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The Integrated Air Transportation System Evaluation Tool

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Chapter 1

Introduction

Throughout the history of the United States, our nation has generally enjoyed exceptional economic growth, driven in part by transportation advancements. Four hundred years ago, wealth was created at seaports, 200 years ago at river- and canal-ports, 100 years ago at railheads, and beginning 50 years ago at interstate highway on/off-ramps. During the 1980s, the introduction of the nation's hub-and-spoke system for air travel continued this economic phenomenon. Looking forward 25 years, when the national highway and skyway systems are saturated, the nation faces new challenges in creating transportation-driven economic growth and wealth.

Several converging forces are fundamentally reshaping transportation demand characteristics in the first decade of the 21st century, including the following:

1. The maturing of the hub-spoke infrastructure into the saturation phase of its natural growth cycle (or "hub-lock") by about 2008;

2. The increasing "gridlock" on the nation's already mature highway system;

3. A potential "third wave" migration of Americans and their jobs from the suburbs to locations farther away from major city centers;

4. The peak of the Baby Boomer generation's spending and traveling;

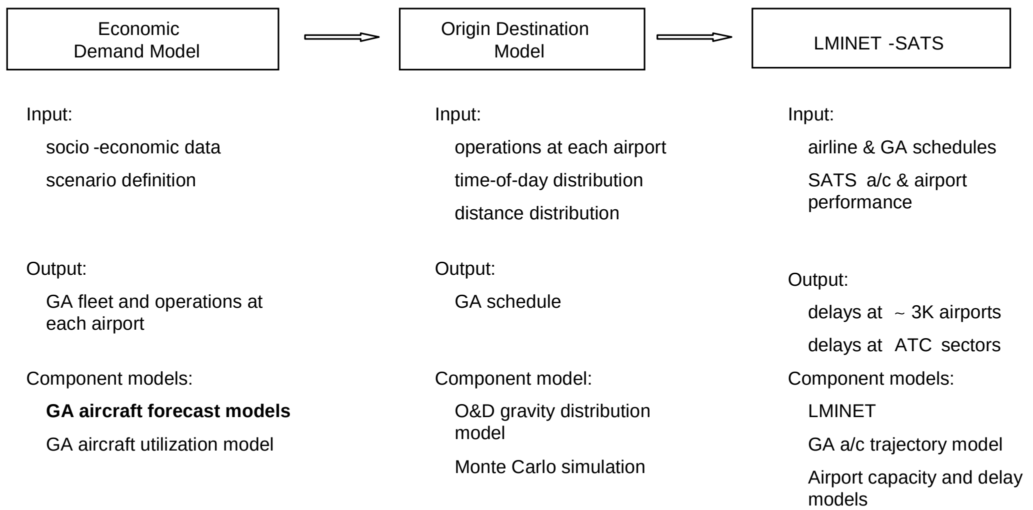
5. The transformation of industry from standardized products and services targeting mass markets to customized products and services targeting segmented markets; and

6. The increasing value of human time during the information age (and therefore, the premium value of doorstep-to-destination speed).

To meet the national requirement for an improved air traffic management system, NASA developed the goal of tripling throughput over the next 20 years, in all weather conditions, while maintaining safety. Analysis of the throughput goal has focused primarily on major airline operations, primarily through the hub-and-spoke system; however, many suggested concepts to increase throughput may operate outside the hub and spoke system. Examples of such concepts include the Small Aircraft Transportation System (SATS), civil tiltrotor, and improved rotorcraft. Proper assessment of the potential contribution of these technologies to the domestic air transportation system requires a modeling capability that includes the country's numerous smaller airports, acting as a fundamental component of the National Airspace System, and the demand for such concepts and technologies.

In FY 2000, NASA began development of such a modeling capability through work undertaken by the Logistics Management Institute. Our research this year used the previously developed SATS Demand Model[1] as a starting point. Figure 1-1 shows the components, inputs, and outputs of the prior modeling chain and the front-end we developed this year (in bold).

Figure 1-1. SATS Demand Model



Under this task, we included higher fidelity demand forecasting that captures the interdependence of short-haul air travel with other transportation modes and explicitly considers the costs of commercial air and other transport modes. To accomplish this work, we generated forecasts of the distribution of general aviation (GA) based aircraft and GA itinerant operations at each of nearly 3,000 airports based on changes in economic conditions and demographic trends. We also built modules that estimate the demand for travel by different modes, particularly auto, commercial air, and GA. We examined GA demand from two perspectives: top-down and bottom-up, both of which are described in greater detail in subsequent chapters of this report.

[1] Dou Long, Jesse Johnson, et al., in NASA/CR-2001-210874.

Chapter 2
Forecasted GA Demand at the Airport Level

One of our fundamental pieces of analysis was to uncover a relationship between economic and demographic data and the level and distribution of historic GA flights. We use the Federal Aviation Administration (FAA) terminology that describes the phrase “general aviation” as a diverse range of aviation activities and includes all segments of the aviation industry except commercial air carriers (including commuter/regional airlines) and military. GA activities include providing training for new pilots, sightseeing, moving heavy loads by helicopter, and flying for corporate, business, and personal reasons. GA aircraft range from one-seat single-engine piston planes to long-range corporate jets. In this parlance, air taxi flights are a subset of GA flights when the pilot is for-hire rather than one of the travelers.

