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The Aviation System Analysis Capability Air Carrier Cost-Benefit Model

Eric M. Gaier, Alexander Edlich, Tara S. Santmire and Earl R. Wingrove III
Logistics Management Institute, McLean, Virginia

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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 is developing 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 the new technologies will be used in the integrated aviation system, NASA aims to balance its aeronautical research program and help speed the introduction of high-leverage technologies. To meet these objectives, NASA is building the Aviation System Analysis Capability (ASAC).

NASA envisions 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 and databases used by analysts and other individuals from the public and private sectors brought together to work on issues of common interest to organizations in the aviation community. ASAC also will be a resource available to the aviation community to analyze; inform; 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. Commercial air carriers, in particular, are an important stakeholder in this community. Therefore, to fully evaluate the implications of advanced aviation technologies, ASAC requires a flexible financial analysis tool that credibly links the technology of flight with the financial performance of commercial air carriers. By linking technical and financial information, NASA ensures that its technology programs will continue to benefit the user community. In addition, the analysis tool must be capable of being incorporated into the wide-ranging suite of economic and technical models that comprise ASAC.

This report describes an Air Carrier Cost-Benefit Model (CBM) that meets these requirements. The ASAC CBM is distinguished from many of the aviation cost-benefit models by its exclusive focus on commercial air carriers. The model considers such benefit categories as time and fuel savings, utilization opportunities, reliability and capacity enhancements, and safety and security improvements. The model distinguishes between benefits that are predictable and those that occur randomly. By making such a distinction, the model captures the ability of air carriers to reoptimize scheduling and crew assignments for predictable benefits. In addition, the model incorporates a life-cycle cost module for new technology, which applies the costs of nonrecurring acquisitions, recurring maintenance and operation, and training to each aircraft equipment type independently.

The CBM calculates core operating costs using an activity-based cost approach, which was first developed for the Functional Cost Module (FCM) of the Air Carrier Investment Model (ACIM). The approach is used to estimate operating costs in six categories in relation to output, input prices, and input productivity. The default parameters of the model for price and productivity are populated with publicly available data from the largest three U.S. carriers. Thus, the default model is developed for a representative airline, which facilitates its use for building consensus about aviation investments. In addition, the model incorporates a database of alternate parameters, which enables the user to customize the analysis for specific air carriers or groups of air carriers.

The basic output of the model includes calculations of net present value (NPV) and duration.[1] In addition, we have supplemented the basic output with a sensitivity analysis and simulation module that allows the user to select variables for sensitivity analysis and input data ranges. The sensitivity analysis algorithm produces a tornado diagram, which summarizes the sensitivity of the results to independent variations in selected variables. The simulation algorithm uses Monte Carlo draws to produce a distribution for the basic output in relation to the simultaneous variation in the selected variables.

This report illustrates the use of the model, in conjunction with other ASAC models, for evaluating the projected costs and benefits of a hypothetical innovation for reducing runway occupancy time and approach separation standards. The hypothetical technology scenario demonstrates net benefits to the representative air carrier, but contains substantial risk. The model identifies the variables that contribute to the range of uncertainty.

Introduction

NASA'S ROLE IN PROMOTING AVIATION TECHNOLOGY

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

Despite the industry's record of success, the difficult business environment of the recent past has stimulated concerns about the U.S. aeronautics industry maintaining its worldwide leadership. Increased competition, both technological and finan-

[1] Duration is the concept, from finance, for measuring the timing of the cash flows. Duration is discussed in a subsequent section of this report.

cial, 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 large U.S. airframe manufacturers to only one (Boeing).

The primary role of NASA in supporting civil aviation is to develop technologies for improving the overall performance of the integrated air transportation system, making air travel safer and more efficient, and 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 U.S. leadership in aviation technology and air transportation held 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 (FAA) and the U.S. aeronautics industry, NASA uses the AST program to develop high-payoff technologies for developing 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 increasing market share for U.S. producers of civil aircraft and aircraft-component and to increasing the effectiveness and capacity of the national air transportation system.

NASA's Research Objective

To assist 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 impacts of advanced aviation technologies and by evaluating how the new technologies will be used in 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 ASAC.

Goal of the ASAC Project: Identifying and Evaluating Promising Technologies

NASA's principal goal for ASAC is to credibly evaluate the economic and technological impacts of advanced aviation technologies on the integrated aviation system. Then NASA will use the evaluations to assist program managers with selecting the most beneficial mix of technologies for NASA to invest in. The technologies encompass both broad areas, such as propulsion or navigation systems, and more specific projects in the broader categories. In general, engineering analyses of this kind require multidisciplinary expertise, possibly using several models of different components and technologies and considering multiple alternatives and outcomes.

ASAC Focus: Airline Economics and Investment Behavior

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. Commercial air carriers, in particular, represent an important stakeholder in this community. Therefore, to fully evaluate the implications of advanced aviation technologies, ASAC must have a flexible financial-analysis tool that credibly links the technology of flight with the financial performance of commercial air carriers. By linking financial and technological information, NASA ensures that its technology programs will continue to demonstrate net benefits to the user community. In addition, the analysis tool must be capable of being incorporated into the wide-ranging suite of economic and technical models that comprise ASAC. The remainder of this report describes an Air Carrier CBM that meets NASA's requirements.

Overview of the Air Carrier Cost-Benefit Model

In creating the Air Carrier CBM, we had some specific goals in mind. Our primary objective was to create a flexible financial analysis tool for credibly estimating the benefits to airline operators from proposed technical and procedural innovations. Underlying the objective was NASA's realization that future technologies must demonstrate net benefits to the user community. In addition, we recognized the notion that existing aggregate-level cost-benefit methodologies, which consider a much broader scope of benefits than those affecting only commercial air carriers, often lack sufficient operational complexity to establish credibility with airline operators. Therefore, because we realized that existing ASAC models are designed to address the broader scope of the integrated aviation community, we chose to focus exclusively on commercial air carriers for this model.

We envisioned a model with the capability of evaluating financial impacts to airlines under a variety of user-defined technology scenarios. Because investment in new technology is subject to a variety of risks, we determined early that a sensitivity-analysis capability was essential. In addition, we envisioned the capability of inputting benefits, costs, and penetration assumptions separately by aircraft type. We envisioned the capability of customizing the analysis to represent specific air carriers or groups of air carriers.

BACKGROUND

To satisfy our objectives, we did several things before developing the model. First, we extensively reviewed a set of literature on cost-benefit analysis in the aviation community that included the following:

- A set of existing aviation cost-benefit methodologies and models
- Approaches and methods for modeling air carrier operating costs
- Material related to forthcoming innovations in aircraft and air-traffic management technologies.

Second, we met with representatives from several major air carriers, a major airframe equipment manufacturer, an industry focus group, and key NASA personnel to discuss the requirements for the model and to obtain input for developing the model. Third, we analyzed the availability and suitability of publicly available data sources for populating the parameters of the model. Fourth, we specified a preliminary design for the model and obtained feedback from the industry and NASA representatives. The most significant findings from our background research are discussed below.

Review of Related Literature

We reviewed nine aviation cost-benefit models and methodologies.[2] To assist in organizing the materials, we developed a two-dimensional classification system. The first dimension was the scope of the costs and benefits considered by the model. The scope of the models ranged from extremely narrow, in which the costs and benefits were limited to a single equipment type, to extremely broad, in which the benefits to the aviation community, flying public, and general society were considered. The second dimension was the level of detail of the modeling approach. Methods ranged from highly detailed bottom-up approaches, in which the operating costs were calculated differentially by phase of flight and equipment type, to aggregate-level top-down approaches, in which industry averages were applied uniformly to all equipment types and carriers. As expected, a high degree of correlation exists between the dimensions. Figure 1 summarizes our findings.

[2] Appendix A contains additional detail about the methodologies we reviewed.

Figure 1. Existing Aviation Cost-Benefit Methodologies

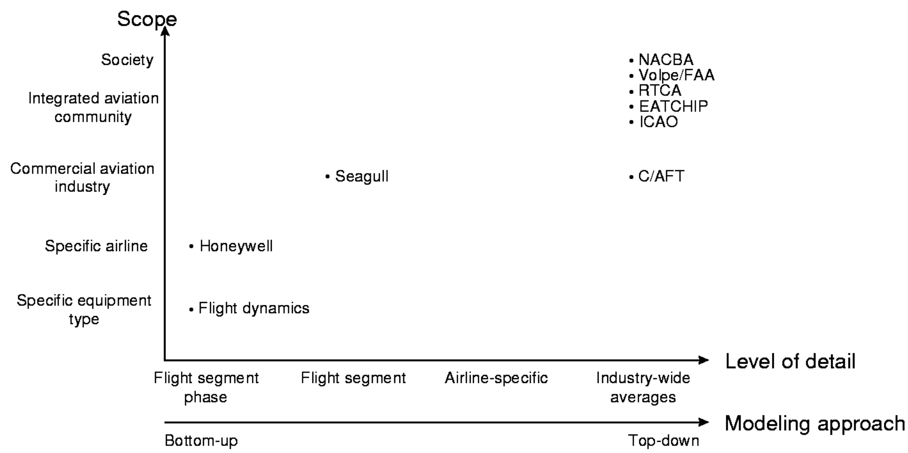


Figure 1 also illustrates the most important finding from our review. Other than airline proprietary analysis, no general CBM exists that focuses exclusively on the air carriers and can be used for modeling operating costs at an appropriate level of detail. Our finding echoes concerns we heard during our visits with industry representatives. Therefore, we concluded that many of the existing models either do not provide enough detail or attempt to provide more detail than can credibly be modeled in a financial analysis. An example of the former is that most models did not distinguish operating costs by aircraft type. An example of the latter is that several of the models differentiated fuel burn by phase of flight through the use of differential thrust settings. Although the latter details are important to consider, we contend that such topics are more appropriately analyzed using an operational model, such as the ASAC Flight Segment Cost Model (FSCM), rather than a financial-analysis model. Therefore, we envisioned a CBM that recognized the important distinction between operational issues and financial issues. Fortunately, the broad scope of ASAC models allows for such a distinction.

From our review of CBMs, we also identified a number of desirable features to incorporate. These include a distinction between predictable and random time and fuel savings, a nonlinear relationship between time savings and additional aircraft use, and an explicit mechanism for sensitivity analysis. In addition, we identified a set of benefit and life-cycle cost categories for including in the model. Benefit categories include time and fuel savings, maintenance reliability enhancements, safety and security enhancements, capacity enhancements, various use and revenue opportunities, and risk mitigation. The life-cycle cost categories include acquisition and installation, operation and maintenance, recurring and nonrecurring training, and infrastructure.

Another issue that emerged from our review of CBMs was the need to establish a baseline scenario from which financial impacts could be assessed. In many of the models we reviewed, the baseline against which the benefits of new technology were being measured was unclear. In the case of time savings, for example, it was not clear whether time savings were measured against the current operating environment or some predicted environment of the future. The ASAC CBM eliminates the confusion by measuring the effect of technology against a clearly defined baseline scenario. Furthermore, the baseline assumptions are fully editable, enabling a user to define a custom baseline.

In reviewing methods for modeling air carrier operating costs, we had three goals in mind. Our first goal was to evaluate various taxonomies used to classify aircraft operating costs. Our second goal was to identify viable alternatives to the functional cost approach developed for the FCM of the ACIM. Our third goal was to research default values for parameters that are not easily deduced from publicly available data sources. With regard to cost taxonomies, we found a high degree of conformity among all of the documents we reviewed. Similarly, we found that the majority of the cost-modeling methods were similar to the activity-based cost approach used in the FCM. However, several methods used a more fundamental parametric cost approach common to engineering applications. On the basis of our experience with the FCM, the need for the model to interact with existing ASAC models, and the suitability of publicly available data, we opted for an activity-based cost approach.

