FLEET PLANNING MODEL

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ABSTRACT

The Fleet Planning Model is a tool to assist in the development of a fleet plan capable of satisfying an airline's projected air traffic demand. The fleet plan specifies the numbers and types of aircraft in the fleet in each year of a 10-year period. The aircraft acquisition and retirement policies which determine the fleet plan may be based on several different objectives. Meeting these objectives involves the minimization of various costs such as direct operating cost, amount spent for new equipment, or operating cost plus cost of capital invested in the fleet. Linear programming is used to obtain the optimal fleet plans. Factors taken into account by the model include required service frequencies, load factor limits, traffic growth rates by market areas, existing fleet composition, committed aircraft purchases and retirements, aircraft buying and selling prices, aircraft range and seating configuration, operating costs, and airline debt constraints and cost of capital.

INTRODUCTION

A knowledge of future equipment needs of the airlines is essential information for the airline planner or aircraft manufacturer.

The fleet plan specifies the types and numbers of aircraft to be purchased or retired, and the timing of these transactions, over a period spanning several years. The use of a planning horizon several years hence gives the visibility necessary to good decision-making in the short term. As conditions change, the planning process should be repeated so that decisions have the benefit of a long-term look with the best information available. The development of a fleet plan may involve a great deal of detailed work and many computer programs to support the various phases of the task. One approach is to develop several alternative plans followed by a detailed financial and operational evaluation of each. The use of the Fleet Planning Model, the subject of this paper, is compatible with this approach. Specifically, the model is designed to generate efficient, feasible fleet plans to serve as starting points for more detailed analysis and evaluation.

A number of other efforts have been made to formulate problems similar to the one discussed in this paper. Etschmaier(1) and Simpson(2) have reviewed much of this past work. The model described in this current paper differs from previously published work known to the authors in the method of treating priority traffic and day and night demand patterns.

STATEMENT OF THE PROBLEM

Several routes are served on a regular, scheduled basis. The number of passengers traveling each route segment per day or per week is assumed known. The minimum flight frequency over each segment is specified. An airline or a collection of airlines operates several types of aircraft over the network. It may not be possible to operate all types over all segments because of range or airport facility limitations. The passenger capacity and the cost of operation of each aircraft over every permissible route segment are known. The airline has an existing fleet and may have firm plans for acquisition and retirement of aircraft. Typically, these plans provide an adequate fleet only for the next very few years. Beyond that, a plan of acquisition and retirement is desired that will satisfy a minimum cost objective while observing various constraints. One of several alternative objectives can be considered when developing the fleet plan: (1) minimization of direct operating cost; (2) minimization of amount spent for new equipment; and (3) minimization of direct operating cost plus the cost of servicing increases in the long-term debt that result from transactions specified by the fleet plan. An excess of fleet productivity over that required by average traffic levels is necessary to be able to accommodate the usual seasonal and random variations in air traffic demand, for schedule reliability, for maintenance requirements, and to offset operational inefficiencies. However, the costs associated with failure to utilize existing equipment to full capability must be accounted for. Equipment procurement and utilization should anticipate requirements several years into the future. This will reveal the disadvantage of purchasing obsolete equipment to satisfy immediate but short-lived needs. Existing equipment may be retired if the projected saving in operating cost of the new aircraft exceeds the cost of servicing the additional long-term debt resulting from selling current equipment and buying new aircraft.

The above situation prevails over a period of several years, and the data associated with each year may differ from that for other years. Furthermore, there are several rules that must be observed concerning the continuity and changes in the fleet from year to year. First, the introduction dates of all planned or proposed aircraft are specified and aircraft may not be introduced prior to the stated dates. Similarly, no aircraft of a given type may be introduced after the date of cessation of production. Second, maximum and minimum introduction rates are specified by year and aircraft type. Aircraft cannot be admitted to the fleet in quantities that violate these limits. Finally, based on estimates of the operator's line of credit and operational problems in assimilating new equipment, there are limitations in the numbers and dollar value of new additions to the fleet.

In a subsequent section dealing with extensions to the basic model there are other important features described including allocation of aircraft to itineraries, itinerary selection, and priority levels for cargo demand. For greater clarity in the mathematical exposition and to aid the reader's understanding, these latter features have not been included in the basic model formulation. A discussion is provided to indicate how these additional capabilities can be put into a linear programming format and incorporated into the model.