There are more than 5,000 airports and approximately 12,000 landing strips in the United States. The most comprehensive databases about these airports are the FAA’s Terminal Area Forecast (TAF) and the National Plan of Integrated Airport Systems (NPIAS). For each airport in the database, TAF maintains information about enplanements, operations, and based aircraft.

The term “enplanement” refers to one passenger boarding a commercial aircraft. There are three categories of enplanements: air carrier, commuter/regional, and air taxi. Because enplanements apply to commercial transportation only, numerous airports report zero enplanements although they have general aviation activity other than air taxi.

“Based aircraft” refers to the number of aircraft, by type, habitually located at an airport. The aircraft types are single-engine based (SEB), multi-engine based (MEB), jet-engine based (JEB), helicopter, and other.[1] Because the aircraft of commercial air carriers are never based at any airport, the reported based aircraft are GA only.

“Operation” is defined as either an aircraft takeoff or landing; therefore, a flight includes two operations by definition. Operations can be classified by purpose. Operations can be itinerant (takeoff at one airport and landing at another airport) or local (takeoff and landing at the same airport). The type of aircraft undertaking the operation can be air carrier, commuter/regional, general aviation, or military. Categories for operations are air carrier itinerant, commuter/regional itinerant, general aviation itinerant, military itinerant, general aviation local, and military local. (There are no local air carrier or local commuter/regional operations).

[1] For simplicity, we assume that the SEB category consists of single-engine piston aircraft and that the MEB category consists of multi-engine piston aircraft and turboprop aircraft.

In the NPIAS, airports are classified as shown in Table 2-1:

- Large hub—enplanements are more than 1 percent of the total U.S. enplanements;
- Medium hub—enplanements are more than 0.25 percent of the total but less than 1 percent;
- Small hub—enplanements are more than 0.05 percent of the total but less than 0.25 percent;
- Non-hub primary—enplanements are more than 10,000 but less than 0.05 percent;
- Other commercial—enplanements are more than 2,500 but less than 10,000 annually; and
- Reliever—GA airports located close to major metropolitan areas.

Table 2-1. Airport Activity Distribution

Airport type	Number of airports	Percentage of all enplanements	Percentage of active GA aircraft
Large hub	29	67.3	1.3
Medium hub	42	22.2	3.8
Small hub	70	7.1	4.7
Non-hub primary	272	3.3	11.4
Other commercial	125	0.1	2.1
Reliever	334	0.0	31.5
Other GA	2,472	0.0	37.3
TAF	Total 3,344	100.0	92.1

Source: NPIAS.

TAF airports cover 98 percent of the domestic U.S. population within 20 miles of airport radii. The airports are distributed roughly one per county in rural areas and often are located near the county seat. Of all TAF airports, 95 percent are considered to have good or fair runway pavement. For the LMINET-SATS model, we consider a network of 2,865 airports after excluding TAF airports in Alaska, Hawaii, Puerto Rico, and Guam and including only those TAF airports that had 10 or more GA itinerant operations in 1998.

In addition to the NPIAS and TAF data, we purchased and worked extensively with the *County Projections to 2025* data from Woods and Poole. This data set consists of economic and demographic projections for every county and metropolitan statistical area in the United States. It also includes historic data for the same set of economic and demographic variables. Example variables include personal income, income per capita, numbers of households by level of household income, retail sales by kind of business (e.g., general merchandise, food stores, automobile dealers), employment by sector of the economy (e.g., farm, construction, manufacturing), and population by age, race, and sex. We matched the 2,865 airports in our LMINET-SATS model to the counties in the Woods and Poole data set. We used these economic and demographic data to forecast the level and distribution of GA aircraft and GA itinerant operations at 2,865 airports in the continental United States. We found that the variables listed in Table 2-2 were most useful to the forecasting task.

Table 2-2. Explanatory Variables

Name	Unit
Total population	In thousands
Income per capita	In 1992 dollars
High income households ($150,000 and above)	In thousands
State and local government employees	In thousands
Federal civilian employees	In thousands
Manufacturing sector employees	In thousands
Service sector employees	In thousands
Agricultural service employees	In thousands
Farm workers	In thousands
Large hub airport located in county	Dummy variable
Medium hub airport located in county	Dummy variable
Small hub airport located in county	Dummy variable
Reliever airports in county	Number
Primary non-hub airports in county	Number
Other commercial service airports in county	Number

When we ran a cross-sectional analysis of the data, we found that many of these explanatory variables were statistically significant and that a high percentage of the total variation was explained by the regression models. From this, we concluded that the active GA fleet in a county is highly correlated to the local economic and demographic conditions. However, year-to-year changes in the socioeconomic variables alone had little explanatory power for annual changes in the GA fleet. We surmise that this phenomenon results from the following factors:

- GA aircraft are an expensive investment that is “lumpy.”
- Use of the existing GA fleet in hours flown per year is low.
- The retirement schedule of specific aircraft because of age or obsolescence was unknown.

Consequently, we opted for a time series approach to forecasting the levels and distribution of based aircraft. We used 1999 as the base year, a 3-year lagged term of the dependent variable, the 3-year change from 1996 to 1999, for various economic and demographic variables, and the airport variables shown previously. The analytic technique we used was step-wise linear regression. Tables 2-3, 2-4, and 2-5 show the results.