Our review of forthcoming aircraft and air traffic management innovations consisted of NASA Ames Concept of Operations [5], FAA National Airspace System Architecture [11], NASA AST Level II Program Plan [2], and various publications from the Air Economics Group [14]. We reviewed the publications to identify the types of innovations that the model should evaluate. We concluded that, although the scope of benefits is broad, by using the benefit categories identified in the literature and the model, in conjunction with other ASAC models, we can adequately address forthcoming aircraft and air traffic management innovations.

Visits with Industry and NASA Representatives

In conjunction with our review of literature, we visited representatives of several major air carriers and a major aircraft manufacturer, an industry focus group, and key NASA personnel. Our goal in meeting with these people was to discuss user requirements and issues related to using cost-benefit analysis in the aviation community. In addition, we intended to obtain feedback on our approach and preliminary design specifications. Among industry representatives, we found strong support for our focus on commercial air carriers exclusively. Many representatives envisioned using the CBM for developing consensus among commercial air carriers regarding the benefits of investments in aviation infrastructure. Therefore, they encouraged us to populate the model with data from a *representative* (as opposed to an actual) airline to facilitate building consensus. They also strongly supported using a probabilistic approach to cost-benefit analysis instead of a deterministic approach. In addition, we obtained positive feedback on the overall approach and received a host of suggestions for improving the model. We found support from

NASA representatives for integrating the CBM with other ASAC models as well as for adding a sensitivity analysis capability. We also received positive feedback on our preliminary model design and incorporated a number of the suggestions.

Data Availability

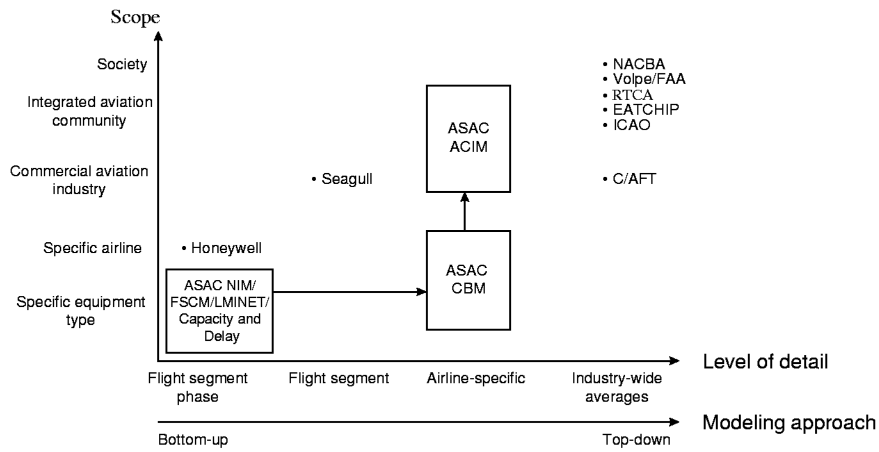
From the beginning, we envisioned a model whose parameters were populated exclusively from publicly available information. Therefore, in the initial phase of the task, we evaluated the suitability of such data for our purposes. Most of the data requirements were satisfied with information derived from Department of Transportation (DOT) Form 41 reports.[3] Form 41 reports contain a host of quarterly and annual operational and financial statistics for each air carrier. Some schedules of the Form 41 reports are available at the aircraft-equipment level of detail and others at the airline level. The schedules containing the equipment level of detail include P-5.1 Aircraft Operating Expenses-Group I Carriers; P-5.2 Aircraft Operating Expenses—Group II and III Carriers; and T-2 Traffic, Capacity, and Operations. In general, we designed the model to take advantage of the finest level of detail available from the Form 41 data. In addition, we supplemented the Form 41 reports with aircraft fleet data from AvSoft's Aircraft Analytical System (ACAS) [1] and cost-of-capital information from Ibbotson Associates [16].

MODELING APPROACH

The ASAC approach, in general, is one in which the data are analyzed by linking the inputs and outputs of distinct models to form an analysis chain. For example, a new air traffic management technology is first evaluated with an operational model, such as the airport capacity model, to determine the impact on capacity. Output from the capacity model subsequently is passed to the airport delay model to evaluate the impact on delay. Finally, delay figures are passed to an economic model of air carrier costs, such as the FCM, to evaluate the potential savings. In this way, the ASAC approach ensures that operational issues are addressed with operational models and economic issues are addressed with economic models. Thus, we envisioned a cost-benefit model that focused primarily on financial analysis issues and relied on other ASAC models for operational inputs. This approach is demonstrated in a later section of this report in the evaluation of a hypothetical technology that reduces runway occupancy times and separation standards. Figure 2 superimposes the ASAC CBM on the findings from our review of existing cost-benefit models.

[3] Appendix B provides additional detail of the DOT Form 41 schedules.

Figure 2. ASAC CBM Approach



As shown in Figure 2, the ASAC CBM receives input from a host of ASAC operational models, including the FSCM and the Airport Capacity and Delay Models. As outlined above, the CBM focuses exclusively on financial analysis of the commercial air carriers. For broader analyses, such as the impact of new technology on aircraft manufacturers or the traveling public, output can be passed to the ACIM. In addition, the ACIM also may provide input to the CBM in the form of fare yield changes and traffic growth rates.

The CBM takes a bottom-up approach in which operating costs are estimated at the aircraft-equipment level and aggregated to obtain airline costs. Thus, the parameters that determine direct aircraft operating costs, such as crew labor rates, are different for each type of equipment. However, some parameters, such as those that determine revenue and indirect operating costs, are only available at the airline level of aggregation. The default parameters of the model are derived from the most recent DOT Form 41 reports for the largest three U.S. carriers—American, Delta, and United. Thus, the parameters of the model represent a hypothetical airline composed of a weighted average of the three carriers. Therefore, financial analysis that uses the default parameters of the model is representative of a large major carrier.

In addition to the default parameters of the model, we also have developed a database of alternative parameters for each carrier or carrier group, such as small majors or nationals. The database allows the analysis to be tailored to a particular set of carriers. Like the default parameters, the alternative parameters are drawn from publicly available Form 41 reports. Further detail about the database of alternative parameters is in a later section of this report.

From the beginning, we envisioned a sensitivity analysis and simulation capability that would assess the sensitivity of the results to variations in key assumptions. We made a distinction between sensitivity analysis, in which the effect of deviations in one assumption are evaluated holding all other assumptions constant, and simulation analysis, in which Monte Carlo draws are used to assess the effect of varying all assumptions simultaneously. To implement this sensitivity analysis and simulation capability, we evaluated several commercial decision-science software packages. However, we required so few of the capabilities of the packages that we could not justify requiring the user to purchase the software to run these functions. In addition, several technical and legal issues were involved with developing a graphical user interface around such packages. Therefore, we decided to develop the sensitivity analysis and simulation capabilities ourselves.

Derivation of the Air Carrier Cost-Benefit Model

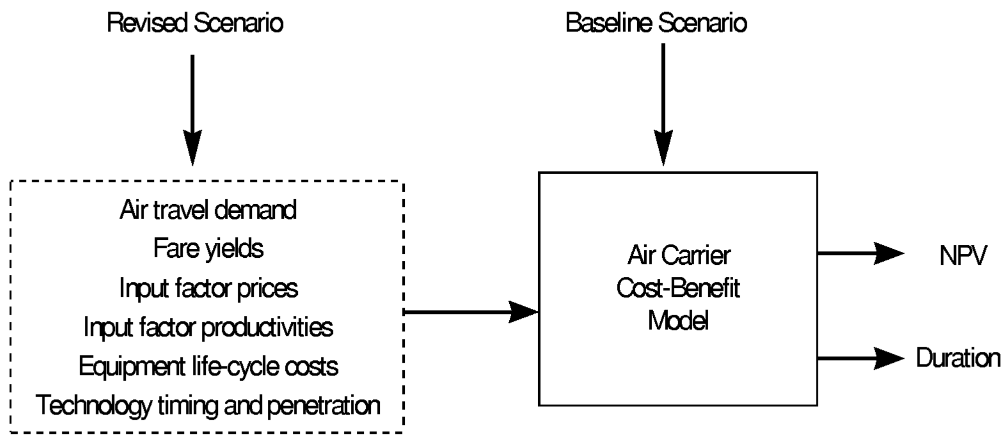
This section describes the derivation of the CBM. We begin with a high-level discussion of the model's structure. We then discuss the types of benefits that can be assessed by the model. The discussion is followed with a description of the life-cycle cost module that is used for estimating cost streams of the new technology. We discuss the model's core operating cost calculations that use a variant of the activity-based cost approach developed for the ACIM. Finally, we discuss the output of the model and refer the interested reader to Appendix C for a discussion of the default baseline assumptions.

STRUCTURE OF THE MODEL

Like other ASAC models, the CBM measures the impact of technological change against a clearly defined baseline. To analyze the change, therefore, requires specifying two distinct scenarios—a baseline scenario and a revised scenario. The baseline scenario is intended to capture the most likely future set of outcomes in the absence of the new technology (other than innovations explicitly treated in the forecast). As described in Appendix C, we have provided a set of default assumptions that we believe accurately reflect the future expectations. However, we also have provided the capability of modifying all of the baseline assumptions so that a user may specify a customized baseline. Conversely, the revised scenario is intended to capture the most likely set of outcomes in the presence of additional new technology. Thus, differences between the revised scenario and the baseline scenario, with regard to the financial status of the carrier, are attributed to the incremental new technology. Figure 3 illustrates the concept.

As shown in Figure 3, the primary inputs to the model consist of a baseline scenario and a set of revised assumptions that capture the effect of technology. The set includes parameters related to air travel demand, airline cost and productivity, life-cycle costs for new equipment and training, and the timing and penetration of the technological impact. The main outputs of the model are NPV and duration calculations. In addition, the user may access a set of additional outputs, such as annual cash flows, operating costs, and operating revenue, by equipment type or aggregated at the airline level. Not shown in Figure 3 is the sensitivity analysis capability, which is discussed in a later section of this report.

Figure 3. Schematic of the Air Carrier CBM



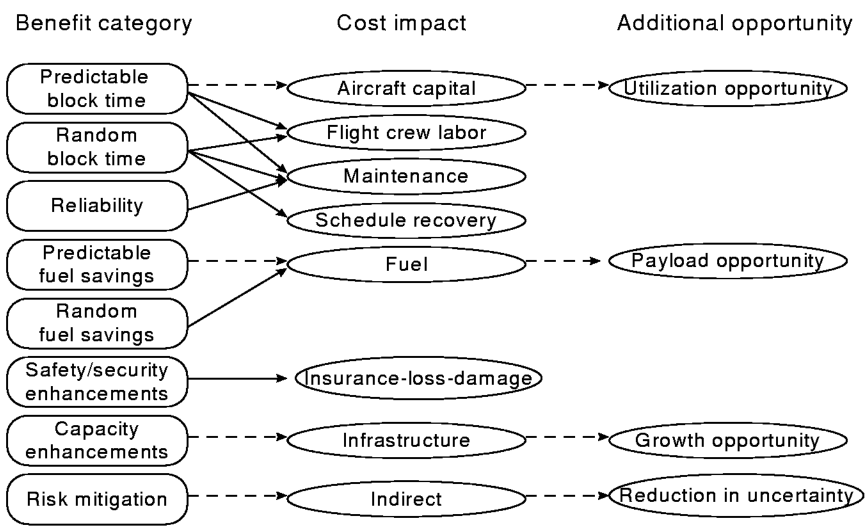
BENEFITS ADDRESSED BY MODEL

Overview

From our review of existing cost-benefit models, we identified a set of standard benefit categories for including in the model. Although all variables in the model may be modified for assessing the benefits of technology, the standard categories represent the most likely drivers of future benefits. In several cases, the categories represent predefined links between the primary impact of an innovation on cost and subsequent secondary impacts, such as revenue enhancement. The main types of benefits that are addressed by the model are shown in the first column of Figure 4. Each benefit category has a primary effect on costs as shown in the second column. Some categories lead to further impacts by offering additional benefit opportunities. For example, in the case of predictable fuel savings, additional payload opportunities arise for flights that have constrained payloads or range. Benefit categories that offer additional opportunities are shown in Figure 4 with dashed lines.

