q + \sum_{i=1}^{4} \rho_i \; \%\Delta \, aircraft\ attributes_i \; \%\Delta w_{aircraft} + \sum_{i=1}^{2} \lambda_i \; \%\Delta \, network\ traits_i \quad \text{[Eq. 7]}$$

where $\%\Delta$ means annual percentage change in the variable.

In Equation 7*, 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 the 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 increases the costs at the rates predicted by the model, given output forecasts, factor cost changes, and changes in aircraft and network characteristics.

AIRCRAFT FLEETS

Estimating the aircraft fleet required to meet the forecasted 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 forecasted change in average aircraft price, and
- the forecasted change in average aircraft size.

Changes in total airline costs were discussed in the previous section. Referring to Equation 5, 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

$$\Delta\ Aircraft\ Cost\ Share = \beta_{aircraft} + \sum_{i=1}^{4} \beta_{aircraft,j} \%\Delta w_j + \sum_{j=1}^{4} \rho_j \%\Delta aircraft\ attributes_j \quad \text{[Eq. 8]}$$

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 are divided into the aircraft investment to get the estimated number of planes in each airline's fleet. In equation form, the formula is

$$number\ of\ aircraft = \frac{(capital\ share \times total\ \cos t)}{(aircraft\ price \times average\ size)} \quad \text{[Eq. 9]}$$

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

FACTOR PRODUCTIVITIES

Once time-series have been generated for RPMs, number of airline workers, and number of planes in the fleet, it is possible to estimate factor productivities for labor and capital. In the baseline scenario, labor productivity increases from 1.25 million RPMs per worker in 1995 to 1.47 million RPMs per worker in 2015. Similarly, capital productivity increases from 132 million RPMs per plane in 1995 to 184 million RPMs per plane in 2015. We make use of these year-by-year baseline factor productivities when alternative scenarios are evaluated. Specifically, except where NASA technologies explicitly impact them, we assume that although other changes in supply and demand variables will impact the airlines' cost equations, factor productivities will not change.

ENHANCEMENTS TO THE BASIC MODEL

Converting Technical Impacts into Economic Effects

In the second generation ACIM, we model the impacts of NASA technologies in the following manner: We first assume that NASA technologies begin to enter the fleet in 2005 and all new aircraft purchased during the period 2006 to 2015 will incorporate the new technology. Additionally, we assume that 5 percent of the existing fleet will be replaced or upgraded annually to take advantage of the new technology. If travel demand grows at a compound annual rate of 5 percent during the period 2005 to 2015 and all the other assumptions hold, approximately 69.3 percent of the RPMs flown in 2015 will be in aircraft that incorporate the new technology. This figure defines the baseline penetration rate for the new technology and can be varied by the user.

Translating the technical impacts of the new technology into economic effects is similarly straightforward. The first step is to estimate the gross impact of the technology in terms of eight functional cost categories. These categories are: flight personnel costs, aircraft fuel, maintenance costs, other variable operating costs, fixed operating costs, flight equipment price, flight equipment productivity, and other capital costs. Gross changes in these functional cost categories are multiplied by the penetration rate and then converted into compound annual rates of change for the 10-year period 2006 to 2015.

Because the ACIM uses four factors of production in the airline cost function, it is necessary to convert the compound annual rates of change in the eight functional cost categories into comparable changes in labor, energy, materials, and capital. The approach we used to create this cross-matrix is described in more detail in Appendix B. The principal relationships are shown in Table 3.

Table 3. Functional Cost Categories versus Factors of Production

Cost Category	Production factors				
	Labor (%)	Energy (%)	Materials (%)	Capital (%)	Totals (%)
Flight personnel	13.8				13.8
A/C fuel		18.4			18.4
Maintenance	4.1		4.2		8.3
Other variable operating costs	11.6		13.9		25.6
Fixed operating costs	5.8		13.4		19.3
Flight equipment				12.7	12.7
Other capital			2.0		2.0
Totals	35.3	18.4	33.5	12.7	100.0
From supply variable estimates	37.6	20.6	29.7	12.1	100.0

We made a simplifying assumption about the way in which we model the impact of NASA technologies. In cases of labor, energy, and materials, gross changes in the functional cost categories are modeled as changes, both positive and negative as necessary, in the factor productivities. The rationale is that NASA technologies are unlikely to change the prices for these factors of production. For capital, we separate the price and productivity effects because some NASA technologies may impact the price of airframes and/or aircraft engines.

Disaggregating the Economic Effects

The next step is to map the high-level estimates from the basic ACIM into a finer level of detail. This enables an appraisal of to whom the economic benefits of investment in new aircraft technology accrue. This appraisal is accomplished by a set of analytical modules that are dynamically linked to the basic ACIM. We refer to these modules as the ACIM Extensions. The Extensions estimate

- the retirement schedule for the 1995 fleet;
- the replacement costs for aircraft retired due to the old age from the current fleet;
- the number, schedule, and costs of Stage 2 aircraft that are replaced prior to their expected retirement date due to noise regulations (rather than hushkitted);

- the seat-size categories for the new Stage 3 aircraft added to meet RPM growth;

- the market shares for the new Stage 3 aircraft added to meet replacement demand and RPM growth; and

- the workyears of employment at airframe manufacturers resulting from the sales of U.S.-manufactured aircraft to U.S. carriers.

The end result is that any change in aircraft or aviation technology can be translated to benefits accruing to any or all of the following three parties:

- the flying public, in the form of lower ticket prices and/or expanded service;

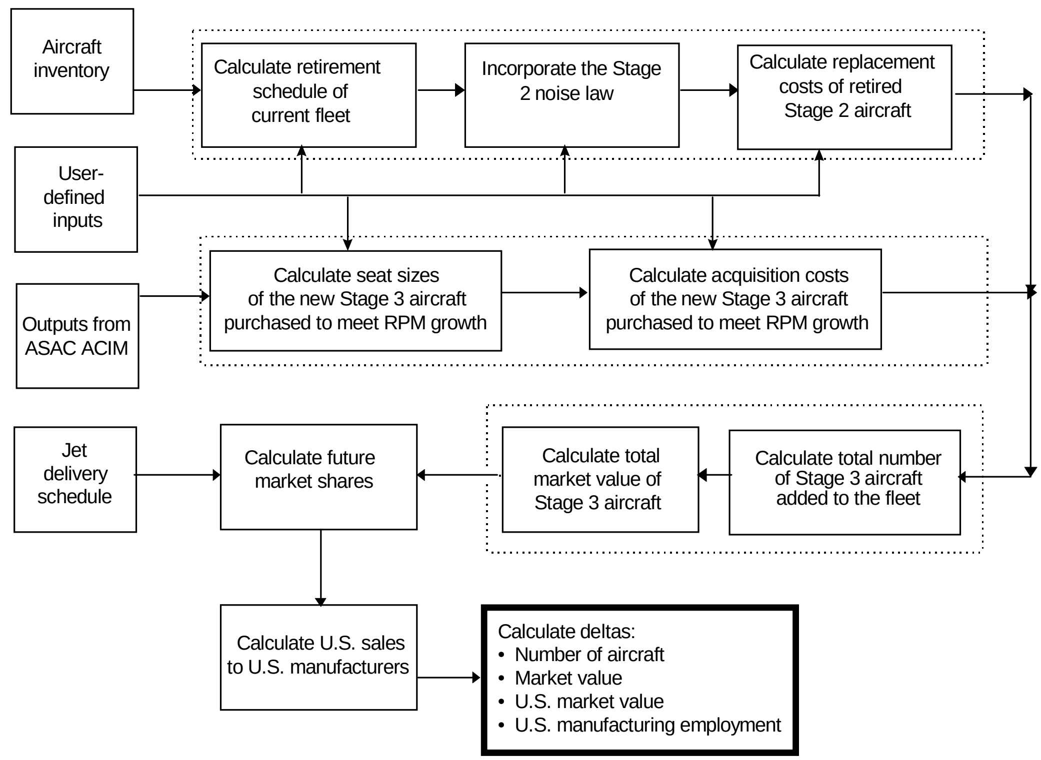
- U.S. aircraft manufacturers, in the form of increased volume of aircraft produced; and

- U.S. passenger air carriers, in the form of jobs and increased traffic.

This implies that alternative technological investment strategies can be evaluated according to the magnitude of the benefits produced and/or the distribution of those benefits.

Figure 2 shows a schematic of the ACIM Extensions. The model starts with various outputs from the basic ACIM. Also used are 2 databases—the aircraft inventory database and the historical jet delivery database—and a set of user-defined specifications or scenarios. There are two tracks of analysis: the first, a steady-state or static type of analysis, whose results include the effects of new technology but are independent from it, and the second, a dynamic analysis whose results are dependent upon the effects of new technology. The results of these two analyses then are combined to estimate national economic effects.