The results shown in Table 2-3 suggest that the number of single-engine based aircraft in a county is positively correlated to the three-year change in the numbers of federal civilian employees, service sector employees, and population. Also, counties with a small hub airport tend to have more single-engine based aircraft than those without one. Conversely, counties with a large hub tend to have fewer single-engine based aircraft. There is also a negative correlation between the number of single-engine based aircraft in a county and the three-year change in state and local government employees, and manufacturing sector employees.

Table 2-3. Single-Engine Based Aircraft Model

Variable	Parameter	T-ratio[2]
Intercept	1.805	3.71
SEB in 1996	0.967	181.73
3-year change in state and local government employees	-6.408	-7.92
3-year change in federal civilian employees	8.440	4.15
3-year change in manufacturing sector employees	-2.821	-4.44
3-year change in service sector employees	0.323	2.71
3-year change in population	0.759	9.80
Large hub in county	-9.209	-1.97
Small hub in county	4.798	1.87

Note: R^2 equals 98.5 percent.

The results shown in Table 2-4 suggest that the number of multi-engine based aircraft in a county is positively correlated to the 3-year change in the numbers of federal civilian employees, farm workers, high income households, population, and per capita income. Also, counties with a small hub airport, medium hub airport, or one or more primary non-hub airports tend to have more multi-engine based aircraft than those without these types of airports. There is a negative correlation between the number of single-engine based aircraft in a county and the 3-year change in service sector employees and manufacturing sector employees.

[2] The partial regression coefficients show the effects of changes in the independent variables (e.g., 3-year change in state and local government employees, large hub in county) on the dependent variable (i.e., single-engine based aircraft). The t-ratios show the degree to which the partial regression coefficients are statistically different from zero. For example, for degrees of freedom over 30, a t-ratio of 1.96 provides 95 percent confidence that the partial regression coefficient is not zero.

Table 2-4. Multi-Engine Based Aircraft Model

Variable	Parameter	T-ratio
MEB in 1996	0.831	95.2
3-year change in federal civilian employees	1.209	1.66
3-year change in manufacturing sector employees	-1.736	-8.27
3-year change in service sector employees	-0.100	-1.87
3-year change in farm workers	4.811	3.09
3-year change in high income households	2.985	3.50
3-year change in population	0.247	10.2
3-year change in per capita income	0.000645	3.08
Medium hub in county	3.063	2.21
Small hub in county	3.317	3.60
Number of primary non-hub airports in county	2.607	5.25

Note: R^2 equals 94.9 percent.

The results shown in Table 2-5 suggest that the number of jet-engine based aircraft in a county is positively correlated to the 3-year change in the numbers of federal civilian employees, service sector employees, and population. Also, counties with a small hub airport and one or more primary reliever airports tend to have more jet-engine based aircraft. Conversely, counties with a large hub or medium hub tend to have fewer jet-engine based aircraft. There is also a negative correlation between the number of jet-engine based aircraft in a county and the 3-year change in state and local government employees, and agricultural service employees.

Table 2-5. Jet-Engine Based Aircraft Model

Variable	Parameter	T-ratio
JEB in 1996	1.011	71.3
3-year change in state and local government employees	-1.870	-7.60
3-year change in federal civilian employees	3.086	4.70
3-year change in service sector employees	0.4918	11.3
3-year change in agricultural service employees	-5.796	6.75
3-year change in population	0.1124	5.11
Large hub in county	-5.677	-3.69
Medium hub in county	-3.980	-3.06
Small hub in county	1.512	1.82
Number of primary reliever airports in county	5.124	9.67

Note: R^2 equals 88.2 percent.

To model GA itinerant operations at the county level, we used the numbers of based aircraft, the levels of economic and demographic variables, and the airport variables to explain the variation in the observed data. We used stepwise linear regression as our analytic technique. The results are shown in Table 2-6.

Table 2-6. GA Itinerant Operations Model

Variable	Parameter	T-ratio
Intercept	6,086	3.33
SEB	149.9	27.2
MEB	259.5	8.40
JEB	199.7	4.81
Agricultural service employees	1,685	5.15
Farm workers	-1,927	-4.98
High income households	417.9	1.87
Population	36.95	11.5
Per capita income	-0.218	-2.28
Large hub in county	11,837	3.19
Small hub in county	15,308	7.23
Number of primary non-hub airports in county	6,840	6.16

Note: R^2 equals 90.8 percent.

The results shown in Table 2-6 suggest that the number of GA itinerant operations is positively correlated with the numbers of based aircraft. This is to be expected because the based aircraft will generate an operation when they take-off en route to other airports and then land at the originating airport at the conclusion of the return trip. The impact of the other explanatory variables is less clear. For example, the number of high income households and population might impact the degree to which based aircraft are used. Large hubs, small hubs, and primary non-hub airports might reflect the attractiveness of the county as a destination for aircraft based in other counties.

We combined these regression results with the forecasted levels of economic and demographic variables from the Woods and Poole dataset to generate forecasts of the numbers and distribution of GA aircraft and GA itinerant at the county level. We distributed county-level aircraft and operations to individual airports according to the proportions implicit in the FAA's TAF. Consequently, we generated four separate matrices consisting of 2,865 rows, each corresponding to an airport, and columns representing the years from 2000 to 2025. Each entry in the matrix represented the share of the total that an airport was expected to represent for single-engine based aircraft, multi-engine based aircraft, jet-engine based aircraft, and GA itinerant operations.