We make a distinction between time and fuel savings that are predictable and random. In general, predictable savings are more valuable than random savings because predictable savings enable the airline to reoptimize the scheduling and fuel-load calculations. The reoptimization is reflected in Figure 4, with predictable time and fuel savings leading to additional opportunities, while random savings do not. In actuality, the value of predictable savings also depends on the time horizon. According to Russell Chew [8], the most valuable savings are those that can be predicted several years in advance because the time horizon for capital planning decisions is long. Similarly, savings that can be predicted at least 12 months in advance are within the time frame for resource (i.e. manpower, and training) planning. Savings that can be predicted at least 90 days in advance are within the time frame for schedule planning. Savings that can be predicted at least 30 minutes in advance are within the time frame for dispatching and fuel-load planning. Thus, our distinction between predictable and random savings abstracts from the full complexity of the time-dimension issue.

Figure 4. Benefit Categories



Both predictable and random time savings reduce operating costs by reducing the block-time requirements for flights of a given length. Predictable time savings also may reduce aircraft capital expenses or lead to additional utilization opportunities as discussed below. Random time savings reduce schedule recovery costs, such as for passenger or baggage misconnects. Reliability enhancements, such as improved software or more durable engine components, primarily affect maintenance costs. Both predictable and random fuel savings reduce fuel expenses. However, predictable fuel savings also are subject to a multiplier effect because less fuel is consumed to carry the fuel load. Safety and security enhancements, such as cargo-hold smoke detectors, primarily affect insurance, loss, and damage rates. As described in Appendix C, capacity enhancements result in increased infrastructure costs but offer additional growth opportunities. Risk mitigation increases indirect costs, but reduces risk. We envision several types of risks that include technical, implementation, financial, market, and political. Risk mitigation will be addressed in the discussion of the sensitivity analysis capability.

Utilization Opportunity

When predictable time savings are realized, an aircraft may be able to fly an additional flight segment at the end of a schedule day. To determine if predictable time savings are sufficiently large, we compare the predicted time savings with a critical value that depends on the flexibility of the airline's decisions about scheduling aircraft and crew. The basic question we are addressing is what magnitude of savings are required to generate additional flight segments at the end of a schedule day. On one extreme, we assume that there is no flexibility in the scheduling decision. In that case, each aircraft in the fleet must generate enough time savings itself to allow an additional flight. So, for example, if a particular aircraft flies 5 flight segments per day at an average block time of 2 hours per flight, then—abstracting from the possibility of increasing the number of daily block hours—a total savings of 20 minutes per flight is required to generate one additional flight. As shown in Equation 1—in which the subscript 0 denotes the period before time savings are realized and 1 denotes the time period after—the algorithm used by the model also incorporates the possibility that the number of daily block hours may be increased.

$$\text{Critical value}_{Low} = \text{Average block time}_0 - \frac{\text{Total block time}_1(\text{per aircraft per day})}{(\text{Daily flight segments}_0(\text{per aircraft per day}) + 1)} \qquad \text{[Eq. 1]}$$

Thus, Equation 1 is used to calculate the minimum amount of time savings required for each aircraft to generate one additional flight segment as a function of the average block time, the number of flight segments per day, and the total block time per day. Therefore, the number of additional flights is given by Equation 2, in which “fleet” denotes the number of aircraft of a particular type.

$$\text{Additional flights}_{Low} = \text{Fleet} \times \text{Truncation}\left(\frac{\text{Time savings (per flight)}}{\text{Critical value}_{Low}}\right) \qquad \text{[Eq. 2]}$$

At the other extreme, we assume that there is unlimited flexibility in the scheduling decision. In this case, the time savings contributed by each aircraft to a general pool determines the number of additional flight segments possible. Equations 3 and 4 represent the critical value and number of additional flights under the assumption of unlimited flexibility.

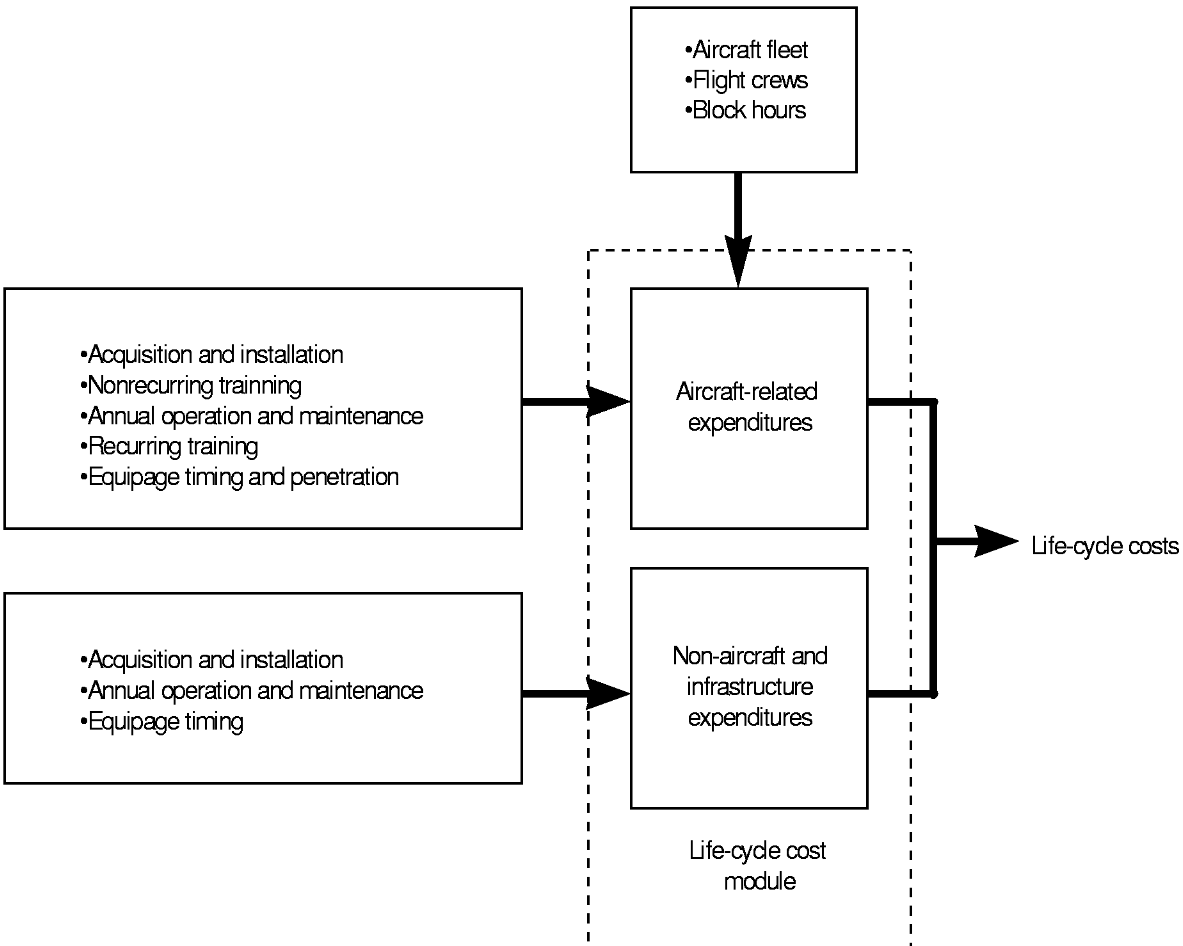
$$\text{Critical value}_{High} = \text{Average block time}_0 - \frac{\text{Total block time}_1(\text{all aircraft per day})}{(\text{Daily flight segments}_0(\text{all aircraft per day}) + 1)} \qquad \text{[Eq. 3]}$$

$$\text{Additional flights}_{High} = \text{Truncation}\left(\frac{\text{Time savings (per flight)}}{\text{Critical value}_{High}}\right) \qquad \text{[Eq. 4]}$$

The actual number of additional flights generated is determined by a weighted average of the low and high estimates. The weights are adjusted by the schedule flexibility parameter that ranges between 0 and 1. When the schedule flexibility parameter has a value of 0, the low estimate receives all of the weight. Conversely, when the schedule flexibility parameter has a value of 1, the high estimate receives all of the weight. Since the time intervals of the model correspond to calendar years, it is very likely that the schedule flexibility is quite high. Therefore, we use a default value of 0.8.

The analysis described above is carried out separately for each aircraft type. We assume that the length, duration, and load factor for additional flights are equal to the average value for the relevant equipment type. We apply the average passenger yield to the traffic generated by the additional flight segments. Also, because aircraft capital expenses are assessed per aircraft per day, the additional flight segments do not incur additional capital expenses. Thus, the net benefit of an additional flight is the difference between the revenue obtained and the variable operating costs incurred.

Figure 5. Schematic of Life-Cycle Cost Module

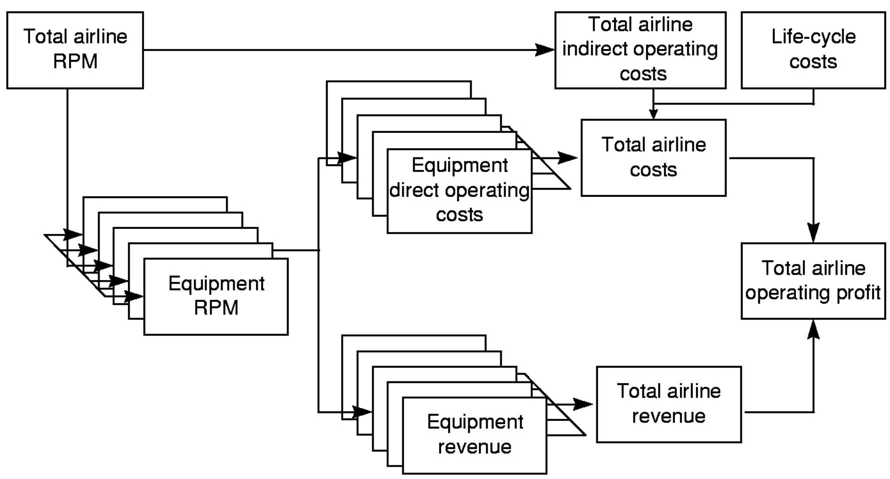


CALCULATING AIR CARRIER OPERATING COSTS

To estimate direct operating costs, the CBM follows an activity-based cost approach originally developed for the FCM of the ACIM [20]. The approach explicitly calculates operating costs in each of six categories as a function of total output, input factor productivities, and per-unit input prices. The cost analysis is based on data from DOT Form 41 in conjunction with detailed aircraft fleet inventories from ACAS and information about airline cost of capital from Ibbotson Associates [16]. The cost data follow each air carrier with annual observations from 1985–1995. Appendix B provides details about the allocation of operating costs to functional cost categories.