Figure 2. Schematic of the ACIM Extensions



The static track performs the replacement analysis of the current fleet. This analysis is static in the sense that replacement purchases are somewhat unresponsive to the introduction of new technology. This unresponsiveness is a function of the huge capital costs of acquiring an aircraft as well as financial losses associated with prematurely retiring an aircraft. Consequently, the introduction of new technology into the existing fleet occurs primarily because new aircraft are used as replacements for retired aircraft. New technology only marginally affects the actual retirement schedule in that some premature retirements will occur among aircraft that are already near the end of their useful lives.

The static analysis consists of three steps: estimation of the retirement schedule of the current fleet, adjustments to that schedule due to noise regulations, and calculation of the replacement costs for retired aircraft.

The dynamic analysis performs an analysis of the additional aircraft purchased to meet future RPM growth. An estimate of the number of additional aircraft purchased in any given year is an output of the basic ACIM. The dynamic analysis decomposes that aggregate number into a distribution of additional aircraft purchased per seat-size category. Then the acquisition costs of those aircraft are estimated.

The total number of new aircraft purchased, as well as their total market value, is then found by summing the results of the static and dynamic tracks. Market share data are used to project the portion of sales to U.S. owned carriers by U.S. airframe manufacturers. Finally, employment effects are estimated.

As a last step, differences in aircraft produced, their corresponding market values, the U.S. portion of those sales, and resulting employment levels may be compared across scenarios. Details of the step-by-step analysis are shown in Appendix C.

SCENARIOS AND FORECASTS

Operating Profit Margins and Fare Yields

An early version of our model predicted increasing profitability for the airline industry during the forecast years. This was clearly unreasonable for the highly competitive airline industry. To make the model reflect actual industry conditions more faithfully, three important characteristics of the industry were incorporated into the model:

- competition among airlines that keeps operating profits at realistic levels,
- links between airline costs and fare yields, and
- interdependency between fares and profitability.

Our model accommodates these features with a straightforward extension. It builds an industry-wide target profit rate into the model. To meet the target profit rate, the model adjusts fare yields until the target is met. This approach incorporates the impact of competition into the forecast and enables the degree of competition to be set directly through the target margins. By choosing an appropriate profit rate, the user can also ensure that adequate capital is available to finance the purchase or lease of the aircraft needed to satisfy the growing demand for air travel.

As implemented in the model, separate target profit rates can be set for each of the four, 5-year intervals within the forecast period. Specifying four distinct periods permits the user to include changes in the economic environment during the forecast period. For example, many financial analysts today claim that airlines will not purchase additional aircraft until their balance sheets are "repaired." One way to implement this concept is to set a higher profit margin during the first 5-year interval and then reset the target at a lower, historically reasonable level. Such a scenario will keep fares and profits at a higher level for 5 years, while reducing the derived demand for aircraft and other inputs.

The model does not impose the margin constraint in every single year. Instead, the model iterates changes in fare yield until the target margin in the final year of each interval is satisfied. Since the model uses a constant rate of fare change within each 5-year interval, the operating margin does not equal the target until the final year of the period. In practice, the profit margin moves in equal increments within the interval. If the target margins are the same at the beginning and end of the 5-year interval, the margin will be the same in each year.

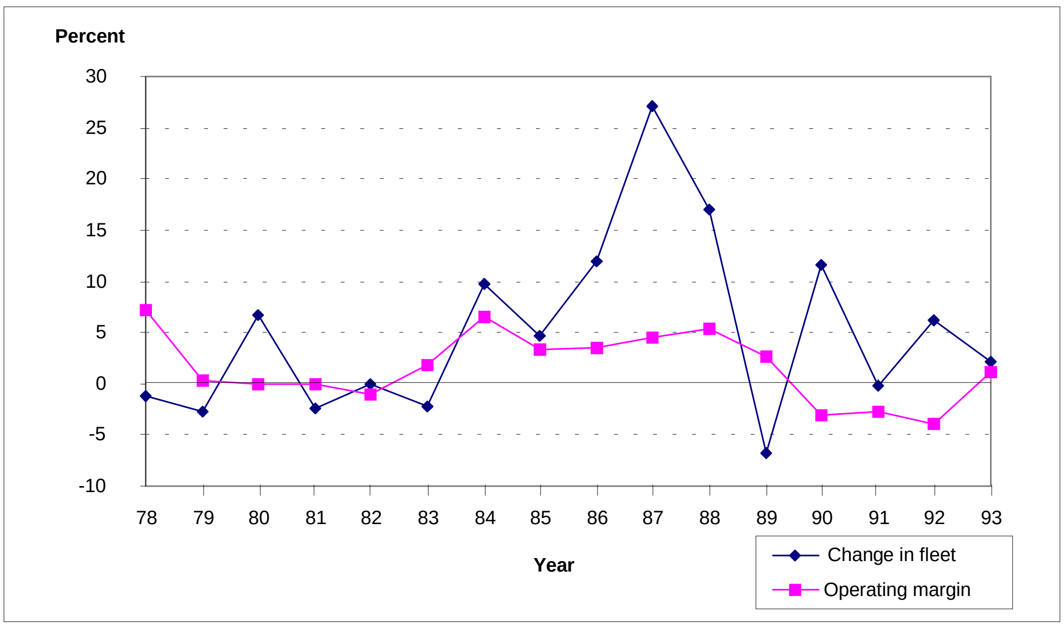
This approach explicitly lets fare changes be set by the degree of competition and the level of costs throughout the industry. It allows for a market-based mechanism for translating cost changes into profits and fare changes. One implication of this approach is that cost-reducing technologies will primarily benefit the traveling public and not result in higher profits for the airlines over the long run. While some airlines may benefit for a short while, competition will eventually drive fares down as most airlines adopt the cost-reducing technology.

This analysis is consistent with economic theory and also appears to be an accurate description of the airline industry. The relatively low profit margins reported by the airline industry demonstrate the speed with which innovations and new technologies diffuse throughout the industry. The ease of entry for new airlines with access to cheap older aircraft keeps profit margins low, and it is unlikely that this situation will change in the near future.

Several alternative profit measures could be used to implement this approach in our model. We chose to use the operating profit margin, which is revenues minus operating costs, divided by revenues. The operating margin does not reflect interest paid on debts or a return to common shareholders, both important elements of cost in a capital-intensive industry such as the airlines. Capital expenses vary significantly from airline to airline, and in particular, will be strongly affected by whether the airline flies new or old aircraft.

An equally important question is what target operating margin should be used in the model. Boeing states that an operating profit margin of about 5 percent is probably required for the airline industry to remain healthy enough to meet increasing travel demands and purchase new aircraft. An examination of the historical data tends to confirm this conclusion. Figure 3 shows operating margins and the percentage change in aircraft fleets for nine major air carriers (American, Continental, Delta, Eastern, Northwest, Trans World, United, USAir, and Southwest) from 1978 through 1993. While there is clearly a great amount of variability in the year-to-year numbers, the years of greatest and most consistent growth in fleets was the mid-1980s. This was also the only extended period of profitability for the industry during these years. While the change in aircraft fleets may be somewhat skewed because of the effect of mergers over this time, the numbers clearly demonstrate a strong correlation between profitability and aircraft inventories. The results are reinforced when one considers that new aircraft deliveries in the early 1990s were frequently from orders placed much earlier. The chart demonstrates clearly the importance of incorporating a limit on airline profits in the investment model.

Figure 3. Operating Profit Margins and Aircraft Fleet Growth for Nine Major Airlines



Baseline Scenario

Using the baseline values specified in Appendix D for the supply and demand variables, the second-generation ASAC Air Carrier Investment Model projects annual growth in travel demand of 4.56 percent for the period of 1995 through 2005. This prediction compares quite favorably with annual growth forecasts of

4.74 percent and 4.36 percent from the Boeing Company (Boeing) and the Federal Aviation Administration (FAA), respectively. In terms of the number of aircraft required to satisfy this growth in travel demand, the second-generation ACIM projects annual growth in the U.S. scheduled passenger airline fleet of 2.63 percent for the period of 1995 through 2005. This prediction is lower than Boeing's forecast of a 3.20 percent annual growth and the FAA's forecast of a 3.05 percent annual growth. The 121 to 170 seat class is projected to have the greatest number of aircraft, while the 171 to 240 seat class is expected to experience the largest growth in percentage terms. Other details for the baseline scenario are found in Appendix D.

Other Scenarios: Comparisons

To demonstrate the reasonableness and utility of our model, we evaluated a set of alternative scenarios that correspond to the effects that various NASA AST program elements might have. These are summarized in Table 4. Details of the technology evaluations and illustrative printouts from the ASAC Air Carrier Investment Model are in Appendix E.