In the absence of any other changes, SATS aircraft would be expected to replace the current vintage of GA aircraft as these are retired. The forecasted distribution of GA aircraft and operations is a baseline against which incremental changes will be made.

Chapter 3
Top-Down Model

Table 3-1 shows characteristics of the general aviation aircraft that were sold in the year 2000. Cruise speed is in terms of nautical miles per hour (knots) and payload range is expressed in seat-nautical miles. It is obvious from these data that GA aircraft are quite expensive relative to the increment in speed and capacity they offer compared to automobiles.

Table 3-1. Characteristics of GA Aircraft Sold in 2000

Category	Average price (dollars)	Seats	Cruise speed (knots)	Payload range (seat-NMI)
Single-engine piston	232,158	3.9	145	2,928
Multi-engine piston	636,821	5.0	182	4,587
Turboprop	3,433,680	9.5	239	15,036
Jet	11,382,886	11.2	477	26,002

Source: GAMA and Jane's.

Table 3-2 shows the composition of GA aircraft sales in the year 2000. Volumes are expressed as both units and dollar value of aircraft sold. Note that although "single-engine piston aircraft" represents the majority of units sold, they are definitely a small part of total dollar sales. Conversely, the dollar value of jets sold in 2000 far exceeds their share in terms of units sold.

Table 3-2. GA Aircraft Sales in 2000

Category	Units	Percent	Dollars ($) (millions)	Percent
Single-engine piston	1,810	64.3	420.2	4.9
Multi-engine piston	103	3.7	65.6	0.8
Turboprop	315	11.2	1,081.6	12.5
Jet	588	20.9	7,051.8	81.8
Total	2,816	100.0	8,619.2	100.0

Source: GAMA and Jane's.

For the GA top-down model, we explored the relationship between the costs to acquire a general aviation aircraft and the historic sales of GA aircraft. Our assumption was that the demand function for SATS aircraft would be roughly equivalent to the demand function for GA aircraft.

We obtained data about general aviation airplane shipments and the estimated dollar values of those shipments from the *2000 GAMA Databook*. For the years 1975 to 1990, GAMA provides separate estimates of the dollar values of single-engine and multi-engine piston airplane shipments. However, for years 1991 to 1999, GAMA provides only an estimate for the dollar value of total piston aircraft, a category that combines single-engine and multi-engine piston aircraft. We used our estimate of the average sales price of multi-engine piston aircraft for the year 2000 ($636,821 as shown in Table 3-1) to estimate the missing price data. Because the GAMA sales data were in nominal (or current year) dollars, we converted them to constant year 2000 dollars using the GDP implicit price deflator.[1] Appendix A contains the price and quantity data we used in our regression analysis. Other explanatory variables include a dummy variable and investment in transportation equipment.[2] The dummy variable is set equal to one in both 1979 and prior years and in 1994 and subsequent years. It is set equal to zero from 1980 to 1993 to reflect the period of time during which civil suits against GA manufacturers proliferated before passage and signing of the General Aviation Product Liability Reform Bill in August 1994.

Results of the regression analysis are shown in Table 3-3. All of the explanatory variables have the expected sign and are statistically significant.

Table 3-3. GA Aircraft Sales: Regression Results

Category	Lagged term	Cost	Dummy variable	Invest in trans equip ($B)	R^2 (percent-age)
Single-engine piston	0.712	-.0210	2375.1		96
	(8.15)	(-2.28)	(4.11)		
Multi-engine piston	0.877	-.00128	413.3		96
	(19.81)	(-2.51)	(4.34)		
Turboprop	0.649	-8.71E-05			68
	(4.39)	(-1.73)			
Jet	0.773	-8.56E-06		1.80	90
	(6.87)	(-1.88)		(4.17)	

Note: T-ratios are shown in parentheses.

We took these regression results and built the top-down model. In general, deliveries are a function of deliveries in the prior year, and the price at which manufacturers offer planes for sale in the current year. In addition, sales and purchases of jet-powered GA aircraft are positively correlated to the level of investment in transportation equipment. Given the time series of forecasted deliveries, the fleet in any year is the fleet in the prior year, plus deliveries, minus retirements, and net exports. Following is a list of input variables an analyst can change:

[1] *Economic Report of the President*, p. 278.

[2] *Economic Report of the President*, p. 296.

- Prices of single-engine piston, multi-engine piston, turboprop, and jet aircraft; gross investment in transportation equipment,
- Annual retirements plus net exports, and
- Hours flown per aircraft per year, speed and time per flight, average number of seats, load factor, and proportion of flight hours transporting passengers.

Following are some outputs from the top-down model:

- Annual deliveries,
- GA fleet,
- GA itinerant operations, and
- GA transported passenger miles (TPMs).[3]

We calibrated the baseline scenario against the FAA's forecast of the active GA fleet.[4] Table 3-4 shows the various baseline steady-state figures.

Table 3-4. Baseline Steady-State

Category	Price ($)	Deliveries	Retirements and net exports
Single-engine piston	206,000	2,675	1,549
Multi-piston	610,000	129	128
Turboprop	3,000,000	238	176
Jet	12,500,000	420	8

The analyst can then use the forecasted distribution of GA aircraft and GA itinerant operations (see Chapter 2) to allocate the national estimate of GA aircraft and flights to the airport level.