PROBLEM FORMULATION

Symbols

$C_k(i)$	Seating capacity of aircraft k over the range of segment group i.
$C'_k(i)$	Cargo capacity of aircraft k over the range of segment group i.
$D_y(i)$	Passenger demand on segment group i in year y.
$D'_y(i)$	Cargo demand on segment group i in year y.
$D''_y(i)$	Satisfied cargo demand on segment group i in year y.
E_y	Amount of the debt in year y resulting from transactions implied by the fleet plan.
F_{ky}	Load factor of aircraft k in year y.
F'_{ky}	Cargo load factor of aircraft k in year y.
H_{ky}	Result of applying the numbers of planned retirements and firm orders to the number of aircraft in the current fleet. (Example: If there are 10 type k units in the fleet now, 6 on order to be delivered before year y, and 2 older models to be retired before year y then $H_{ky} = 14$.)
I	Annual rate of interest.
$K_k(i)$	Direct operating cost of one trip of aircraft type k over the range of segment group i.
$M_y(i)$	Minimum flight frequency permitted on segment group i in year y.

$N_y(i)$	Maximum flight frequency permitted on segment group i in year y.
P_k	Price of an aircraft of type k.
Q_k	Productivity adjustment factor. Some airlines work their aircraft harder than others. The purpose of Q_k is to adjust the nominal utilization as obtained from the formula built into the model in order to agree with actual utilization data.
R_{ky}	Introduction rate limit on type k aircraft in year y
S_k	Introduction cost of type k aircraft. This includes crew training and initial spares. It is a one-time cost for each aircraft of type k.
$T_k(i)$	Block time of aircraft type k on segment group i.
$U(\tau)$	Utilization of an aircraft over ranges for which block time is τ.
V_{ky}	Resale price of used aircraft of type k in year y.
W_{ky}	Number of aircraft of type k sold in year y (excludes firm retirements resulting from input assumptions).
$X_{ky}(i)$	Flight frequency of aircraft type k on segment group i in year y.
Y_{ky}	Number of idle aircraft of type k in year y. This is an equivalent number of aircraft from a point of view of excessive productivity. If indeed there were an excess of productivity the airline would probably lower the utilization on all aircraft of type k rather than idling some and working others to maximum utilization.
Z_{ky}	Number of newly purchased aircraft of type k to be delivered in year y (excludes firm deliveries resulting from input assumptions).

Passenger Demand Requirements

Since the airline fleet is required to perform on many different routes, the flight operations must be represented in the input data as many separate routes or segments each with its own characteristics of range, minimum service requirements, traffic, and traffic growth rate. This provides a more realistic description of flight operations so that aircraft of the appropriate types are brought into the fleet in the proper numbers. Similar segments are then aggregated to form segment groups to which aircraft are allocated.

For every segment group the service provided must be capable of handling the passenger volume projected for future years. Thus, for every segment group i and for every year y it is required that

$$D_y(i) \leqslant \sum_k C_k(i) F_{ky} X_{ky}(i)$$

Minimum and Maximum Flight Frequencies

The minimum flight frequency over segment group i in year y is denoted by $M_y(i)$ and is determined by considerations of adequate service and competition among airlines. These values provide the additional constraints

$$M_y(i) \leqslant \sum_k X_{ky}(i) \text{ for all y and all i}$$

If flight frequencies are to be limited from above also, then the above constraints become

$$M_y(i) \leqslant \sum_k X_{ky}(i) \leqslant N_y(i) \text{ for all y and all i}$$

Aircraft Balance Equations

The status of the fleet at the start of the planning period, firm orders for future delivery, and firm plans for equipment retirement exert great influence on decisions related to new acquisitions in the short term. Accordingly, this information is treated as input data to the model.

Short run variations in air travel demand require that the fleet have a productivity that exceeds that required for the average level of demand. Maintenance problems, deadheading requirements, and all other sources of operational inefficiency further contribute to the requirement for a reserve capability. The amount of reserves required may change from one airline to another because of differences in operation and the peculiarities of the network served.

Data for past years can be used to estimate the reserve seat-mile capability that has been found necessary in actual practice. Therefore, historical information can be used to calibrate the model. The calibration process serves to remove possible bias in the ideal utilization curves built into the model.

Projected air travel demand at some time in the future will outstrip the capability of the fleet even with the planned deliveries. Then it will be necessary to acquire new equipment. Once purchased, these new aircraft will remain in the fleet and will either be scheduled on revenue-producing routes or allowed to lie idle in which case a cost must be paid. The input idle cost discourages new additions to the fleet unless the planned retirements of the growth in traffic require more equipment.

Consideration of the factors mentioned in the foregoing discussion requires that the following equation hold for each year and each aircraft type.