Table 4. Baseline and Other Scenario Forecasts

Technology	Gross changes for affected variables (%)	Compound annual rates of change in travel demand (2005-2015) (%)	Compound annual rates of change in airline employment (2005-2015) (%)	Compound annual rates of change in aircraft fleet (2005-2015) (%)
Baseline	N/A	4.17	3.42	2.53
A	A/C fuel = -5	4.23	3.47	2.58
B	A/C fuel = -14 A/C price = +2	4.31	3.56	2.67
C	Flight crew = -4 A/C fuel = -4 Maintenance = -4 A/C productivity = +4	4.31	3.41	2.38

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 second-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. scheduled passenger air carriers. It uses detailed information about their fleets in 1995 to make predictions about future aircraft purchases. It 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, and changes in aircraft manufacturing employment under various user-defined scenarios. Future work will extend the analysis to other regions of the world, most notably Europe and Asia.

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Appendix A
Airline Production Data Description

INTRODUCTION

The airline production data set includes four inputs: labor; energy; flight capital; and a residual category called materials that includes supplies, outside services, and nonflight capital. The data set also includes two outputs: scheduled and non-scheduled revenue passenger-miles—and two network traits: stage length and load factor. Flight capital is described by four aircraft attributes: the average size (measured in seats); the average age; and the separate proportions of aircraft in the fleet that are jet-powered or wide-bodied designs.

Our most comprehensive data set includes information for the 17 largest U.S. air carriers that were operating at the time of deregulation or their descendant airlines. The carriers included are American, Braniff International, Continental, Delta, Eastern, Frontier, North Central, Northwest, Ozark, Piedmont, Republic, Southern, Texas International, Trans World, United, USAir, and Western. This provides nearly total coverage of scheduled air traffic in 1970, the beginning of the data, to more than 85 percent of the scheduled passenger air traffic by 1994, the data set's end. This information is quarterly, air carrier-specific information and results in 1,137 total observations. Attention was restricted to the traditional certificated carriers because routine data reporting was well-established for them at the time of deregulation. New entrants can be added to our data set with some difficulty. However, it should be remembered that these carriers have little experience in providing the often burdensome reporting required by Department of Transportation (DOT) Form 41 and that noncompliance results in virtually no sanctions. Consequently, new entrant data tends to be of significantly lower quality. The version of the data described in more detail below provides the largest, cleanest data available on the production of U.S.-scheduled passenger air transport.

The procedure used in constructing the data set has changed considerably over the last decade. As more and more data sources become available, it will change further. One of the most significant factors in these changes has been an adaptation to the changes in the reporting requirements of DOT Form 41. In order to maintain comparability over time, data from all versions of Form 41 must be mapped into a single version. The latest significant revision, which occurred in 1987, eliminated many of the specific functional accounts that were used previously. The most significant changes occurred in the areas of labor, supplies, and outside services. This latest version of Form 41 data is the most restrictive in that it provides the least detail in most cases. In other instances, the 1985 revision of Form 41 data is somewhat more restrictive. However, many of these changes were in place for only a short period of time. Where the 1985 restrictions were most severe, 1987-equivalent accounts were estimated. This occurred most seriously in the area of ground-based capital, where lease payments and capitalized leases had to be allocated between flight and ground capital. In other cases, it seemed reasonable to estimate 1985 accounts from the 1987 data provided. The objective was to maintain as much detail as possible in all areas of air carrier production.

The construction of the individual input and output categories is described in the next several sections. In cases where price and quantity pairs for a specific input or output are constructed, several subcomponents to that input or output are first constructed. Then these are aggregated into a single input or output using a multilateral Tornqvist-Theil index number procedure.[1] The result of this procedure is a price index (much like the consumer price index) that aggregates price information for commodities having disparate physical units. When total expenditures of the input or output category are divided by this price index, an implicit quantity index is produced.

Labor, energy, materials, flight capital, and output are discussed in the sections below.

LABOR

The labor input was composed of 93 separate labor accounts aggregated into five major employment classes (flight deck crew, flight attendants, mechanics, passenger/cargo/aircraft handlers, and other personnel). This is shown in Table A-1. We do not attempt to correct for differing utilization rates since we do not have information on the number of hours worked by the labor inputs. Expenditures in

[1]This mathematical technique derives indexes from underlying utility, cost, production, revenue, profit, or transformation functions. In this case, the transcendental logarithmic (translog) cost function is underlying; expenditure shares are used to weight each subcomponent's contribution to the overall index number. For a detailed explanation, refer to Diewert (1976); Caves, Christensen, and Diewert (1982); and Good, Nadiri, and Sickles (1992) in the Bibliography.

these five subcomponents are constructed from the expenditure data in DOT Form 41 Schedules P5, P6, P7, and P8.

Following the 1987 modification in Form 41, Schedules P7 and P8 were dramatically simplified, eliminating many separate expense accounts. "Mechanics" and "handlers" appear as lines 5 and 6 of the new Schedule P6. In order to be more compatible with the new Schedule 6, trainees and instructors were moved into the "other personnel" category. "Flight attendant" expense was calculated by subtracting accounts 5123 and 5124 from Schedule P5 from line 4 ("total flight personnel") on the new Schedule P6.

Other labor-related expenses—such as personnel expenses, insurance, pension, and payroll taxes—were included as labor expenses. The labor-related expenses, accounts, and schedules from which they were obtained are listed in Table A-2.

Table A-1. Labor Costs

Schedule	Accounts	Subcomponent
P5	5123+5124	Flight deck crew
P6	5524	Flight attendants
P5 and P6	5225.1+5225.2+5225.3+5225.9+5325.9+ 5328.1+5328.2	Mechanics
P7 and P8	6126.1+6126.2+6128.1+6226.1+6226.3+ 6228.1+6326.1+6328.1+6526.1+6526.3+ 6526.4+6528.1+6628.1+6828.1	Passenger/cargo/aircraft handlers
P6, P7, and P8	5330+5331+5334+5335+5530+5531+5535+ 6130+6131+6135+6230+6231+6235+6330+ 6331+6335+6530+6531+6533+6535+6630+ 6631+6635+6830+6831+6832+6834+6835+ 5128.1+5528.1	Other personnel

Table A-2. Labor-Related Expenses

Schedule	Accounts	Subcomponent
P5, P6, P7, and P8	5136+5336+5536+6136+6236+6336+6536+ 6636+6836	Personnel expenses
P5, P6, P7, and P8	5157+5357+5557+6157+6257+6357+6557+ 6657+6857	Insurance and pension
P5, P6, P7, and P8	5168+5368+5568+6168+6268+6368+6568+ 6668+6868	Payroll taxes

Since labor-related expenses are provided on functional lines rather than on an employment class basis, they were allocated to each of the five employment groups on the basis of the expenditure share of that class. After the 1987 Form 41 changes, these three expenditure categories were provided on Schedule P6 as lines 10, 11, and 12, respectively.

The accounts and schedules from the DOT Form 41, from which the carrier employment quantity data were obtained, are shown in Table A-3.

Table A-3. Labor Head Counts

Schedule	Accounts	Subcomponent
P10	5123+5124	Flight deck crew
P10	5524	Flight attendants
P10	25	Mechanics
P10	6126.1+6226.1+6326.1+6526.1+6126.2+ 6226.3+6526.3+6226.4+6526.4+7100	Passenger/cargo/aircraft handlers
P10	99 minus accounts above	Other personnel
P1A	—	Full-time employees
P1A	—	Part-time employees

The quarterly total head count of full-time equivalent personnel was found by averaging the monthly full-time personnel plus one-half of the part-time employees over the relevant quarter.

In 1977, Schedule P10 was changed from a quarterly to an annual filing cycle. This meant that allocations of head counts into specific employment categories could not be done directly except for the fourth quarter of each calendar year. Instead, the distribution of head counts among the five labor groups was interpolated using the annual figures. The estimated head count in each group was found by multiplying the interpolated percentage by the calculated full-time equivalent headcount for that quarter. In 1983, Schedule P10 was simplified. This simplification collapsed the handlers category into a smaller number of separate accounts, but did not change the overall structure of our procedure.

Using the expense and head count information from above, the expense per person quarter and the number of person quarters were calculated. The multilateral Tornqvist-Theil price and quantity indices for the labor input were then derived.

ENERGY

The objective of the energy input category is to capture aircraft fuel only. Fuel that is used for ground operations and electricity are both captured in the materials index. The energy input was developed by combining information on aircraft fuel gallons used with fuel expense data per period. The schedules and accounts are listed in Table A-4.

Table A-4.

Schedule	Accounts	Subcomponent
P5	5145.1	Aircraft fuel (cost in dollars)
T2	Z921	Aircraft fuel (gallons)

This input has undergone virtually no change because these accounts remained substantially unchanged over the 23-year span of our data set. Even though only one component exists, the multilateral Tornqvist-Theil index number procedure is used to provide normalization of the data.