Whereas the FCM focuses on 26 air carriers and calculates operating costs at the airline level of aggregation, the CBM focuses on a single carrier and calculates operating costs at the aircraft-equipment level. Figure 6 illustrates the CBM concept. The more finely detailed approach of the CBM enables users to evaluate the impact of technology differentially by equipment type. The model can consider as many as 23 different equipment types.[4] This set of equipment types includes the 18 equipment types in use at the end of 1996 by the largest three carriers, an additional 4 equipment types in use by the alternative carriers, and an unspecified equipment type for evaluating future aircraft models. Thus, the default model has vacancies for up to 5 new equipment types. To facilitate various types of analysis, the model accepts input parameters at the equipment level of detail, by groupings of equipment types, or globally. The predefined groupings capture such characteristics as single-aisle aircraft, multi-aisle aircraft, Boeing aircraft, and Airbus aircraft

Figure 6. Calculations of Airline Operating Costs



As shown in Figure 6, the algorithm begins with the projected revenue passenger miles (RPM) for the entire airline.[5] Then the aggregate traffic forecast is allocated to each equipment type in accordance with assumptions about RPM shares specified by the user. The assumptions allow the user the flexibility to phase out older equipment types, increase existing equipment types, and add new equipment

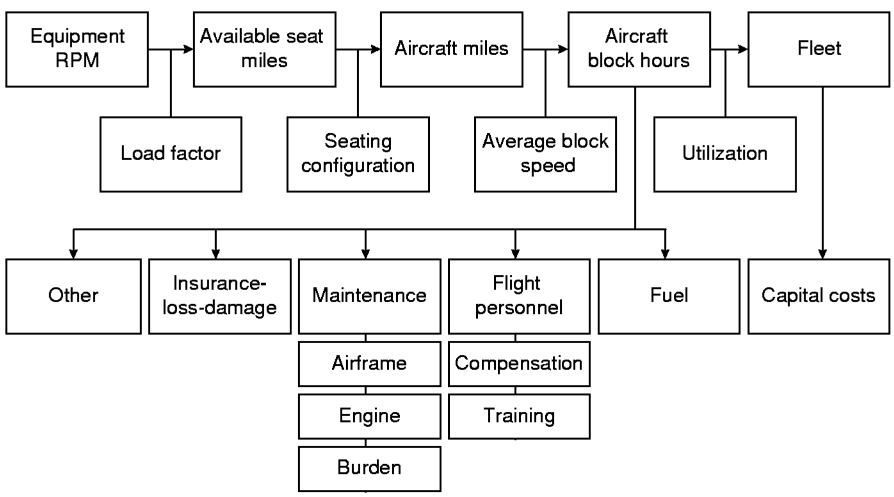
[4] As described in Appendix D, we generally follow the DOT Form 41 conventions for specifying equipment types. In a number of cases, however, we combined equipment types that are separate in Form 41 reports.

[5] One revenue passenger (a person receiving air transportation from the air carrier for which the carrier is remunerated) transported one statute mile.

types. Passenger traffic at the equipment level, as measured by RPM, subsequently drives the calculation of direct operating costs and revenue. Next, the equipment-level calculations of direct operating costs and revenue are aggregated at the airline level. Estimates of indirect operating costs, derived from the airline-level traffic, are combined with cost estimates from the life-cycle cost module to obtain total airline costs. Finally, total operating expenses are compared with total operating revenues to determine operating profits.

Estimating equipment-level operating costs from equipment-level traffic projections requires several intermediate steps. As shown in Figure 7, the equipment-level RPM forecast is first converted to available seat miles (ASM) by using a set of assumptions about equipment-specific load factors.[6] From ASM, we obtain the required aircraft miles by using the seating configuration used by the carrier. By using a set of equipment-specific assumptions regarding block speed, we obtain the number of block hours flown from the number of aircraft miles. Finally, we obtain the aircraft fleet requirements from the number of block hours using a set of assumptions of equipment-specific utilization.

Figure 7. Calculations of Equipment-Level Direct Operating Costs



As shown in Figure 7, the majority of the operating costs are derived from the block-hour projections. The operating costs consist of fuel, flight personnel labor, maintenance, insurance, loss, damage, and other direct expenses. Aircraft capital costs, however, are driven by the number of aircraft in the fleet as opposed to the number of block hours flown. This distinction allows the airline to take full advantage of additional aircraft utilization benefits without incurring additional capital charges. Some cost categories contain more than one cost item. Maintenance costs, for example, are composed of aircraft and engine subcategories in addition to overhead, or burden. Maintenance burden is a function of the sum of airframe and engine maintenance costs, as opposed to block hours.

[6] One available seat of capacity transported a statute mile.

Not shown in Figure 7 are the revenue calculations that apply the airline-level passenger yield assumptions to the equipment-level traffic projections. Such an approach abstracts from the fact that passenger yield varies significantly between equipment types mainly because of differences in average stage length. Unfortunately, DOT Form 41 revenue data are available only for the airline level of agregation. In an attempt to disaggregate the revenue data, we developed an econometric model of passenger yield as a function of stage length by using DOT origin and destination data. Although we obtained outstanding statistical results from the sample data, we found that the model failed to accurately estimate data points outside the sample range. In particular, because our data set was restricted to U.S. domestic operations, the model failed to accurately estimate yields for stage lengths in excess of 3,000 miles. Therefore, we fell back on the initial approach of applying the assumptions about airline-level yield to the equipment-level traffic projections.

Also not shown in Figure 7 are the calculations of air cargo. Projections of air cargo traffic are obtained by applying assumptions about equipment-specific cargo loads to aircraft mile estimates. The result is a projection for the number of cargo revenue ton miles (RTM) flown by each equipment type.[7] Applying assumptions about airline-level cargo yields to the equipment-level RTM projections produces an estimate of cargo revenue by equipment type. Finally, the revenue estimates are aggregated to obtain airline-level cargo revenues.

In each cost category, the operating expenses are determined by the interaction of one or more productivity parameters and a per-unit input cost parameter. For example, in the case of fuel expenses, total costs are the product of total block hours flown (output), fuel consumption per block hour (productivity), and fuel price per gallon (input price). Figure 8 illustrates the calculations used by the model for each cost category. Appendix B provides additional detail about the allocation of costs items to functional cost categories.

[7] One ton (2,000 pounds) of revenue traffic transported one statute mile.

Figure 8. Operating Cost Calculations

$$Fuel\ costs = block\ hours \times \frac{fuel\ price}{gallon} \times \frac{gallons}{block\ hours}$$

$$Flight\ personnel\ compensation = block\ hours \times labor\ rate\ (burdened)$$

$$Engine\ maintenance = block\ hours \times \frac{(maint.\ labor + maint.\ mat)}{block\ hour}$$

$$Airframe\ maintenance = block\ hours \times \frac{(maint.\ labor + maint.\ mat)}{block\ hour}$$

$$Maintenance\ burden = burden\ rate \times (airframe + engine\ maint.)$$

$$Flight\ equipment\ capital\ costs = aircraft \times \frac{capital\ charges}{aircraft}$$

$$Insurance\ loss\ damage\ costs = block\ hours \times insurance\ loss\ damage\ rate$$

$$Other\ DOC = block\ hours \times other\ DOC\ rate$$

With the exception of aircraft capital charges, each parameter is derived from the equipment-specific base-year DOT Form 41 observations. Thus, for each equipment type the base-year cost estimates exactly match the carrier's Form 41 filing. To the extent that the parameters follow predictable trends, the cost estimates remain accurate over the forecast horizon.

We estimated the capital costs of flight equipment in an especially detailed manner. We began with the 1996 inventory of aircraft from the AvSoft fleet database. The database contains detailed information about the age of each aircraft in a carrier's fleet. By using model-specific resale price information from Airclaims' *International Aircraft Price Guide* [17], we estimated the value of each aircraft as a function of its age. Totaling all of the aircraft in a carrier's fleet gives a measure of the total value of the flight equipment.

We applied depreciation and cost-of-capital charges to the value of the flight equipment. The parameter for depreciation charges is 3.3 percent, which results from the standard straight-line approach with a useful life of 30 years and no residual value. The parameter for cost-of-capital charges is 9.8 percent, which was derived by aggregating carrier-specific cost-of-capital charges published by Ibbotson Associates [16]. Thus, the flight equipment capital costs were calculated as 13.1 percent of the carrier's aircraft inventory value. As with all parameters in the CBM, the cost-of-capital parameter represents a constant-dollar value.

The advantage of our approach is that the resulting measure of capital cost includes the opportunity cost of the carrier's investment in equipment whereas depreciation charges taken directly from Form 41 reports do not. We use an economic approach for determining the costs of capital instead of the less desirable accounting approach. Nevertheless, the impact of this economic approach must be considered when interpreting the operating profits output by the model. As in the FCM, a discrepancy exists between the operating profits determined by the model and those reported in Form 41, which is caused by the opportunity cost of flight equipment capital. We call the profits measured by our approach *adjusted operating profit*.

To evaluate the impact of the opportunity costs on profit rates, we compared the base-year-adjusted operating profit margin measured by the model with the reported accounting profit margins. Industry-wide, the discrepancy was approximately 2 percent and was of similar magnitude for each carrier. Because the industry generally expects to earn approximately a 5 percent operating profit margin to finance expansion and fleet acquisition, we expect our model to produce adjusted operating profit margins of approximately 3 percent. As discussed in Appendix C, our baseline scenario meets these expectations.

With regard to indirect operating costs, we distinguish three cost categories. The categories are landing fees, air traffic control charges, and other indirect charges. Although landing fees are incurred system-wide, air traffic control charges are incurred only during international operations. An exception would be a flight between U.S. domestic locations that passes under the jurisdiction of a foreign air traffic control authority, such as NAV Canada. Indirect charges are calculated using the same activity-based cost approach as for direct charges. The cost driver for landing fees is the number of operations, while the driver for other indirect charges is ASM. Similarly, air traffic control charges are a function of the block-hour rate and the percentage of block hours subject to charges. We approximate the percentage by the proportion of block hours incurred in international service.

MODEL OUTPUT

In addition to the sensitivity analysis capability, the model has several basic outputs. One output is a calculation of the net present value of the technology investment under consideration. Another output is a calculation of duration, which measures the time dimension of the cash flows. In addition, the model provides access to many underlying calculations, such as the discounted and nondiscounted cash flows, total airline revenues and expenses under the baseline and revised scenarios, and equipment-specific cost calculations under the baseline and revised scenarios. The following paragraphs discuss the model's basic output.

Net Present Value

The calculation of net present value represents the most fundamental output of the model. The variable summarizes the value of the net discounted cash flows of the technology of the revised scenario. Specifically, for each year of the forecast period, the model calculates the difference between the baseline operating profit stream and the revised operating profits. The differences subsequently are discounted at a rate specified by the user and summed to obtain NPV. Thus, the revised scenario, which includes both the cost and benefit impacts of the new technology, is measured against a clearly defined baseline. In calculating the NPV, the model implicitly assumes that all profit streams are realized at the end of the calendar year.

Duration

Duration, a concept from finance, measures the speed at which cash flows are realized.[8] Because investment decisions are highly sensitive to changes in the underlying assumptions—even beyond those that can be addressed with sensitivity analysis—the concept of duration also is often associated with risk. That is, an investment with a payback period of 1 year is far less susceptible to unanticipated risk than an investment with a 10-year payback, even if the results have been suitably discounted. We included duration as an output of the model to address similar concerns that were raised during our visits with airline representatives. Specifically, airline representatives cautioned that a positive business case required attention to the timing of the cash flows in addition to a suitably positive NPV.

To illustrate the concept of duration, consider the examples presented in Table 1. Although both investments have the same NPV, assuming an 8 percent discount rate, investment B generates the cash flows twice as fast as investment A. To the extent that both investments may involve unanticipated risk in the outyears, investment B is superior. Thus, the concept of duration measures the speed with which the cash flows are realized.

Table 1. Duration Example

Year	Investment A	Investment B
0	-$1,000	-$1,000
1	$0	$4,000
2	$0	$3,000
3	$0	$2,000
4	$11,698	$1,000
NPV at 8 percent	$7,598	$7,598
Duration	4.53	2.18

[8] For more information on the concept of duration see *Financial Management Theory and Practice*, 8th edition [7].

Other Output

In addition to the basic calculations of NPV and duration, the model provides a set of outputs including traffic, revenues, and expenses of the air carrier under each scenario. The set of outputs that are provided consist of

- equipment-specific traffic, revenue, life-cycle cost, and direct operating expenses by functional cost category for each scenario;
- airline-level traffic, revenue, life-cycle cost, direct and indirect operating expenses by functional category, and operating profits for each scenario; and
- airline-level annual discounted and nondiscounted cash flows.

The main benefit of accessing equipment-specific results is that the differential impact of new technology on different equipment types can be evaluated. The next section discusses the sensitivity analysis and simulation capabilities that supplement the basic outputs.