[3] A transported passenger mile (TPM) is one passenger transported one statute mile in a general aviation aircraft. The concept is analogous to the revenue passenger mile measure used for measuring the output of U.S. commercial air carriers.

[4] *FAA Aerospace Forecasts*, March 2001, Table 27, p. X-29

Chapter 4
Bottom-Up Model

For the bottom-up model, we anticipated that GA aircraft potentially could be competitive with travel by automobile or commercial air in a trip length range of between 200 miles and 1,000 miles. For trips shorter than 200 miles, cars almost certainly will serve most of the need. For trips longer than 1,000 miles, scheduled air carriers almost certainly will dominate. Because of differing values for the traveler's time, the exact trade-off points among the competing modes are expected to be a function of both the traveler's income and the purpose of the trip.

Automobile trips between 200 miles and 600 miles are one potential market opportunity for GA aircraft. Determining factors are total trip cost (including the value of time), and other factors such as comfort, noise level, safety, payload, and dispatch reliability. As the performance of the GA aircraft increases relative to the automobile, we expect that the market opportunity will expand. Similarly, congestion at major airports and the hub-and-spoke network makes GA aircraft more competitive for trips ranging from 600 miles to 1,000 miles by increasing the total travel time of trips taken on commercial airlines. We would expect that travelers will divert onto GA aircraft as congestion delays at major airports increase or layovers at hub airports increase in length or frequency and the relative attractiveness of traveling on GA aircraft improves. Again, factors such as comfort, noise level, safety, payload, and dispatch reliability will modify the demand for GA travel.

A second fundamental piece in our analysis was to uncover a relationship between economic and demographic data and the level and distribution of historic automobile and commercial air trips. We derived these factors from the *1995 American Travel Survey* produced and reported by the U.S. Department of Transportation. Approximately 80,000 randomly selected households nationwide were interviewed for the ATS. The survey collected information about all trips of 100 miles or more, one way, taken by household members in 1995. Each trip was classified according to the means of transportation used for most of the distance from the origin to the destination. A personal use vehicle trip is defined as any trip in which the principal means of transportation was car, pickup truck, or van; rental car, truck, or van; recreational vehicle or motor home; or motorcycle or moped. An airplane trip is defined as any trip in which the principal means of transportation was commercial airplane or corporate or personal airplane. Respondents were also asked to indicate the main reason motivating the travel. A business trip is any trip where the purpose of the trip is given as business, combined business with pleasure, or convention, conference, or seminar. A pleasure trip is any trip where the purpose of the trip is given as visiting friends or relatives, rest or relaxation, sightseeing, outdoor recreation, entertainment, or shopping. A personal business trip is defined as any trip where the purpose of the trip is given as school-related activity, or personal or family business including weddings and funerals.

Variables of interest for our study included mode of travel (e.g., personal use vehicle, commercial airplane, charter or tour buses), purpose of travel (business, personal business, or pleasure), great circle distance from the origin to destination (GCDOD), and household income (HHINC) of the traveler. We used these data to estimate per capita levels of travel by purpose, great circle distance, and household income. Extracts from the matrices of long-distance round trips per capita, by reason, household income, and great circle distance from origin to destination are shown in Tables 4-1, 4-2, and 4-3. Note that per capita trips for distances beyond 500 statute miles were estimated but are not shown because of space limitations.

Table 4-1. Per Capita Trips in 1995 for All Reasons

GCDOD	All distances	(0-99)	(100-199)	(200-299)	(300-399)	(400-499)
HHINC						
All income levels	3.95	0.71	1.49	0.55	0.25	0.16
Less than $10,000	1.48	0.30	0.60	0.20	0.11	0.05
$10,000 to $29,999	2.73	0.56	1.09	0.38	0.17	0.10
$30,000 to $39,999	3.63	0.71	1.47	0.48	0.21	0.16
$40,000 to $49,999	4.29	0.90	1.68	0.61	0.22	0.15
$50,000 to $59,999	4.74	0.83	1.87	0.60	0.31	0.19
$60,000 to $74,999	4.95	0.77	1.79	0.78	0.33	0.20
$75,000 to $99,999	6.12	0.84	2.20	0.89	0.38	0.27
$100,000 to $124,999	7.31	1.25	2.31	0.91	0.56	0.31
$125,000 to $149,999	8.01	0.88	2.18	1.44	0.55	0.40
$150,000 or more	10.14	1.08	2.40	1.25	0.72	0.43

Table 4-2. Per Capita Trips in 1995 for Business Reasons

GCDOD	All distances	(0-99)	(100-199)	(200-299)	(300-399)	(400-499)
HHINC						
All income levels	0.88	0.15	0.30	0.11	0.06	0.04
Less than $10,000	0.19	0.03	0.10	0.03	0.01	0.01
$10,000 to $29,999	0.44	0.11	0.16	0.06	0.02	0.02
$30,000 to $39,999	0.75	0.13	0.33	0.09	0.05	0.03
$40,000 to $49,999	0.92	0.21	0.35	0.12	0.05	0.03
$50,000 to $59,999	1.07	0.18	0.37	0.12	0.07	0.05
$60,000 to $74,999	1.20	0.15	0.40	0.18	0.10	0.05
$75,000 to $99,999	1.75	0.27	0.46	0.24	0.11	0.09
$100,000 to $124,999	2.21	0.32	0.51	0.26	0.21	0.12
$125,000 to $149,999	2.73	0.27	0.47	0.31	0.30	0.25
$150,000 or more	3.68	0.24	0.55	0.48	0.24	0.15