Aircraft assigned to revenue-producing routes (includes reserves)	+ idle aircraft	= aircraft in current fleet
		+ firm orders for future delivery
	− planned retirements	
	+ new acquisitions	

The first three terms on the right-hand side are input data. All other terms are determined during the optimization process. In symbols, the above equation becomes

$$\sum_i [T_k(i)/Q_k U(T_k(i))] X_{ky}(i) + Y_{ky}$$

$$= H_{ky} + \sum_{j=1}^{y} (Z_{kj} - W_{kj}) \text{ for all k and all y}$$

Introduction Rate Constraints

Let it be assumed that no more aircraft can be introduced in a given year than can be produced in that same year. This condition can be imposed by the requirements that

$$Z_{ky} \leqslant R_{ky} \text{ all k and all y}$$

The introduction rate may be limited by airline considerations also. These constraints are of the same form as those above. It is necessary to consider only the most severe of the two conditions.

New Debt Bookkeeping Equations

In order to keep track of the current indebtedness resulting from previous purchases and sales, the following equations are set up. They provide information to the cost objective function and permit application of constraints on the amount of indebtedness as a function of time.

$$\sum_k \sum_{j=1}^{y} (Z_{kj}(P_k + S_k) - W_{kj} V_{kj}) = E_y \text{ all y}$$

The quantities E_y are the result of transactions determined by the program only. Firm future deliveries and retirements supplied as inputs to the model are not considered. Similarly, the airline will have an initial indebtedness as a result of past events. These effects are not considered.

Planning Objectives

Any one of three different objectives can be selected.

1. Minimization of direct operating cost (DOC) of all scheduled operations over all years of the planning period

$$\sum_{y} \sum_{k} \sum_{i} K_k(i) X_{ky}(i)$$

2. Minimization of amount spent for new equipment (excludes future deliveries resulting from input assumptions).

$$\sum_{y} \sum_{k} Z_{ky} (P_k + S_k)$$

3. Minimization of the sum of DOC and cost of additional capital resulting from transactions implied by the fleet plan (excludes future deliveries resulting from input assumptions). Under the assumption of a uniform interest rate, the imputed interest on the inventory investment is given by the sum of the products of interest rate and the indebtedness determined at each year of the planning period.

$$\sum_{y} \sum_{k} \sum_{i} K_k(i) X_{ky}(i) + \sum_{y} IE_y$$

An easy modification of the above objective function can be made to treat separately the annual cost of ownership of an aircraft and the other components of direct operating cost that are tied closely to the number of hours of operation. The benefits of this formulation are a more accurate representation of the direct operating costs and a proper assessment of cost penalties for under-utilization or idling of aircraft.

The modified objective is

$$\sum_{y} \sum_{k} \sum_{i} \left[K'_k(i) + \beta_k(i) K''_k\right] X_{ky}(i) + \sum_{y} \sum_{k} K''_k Y_{ky}$$

$$+ \sum_{y} IE_y$$

where $K'_k(i)$ is the direct operating cost of one flight of aircraft k on segment group i (excluding insurance and depreciation) and where K''_k is the annual cost of ownership of an aircraft of type k. The quantity $\beta_k(i)$ converts frequency on a given segment group to numbers of aircraft. In symbols

$$\beta_k(i) = T_k(i)/Q_k \, U(T_k(i)).$$

Other Features

There are many additional features that can be made available with little or no change to the program. The following examples are intended to give the reader a general feeling for the possibilities.

1. The introduction of new aircraft can be made to conform with production rates and available delivery positions.

2. The dollar value or number of new aircraft purchased can be made to be below stated levels. This may force the airline to retain old equipment for a longer period and defer the introduction of new aircraft.

3. A given number of aircraft can be forced into the fleet over a specified time period. The program will then space out the individual deliveries over the planning period and retire current aircraft in an optimal fashion.

4. The manner in which aircraft are allocated to the segment groups can be constrained in several ways. For example, it is possible to require that a stated percentage of the annual seat-miles in a given submarket be performed by a certain aircraft type; or one may demand that departure frequencies be shared in stated proportions among several aircraft.