DATABASE OF ALTERNATIVE PARAMETERS

To support analysis tailored to specific airlines or groups of airlines, we developed a database of alternative parameter values. We integrated the database with the graphical user interface so the default parameters may be overwritten easily. A total of 16 airlines can be considered, as well as four airline groups. The groups correspond to the groups identified in *The ASAC Air Carrier Investment Model (Third Generation)* [20]. Table 2 summarizes the airlines and airline groups available from the database of alternative parameters.

Table 2. Air Carriers Available in the Database of Alternative Parameters

Air carrier	Associated group
Alaska Airlines	Nationals
Aloha Airlines	Shuttles
American Airlines	Large majors
America West Airlines	Nationals
Carnival AirLines	Nationals
Continental Airlines	Small majors
Delta Airline	Large majors
Kiwi International	Nationals
Midwest Express Airlines	Nationals
Northwest Airlines	Small majors
Reno Air	Nationals
Southwest Airlines	Nationals

Table 2. Air Carriers Available in the Database of Alternative Parameters (Continued)

Air carrier	Associated group
Trans World Airlines	Small majors
United Airlines	Large majors
U.S. Airways	Small majors
U.S. Airways Shuttle	Shuttles

When substituting parameters from a specific airline for the default parameters of the model, the baseline assumptions may no longer be appropriate. For example, the default assumptions for traffic growth rates among the large majors may not apply for shuttle operations. Therefore, we caution the user to examine the baseline assumptions carefully when customizing an analysis to particular air carriers.

Derivation of the Sensitivity Analysis and Simulation Capabilities

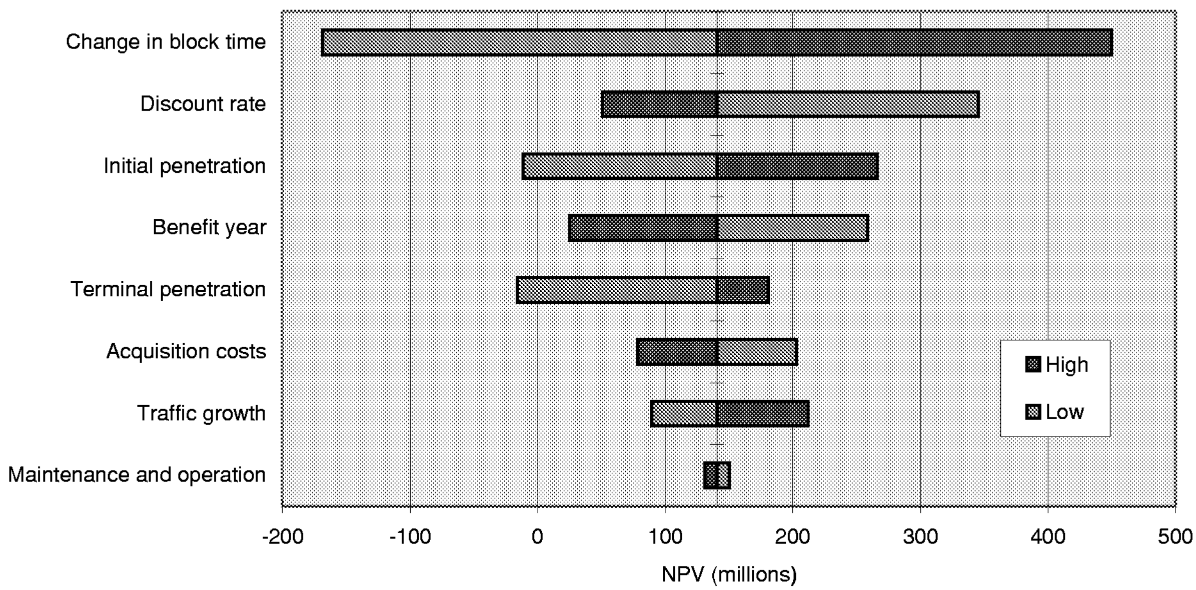
Because investment analysis is often highly sensitive to changes in the underlying assumptions, we envisioned a sensitivity analysis capability to supplement the basic output of the model. To support the capability, we developed two distinct types of analysis. First, we developed a sensitivity analysis capability that independently isolates the effect of each variable on the basic results. The output of this algorithm is a tornado diagram that summarizes the range of the basic outputs, given a range for each of the input variables, holding all other variables constant. Second, we developed a simulation capability that uses Monte Carlo draws to vary each input simultaneously. The output of this algorithm is a probability density function that summarizes the distribution of outcomes given ranges for each input variable. The following sections discuss each of the capabilities in greater detail.

Sensitivity Analysis Capability

To execute the sensitivity analysis capability, the user first identifies a set of variables for evaluation. Next, the algorithm requires a range of values defined by an upper and lower limit for each variable. We adopt the standard industry interpretation for the upper and lower limits as representing the 90 percent confidence interval. That is, with 90 percent probability, an observation will fall within the range specified by the high and low values. Thus, we adopt the convention that the limits represent the highest and lowest "reasonable" limits rather than the highest and lowest "conceivable" limits.

Once the sensitivity analysis variables have been identified and the range limits have been input, the algorithm varies each variable independently from its high value to its low value, holding all other variables constant. The algorithm records the effects of each value on the basic output and repeats the process for the next input variable. When the algorithm has iterated through all of the selected input variables, a standard tornado diagram is produced to summarize the results. Figure 9 illustrates a sample tornado diagram.

Figure 9. Sample Sensitivity Output



As shown in Figure 9, the tornado diagram arranges the input variables in descending order of impact. The magnitude of the impact is measured by the width of the horizontal bar. Similarly, the position of the vertical axis identifies the expected value for the output variable from the basic model. Thus, the interpretation of the first row of Figure 9 is that the expected value for NPV is approximately \$140 million, but varies from approximately -\$170 million to \$450 million as the change in block time is varied from its low value to its high value. Other lines have similar interpretations.

The sensitivity analysis capability is useful for evaluating the benefits of mitigating risk by identifying the variables responsible for the largest variation in the results. The identification enables decision-makers to focus on the most important risks to the success of an innovation. For risks under the control of the carrier, such as equipage penetration, the analysis shows the benefits of taking action to reduce the range of uncertainty. For risks not under the control of the carrier, such as traffic growth rates, the analysis shows the benefits of discovering more precise information about the range of uncertainty. In either case, the CBM shows the benefits of mitigating risk as reductions in the range of uncertainty. In addition, the benefits of risk mitigation are addressed with the simulation capability.

SIMULATION CAPABILITY

The inputs required by the simulation algorithm are identical to those required by the sensitivity analysis capability. We adopt the convention that the middle values for input parameters represent the most likely value. The user identifies the set of variables for consideration and inputs values for the upper and lower limits for each input variable. As in the sensitivity analysis algorithm, the simulation algorithm adopts the standard convention of the 90-percent confidence interval.

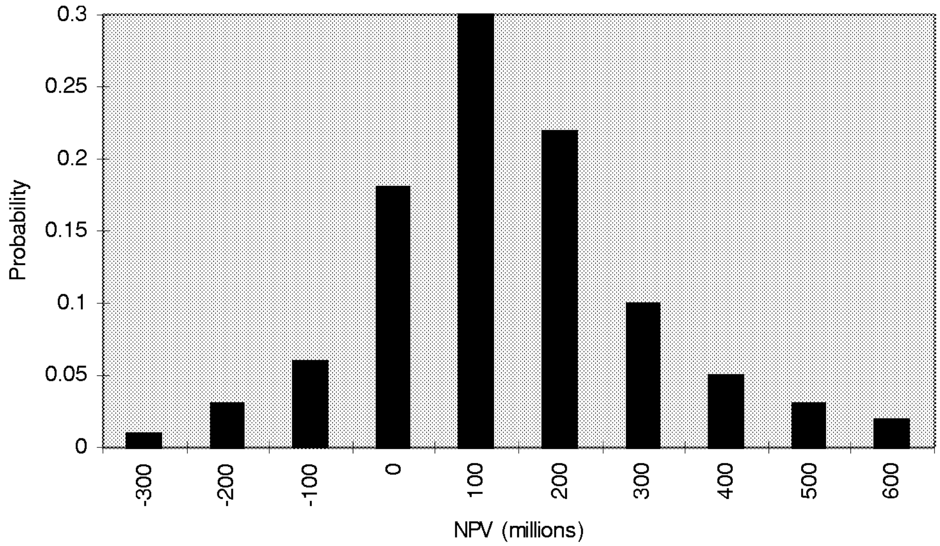
The execution of the simulation algorithm is more complex than the sensitivity analysis algorithm. For each input variable, the algorithm first translates the upper and lower limits into a probability distribution. For simplicity, we use a triangle distribution to translate the limits. The triangle distribution was a natural candidate because it represents a linear approximation of the normal distribution, but can be fully specified in terms of the upper and lower limits in conjunction with the most likely value. In translating from the upper and lower limits to a probability distribution, an adjustment is made to account for the interpretation of the limits as the 90-percent confidence interval. The adjustment is necessary because the triangle distribution requires input in the form of 99.99-percent confidence interval. Thus, with approximately 10 percent probability, the simulation algorithm may draw values outside the user-defined bounds of the 90-percent confidence interval. The cumulative distribution function for the triangle distribution is given in Equation 5.

$$\begin{aligned} F(x) &= \frac{(x-a)^2}{(b-a)(c-a)} \text{ for } a \le x \le b \\ F(x) &= 1 - \frac{(c-x)^2}{(c-a)(c-b)} \text{ for } b \le x \le c \end{aligned} \qquad \text{[Eq. 5]}$$

In Equation 5, a represents the lower bound (99.99-percent confidence interval), b represents the most likely value, and c represents the upper bound. Thus, a translation is required between the 10-percent confidence bounds input by the user and the 99.99-percent confidence bounds required by the simulation algorithm.

The simulation algorithm next draws a value for each input variable according to the appropriate probability distribution. This set of inputs is used by the model to calculate the set of outputs, which then are recorded. Next, the algorithm draws a new set of input values from the probability distributions and recomputes the model's output. The process is repeated a number of times and each iteration is recorded. Finally, the simulation algorithm summarizes the total variation in the output variables with a probability density function. Figure 10 illustrates a sample simulation output.

Figure 10. Sample Simulation Output



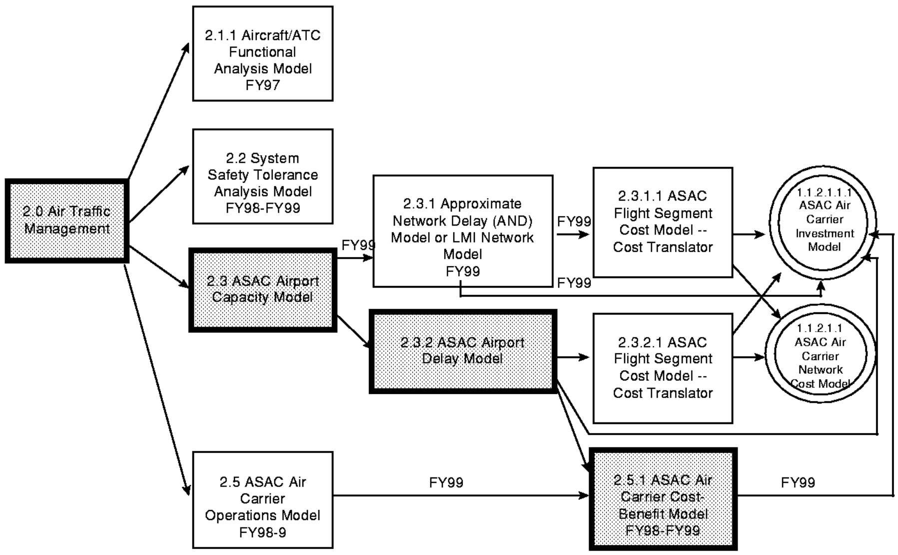
As shown in Figure 10, the total variation in NPV for the sample output is from approximately -\$300 million to \$600 million, with an expected value of approximately \$140 million. The next section demonstrates the use of the CBM for evaluating a hypothetical investment scenario.