Table 4-3. Per Capita Trips in 1995 for Pleasure, Personal Business, and Other Reasons

GCDOD	All distances	(0-99)	(100-199)	(200-299)	(300-399)	(400-499)
HHINC						
All income levels	3.06	0.56	1.20	0.43	0.19	0.12
Less than $10,000	1.29	0.27	0.50	0.17	0.10	0.05
$10,000 to $29,999	2.29	0.45	0.93	0.32	0.15	0.08
$30,000 to $39,999	2.88	0.58	1.14	0.39	0.16	0.13
$40,000 to $49,999	3.37	0.69	1.33	0.49	0.18	0.12
$50,000 to $59,999	3.68	0.65	1.51	0.47	0.23	0.15
$60,000 to $74,999	3.75	0.63	1.39	0.60	0.23	0.15
$75,000 to $99,999	4.37	0.57	1.74	0.65	0.27	0.18
$100,000 to $124,999	5.10	0.93	1.79	0.65	0.36	0.19
$125,000 to $149,999	5.29	0.61	1.72	1.13	0.26	0.15
$150,000 or more	6.46	0.84	1.85	0.76	0.48	0.27

Some interesting observations emerge from the data. The first is that the number of per capita round trips increases as household income increases. This effect can be decomposed into travel for business and non-business reasons. There is clearly a strong correlation between the number of per capita trips taken for non-business reasons and household income. This is logical because long-distance travel for non-business reasons is a luxury good rather than a necessity. High-income households have both the economic resources and the desire for long-distance travel. There is an even stronger correlation between the number of per capita roundtrips taken for business reasons and household income. Here the causality is less clear: do higher paid individuals have a taste for long distance travel as part of their occupations or is the ability and/or willingness to do a lot of long-distance travel a prerequisite to earning higher salaries?

Our modeling scheme was relatively straightforward. We considered two principal reasons for travel: (1) business; and (2) pleasure, personal business, and other. We also considered three principal modes of travel: (1) personal use vehicle; (2) commercial airplane; and (3) corporate or personal airplane. We generated a list of variables that describe transportation by a particular mode. These mode variables capture the out-of-pocket expenses to make a trip and also reflect the value of the time expended, modified by the quality of the travel experience in terms of comfort, noise level, perceived safety, reliability, and flexibility of the itinerary.[1] Appendix B contains a listing of these mode variables and their default (or baseline) values. The user has complete flexibility to modify any of the mode variables, as well as to define a new mode of transportation.

[1] See Brand, et al., for the implied values of travel time by mode and trip purpose. The authors forecasted high-speed rail ridership as an alternative to travel by automobile and air.

Hourly wages were estimated from the ATS household income levels by first scaling from year 1995 dollars to year 2000 dollars, then dividing household income by the number of estimated wage earners per household, and finally by dividing the yearly wage by an assumed 2,000 hours worked per year. The various "costs" (monetary and non-monetary) of a trip are added together, then divided by the number of people in the travel party to estimate the per-person trip cost. In our model, personal use vehicles and corporate/personal airplanes are private conveyances and commercial airplanes are public conveyances. The formulas used to estimate the per-person trip costs are shown in Figures 4-1 and 4-2.

Figure 4-1. Private Conveyance Formulas

Travel Party Costs:

1. Fixed cost
2. Fixed transportation + distance × variable transportation

Person Costs:

1. Distance/speed × wage × line-haul coefficient
2. Fixed time × wage × access/egress coefficient
3. INT [Distance/(8 × speed)] × per diem

Per person cost=[travel party costs + (number in travel party × person costs)]/number in travel party

Figure 4-2. Public Conveyance Formulas

Travel Party Costs:

1. Fixed cost

Person Costs:

1. Distance/speed × wage × line-haul coefficient
2. Fixed time × wage × access/egress coefficient
3. Fixed transportation + distance × variable transportation
4. INT [Distance/(8 × speed)] × per diem

Per person cost=[travel party costs + (number in travel party × person costs)]/number in travel party

We made the simplifying assumption that the mode with the lowest per-person cost for a particular travel reason and great circle origin to destination distance would capture all of the trips in that cell of the per capita trip matrix. After all of the per capita trip cells are allocated to the travel modes, the cells are added together across all distances and travel reasons, then multiplied by the numbers of people in the various household income categories.[2] These trips are then added together across the income categories. Tables 4-4 and 4-5 show how the baseline scenario compares with the actual data in 1995.

[2] See Appendix C for a description of how we harmonized the ATS income data with the Woods and Poole projections.