EXTENSIONS

Cargo and Passenger Traffic

The basic model formulation in which the aircraft are allocated to groups comprised of similar nonstop flight segments is described in the foregoing section. Also, the traffic demand consists of passengers only. How passenger traffic, and freight carried in the bellies of passenger airplanes, can be treated simultaneously is detailed in this section. Additional constraints are added to the basic formulation of the preceding section in order to limit the amount of allocated cargo to the capacity available. Passenger traffic is treated just as before. All passengers must be carried; however, the amount of cargo carried is limited by the available capacity or the amount of cargo demand, whichever is smaller. Additional variables are added to represent the amount of cargo demand carried for each segment group. The objective function is modified to include the negative of the revenue obtained from allocated cargo. In symbols,

$$D''_y(i) \leqslant \sum_{k} C'_k(i) F'_{ky} X_{ky}(i)$$

$$D''_y(i) \leqslant D'_y(i).$$

Itineraries

Aircraft can be allocated to flight itineraries instead of groups of nonstop segments. This capability eliminates the need for aggregation of segments and results in assignments of aircraft that preserve the input sequence of flight legs. Also, the resulting data are more readily interpreted by the analyst. No changes in the rows or columns of the matrix of coefficients are necessary. The itineraries play the role of segment groups. The capacity necessary for an itinerary is determined by the passenger demand on the most heavily traveled leg of the itinerary. The ranges of the legs are input and used to compute utilization and aircraft requirements by entering the input function $U(\tau)$.

Traffic Assignment and Service Planning

The methodology described in this paper accepts passenger loads on flight segments and plans the service to satisfy the passenger loads. That is, the model selects aircraft types and determines frequency on the segments or itineraries. It is possible to formulate mathematical programming models that assign the traffic to the flights in addition to planning the service. Air traffic requirements for such models are input as origin-to-destination traffic and the model will allocate the traffic to itineraries and thus build up the segment loads.

Priority Traffic and Night-Day Demand

This feature is used in conjunction with the version of the model which performs both the traffic assignment and service planning functions simultaneously. In such models priority cargo traffic can be treated as described in this section. Freight is carried in the bellies of passenger airplanes and on freighter aircraft. The freighters are active at night and the nightly pattern of movement of aircraft and freight may differ greatly from that of daytime. Furthermore, priority goods such as first class mail may move nonstop while a stopping service or connecting service may be adequate for other cargo. To treat the priority problem, the origin-destination demand is stated for three priority levels. Also, a permissible set of routes or itineraries is associated with a given origin-destination pair. Some routes provide nonstop, others provide stopping services from origin to destination. Additional constraints are required to ensure that no more than the amount of the priority three goods are assigned to connecting services and at least the amount of the priority one traffic is assigned to nonstop flights. Additional variables are necessary also in order to keep track of the amount of total traffic allocated to the three levels of service.

The night-day demand feature is accomplished by providing two sets of candidate aircraft routings, one set for nighttime and the other for daytime flights. Similarly, independent sets of origin-destination cargo demands are provided for each of the two time periods. Thus, with three levels of priority and two time periods the cargo demands are characterized by six input quantities. This version of the formulation has not been used in a multiperiod model because of the problem size and long computation times.

MACHINE IMPLEMENTATION

The Fleet Planning Model developed in the preceding sections is in the form of a linear programming (LP) problem. Solutions of small examples of such problems can, of course, be hand-worked by means of the simplex algorithm. However, for small problems, even on a "one-shot" basis, it is easier to use one of the special software packages available for virtually all of the large computing systems. All that one needs to do is to name and type the rows and columns, input the matrix of coefficients and right-hand side values in the correct format, write a short control or agenda program, and finally assemble the deck in the prescribed sequence with the proper control cards.

Matrix Generator

Unfortunately, fleet planning problems of a useful size are too large to be loaded in the way described above. First, several hundreds of rows and several thousands of columns are involved. Second, the coefficients and right-hand side values are complex functions of more fundamental data. This leads to a requirement for a machine program that will calculate the values of the coefficients and right-hand sides and put them in the proper locations in the matrix. Row and column names also must be generated internally by the program.

Problem Solution

The IBM software development, MPSX, is used to obtain solutions to the fleet planning problem because it was readily available and possesses the required capabilities. A description of the capabilities of MPSX will not be attempted here. The interested reader should refer to the appropriate IBM manuals.

Report Writer

The standard MPSX output that describes the solution of a large-scale linear programming problem will contain a large amount of information. Much of this information may not be needed. Furthermore, the data that are pertinent to the problem must be summarized and a considerable amount of arithmetic must be performed in order to prepare a report that is meaningful to the user. Therefore, there must be a report writer to accept the solution data and perform the editing, sorting, and tabulation necessary to produce the desired output.

EXAMPLE

A sample problem used as a test case in 1971 is presented in this section. Some of the data have been disguised for proprietary reasons.