MATERIALS

The materials input is comprised of 69 separate expenditure accounts aggregated into 12 broad classes of materials or other inputs that did not fit into the labor, energy, or flight capital categories. Carrier-specific price or quantity deflators for these expenditure groups were unavailable. Instead, industry-wide price deflators were obtained from a variety of sources. These price deflators were normalized to 1.0 in the third quarter of 1972. The classification of these expenditure accounts are presented in Table A-5 along with the corresponding source for the price deflator.

In 1987, the modifications of Schedules P6 and P7 led to the elimination of hundreds of separate account categories. In most cases, this did not affect the ability to reconstruct the categories. The sources of information did change, however. Advertising expense, passenger food, and landing fees appear as line 22, line 6, and line 12 of the new Schedule P7, respectively. Expenses for aircraft maintenance materials, communications, insurance, outside services and outside maintenance, and passenger and cargo commissions appear as line 17, line 23, line 24, line 25 + line 28, and line 26 + line 27 of the new Schedule P6. Ground equipment rental expense was line 31 of Schedule P6 minus account 5147 from Schedule P5. Amounts for other supplies and utilities appear aggregated together as line 19 of new Schedule P6. These amounts were apportioned to the supplies and utilities categories using the carrier's average proportion in these groups over the 1981 through 1986 periods. Ground equipment that is owned was unaffected by the 1987 accounting changes.

FLIGHT CAPITAL

The number of aircraft that a carrier operated for each different model of aircraft in the airline's fleet was collected from DOT Form 41, Schedule T2 (account Z820). Data on the technological characteristics for the approximately 60 types of aircraft in significant use over the period 1970 through 1992 were collected from *Jane's All the World's Aircraft* (1945 through 1982 editions).

First, for each quarter, the average number of aircraft in service was constructed by dividing the total number of aircraft days for all aircraft types by the number of days in the quarter. This provides a gross measure of the size of the fleet (number of aircraft).

In order to adjust this measure of flight capital, we also construct the average equipment size. This was measured with the highest density single-class seating configuration listed in *Jane's* for each aircraft type. The fleetwide average was weighted by the number of aircraft of each type assigned into service. In some cases, particularly with wide-bodied jets, the actual number of seats was substantially less than described by this configuration because of the use of first-class and business-class seating Our purpose was to describe the physical size of the aircraft rather than how carriers chose to use or configure them.

We use the average number of months since the Federal Aviation Administration's type-certification of aircraft designs as our measure of fleet vintage. Our assumption is that the technological innovation in an aircraft does not change after the design is type-certified. Consequently, our measure of technological age does not fully capture the deterioration in capital and increased maintenance costs caused by use. Our measure does capture retrofitting older designs with major innovations, if these innovations were significant enough to require recertification of the type.

Finally, it is clear that the major innovation that took place during the 1960s and 1970s was the conversion to jet aircraft. While many carriers had largely adopted this innovation prior to the study period, it was by no means universal. Many of the local service airlines used turboprop aircraft as a significant portion of their fleets. We implement this aspect by measuring the proportion of aircraft in the fleet that are jet powered. The proportion of wide-bodied aircraft was also calculated.

Table A-5. Materials

Schedule	Accounts	Price index	Classification
P5	5246.1+5246.2+5246.3+ 5243.1+5243.2+5243.3	Producer prices: metals and metal products	Aircraft maintenance materials
P8	6660+6662	McCann Erickson Advertising Index	Advertising
P6, P7, P8	5337+5537+6137+6237+ 6337+6537+6637+6837	Consumer prices: telephone services	Communications
P5, P6	5155.1+5355.1+6855.1+ 6256.0+5556.0	Industry average expense per aircraft mile flown	Insurance
P6, P7, P8	5243.9+5343.9+5543.9+ 6143.9+6243.9+6343.9+ 6543.9+6643.9+6843.9	Gross National Product deflator for services	Outside services and aircraft maintenance
P6, P7, P8	5350+5550+6150+6250+ 6350+6550+6650+6850+ 5353+5553+6153+6253+ 6353+6553+6653+6853+ 5354+5554	Producer prices: total manufacturing nondurables	Supplies
P6, P7, P8	5338+5538+6138+6238+ 6338+6538+6638+6838	Consumer prices: electric, gas (89%), and sanitary service (11%)	Utilities
P6	5551	Producer prices: processed foods	Passenger food
P8	6539.1+6539.2	Consumer prices: air fares	Commissions
P6, P7, P8	5347+5547+6147+6247+ 6347+6547+6647+6847	GNP deflator for nonresidential fixed investment	Ground equipment, rented
B1, P6, P7	(See note below)	Jorgensen-Hall user price	Ground equipment, owned
P7	6144	Landing fees per capacity-ton landed	Landing fees

Note: Total expenditures associated with ground equipment and structures were calculated using a perpetual inventory method with a 1958 benchmark, assuming a 20-year expected life, straight-line depreciation, and interest rates assuming a Moody's BAA bond rating. The tax advantages, including investment tax credits (along with the special transition rules under the 1986 tax revisions) relevant at the time were also incorporated into the carrier's expenditure on ground capital owned. As with the labor index, a multilateral Tornqvist-Theil index number procedure was used to generate price quantity combinations for each carrier at each quarter over the 23-year span of the data.

Output

Our data set provides several measures of airline output and its associated characteristics. The most commonly used measure of carrier output is the revenue ton-mile. Our data set provides this measure as well as measures of revenue output that are disaggregated into scheduled and nonscheduled output. Nonscheduled output includes cargo and charter operations. We further provide measures of airline capacity. This again can be disaggregated into scheduled and nonscheduled operations. Revenue and traffic data were available from DOT Form 41. These data enabled us to construct price and quantity figures for seven different outputs produced by the typical airline. These different services and the accounts from which the revenue data were obtained are given in Table A-6. Again, the price per unit (passenger-mile or ton-mile) of the relevant service was constructed by dividing the revenue generated in the category by the physical amount of output in that category. These prices were normalized to 1.0 in the baseline period (the third quarter of 1972).

In cases where a carrier offered only one type of service (the convention was to call this "first class"), the service was redefined to be coach class. The reporting of revenue and traffic in charter operations between cargo and passenger service was very sporadic. These two outputs were combined into a single category with passenger-miles converted to ton-miles, assuming an average weight of 200 pounds per passenger (including baggage). Changes in DOT Form 41 in 1985 led to the elimination of the distinction between express cargo and air freight. Consequently, these two categories also were collapsed.

Table A-6. Carrier Revenues and Output Quantities

Schedule	Accounts	Type of service
P3	3901.1	First class passenger revenue
T1	K141	First class passenger-miles
P3	3901.2	Coach passenger revenue
T1	K142	Coach passenger-miles
P3	3905	Mail transportation revenue
T1	Z243+Z244+Z245	Mail ton-miles
P3	3906.1	Express cargo revenue
T1	K246	Express cargo ton-miles
P3	3906.2	Air freight revenue
T1	K247	Air freight ton-miles
P3	3907.1	Charter passenger revenue
T1	V140	Charter passenger-miles
P3	3907.2	Charter cargo revenue
T1	V246+V247	Charter cargo ton-miles

Three different price and quantity index pairs are generated. The first is total revenue-output and uses the multilateral Tornqvist-Theil index number procedure on all of the revenue-output categories. The second uses the Tornqvist-Theil index number procedure on the two passenger categories. The third results from the use of the index number procedure on mail, cargo, and charter services.

The capacity of flight operations is also provided in our data set. This describes the total amount of traffic generated, regardless of whether or not it was sold. While it is possible to distinguish between an unsold coach seat and an unsold first-class seat (they are of different sizes), such distinctions are not logically possible in the case of cargo operations (mail and cargo could be carried in the same location). Consequently, our measure of airline capacity includes only three broad categories: first-class seat-miles flown, coach seat-miles flown, and nonscheduled ton-miles flown. The accounts and schedules from Form 41 are shown in Table A-7.

Table A-7. Capacity Measures

Schedule	Accounts	Type of service
T1	K321	First-class seat-miles
T1	K322	Coach seat-miles
T1	Z280 – (K321+K322)/10	Nonscheduled ton-miles

With the change to T100 as the primary data base for airline traffic in 1990, carriers are no longer required to report available seat-miles, revenue seat-miles, or revenues by the level of passenger service. Instead, these amounts are aggregated with revenues supplied as account 3901 on Schedule P1 after 1990.

Again, the convention that a passenger along with baggage is 200 pounds (one-tenth of a ton) is used to construct the nonscheduled ton-miles. Potential revenues that could be collected, if all services were sold, are constructed assuming that the prices for each of these categories remain the same as for output actually sold. In other words, the price for first-class revenue passenger-miles flown is imputed to first-class available seat-miles flown. Again, the Tornqvist-Theil index number procedure is used to generate price and quantity pairs for total capacity output, passenger capacity output, and nonscheduled capacity output.