Example Scenario

To illustrate the use of the CBM in the context of other ASAC models, this section shows an analysis chain that evaluates the benefits of a hypothetical set of air traffic management technologies. The set of technologies considered is designed to reduce air traffic congestion in the airport terminal area by reducing runway occupancy times (ROT) and separation standards in poor visibility conditions.[9] For this technology scenario, implementing lower ROT and separation standards requires installing several types of equipment on the ground and in the cockpit. Figure 11 illustrates the analysis chain.

[9] This scenario is for demonstration only and should not be viewed as an evaluation of an existing or proposed technology initiative.

Figure 11. Analysis Chain



As shown in Figure 11, we begin with the ASAC airport capacity model.[10] We model the effect of the new technologies on airport capacity independently for each of five major airports.[11] Airport capacity is a function of wind and weather conditions, airport configuration, and a set of technology-related parameters, such as ROT and arrival separation. Output from the airport capacity model subsequently is passed to the ASAC airport delay model, which projects delay in arrival and departure as a function of hourly demand and airport capacity. For each airport, we estimate delay with and without the capacity-enhancing technologies. The projected difference between the two scenarios becomes input for the ASAC CBM as described below.

DERIVING MODEL INPUTS

We model the effect of the hypothetical technologies on airport capacity by modifying the poor visibility, instrument meteorological conditions (IMC), arrival ROT, and separation standards to equal the good visibility, visual meteorological conditions (VMC), and values for each aircraft class. The result is a revised capacity for poor weather conditions for each airport configuration that approximates the good weather capacity.

Our technology scenario is based on the assumption that the benefits of the new technologies will be realized beginning in the year 2005. Accordingly, we specify projected traffic demand patterns for 2005 at each airport in the airport delay

[10] For more information on the ASAC airport capacity and delay models, see David A. Lee, et al. [18].

[11] The airports considered are ATL (Atlanta), DFW (Dallas-Ft.Worth), DTW (Detroit-Wayne County), LAX (Los Angeles), and LGA (New York LaGuardia).

model. The model uses a queuing engine to calculate the average arrival and departure delay on an hourly basis for each airport. For this analysis, we exercised the airport delay model over an entire year of actual meteorological conditions for each airport. We then aggregated the hourly and daily results to obtain average delay statistics for arriving and departing flights on an annual basis. We analyzed both a baseline and an improved technology scenario. The results from the airport capacity and delay models are summarized in Table 3.

Table 3. Projected 2005 Delay Statistics

Airport	Scenario	Average arrival delay (minutes)	Average departure delay (minutes)
ATL	Baseline	59.81	29.42
	Technology	55.52	25.92
DFW	Baseline	16.17	15.80
	Technology	15.85	16.02
DTW	Baseline	15.61	*
	Technology	12.72	*
LAX	Baseline	24.28	20.57
	Technology	23.90	20.36
LGA	Baseline	21.95	20.65
	Technology	19.71	18.60

*The Web version of the DTW airport delay model does not calculate departure delay.

Because the CBM requires input in the form of changes in block time, the next step was to convert the figures from Table 3 to percent changes in block time. The conversion requires an assumption about the average block time for departing and arriving flights at each airport. We used the 1995 DOT T-100 reports to define the current average block time for each. The averages subsequently were adjusted by the projected increase in delay from 1995 to 2005 to determine the projected average block times for 2005. As described in an earlier section, the default parameters and assumptions of the CBM represent a large major carrier. Therefore, we used the T-100 reports for the largest three carriers only to project average block time. The result was a projected change in arrival and departure average block times from the baseline scenario to the revised scenario for each airport.

To aggregate the effect of the technologies for all five airports, we constructed weights according to the number of operations at each airport by the largest three carriers. The result is a weighted average change in block time that will be used to extrapolate to the systemwide impact. Table 4 illustrates the methodology.

Table 4. Deriving Cost-Benefit Model Input

Airport	Annual operations[a]	Change in arrival block time (percent)	Change in departure block time (percent)
ATL	199,073	-2.7118	-2.6593
DFW	246,276	-0.2014	0.1385
DTW	12,476	-2.3990	-2.3990[b]
LAX	98,331	-0.1863	-0.1110
LGA	52,147	-1.6803	-1.3773
Weighted average	—	-1.1924	-0.9997

[a]1995 operations for American, Delta, and United.

[B]In the absence of departure delay information for DTW, we assume that departure delay equals arrival delay.

The final step in deriving the CBM inputs is to project the proportion of air traffic that will benefit from the new technology. Our hypothetical scenario is based on the assumption that the technologies will be in place at the 10 terminal area productivity (TAP) airports by 2005.[12] In addition, we assume that the technologies will be installed incrementally at the next largest 10 airports over the remainder of the forecast horizon.[13] To determine a benefit penetration curve for our representative air carrier, we further examined 1995 T-100 reports. For each flight segment in the T-100 report, one of four possibilities must be realized. The possibilities are the following:

1. The flight segment both departs from and arrives at airports with the new technologies.
2. The flight segment departs from an airport with the new technologies, but arrives at one without.
3. The flight segment departs from an airport without the new technologies, but arrives at one with.
4. The flight segment both departs from and arrives at airports without the new technologies.

Categorizing each flight segment according to the criteria above yields estimates of the proportion of flights benefiting from the new technology. We exercised the criteria separately for 2005, with the 10 TAP airports, and 2016 for the top 20 airports. However, because the CBM can incorporate only a single parameter for change in block time, constructing a weighted average across the categories was

[12] The 10 TAP airports are ATL, BOS (Boston), DFW, DTW, EWR (Newark), JFK (New York Kennedy), LAX, LGA, ORD (Chicago O'Hare), and SFO (San Francisco).

[13] The next 10 largest airports, by operations, are CLT (Charlotte), DEN (Denver), IAH (Houston), LAS (Las Vegas), MIA (Miami), MSP (Minneapolis-St. Paul), PIT (Pittsburgh), PHX (Phoenix), SEA (Seattle), and STL (St. Louis).

necessary to represent the benefit penetration. The methodology is illustrated in Table 5.

Table 5. Penetration Assumptions

Departure airport	Arrival airport	Operations 2005 (percent)	Operations 2016 (percent)	Change in block time (percent)
New technology	New technology	14.9	31.3	-2.1921
New technology	Baseline	31.6	28.7	-0.9997
Baseline	New technology	31.6	28.7	-1.1924
Baseline	Baseline	21.9	11.3	0.0000
2005 weighted average*	___	___	___	-1.3049

*Conditional on at least one airport having the new technology.

Thus, we adopt an initial benefit penetration of 78.1 percent with an initial reduction of 1.3049 percent in block time. Over the forecast period, the penetration grows to 88.7 percent, although the impact remains constant. This assumption does not account for the effect of further block time reductions as more and more flights both depart from and arrive at airports with the new technology. Thus, our estimates of the benefits of the hypothetical technology should be viewed as conservative.

We make the following assumptions regarding the life-cycle costs of the new technology for airline operators:

- $355,200 per aircraft for acquisition and installation of new cockpit avionics
- $2,500 per flight crew as initial training expense
- $1.15 per block hour as operation and maintenance expense
- $500 per flight crew as recurring annual training expense.

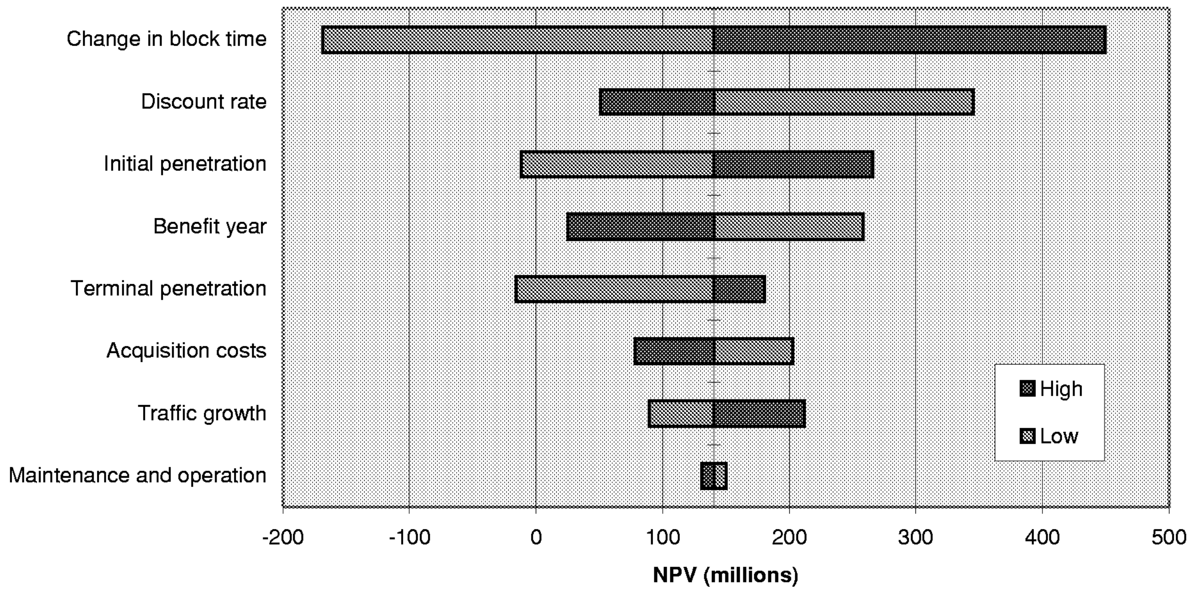
Our equipage penetration assumption is that all aircraft will be equipped during 2005 to take advantage of the block time benefits.

SCENARIO RESULTS

We exercised the model under the assumptions discussed above. The main result shows that the hypothetical technologies do benefit the representative carrier modestly. We estimate the NPV of the investment to be $140.62 million at a discount rate of 8 percent. In addition, the investment has a large duration of 25.34, which correctly indicates that the stream of benefits is far into the future.

To analyze the sensitivity of the main results to variation in the input data, we exercised the sensitivity analysis module for several key variables. As shown in Figure 12, the variables include change in block time, discount rate, penetration assumptions, life-cycle costs, and traffic-demand growth. In exercising the sensitivity analysis module, we made a simple assumption that the low and high values were 50 and 150 percent of the middle values, respectively.

Figure 12. Sensitivity Results



Under these assumptions, the hypothetical technologies clearly contain several risks that threaten the projected benefits. The most substantial risk is caused by uncertainty in the magnitude of the savings of block time. The uncertainty issue might be particularly risky if the magnitude of the time savings depended on the equipage of other carriers' aircraft. The dependence is likely when considering air traffic management technologies that affect variables such as separation standards. Other important risks are caused by the timing and penetration assumptions. If the technology benefits slip in relation to the year of equipage, the benefits will erode quickly. Thus, the analysis indicates several variables that decision-makers would need to investigate further before committing valuable resources.

Conclusions

This report describes an Air Carrier CBM that meets the requirements of NASA and the integrated aviation community for assessing the financial impact on commercial air carriers of investments in aviation technology. The ASAC CBM is a flexible financial analysis tool that integrates well with other ASAC models to form comprehensive analysis chains. In this way, the CBM focuses on financial analysis issues and relies on other ASAC models for operational inputs.

To conduct financial analysis, the CBM integrates an activity-based model of aircraft operating costs with a life-cycle cost module for new equipment acquisition and training. By using a variant of the operating cost model developed for the FCM, the CBM calculates aircraft DOCs at the equipment level of aggregation. This feature allows the user to model the effects of new technology differentially by equipment type. The model addresses a large set of benefit categories, including time and fuel savings, utilization opportunities, reliability benefits, safety and security benefits, capacity enhancements, and risk mitigation.

The model's benefit calculations are driven by differences between an established baseline scenario and a revised technology scenario. By comparing the differences, the CBM eliminates ambiguity in interpreting the relative benefits. The basic outputs of the model are calculations of NPV and duration and projections of revenue, cost, and traffic under the baseline and revised scenarios. The calculations are available at the equipment level of detail.