Table 4-4. Personal Use Vehicle Trips in 1995

Household Income	Baseline (in millions)	Actual (in millions)
Total round trips	870.9	825.8
Less than $10,000	33.3	29.8
$10,000 to $29,999	177.0	164.3
$30,000 to $39,999	123.7	118.9
$40,000 to $49,999	150.4	145.4
$50,000 to $59,999	125.0	119.2
$60,000 to $74,999	112.8	107.3
$75,000 to $99,999	83.5	80.3
$100,000 to $124,999	36.1	33.8
$125,000 to $149,999	11.7	10.7
$150,000 or more	17.5	16.1

Table 4-5. Airplane Trips in 1995

Household Income	Baseline (in millions)	Actual (in millions)
Total round trips	171.7	187.8
Less than $10,000	2.7	3.5
$10,000 to $29,999	17.1	21.5
$30,000 to $39,999	16.2	17.3
$40,000 to $49,999	21.1	22.5
$50,000 to $59,999	24.7	27.3
$60,000 to $74,999	27.3	29.5
$75,000 to $99,999	26.1	27.0
$100,000 to $124,999	13.5	14.6
$125,000 to $149,999	6.0	6.8
$150,000 or more	17.0	17.8

We estimated the transported passenger miles for each mode by multiplying the numbers of round trips by two (to account for the outbound and return legs) and multiplying again by the trip distances before summing. We also estimated the annual utilization of GA aircraft. Given the average stage length of flights, the number of operations per aircraft, the number of seats, and the load factor, gave us an estimate of the transported passenger miles per GA aircraft and GA itinerant operation. The forecasted distribution of GA aircraft and GA itinerant operations (see Chapter 2) are then used to allocate the national estimate of aircraft and operations to the airport level.

Chapter 5
Conclusion

In this report, we documented a higher fidelity demand model that captures the interdependence of short-haul air travel with other transportation modes and explicitly considered the costs of commercial airplanes and commercial use vehicles. To accomplish this work, we generated forecasts of the distribution of general aviation (GA) based aircraft and GA itinerant operations at each of nearly 3,000 airports based on changes in economic conditions and demographic trends. We also built analytical models that estimate the demand for travel by different modes, particularly auto, commercial air, and GA. We examined GA demand from two perspectives: top-down and bottom-up. The two perspectives are complementary and we recommend that analysts use both approaches when evaluating new general aviation concepts and technologies.

The top-down and bottom-up models were provided to NASA in two forms: as a series of Excel spreadsheets and as a stand-alone program. The bottom-up model currently generates national-level forecasts, with the results then allocated to 2,865 airports. Because the initial emphasis of the modeling effort was on short-haul modes of transportation, travel patterns were examined in detail for the great circle distance from origin to destination in the range of zero to 3,000 statute miles. All travel for distances beyond 3,000 miles was aggregated. If there is research interest and funding, it would be possible to disaggregate long-distance travel to examine such concepts as the high-speed, subsonic cruiser. It would also be possible to reduce the scope of the bottom-up model to examine travel within a particular state or region of the country.

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Appendix A

General Aviation Airplane Shipment Data

Table A-1. Annual New U.S. Manufactured General Aviation Airplane Shipments by Type of Airplane

Year	Single-engine piston	Multi-engine piston	Turboprop	Jet
1975	11,441	2,116	305	194
1976	12,785	2,120	359	187
1977	14,054	2,195	428	227
1978	14,398	2,634	548	231
1979	13,286	2,843	639	282
1980	8,640	2,116	778	326
1981	6,608	1,542	918	389
1982	2,871	678	458	259
1983	1,811	417	321	142
1984	1,620	371	271	169
1985	1,370	193	321	145
1986	985	138	250	122
1987	613	87	263	122
1988	628	67	291	157
1989	1,023	87	268	157
1990	608	87	281	168
1991	564	49	222	186
1992	552	41	177	171
1993	516	39	211	198
1994	444	55	207	222
1995	515	61	255	246
1996	524	67	290	233
1997	898	86	223	342
1998	1,434	94	259	413
1999	1,634	114	239	517
2000	1,810	103	315	588

Source: 2000 GAMA Databook.

Table A-2. Estimated Unit Prices of New U.S. Manufactured General Aviation of Airplanes Shipped by Type of Airplane (In Dollars)

Year	Single-engine piston	Multi-engine piston	Turboprop	Jet
1975	67,773	353,804	1,577,948	3,872,795
1976	74,414	381,926	1,677,443	3,964,525
1977	80,013	422,406	1,644,175	3,445,641
1978	79,531	415,355	1,595,526	3,631,350
1979	80,636	399,885	1,756,705	3,922,508
1980	84,916	357,368	2,110,350	4,696,762
1981	84,920	387,280	2,093,655	4,962,868
1982	112,542	524,219	2,081,163	6,175,258
1983	124,412	428,523	2,226,718	8,207,016
1984	135,946	537,084	2,410,356	8,563,563
1985	133,582	511,739	2,370,955	7,141,978
1986	115,427	442,835	2,444,451	8,259,225
1987	180,047	285,436	2,502,179	8,922,220
1988	140,237	238,992	2,732,941	10,555,990
1989	130,670	354,576	2,513,121	9,406,701
1990	138,371	341,296	2,835,429	9,367,356
1991	165,732	358,041	2,833,769	8,651,347
1992	174,450	380,043	3,028,714	8,750,695
1993	137,117	403,496	3,209,085	8,466,117
1994	150,137	429,749	3,204,318	8,441,192
1995	206,411	457,294	2,793,891	9,162,874
1996	227,678	487,751	2,638,843	10,064,495
1997	183,999	520,169	3,422,535	11,213,517
1998	202,003	558,600	3,054,685	11,719,861
1999	198,955	598,358	2,812,526	13,436,525
2000	232,158	636,821	3,433,680	11,992,929

Source: 2000 GAMA Databook and LMI estimates.