Two important measures of the carrier's network are also generated. The first is a passenger load factor. This is found by dividing revenue passenger-miles by available seat-miles (i.e., [K141+K142]/[K321+K322]). This measure is generally related to flight frequency with a lower number indicating more frequent flights and consequently a higher level of service. Other definitions of load factor are possible, such as dividing the total passenger revenue collected (3901.1+3901.2) by the total that would be collected were the planes flown full (derived from the passenger capacity output times passenger capacity price). If desired, these can easily be constructed using information in the data set. Stage length also provides an important measure of carrier output. Generally, the shorter the flight, the higher the proportion of ground services required per passenger-mile and the more circuitous the flight (a higher proportion of aircraft miles flown is needed to accommodate the needs of air traffic control). This generally results in a higher cost per mile for short flights than for longer flights. Average stage length is found by dividing total revenue aircraft miles flown (Z410) by total revenue aircraft departures (Z510).

Appendix B
Converting Technical Impacts into Economic Effects

The basic Air Carrier Investment Model uses a supply function that incorporates four factors of production: labor, energy, materials, and capital. To translate the likely effects of NASA-developed technologies (which are usually thought of in terms of reduced block times, less fuel burned, lower maintenance costs, etc.) into appropriate reductions in the costs of these four factors of production, we had to create a matrix of functional cost categories versus factors of production.

Because we were interested in fully accounting for airline operating costs, we used Department of Transportation Schedule P-6 (*Operating Expenses by Objective Groupings*). This report is only filed by Group II and III air carriers. See Table B-1 for the elements of the various lines of this schedule.

Table B-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 cells is shown in Table B-2.

Table B-2. Derivation of Matrix (Reference Lines From Schedule P-6)

Category	Labor	Energy	Materials	Capital
Flight personnel	4*	—	—	—
Aircraft fuel		16	—	—
Maintenance	5*	—	17+25	—
Other variable operating costs	6*	—	18+26+27+30	—
Fixed operating costs	(3+7)*	—	19+22+23+24+28+ 34+35	—
Flight equipment	—	—	—	13.6% times flight equipment
Other capital	—	—	13.6% times ground property and equipment	—

* = plus an allocated share of lines 10, 11, and 12.

We collected Schedule P-6 data for 10 years (1980, 1982, 1983, 1985, 1987, 1988, 1990, 1992, 1993, and 1995) for 12 carriers (American, Braniff, Continental, Delta, Eastern, Northwest, Ozark, Piedmont, Republic, Trans World, United, and USAir). The choice of years and airlines were made to be as consistent as possible with the econometric study of airline costs performed by Sickles and Good (described in the main body of the report).

The two cells labeled "flight equipment" and "other capital" deserve separate explanation. We generated a time series for the estimated economic value of a carrier's aircraft fleet as follows. A key driver was the number of aircraft days. We divided this figure by 365.25 to derive the average number of aircraft in a carrier's fleet for the year. This estimate therefore includes both owned and leased aircraft. If the average number of aircraft increased from one year to the next, the difference was multiplied by the industry-wide average cost of new aircraft shipped in that year. This figure represented the value of new aircraft in a carrier's fleet. The value of old aircraft in a carrier's fleet was depreciated by 3.33 percent per year (which implicitly assumes an economically useful lifetime of 30 years). For years in which the average number of aircraft decreased from one year to the next, the depreciated value of the old aircraft was scaled by the ratio of the latest year's number of aircraft compared with the prior year's number to account for retirements. The time series for the value of ground property and equipment was pulled directly from Form 41 balance sheet data (element 1649.0 without any accumulated depreciation).

In any given year, the economic value of aircraft was multiplied by the sum of air carriers' weighted average cost of capital (separately estimated at 10.3 percent) plus depreciation of 3.3 percent to estimate the return to flight equipment capital. Similarly, the value of ground property and equipment was also multiplied by 13.6 percent to estimate the return to other capital. Because we used this procedure to separately estimate the cost of airline capital, no use was made of lines 31 to 33 of the P-6 Schedule.

For the 10 years and 12 carriers, we collected the Schedule P-06 cost data and estimated the returns to capital as described above. The average cost shares are as shown in Table B-3. In comparing our shares with those implicit in the ASAC Air Carrier Investment Model, there is a high degree of agreement.

Table B-3. Mean Cost Shares

Category	Labor (%)	Energy (%)	Materials (%)	Capital (%)	Totals (%)
Flight personnel	13.8	—	—	—	13.8
Aircraft fuel	—	18.4	—	—	18.4
Maintenance	4.1	—	4.2	—	8.3
Other variable operating costs	11.6	—	13.9	—	25.6
Fixed operating costs	5.8	—	13.4	—	19.3
Flight equipment	—	—	—	12.7	12.7
Other capital	—	—	2.0	—	2.0
Totals	35.3	18.4	33.5	12.7	100.0
From supply variable estimates	37.6	20.6	29.7	12.1	100.0

As shown in Table B-4, there was some variability in these cost shares. Energy was particularly volatile, declining from a high share of 28.9 percent in 1980 to a low share of 11.6 percent in 1995. The materials subcategory of other variable operating costs had its low share of 9.5 percent in 1980 and its high share of 17.8 percent in 1993.

Table B-4. Standard Deviations of Cost Shares

Category	Labor (%)	Energy (%)	Materials (%)	Capital (%)	Totals (%)
Flight personnel	0.8	—	—	—	0.8
Aircraft fuel	—	6.1	—	—	6.1
Maintenance	0.2	—	0.8		0.8
Other variable operating costs	0.8	—	2.7		2.1
Fixed operating costs	0.3	—	1.9		1.8
Flight equipment	—	—		1.7	1.7
Other capital	—	—	0.2		0.2
Totals	1.4	6.1	5.1	1.7	0.0

Appendix C

Derivation of the Air Carrier Investment Model Extensions

The goal of the ACIM Extensions is to translate the high-level estimates from the basic ACIM into a finer level of detail. This appendix gives a detailed explanation of how this is done.

INPUT STRUCTURE

There are four sets of input streams needed to run the ACIM Extensions. They are

1. a subset of the output stream from the basic ACIM;
2. an aircraft inventory database that describes the 1995 fleet;
3. a matrix of market shares that was estimated from historic aircraft sales data; and
4. a set of user-defined inputs that describe/specify a scenario.

Each of the four sets of inputs are described in a section below.

INPUT #1, ASAC OUTPUT STREAM

The basic ACIM generates supply and demand estimates in the form of time-series for revenue passenger miles, airline employment, number of aircraft in the fleet, and operating profit margins. A sample of the aircraft fleet time-series is shown in Table C.1.

Table C-1. Aircraft Fleet Time-Series

Year	Baseline number of aircraft
1995	4,179
1996	4,279
1997	4,419
1998	4,545
1999	4,676
2000	4,812
2001	4,932
2002	5,055
2003	5,183
2004	5,315
2005	5,451
2006	5,587
2007	5,727
2008	5,872
2009	6,021
2010	6,175
2011	6,329
2012	6,488
2013	6,652
2014	6,821
2015	6,995

The time-series of number of aircraft in the fleet of the U.S. scheduled passenger carriers can be used to estimate the number of new aircraft purchased in any year to meet RPM growth; this is given by

$$\text{aircraft purchased to meet RPM growth}_t = \text{aircraft in fleet}_t - \text{aircraft in fleet}_{t-1}.$$

INPUT #2, AIRCRAFT INVENTORY

The DOT Schedule B-43 Airframe Inventory for 1995 was used to estimate the initial distribution of aircraft by seat-size category and the expected retirement schedule of the fleet. The first 15 lines of B-43 data for American Airlines are shown in Table C.2. LMI added noise stage data to the aircraft inventory data-base.