The model's default parameters are derived from DOT Form 41 reports for the largest three U.S. carriers. By using this basis for the default parameters, we can ensure that the model characterizes a representative airline and is applicable for consensus building. The model also incorporates a database of alternative parameters by airline and by airline group. The database enables the analyst to customize analysis to specific air carriers.

The model incorporates a sophisticated sensitivity analysis and simulation capability. This feature enables the user to evaluate the impact of variation in the input parameters on the basic outputs of the model. The sensitivity analysis capability varies each input parameter independently while holding all other variables constant. The simulation capability uses Monte Carlo simulation to vary each of the input parameters simultaneously. The output of the sensitivity analysis algorithm is a standard tornado diagram, and the output of the simulation algorithm is a probability distribution.

This report illustrates the CBM in the context of an air traffic management analysis chain. The hypothetical technology scenario demonstrates net benefits, but also exhibits substantial risks. The sensitivity analysis module identifies several variables that can be further investigated to clarify the most important dimensions of the uncertainty.

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[12] *Current Market Outlook* (various editions), Boeing Commercial Airplane Group, Seattle, Washington.

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[20] NASA Contractor Report, NS702S1, *The ASAC Air Carrier Investment Model (Third Generation)*, Earl R. Wingrove, et. al., April 1998.

[21] *World Air Cargo Forecast 1996/1997*, Boeing Commercial Airplane Group, Seattle, Washington, October 1996.

Appendix A
Review of Existing Cost-Benefit Methodologies

A primary objective of the first phase of the task to develop the ASAC Air Carrier CBM was to review existing aviation cost-benefit methodologies. To accomplish this goal, we gathered a wide variety of material ranging from comprehensive aggregate-level methodologies, such as the International Civil Aviation Organization (ICAO) guidelines, to specific cost-benefit analyses, such as the Flight Dynamics' model. We gathered documentation for and reviewed a total of nine existing cost-benefit models and methodologies.[1] These materials consist of the following:

[1] "Benefit and Cost Analysis Appropriate to the Flight Avionics and Airline Industry—An Introductory Guide." Unpublished technical document, Honeywell, Inc., April 1993.

[2] "Cost-Benefit Model." Unpublished technical document, Flight Dynamics, Inc., August 1996.

[3] *Cost, Benefit, and Risk Assessment Guidelines for RE&D Investment Portfolio Development*. Document prepared for the Program Analysis and Operations Research, ASD-400 and Research Division, AAR-200 of the Federal Aviation Administration by Volpe National Transportation Systems Center. Cambridge, Massachusetts: December 1996.

[4] *Economics of Satellite-Based Air Navigation Services—Guidelines for Cost-Benefit Analysis of Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) Systems*. Montreal, Canada: International Civil Aviation Organization, 1995.

[5] "Estimating CTAS Benefits Nationwide." Briefing materials prepared by George Hunter, Seagull Technology, July 1995.

[6] *Guidelines for the Economic Appraisal of EATCHIP Projects—the Effective Use of Cost-Benefit Studies*. Geneva Switzerland: International Air Transport Association (IATA), June 1996.

[7] Model and supporting documents regarding the RTCA Project Free Flight Business Model.

[8] *NASA Aeronautics Cost-Benefit Analysis (NACBA) Model—User's Manual*. Jenkintown, Pennsylvania: GRA, INC., July 1997.

[1] A comprehensive review of the cost-benefit models is available separately from the authors.

[9] Presentations and various supporting documents regarding the cost-benefit approach of the CNS/ATM-focused team (C/AFT).

In order to characterize each of the cost-benefit methodologies, we developed a set of classification criteria that are summarized in Table A-1.

Table A-1. Characteristics of Existing Cost-Benefit Methodologies

Cost-benefit material	Methodology or model	Primary user	Scope of costs and benefits	Modeling approach	Level of detail
Honeywell	Methodology with examples	Airline operator	Airline operator	Bottom-up	Phases of a flight segment
Flight Dynamics	Model	Airline operator	Airline operator	Bottom-up	Phases of a flight segment
Volpe	Methodology	Government decision-maker	Integrated aviation community	Top-down	Industry-wide equipment-level averages
ICAO	Methodology with examples	Government decision-maker	Integrated aviation community	Top-down	Industry-wide averages
Seagull	Methodology with examples	Government decision-maker	Commercial aviation	Bottom-up	Flight segment
EATCHIP	Methodology	Government decision-maker	Integrated aviation community	Top-down	Industry-wide averages
RTCA	Model	Government decision-maker	Integrated aviation community	Top-down	Industry-wide averages
NACBA	Model	Government decision-maker	Integrated aviation community	Top-down	Industry-wide averages
C/AFT	Methodology with examples	Airline operators	Airline operators	Top-down	Phases of a flight segment

As shown in Table A-1, two basic types of materials are aggregate-level cost-benefit methodologies and the finely detailed cost-benefit models. Some methodologies, such as the ICAO guidelines, were also accompanied by sample calculations that are not referred to as models per se. Generally, the primary users of the aggregate-level methodologies were government decision makers while the intended users of the finely detailed models were airline operators. Two important exceptions to this generalization are NASA Aeronautics Cost-Benefit Analysis (NACBA), which is an aggregate-level model intended for decision-makers at NASA, and C/AFT, which is a finely detailed methodology intended for airline operators. Generally, the scope of the costs and benefits considered by the aggregate-level methodologies was the integrated aviation community and the scope of the models was limited to airline operators. The methodologies generally took a top-down approach in which industry-wide average values are used to populate parameters at a highly aggregated level of detail. Conversely, the models tended to take a bottom-up approach in which the results from specific flight segments are extrapolated to obtain airline-level estimates.

The top-down modeling approach embodied in many of the aggregate-level methodologies has been criticized by representatives from commercial aviation as lacking sufficient detail for credibility with the airlines.[2] A primary criticism of the aggregate-level approach has been a failure to treat the aviation system as a highly integrated environment in which the relaxation of a constraint in one area may lead to additional constraints in other areas. For example, a technology that reduces final-approach separation standards may simply shift the bottleneck from the approach airspace to the taxiway and gate areas. In such cases, the benefits derived from an aggregate-level approach that does not consider the full complexity of the airspace environment tend to be overestimated. One of the primary objectives of the C/AFT is to develop a more appropriate cost-benefit methodology that takes into consideration the highly integrated nature of the air transportation system.

[2] See, for example, References [4] and [9].

Appendix B
Operating Expenses

This appendix consists of two sections. The first documents the accounting items and schedules that comprise the DOT Form 41 reports. The second describes how we allocated various accounts to functional categories for developming the Air Carrier Cost-Benefit Model.

DOT Form 41 Report Schedules

The DOT Form 41 reports consist of a series of schedules that document the financial and operational status of the air carrier. Table B-1 summarizes the Form 41 schedules.

Table B-1. Form 41 Report Schedules

Schedule	Title	Frequency	Aggregation
A	Certification	Quarterly	Airline
B-1	Balance Sheet	Quarterly	Airline
B-12	Statement of Cash Flows	Quarterly	Airline
B-43	Inventory of Airframes and Aircraft Engines	Annually	Airline
B-7	Airframe and Aircraft Engine Acquisition and Retirement	Quarterly	Airline
P-1	Interim Income Statement	Monthly	Airline
P-1.2	Statement of Operations	Quarterly	Airline
P-2	Notes to RSPA Form 41 Report	Quarterly	Airline
P-5.1	Aircraft Operating Expenses—Group I carriers	Quarterly	Equipment
P-5.2	Aircraft Operating Expenses-Group II and III carriers	Quarterly	Equipment
P-6	Aircraft Operating Expenses by Objective Groups	Quarterly	Airline
P-7	Aircraft Operating Expenses by Functional Groups	Quarterly	Airline
P-10	Employment Statistics by Labor Category	Annually	Airline
P-12	Fuel Consumption by Type of Service and Entity	Monthly	Airline
T-100	Traffic and Segment (Origin and Destination)	Monthly	Airline
T-2	Traffic, Capacity, and Operations	Quarterly	Equipment

In developing the CBM, we made extensive use of several of the schedules indicated in Table B-1. In particular, we used schedules P-1.2, P-5.2, and P-7. The accounts for each of these schedules is illustrated in Tables B-2 through B-4.

Table B-2. Accounts of Schedule P-1.2, Statement of Operations

Category	Account	Description
Operating revenue	3901.1	Passenger—first class
	3901.2	Passenger—coach
	3905.0	Mail
	3906.1	Property—freight
	3906.2	Property—excess passenger baggage
	3907.1	Charter—passenger
	3907.2	Charter—freight
	3919.1	Reservation cancellation fees
	3919.2	Miscellaneous operating revenue
	4808.0	Public service—subsidy
	4898.0	Transport-related
	4999.0	Total operating revenue
Operating expense	5100.0	Flying operations
	5400.0	Maintenance
	5500.0	Passenger service
	6400.0	Aircraft and traffic servicing
	6700.0	Promotion and sales
	6800.0	General and administrative
	7000.0	Depreciation and amortization
	7100.0	Transport-related
	7199.0	Total operating expenses
	7999.0	Operating profit (loss)
Non-operating income/expense	8181.0	Interest on debt and capital lease
	8182.0	Other interest expense
	8185.0	Foreign exchange gains (losses)
	8188.5	Capital gains
	8188.6	Capital losses
	8189.0	Other income and expense
	8199.0	Non-operating income (expense)
	8999.0	Income before taxes
Income taxes	9100.0	Income taxes
	9199.0	Income after income tax
Discontinued operations	9600.0	Discontinued operations
Extraordinary items	9796.0	Extraordinary items
	9797.0	Taxes for extraordinary items
Accounting changes	9800.0	Accounting changes
Net income	9899.0	Net income

Table B-3. Accounts of Schedule P-5.2,
Aircraft Operating Expenses—Group II and III Carriers

Category	Account	Description
Flying operations	5123.0	Pilots and copilots
	5124.0	Other flight personnel
	5128.1	Trainees and instructors
	5136.0	Personnel expense
	5145.1	Aircraft fuel
	5145.2	Aircraft oil
	5147.0	Aircraft rental
	5153.0	Other supplies
	5155.1	Insurance purchase general
	5157.0	Employee benefits and pensions
	5158.0	Injuries, loss, and damage
	5168.0	Taxes—payroll
	5169.0	Taxes—other than payroll
	5171.0	Other flying operations expense
	5199.0	Total flying operations expense
Maintenance—flight equipment	5225.1	Labor—airframes
	5225.2	Labor—aircraft engines
	5243.1	Airframe repairs
	5243.2	Aircraft engine repairs
	5143.7	Aircraft interchange charges
	5246.1	Maintenance materials—airframe
	5246.2	Maintenance materials—engines
	5272.1	Airworthiness allowance—airframe
	5278.0	Total direct maintenance—flight equipment
	5279.6	Applied maintenance burden—flight equipment
	5299.0	Total flight equipment maintenance
Net obsolescence	7073.9	Obsolescence and deterioration
Depreciation—flight equipment	7075.1	Depreciation—airframes
	7075.2	Depreciation—aircraft engines
	7075.3	Depreciation—airframe parts
	7075.4	Depreciation—aircraft engine parts
	7075.5	Depreciation—other flight equipment
	7076.1	Amortization—capital leases
Total aircraft operating expense	7098.9	Total aircraft operating expense

Table B-4. Accounts of Schedule P-7,
Aircraft Operating Expenses by Functional Groupings

Category	Account	Description
Aircraft operating expense	2	Aircraft operating expense
Passenger service expense	5	Flight attendant
	6	Food
	7	Other in-flight service
	8	Total passenger service
Aircraft service expense	10	Line servicing
	11	Traffic control
	12	Landing fees
	13	Total aircraft service
Traffic service expense	15	Directly assignable—passenger
	16	Directly assignable—cargo
	17	Not directly assignable
	18	Total traffic service
Reservation and sales expense	20	Directly assignable—passenger
	21	Directly assignable—cargo
	22	Not directly assignable
	23	Total reservation and sales
Advertising and promotion expense	25	Directly assignable—passenger
	26	Directly assignable—cargo
	28	Total advertising and promotion
General and administrative expense	29	Total general and administrative
Ground property and equipment expense	31	Maintenance
	32	Depreciation
	33	Total maintenance and depreciation
Depreciation expense	34	Depreciation expense—maintenance equipment
Amortization	35	Amortization—other than flight equipment
Total servicing, sales, and operating expense	36	Total servicing, sales, and operating expense
Transport-related expense	37	Transport-related expense
Total operating expense	38	Total operating expense

ALLOCATING FORM 41 ACCOUNTS TO FUNCTIONAL COST CATEGORIES

As described in the main body of this report, the core calculations of the Air Carrier CBM are based on a functional decomposition of airline operating costs. Passenger and cargo revenue parameters are derived at the airline level of aggregation from Schedule P-1.2. Direct operating costs are derived at the equipment level of detail from Schedule P-5.2. Finally, indirect operating costs are derived at the airline level of aggregation from schedule P-7. Tables B-5 through B-7 illustrate the derivation of the cost and revenue parameters.