Appendix B

Default Values for the Bottom-Up Model

Table B-1. Business Travel

Mode variables	Personal use vehicle	Commercial airplane	Corporate or personal airplane
Type	Private conveyance	Public convey-ance	Private conveyance
Speed (MPH)	50	355	400
Fixed cost ($)	0	100	100
Fixed time (hour)	0	2.5	1
Transportation fixed cost ($)	0	58.43	0
Transportation variable cost ($ per mile)	.34	.1122	1.95
Per diem cost ($ per person per day)	80	80	80
Coefficient on line-haul time	1.0	1.3	1.0
Coefficient on access/egress time	0.7	0.9	0.9

Table B-2. Pleasure, Personal Business, and Other Travel

Mode variables	Personal use vehicle	Commercial airplane	Corporate or personal airplane
Type	Private conveyance	Public conveyance	Private conveyance
Speed (MPH)	50	355	246.1
Fixed cost ($)	0	200	200
Fixed time (hour)	0	2.5	3
Transportation fixed cost ($)	0	58.43	0
Transportation variable cost ($ per mile)	.11	.0561	.7720
Per diem cost ($ per person per day)	50	50	50
Coefficient on line-haul time	0.5	1.5	.35
Coefficient on access/egress time	0.3	1.0	1.0

Notes:

Fixed cost includes expenses such as parking, taxi, rental car.

Fixed (access/egress) time includes activities such as travel to the airport, rental car drop off, parking to gate, and gate to boarding.

Appendix C
Population by Household Income

The household income data from the 1995 American Travel Survey were measured in then-year (1995) dollars, while the Woods and Poole projections of households with money income are measured in constant 1990 dollars. Unfortunately, a more significant complication arises from the definition of personal income used by Woods and Poole. Woods and Poole use the most comprehensive measure available, total personal income. Another commonly used measure of income is money income. Money income is the concept used by the Bureau of the Census and is widely used in other sources. Total personal income includes all of money income plus the exclusions to money income.[1] For the United States as a whole, money income is approximately 25 percent less than total personal income. Woods and Poole state, "when (our) income data are higher than data from another source, once inflation adjustments are taken into account, it is probably because the other source uses money income base data."

To calibrate the ATS data and the Woods and Poole data, scaling factors were generated, which forced the numbers of people in the various household income categories to exactly match in 1995. A comparison of the last two columns of Table C-1 shows that the general effect of the scaling factors applied to the Woods and Poole data is to shift people from the higher categories into the lower categories. This is consistent with the previous discussion of the differences between the two measures of income used by these sources.

Table C-1. Scaling Factors

Household income	Household size from American travel survey data	Scaling factors applied to Woods and Poole projections
Less than $10,000	1.88	1.80
$10,000 to $29,999	2.14	2.29
$30,000 to $39,999	2.73	2.61
$40,000 to $49,999	2.78	3.39
$50,000 to $59,999	2.93	3.75
$60,000 to $74,999	3.09	3.69
$75,000 to $99,999	3.13	3.27
$100,000 to $124,999	3.24	3.20
$125,000 to $149,999	3.10	2.51
$150,000 or more	2.94	2.04

[1] Exclusions from money income consist of adjustments such as payments-in-kind like food stamps, the imputed rental value of owner-occupied housing, capital consumption adjustments for proprietors, inventory valuation adjustments, and lump-sum payments such as liability judgments and consumer defaults on debts to businesses.

Appendix D

Abbreviations

ATS	American Travel Survey
FAA	Federal Aviation Administration
GA	general aviation
GCDOD	great circle distance, origin to destination
GDP	gross domestic product
HHINC	household income
JEB	jet-engine based aircraft
LMINET	a queuing network model of the U.S. National Airspace
MEB	multi-engine based aircraft
NASA	National Aeronautics and Space Administration
NPIAS	National Plan of Integrated Airport Systems
SATS	Small Aircraft Transportation System
SEB	single-engine based aircraft
TAF	terminal airport forecast
TPMs	transported passenger miles

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Throughout U.S. history, our nation has generally enjoyed exceptional economic growth, driven in part by transportation advancements. Looking forward 25 years, when the national highway and skyway systems are saturated, the nation faces new challenges in creating transportation-driven economic growth and wealth. To meet the national requirement for an improved air traffic management system, NASA developed the goal of tripling throughput over the next 20 years, in all weather conditions, while maintaining safety. Analysis of the throughput goal has primarily focused on major airline operations, primarily through the hub and spoke system. However, many suggested concepts to increase throughput may operate outside the hub and spoke system. Examples of such concepts include the Small Aircraft Transportation System, civil tiltrotor, and improved rotorcraft. Proper assessment of the potential contribution of these technologies to the domestic air transportation system requires a modeling capability that includes the country's numerous smaller airports, acting as a fundamental component of the National Airspace System, and the demand for such concepts and technologies. Under this task for NASA, the Logistics Management Institute developed higher fidelity demand models that capture the interdependence of short-haul air travel with other transportation modes and explicitly consider the costs of commercial air and other transport modes. To accomplish this work, we generated forecasts of the distribution of general aviation based aircraft and GA itinerant operations at each of nearly 3,000 airports based on changes in economic conditions and demographic trends. We also built modules that estimate the demand for travel by different modes, particularly auto, commercial air, and GA. We examined GA demand from two perspectives: top-down and bottom-up, described in detail.

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