Table C-2. Extract from B-43 Data

Owned/ lease/capital lease	Carrier code	A/C manufacturer	A/C type	Tail number	Year of first delivery	Serial number	A/C type numeric code	Number of seats as specified by carrier
CL	AA	BOE	B-727-2	N701AA	81	22459	715	150
CL	AA	BOE	B-727-2	N702AA	81	22460	715	150
CL	AA	BOE	B-727-2	N703AA	81	22461	715	150
CL	AA	BOE	B-727-2	N705AA	81	22462	715	150
CL	AA	BOE	B-727-2	N890AA	80	22006	715	150
CL	AA	BOE	B-727-2	N891AA	80	22007	715	150
CL	AA	BOE	B-727-2	N892AA	80	22008	715	150
CL	AA	BOE	B-727-2	N893AA	80	22009	715	150
CL	AA	BOE	B-727-2	N894AA	80	22010	715	150
CL	AA	BOE	B-727-2	N895AA	80	22011	715	150
CL	AA	BOE	B-727-2	N896AA	80	22012	715	150
CL	AA	BOE	B-727-2	N897AA	80	22013	715	150
CL	AA	BOE	B-727-2	N898AA	80	22014	715	150
CL	AA	BOE	B-727-2	N899AA	80	22015	715	150
CL	AA	BOE	B-757	N634AA	90	24592	622	194
CL	AA	BOE	B-757	N635AA	90	24593	622	194

INPUT #3, MARKET SHARE DATA

The estimation of market shares begins with historic jet airplane deliveries to U.S. customers. This set of data contains the name of the manufacturer and type of every jet delivered to U.S. customers from 1966 to 1995. The data first are split into the eight seat-size categories. For each category, a regression is run to predict the market share by firm. The firm-level market shares are then summed to produce market shares by manufacturing country. Then, a set of category-by-category corrections are made. In the largest seat class (>350 seats) and the 171 to 240 seat class, only U.S.-based manufacturers have delivered these types of jets to U.S. customers. Airbus has delivered similar size jets to non-U.S. customers and it also has undelivered orders to U.S. customers. To correct the regression results for these two categories, it is assumed that manufacturers take 10 years to attain a first sale in a new market. After that, the firm gets an exponential growth rate based on capturing 12 percent of the market after another 10 years. The regression results for the other seat-size categories were corrected by using an exponential smoothing algorithm that incorporates a time- and number-weighted moving average of the previous 10 years' sales. This correction generates future market share estimates that consistently lie between exponentially smoothed, continuous, and bounded long-run market share estimates.

INPUT #4, USER-DEFINED INPUTS

The last set of inputs are user-defined variables that enable analysts to further define or refine a scenario, perform sensitivity analysis over a small subset of variables, or perform simple what-if types of analyses. The variables are initially set to a baseline value, but users may enter alternative values. The user-defined inputs are easily classified into one of the following categories:

- Retirement age data
- Aircraft cost data
- Interest rate data
- Other data.

The retirement age data specify the ages at which aircraft are nominally retired. Retirement age rules vary in two dimensions: the year in which the retirement rules are changed and narrow-body versus wide-body aircraft.

The baseline aircraft cost figures were derived from the *Boeing 1995 Current Market Outlook*. These data specify the acquisition costs of new aircraft by seat-size category.

The interest rate data specify the real interest rate in terms of its two components, the nominal interest rate (or airline cost of capital) and the rate of price increase. The actual values of both components are subject to debate and a variety of values can be used and justified. Therefore, it is advisable to determine the sensitivity of any solution to these parameters.

The other data represent a set of varied single inputs. The year of noise law enforcement enables users to explicitly examine the effects of changing the year in which Stage 2 aircraft may no longer operate in the United States. The figure for aircraft shipments per airframe manufacturing worker allows for varying these workers' productivity. The user-defined inputs are shown in Table C-3.

Table C-3. User-Defined Inputs

Data description	Baseline value
Entry in service year for incorporation of newer retirement rules for passenger aircraft	1980
Average age at which narrow body aircraft are retired prior to incorporation of new rules	25
Average age at which narrow body aircraft are retired after incorporation of new rules	28
Average age at which wide body aircraft are retired prior to incorporation of new rules	28
Average age at which wide body aircraft are retired after incorporation of new rules	31
Acquisition cost of a new aircraft by number of seats:	
>350	$160,000,000
241-350	$116,700,000
171-240	$58,000,000
121-170	$44,000,000
91-120	$28,000,000
70-90	$22,000,000
50-69	$19,400,000
Under 50	$14,800,000
Nominal interest rate or airline cost of capital	10.3%
Nominal rate of price increase	3.0%
Year by which 100 percent of the fleet must be Stage 3	2000
Aircraft shipments per airframe manufacturing worker	$122,700

STATIC ANALYSIS

The static analysis performs the replacement analysis of the current fleet. Starting with the aircraft inventory database, an expected retirement year is assigned to each aircraft by the user-defined age rules. The number of aircraft retired per year is found by summing all the retirements that are expected to occur in a particular year. This represents the minimal replacement schedule (new aircraft added to replace those retiring due to old age).

The first retirement schedule estimated is for Stage 3 passenger aircraft. The second retirement schedule estimated is for Stage 2 passenger aircraft. Stage 2 passenger aircraft are further analyzed with respect to noise regulations. The Stage 3 noise law forces all Stage 2 aircraft from the fleet by its year of implementation. A break-even calculation is performed to determine which of the Stage 2 planes subject to early retirement should be hushkitted and which should be immediately replaced. The Stage 2 passenger aircraft retirement schedule is then modified to include this effect.

These two retirement schedules are combined to generate the baseline retirement schedule for the fleet. Our assumption is that aircraft retired due to old age are replaced with Stage 3 aircraft of the same seat-size category. For each year, the baseline retirement schedule of the fleet is multiplied by the acquisition cost of a new passenger aircraft of that seat size.

Since this analysis is based on the 1995 year-end inventory, it will only need to be redone if the following inputs are changed:

- Retirement ages or rules
- Year of the noise law incorporation
- Acquisition cost of an aircraft by seat size
- Either of the two components of the real interest rate.

Dynamic Analysis

The dynamic analysis allocates the aircraft purchased to meet future RPM growth over the eight seat-size categories by the following method. We first take the time-series of the number of planes in the fleet from the basic ACIM and calculate the yearly differences of this time series. These differences are the aircraft added to meet RPM growth.

We use the growth rate in seats per aircraft from the user inputs to create a time series starting with the average seats figure estimated from the aircraft inventory database.

We estimate the average-seats figure for the new aircraft by the following formula:

(Average seats per aircraft$_t$ * Total aircraft$_t$ - (Average seats per aircraft$_{t-1}$ * Total aircraft$_{t-1}$ * (1+ growth rate in the stage length))/Aircraft added$_t$

Fifty percent of the aircraft added to meet RPM growth are allocated to the seat-size category in which the average-seats figure falls. The remaining aircraft added to meet RPM growth are distributed across all eight seat-size categories according to the 1995 distribution schedule. The resulting composition of the fleet is tracked at the seat-size category level, year by year.

NEW AIRCRAFT SUMMARY

Once both the number and costs of the replacement passenger aircraft and the new growth passenger aircraft are known, they are summed to produce the total number of Stage 3 aircraft added to the fleet and its corresponding market value.

U.S. SALES TO U.S. AIR CARRIERS

The U.S. sales calculation is an estimate of the portion of new aircraft sales that accrue to U.S. airframe manufacturers. For each year, the total market value of the Stage 3 aircraft by seat-size category is multiplied by the corresponding U.S. market share. When summed over a year, this gives the sales of U.S.-manufactured aircraft to U.S. passenger air carriers in a particular year.

U.S. MANUFACTURING EMPLOYMENT

The additional U.S. airframe manufacturing employment resulting from the sales of new Stage 3 aircraft is estimated in the summary section. The average sales per worker is a user input. Work years of employment generated are found by dividing the U.S. sales in each seat-size category by the average sales per airframe manufacturing worker, summed across all seat classes.

SUMMARY CALCULATIONS

The summary calculations present the key data in terms of differences between the baseline scenario and the user-defined scenario, which is usually characterized as the introduction of a new technology. The relevant data are the differences across the baseline and user-defined scenarios for

- the number, by seat-size category, of Stage 3 aircraft purchased;
- the total market value of Stage 3 aircraft purchased;
- the U.S. share of Stage 3 aircraft purchased;
- the market value of the U.S.-manufactured Stage 3 aircraft; and

- the airframe manufacturing employment arising from the U.S.-manufactured Stage 3.

Appendix D
Baseline Scenario

Default Values

Table D-1 shows the default values for the annual changes (from 1995 through 2015) of the key variables in the ASAC Air Carrier Investment Model.

Table D-1. Default Values

Variable	Boeing[a] (%)	Federal Aviation Administration[b] (%)	LMI (%)
Change in fare yield	–1.10	–1.18	–1.07
Income growth	2.40	2.62	2.51
Population growth	—	—	0.94
Change in unemployment rate	—	—	0.00
Labor price change	0.00	—	0.00
Labor productivity effect	1.60	—	1.60
Fuel cost change	–1.60 (reflects 0.9% increase in fuel price minus 2.5% increase in fuel efficiency)	—	–1.60
Materials cost change	—	—	0.00
Capital price change	0.00	0.00	0.00
Capital productivity effect	0.40 (reflects more miles flown per year per aircraft)	0.52 (reflects more airborne hours per year per aircraft)	0.46
Change in stage length	—	0.38	0.38
Change in load factor	0.30	0.10	0.20
Change in average seats per aircraft	0.60	0.80	0.70
Change in average age of aircraft	—	—	0.74
Change in proportion of jet aircraft	—	—	0.00
Change in proportion of wide-bodied aircraft	—	0.002275	0.002275

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

[a]The Boeing figures are an amalgamation of forecasts from the 1993 through 1996 editions of the *Current Market Outlook*. If forecasts from multiple years were available, preference was given to the latest edition. Additionally, preference was given to U.S.-specific forecasts; otherwise, worldwide forecasts were substituted.