Table B-5. Revenue Components

Revenue category	Accounts from schedule P-1.2
Passenger revenue	3901.1, 3901.2, 3906.2, 3907.1, 3919.1
Cargo revenue	3905.0, 3906.1, 3907.2
Other revenue	3919.2, 4808.0, 4898.0

Table B-6. Direct Operating Cost Components

Functional cost category	Accounts from schedule P-5.2
Fuel	5145.1, 5169.0
Flight personnel compensation	5123.0, 5124.0, 5136.0, 5157.0, 5168.0
Flight personnel training	5128.1
Airframe maintenance	5225.1, 5243.1, 5243.7, 5246.1, 5272.1
Aircraft engine maintenance	5225.2, 5243.2, 5246.2, 5272.6
Maintenance burden	5279.6
Insurance-loss/damage	5155.1, 5158.0
Other direct operating expenses	5145.2, 5153.0, 5171.0, 7073.9

Because we develop our own measures of aircraft capital expenditures, we do not make use of the aircraft rental expenses from account 5147.0 and aircraft-related depreciation and amortization expenses from accounts 7075.1 through 7076.1.

Table B-7. Indirect Operating Cost Components

Indirect cost category	Accounts from schedule P-7
Air traffic control expense	11
Landing fees	12
Other indirect operating expense	8, 10, 18, 23, 28, 29, 33, 34, 35, 37

Appendix C

Baseline Assumptions

As described in the main body of this report, an important feature of the ASAC Air Carrier CBM is the identification of a baseline scenario against which changes in technology are measured. To specify default values for these assumptions, we examined several aviation forecasts as well as other published materials. These included the *FAA Aviation Forecast Fiscal Years 1998–2000* [6], *The 1996/1997 Boeing World Air Cargo Forecast* [21], *The Economic Impacts of Air Traffic Congestion* [15], and a database of historical data derived from DOT Form 41 reports. In specifying values for the key assumptions, we gave priority to the published sources whenever possible, although in many instances we resorted to recent trends from the Form 41 database. Although the baseline scenario represents our best attempt to project future developments in aviation in the absence of technological innovation, the model enables the user to modify the baseline assumptions to reflect a customized baseline.

As described in the main body of this report, the base-year parameters are derived directly from Form 41 reports. The assumptions of the model represent constant-dollar compound annual rates of change from the base-year value for each variable. Thus, the assumptions represent real changes in a variable as opposed to nominal changes. Table C-1 documents the value and source for the assumptions of the baseline scenario.

In defining the baseline scenario, it is important to recognize that the current airspace operating environment is rapidly becoming congested. In the absence of new technology or other capacity enhancements, the air carriers are unlikely to continue operating as they do today. Nevertheless, published forecasts, such as References [6], [12], and [20] tend to be driven exclusively by demand conditions and generally are based on the assumption that capacity will expand to meet the forecast demand. In evaluating the benefits of these capacity enhancements, however, establishing a baseline scenario that accurately reflects the constrained environment projected in the absence of new technology is essential. As described in Reference [15], we have developed a forecast methodology in the face of capacity shortfalls. The baseline assumptions illustrated in Table C-1 reflect the results of this research. Therefore, we measure the benefits of new technology against a baseline scenario in which capacity constraints are evident.

Table C-1. Default Baseline Scenario Assumptions

Variable	Value	Source
Passenger traffic	3.64	Congestion Report
Load factor	0.00	FAA Forecast
Fare yield (97-01)	-1.37	Congestion Report
Fare yield (02-06)	-0.13	Congestion Report
Fare yield (07-11)	0.08	Congestion Report
Fare yield (12-16)	0.20	Congestion Report
Average cargo load	1.50	Form 41
Cargo yield	-1.00	Boeing World Air Cargo Forecast
Fuel price	0.30	FAA Forecast
Flight personnel labor	0.84	Form 41
Maintenance burden rate	0.00	Form 41
Other direct operating costs	0.00	Form 41
Air traffic control fees	-3.77	Form 41
Landing fees	1.66	Form 41
Other indirect costs	-3.60	Form 41
Utilization	1.19	Congestion Report
Average stage length	2.14	Form 41
Average block time	2.33	Congestion Report
Fuel efficiency	0.00	Form 41
Airframe maintenance	-1.70	Form 41
Engine maintenance	-2.51	Form 41
Aircraft capital	0.00	Form 41
Insurance-loss/damage	0.00	Form 41
Flight personnel training	0.00	Form 41

Note: All values represent compound annual rates of growth in the indicated variable.

In addition to the assumptions illustrated in Table C-1, we made a set of assumptions regarding the proportion of traffic carried by various equipment types. Recognizing that the default assumptions are derived for a representative large major air carrier is important. We began by allocating each equipment type to one of four categories on the basis of its noise characteristics and our expectation for future fleet acquisitions and retirements. The four categories consist of Stage 2 aircraft, Stage 3 aircraft no longer in production, Stage 3 aircraft in production for which we expect minimal growth in fleet, and Stage 3 aircraft in production for which we expect substantial growth.[1] The default assumptions retire the Stage 2 aircraft from the fleet by 2000 and the Stage 3 aircraft no longer in production by the end of the forecast period. The Stage 3 aircraft for which we expect minimal growth are assumed to hold their present share of the total traffic, and all of the growth is distributed to the remaining Stage 3 aircraft. As for other baseline assumptions, the assumptions of the aircraft's RPM share are editable by the user.

The results derived from the baseline scenario are summarized by Table C-2.

Table C-2. Baseline Results

Variable	1996 Value	2001 Value	2006 Value	2011 Value	2016 Value
RPM (billions)	105.10	125.70	150.30	179.70	214.90
Block hours (millions)	2.10	2.70	3.60	4.80	6.50
Aircraft fleet	582.00	640.00	799.00	1,005.00	1,2640.00
Operating revenue (billions)	14.90	16.90	20.20	24.40	29.50
Operating expense (billion)	14.40	16.50	19.50	23.4	28.60
Adjusted operating profit margin (percent)	3.68	2.41	3.65	4.0	3.10

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

Appendix D
Aircraft Equipment Types

As described in the main body of this report, the parameters of the model are populated at the equipment level of detail. In general, we adopted the equipment-type definitions from DOT Form 41 reports. In a few cases, we chose to consolidate closely related equipment types, such as the Lockheed L1011-50, -100, and -500. The model explicitly considers only those equipment types in the fleet of the specified carriers as of year end 1996. Table D-1 summarizes the equipment types addressed by the model.

Table D-1. Aircraft Models Considered by the Model

Aircraft model	Manufacturer	Model type
A-300-600/R/CF/RCF	Airbus	Multi-aisle
A-300-B4	Airbus	Multi-aisle
A320-200	Airbus	Single-aisle
B727-200	Boeing	Single-aisle
B737-100/200/200C	Boeing	Single-aisle
B737-300	Boeing	Single-aisle
B737-400	Boeing	Single-aisle
B737-500	Boeing	Single-aisle
B747-100/200B/F	Boeing	Multi-aisle
B747-400	Boeing	Multi-aisle
B757-200/EM	Boeing	Single-aisle
B767-200/EM/ER	Boeing	Multi-aisle
B767-300/ER	Boeing	Multi-aisle
B777-200	Boeing	Multi-aisle
MD-80 (all versions)	Boeing	Single-aisle
DC-10-10/30/40/C/CF	Boeing	Multi-aisle
DC-9 (all versions)	Boeing	Single-aisle
F28-4000	Fokker	Single-aisle
F100	Fokker	Single-aisle
L1011-50/100/500	Lockheed	Multi-aisle
MD-11	Boeing	Multi-aisle
MD-90/B717	Boeing	Single-aisle

Appendix E

Glossary of Airport Identifiers

ATL	The William B. Hartsfield Atlanta International Airport, Atlanta, Georgia
BOS	General Edward Lawrence Logan International Airport, Boston, Massachusetts
CLT	Douglas Airport, Charlotte, North Carolina
DEN	Denver International Airport, Denver, Colorado
DFW	Dallas-Fort Worth International Airport, Dallas/Fort Worth, Texas
DTW	Detroit Metropolitan Wayne County Airport, Detroit, Michigan
EWR	Newark International Airport, Newark, Ohio
IAH	Houston Intercontinental Airport, Houston, Texas
JFK	John F. Kennedy International Airport
LAS	McCarran International Airport, Las Vegas, Nevada
LAX	Los Angeles International Airport, Los Angeles, California
LGA	La Guardia Airport, New York, New York
MIA	Miami International Airport, Miami, Florida
MSP	Minneapolis-Saint Paul International Airport, Minneapolis-Saint Paul, Minnesota
ORD	Chicago O' Hare International Airport
PHX	Phoenix (Sky Harbor) International Airport, Phoenix, Arizona
PIT	Pittsburgh International Airport, Pittsburgh, Pennsylvania
SEA	Seattle-Tacoma International Airport, Seattle, Washington
SFO	San Francisco International Airport, San Francisco, California
STL	Lambert Field, Saint Louis, Missouri

Appendix F
Abbreviations

ACAS	Aircraft Analytical System
ACIM	Air Carrier Investment Model
ASAC	Aviation System Analysis Capability
ASM	available seat miles
AST	Advanced Subsonic Technology
CBM	cost-benefit model
DOC	direct operating costs
DOT	Department of Transportation
FAA	Federal Aviation Administration
FCM	Functional Cost Module
FSCM	Flight Segment Cost Model
IMC	instrument meteorological conditions
NPV	net present value
ROT	runway occupancy times
RPM	revenue passenger miles
RTCA	Radio Technical Commission for Aeronautics
RTM	revenue ton miles
TAP	terminal area productivity
VMC	visual meteorological conditions

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13. ABSTRACT *(Maximum 200 words)*

To accomplish its objective of assisting the U.S. aviation industry with the technological challenges of the future, 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 industry is central to its conception. Commercial air carriers, in particular, are an important stakeholder in this community. Therefore, to fully evaluate the implications of advanced aviation technologies, ASAC requires a flexible financial analysis tool that credibly links the technology flight with the financial performance of commercial air carriers. By linking technical and financial information, NASA ensures that its technology programs will continue to demonstrate benefits to the user community.
This report describes an Air Carrier Cost-Benefit Model (CBM) that meets these requirements. The ASAC CBM is distinguished from many aviation cost-benefit models by its exclusive focus on commercial air carriers. The model considers such benefits as time and fuel savings, utilization opportunities, reliability enhancements, and safety and security improvements. The model incorporates a life-cycle cost module for new technology, which applies the costs of acquisition, recurring maintenance and operation, and training to each aircraft type independently. The CBM calculates operating costs using an activity based cost approach developed for the ASAC Air Carrier Investment Model. The main outputs of the model are net present value and duration calculations that summarize the financial impact of investment in new technology. Finally the model incorporates a sensitivity analysis and simulation capability.

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