[b]The FAA figures were derived from *FAA Aviation Forecasts: 1996-2007*. The FAA focuses exclusively on U.S. carriers.

FORECASTED VALUES

When the consensus figures are inserted into the ASAC Air Carrier Investment Model, the values of future travel and aircraft requirements, shown in Table D-2, are predicted for the period 1995 through 2005. These forecasts may be compared with those from Boeing and the FAA.

Table D-2. Forecasted Values

Variable	Boeing[a]	FAA[b]	LMI
Revenue passenger-mile (RPM) growth	4.74%	4.36%	4.50%
Absolute RPMs (billions) in 2005	888.5	834.1	855.6
Growth in number of aircraft	3.20%	3.05%	2.69%
Absolute number of aircraft in 2005[c]	5,332	5,537	5,451

Note: The Boeing, FAA, and LIM figures for number of aircraft in the 1995 fleet were 3,890; 4,100; and 4,179 respectively.

[a]The Boeing figures are an amalgamation of forecasts from the 1993 through 1996 editions of the *Current Market Outlook*. If forecasts from multiple years were available, preference was given to the latest edition. Additionally, preference was given to U.S.-specific forecasts; otherwise, worldwide forecasts were substituted.

[b]The FAA figures were derived from *FAA Aviation Forecasts: 1996-2007*. The FAA focuses exclusively on U.S. carriers.

[c]Cargo aircraft are excluded.

Table D-3 shows the projected distribution of aircraft in 2005 by seat size category.

Table D-3. Projected Distribution of Aircraft by Seat Size in 2005

Seat size	Under 50	50-69	70-90	91-120	121-170	171-240	241-350	Over 350	Total
Number of aircraft	612	115	97	846	2,484	810	349	138	5,451

Appendix E

Details of Alternative Scenarios

TECHNOLOGY A

Technology A is hypothesized to reduce the weight of key components of the airframe. As a consequence, block fuel is reduced for the average flight by five percent. Assuming a penetration rate of 69.3 percent by the year 2015, this improvement is modeled as a 0.35 percent compound annual reduction in fuel costs during the period 2006 to 2015. When the target operating margin constraints are binding at five percent, the reduced airline operating costs are passed along to the traveling public as fare reductions. Consequently, an additional 34.1 billion revenue passenger miles are flown, airline employment increases by nearly 24,000 work-years, and the number of aircraft in the fleet increases by 37. The estimated total value of these aircraft is $1.9 billion (in 1995 dollars) and the U.S. market share is projected at 76 percent. This is expected to generate 11,968 work-years of employment at U.S. airframe manufacturers.

Table E-1. RPM Growth for Technology A

Year	Baseline Total RPM (billions)	Revised Total RPM (billions)
1995	550.7	550.7
1996	576.6	576.6
1997	603.8	603.8
1998	632.3	632.3
1999	662.1	662.1
2000	693.3	693.3
2001	723.1	723.1
2002	754.1	754.1
2003	786.6	786.6
2004	820.4	820.4
2005	855.6	855.6
2006	891.7	892.2
2007	929.2	930.3
2008	968.4	970.0
2009	1,009.2	1,011.5
2010	1,051.7	1,054.7
2011	1,095.2	1,098.8
2012	1,140.5	1,144.8
2013	1,187.6	1,192.7
2014	1,236.7	1,242.6
2015	1,287.8	1,294.6
Growth Rate	4.34%	4.37%
Gross Change		34.1

Table E-2. Airline Employment for Technology A

Year	Baseline Employment	Revised Employment
1995	438,983	438,983
1996	455,299	455,299
1997	472,316	472,316
1998	490,068	490,068
1999	508,590	508,590
2000	527,917	527,917
2001	545,799	545,799
2002	564,383	564,383
2003	583,700	583,700
2004	603,780	603,780
2005	624,659	624,659
2006	645,810	646,173
2007	667,787	668,539
2008	690,626	691,794
2009	714,365	715,975
2010	739,041	741,124
2011	764,055	766,580
2012	790,041	793,036
2013	817,042	820,537
2014	845,101	849,126
2015	874,262	878,852
Growth Rate	3.50%	3.53%
Gross Change		23,608

Table E-3. Fleet Size for Technology A

Year	Baseline Number of Aircraft	Revised Number of Aircraft
1995	4,179	4,179
1996	4,297	4,297
1997	4,419	4,419
1998	4,545	4,545
1999	4,676	4,676
2000	4,812	4,812
2001	4,932	4,932
2002	5,055	5,055
2003	5,183	5,183
2004	5,315	5,315
2005	5,451	5,451
2006	5,587	5,590
2007	5,727	5,734
2008	5,872	5,882
2009	6,021	6,035
2010	6,175	6,193
2011	6,329	6,350
2012	6,488	6,513
2013	6,652	6,680
2014	6,821	6,853
2015	6,995	7,032
Growth Rate	2.61%	2.64%
Gross Change		37

TECHNOLOGY B

Technology B is hypothesized as an improvement in jet propulsion technology. As a consequence, block fuel is reduced for the average flight by 14 percent, but the price of the airframe/engine combination increases by 2 percent. Assuming a penetration rate of 69.3 percent by the year 2015, these changes are modeled as a 1.02 percent compound annual reduction in fuel costs and a 0.14 percent compound annual increase in capital price during the period 2006 to 2015. When the target operating margin constraints are binding at 5 percent, the reduced airline operating costs are passed along to the traveling public as fare reductions. Consequently, an additional 86.8 billion revenue passenger miles are flown, airline employment increases by over 60,000 work-years, and the number of aircraft in the fleet increases by 93. The estimated total value of these aircraft is $4.9 billion (in 1995 dollars) and the U.S. market share is projected at 76 percent. This is expected to generate 30,231 work-years of employment at U.S. airframe manufacturers.

Table E-4. RPM Growth for Technology B

Year	Baseline Total RPM (billions)	Revised Total RPM (billions)
1995	550.7	550.7
1996	576.6	576.6
1997	603.8	603.8
1998	632.3	632.3
1999	662.1	662.1
2000	693.3	693.3
2001	723.1	723.1
2002	754.1	754.1
2003	786.6	786.6
2004	820.4	820.4
2005	855.6	855.6
2006	891.7	893.0
2007	929.2	931.9
2008	968.4	972.6
2009	1,009.2	1,015.1
2010	1,051.7	1,059.4
2011	1,095.2	1,104.5
2012	1,140.5	1,151.5
2013	1,187.6	1,200.5
2014	1,236.7	1,251.6
2015	1,287.8	1,304.9
Growth Rate	4.34%	4.41%
Gross Change		86.8

Table E-5. Airline Employment for Technology B

Year	Baseline Employment	Revised Employment
1995	438,983	438,983
1996	455,299	455,299
1997	472,316	472,316
1998	490,068	490,068
1999	508,590	508,590
2000	527,917	527,917
2001	545,799	545,799
2002	564,383	564,383
2003	583,700	583,700
2004	603,780	603,780
2005	624,659	624,659
2006	645,810	646,745
2007	667,787	669,722
2008	690,626	693,630
2009	714,365	718,510
2010	739,041	744,405
2011	764,055	770,515
2012	790,041	797,668
2013	817,042	825,909
2014	845,101	855,286
2015	874,262	885,850
Growth Rate	3.50%	3.57%
Gross Change		60,109

Table E-6. Fleet Size for Technology B

Year	Baseline Number of Aircraft	Revised Number of Aircraft
1995	4,179	4,179
1996	4,297	4,297
1997	4,419	4,419
1998	4,545	4,545
1999	4,676	4,676
2000	4,812	4,812
2001	4,932	4,932
2002	5,055	5,055
2003	5,183	5,183
2004	5,315	5,315
2005	5,451	5,451
2006	5,587	5,595
2007	5,727	5,744
2008	5,872	5,898
2009	6,021	6,056
2010	6,175	6,220
2011	6,329	6,383
2012	6,488	6,551
2013	6,652	6,724
2014	6,821	6,903
2015	6,995	7,088
Growth Rate	2.61%	2.68%
Gross Change		93

TECHNOLOGY C

Technology C is hypothesized to reduce the block time for the average flight by 4 percent. Assuming a penetration rate of 69.3 percent by the year 2015, this improvement is modeled as 0.14 percent, 0.28 percent, and 0.03 percent compound annual reductions in labor, fuel, and materials costs, respectively, during the period 2006 to 2015. Additionally, the compound annual improvement in capital productivity is 0.27 percent. When the target operating margin constraints are binding at 5 percent, the reduced airline operating costs are passed along to the traveling public as fare reductions. Consequently, an additional 83.8 billion revenue passenger miles are flown. However, because of the productivity improvements, airline employment decreases by over 4,000 work-years and the number of aircraft in the fleet decreases by 100. The estimated value of these is a drop of $5.2 billion (in 1995 dollars) from the baseline scenario. The projected U.S. market share remains at 76 percent. This is expected to cost 32,408 work-years of employment at U.S. airframe manufacturers.

Table E-7. RPM Growth for Technology C

Year	Baseline Total RPM (billions)	Revised Total RPM (billions)
1995	550.7	550.7
1996	576.6	576.6
1997	603.8	603.8
1998	632.3	632.3
1999	662.1	662.1
2000	693.3	693.3
2001	723.1	723.1
2002	754.1	754.1
2003	786.6	786.6
2004	820.4	820.4
2005	855.6	855.6
2006	891.7	892.9
2007	929.2	931.8
2008	968.4	972.3
2009	1,009.2	1,014.7
2010	1,051.7	1,058.8
2011	1,095.2	1,104.0
2012	1,140.5	1,151.1
2013	1,187.6	1,200.2
2014	1,236.7	1,251.4
2015	1,287.8	1,304.8
Growth Rate	4.34%	4.41%
Gross Change		83.8

Table E-8. Airline Employment for Technology C

Year	Baseline Employment	Revised Employment
1995	438,983	438,983
1996	455,299	455,299
1997	472,316	472,316
1998	490,068	490,068
1999	508,590	508,590
2000	527,917	527,917
2001	545,799	545,799
2002	564,383	564,383
2003	583,700	583,700
2004	603,780	603,780
2005	624,659	624,659
2006	645,810	645,761
2007	667,787	667,686
2008	690,626	690,470
2009	714,365	714,148
2010	739,041	738,761
2011	764,055	763,648
2012	790,041	789,499
2013	817,042	816,355
2014	845,101	844,259
2015	874,262	873,257
Growth Rate	3.50%	3.50%
Gross Change		-4,285

Table E-9. Fleet Size for Technology C

Year	Baseline Number of Aircraft	Revised Number of Aircraft
1995	4,179	4,179
1996	4,297	4,297
1997	4,419	4,419
1998	4,545	4,545
1999	4,676	4,676
2000	4,812	4,812
2001	4,932	4,932
2002	5,055	5,055
2003	5,183	5,183
2004	5,315	5,315
2005	5,451	5,451
2006	5,587	5,579
2007	5,727	5,711
2008	5,872	5,847
2009	6,021	5,988
2010	6,175	6,132
2011	6,329	6,276
2012	6,488	6,424
2013	6,652	6,576
2014	6,821	6,733
2015	6,995	6,895
Growth Rate	2.61%	2.54%
Gross Change		-100

Appendix F
User's Guide

STARTING ACIM

The file name for the model is ACIM.xls. To run the model:

- Download ACIM.xls from the ASAC website.
- Make sure that Microsoft Excel is NOT running.
- Locate ACIM.xls in File Manager, Windows Explorer, or a similar utility.
- Double click on the file name or file icon.

The main dialog box of the ACIM will appear. This dialog box has four buttons, that will be explained in turn.

RUN MODEL

Clicking the Run Model button displays the Run Model dialog box, which has five buttons that will be described below.

Choose Scenario

Clicking the Choose Scenario button displays the Choose Scenario dialog box. This dialog box contains a drop down list of scenarios of the available scenarios. The user can select a scenario from this list and then return to the Run Model dialog box by clicking on the Return to Run Model button.

Edit Scenario

Clicking the Edit Scenario button displays the Edit Scenario dialog box. This dialog box contains eight buttons. The first 5 buttons display dialog boxes where the user can view and edit the scenario parameters of the chosen scenario. The sixth button displays a dialog box where the user can enter or edit notes about the scenario. The seventh button displays the Edit Aircraft Replacement Parameters dialog box. The eighth button returns the user to the Run Model dialog box.

TRANSLATOR UTILITY

The first dialog box accessed from the Edit Scenario dialog box is the Edit Gross Changes in Cost dialog box. There is a button on this box marked Translator. Clicking this button displays the Translator dialog box, which has four buttons. This dialog box is used to select a baseline case file and a revised case file which have been downloaded previously to the user's system. Use the first button to choose the baseline case file and the second button to choose the revised case file. Use the Update Gross Changes in Cost button to calculate changes for Flight Personnel, Aircraft Fuel, and Maintenance from the selected files and display the new figures in the Edit Gross Changes in Cost dialog box. Use the cancel button to return to the Edit Gross Changes in Cost dialog box without making any changes from the Translator Utility.

EDIT AIRCRAFT REPLACEMENT PARAMETERS

Clicking the Edit Aircraft Replacement Parameters button displays the Edit Aircraft Replacement Parameters dialog box. This dialog box has five buttons. The first four buttons display dialog boxes where the user can view and edit additional parameters for the chosen scenario. These parameters affect when and with what types of equipment various aircraft will be replaced. The fifth button returns the user to the Edit Scenario dialog box.

Save or Delete Scenario

Clicking the Save or Delete Scenario button displays the Save or Delete Scenario dialog box. This dialog box has a drop down list from which the user can select a scenario name. The user can delete a selected scenario by clicking the Delete Scenario button after selecting a scenario. The user can save new edits to an old name by selecting the name and clicking the Save Current Scenario button. The user can save to a new name by typing a name into the edit box or editing a name that appears in the edit box after selecting it from the list and then clicking on the Save Current Scenario button. The only exception to this is that the baseline case and the three technology cases that come with the model cannot be deleted or modified under their old names. Clicking the Return to Run Model Dialog Box button displays the Run Model dialog box without saving or deleting a scenario.

Solve Scenario

Clicking the Solve Scenario button displays the Solve Scenario dialog box. This dialog box has three buttons. The first solves the scenario given the target operating margins specified by the user and calculates fare yields. The second solves the scenario given the fare yields specified by the user and calculates operating profit margins. The third returns the user to the Run Model dialog box without solving the model.

Return to Main Dialog Box

Clicking the Return to Main Dialog Box button returns the user to the Main dialog box, which is the first dialog box to appear when starting the model.

VIEW, PRINT, OR SAVE RESULTS

Clicking the View, Print, or Save Results button displays the View, Print, or Save Results dialog box. This dialog box has four buttons.

View Results

Clicking the View Results button displays the View Results dialog box. This dialog box contains a drop down list of the results pages that may be viewed. The user selects one and then clicks the OK button to view it. The result page will be displayed until the user double clicks somewhere on the result screen. At that point, the View, Print, or Save Results dialog box will be displayed.

Print Results

Clicking the Print Results button displays the Print Results dialog box. This dialog box contains a drop down list of the results pages that may be printed. The user selects one and then clicks the OK button to print it. The result will be printed on the default printer and the View, Print, or Save Results dialog box will be displayed.

Save Results to File

Clicking the Save Results to File button displays the Save Results dialog box. This dialog box allows the user to select a location and file name under which all results will be saved. This file can then be accessed later by the user. Upon leaving this dialog box, the View, Print, or Save Results dialog box will be displayed.

Return to Main Dialog Box

Clicking the Return to Main Dialog Box button displays the Main dialog box.

VIEW OR PRINT DATA OR SCENARIO

Clicking the View or Print Data or Scenario button displays the View or Print Data or Scenario dialog box. This dialog box has three buttons.

View or Print Data

Clicking the View or Print Data button displays the View or Print Data dialog box. This dialog box contains a drop down list of the data elements that can be viewed or printed. The user selects one from the list and then views or prints it by clicking the appropriate button.

View or Print Scenario

Clicking the View or Print Scenario button displays the View or Print Scenario dialog box. This dialog box contains a drop down list of the scenarios that can be viewed or printed. The user selects one from the list and then views or prints it by clicking the appropriate button.

Return to Main Dialog Box

Clicking the Return to Main Dialog Box button displays the Main dialog box.

EXIT MODEL

Clicking the Exit Model button exits the ACIM.

GENERAL INSTRUCTIONS

The most common set of actions when running the model is as follows:

- choose a scenario,

- edit the scenario parameters as desired,
- save the scenario,
- solve the scenario, and
- view the results.

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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 second-generation Air Carrier Investment Model that meets these requirements. The enhanced model incorporates econometric results from the supply and demand curves faced by U.S.-scheduled passenger air carriers. It uses detailed information about their fleets in 1995 to make predictions about future aircraft purchases. It enables analysts with the ability 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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