Statement of the Problem

An airline's fleet (in 1971) consists of the following aircraft:

3 – Type 1 (83 seats, medium range)
9 – Type 2 (40 seats, short range)
6 – Type 3 (112 seats, medium range)
8 – Type 4 (139 seats, intercontinental range).

Next year (1972) all three of the Type 1 aircraft will be retired and two additional Type 3 aircraft will be delivered. Two more of Type 3 will be delivered in the following year. Beyond this, the airline's management has no firm plans except that it intends to buy long-range wide-body aircraft for its international routes and realizes that additional aircraft will be required for the domestic market over the next 10 years.

Question: Assess the airline's equipment needs over the next 10 years and produce a "rough-cut" aircraft acquisition plan for that time period. Further study of the airline reveals that it serves two distinct market types domestic and international. The Type 4 aircraft fly international routes only and the other aircraft satisfy domestic needs. The airline has no immediate plans for retiring Type 4 equipment. Also, these two market areas have greatly different growth characteristics. For purposes of this study it was assumed that growth in the international market would be satisfied by wide-body aircraft and additional Type 3 aircraft would be available to satisfy domestic needs. The existing Type 4 intercontinental range fleet is allowed to be retired if the operating cost advantages of the incoming wide-body aircraft over the planning period are great enough to overcome introduction costs and the increased burden of servicing the additional long-term debt. Replacement decisions for all other aircraft are made after similar considerations.

Summary of Results

The airline plans to have two Type 3 (112-seat medium-range aircraft) delivered in 1972 and two more in 1973. Results of this analysis indicate that one of the 1973 deliveries perhaps should be moved up to 1972 and the other one cancelled. Otherwise, the retirement of the Type 1 fleet may create a shortage of capacity. Another round of Type 3 deliveries should begin in 1975 with three additional aircraft purchased over the next few years as traffic grows and two of the nine Type 2 are retired. This will give the airline a total of 12 Type 3 aircraft in 1979. There are six in the fleet now.

Another observation is in order regarding the domestic fleet. The cost advantage (cents per seat-mile) that the Type 3 enjoys over the Type 2 causes the latter aircraft to be retired. Why then doesn't the program retire the entire Type 2 fleet early in the planning period to gain the benefit of a longer period of reduced operating costs available from the Type 3? The answer is that the flight frequencies must be maintained and to introduce the larger aircraft at a more rapid rate would reduce load factors to the point where it makes better economic sense to use the less efficient but smaller machine.

The initial wide-body aircraft is needed in 1972 or 1973 and requirements build gradually to approximately five aircraft by 1979. This purchase assumes that none of the eight Type 4 aircraft are retired. The program considered replacement of the Type 4 fleet with wide-body aircraft but on a purely economic basis the operating cost advantage of the wide-body could not displace the fully depreciated Type 4. Hand calculations indicate that the preference is slight. If the acquisition cost of the wide-body were slightly lower, then much of the Type 4 fleet would be replaced as the traffic builds up.

Input Data

Numerical data for a representative case, although not essential to this presentation, are shown in this section in order to give the reader a general appreciation for the form of the input data and some of the types of output reports available.

1970 Airline Traffic Model – The traffic model consists of daily numbers of passengers and minimum and maximum allowable daily trips for each segment group in the traffic model (see Table 1). A segment group is a collection of route segments with similar characteristics. For example, route segments may be put into the same group if they have comparable ranges, traffic density, growth characteristics, and geographic market area. Further, each segment group is given a submarket number. This number identifies growth characteristics for the segment group and a set of candidate aircraft that are permitted to fly the routes.

Initial Fleet Minus Retirements Plus Firm Orders – This information results from applying firm plans for retirement and acquisition to the current fleet (Table 2). If no further fleet planning decisions were made, the actual fleet composition in future years would be exactly as shown.

Aircraft Characteristics – The reader will find that most of the aircraft characteristics listed in Table 3 are self-explanatory. The purpose of the productivity adjustment factor is to account for differences in maintenance and operational practices from one airline to another. The cost of introduction includes such items as crew training and initial spares. The annual cost of idle aircraft is included to ensure that insurance, depreciation, and some maintenance costs are considered when aircraft are not fully utilized. These items represent the cost of ownership and for that reason are not included in the expression for operating cost which is a function of utilization.

Estimated Average Selling Price – The equipment retirement plan will be carried out as specified by the input data. However, additional retirement decisions may be made by the program based on economic considerations. More specifically, the program compares the operating cost benefits of a new aircraft with the additional burden of the larger debt resulting from replacement. The increase in debt is the acquisition cost of the new aircraft minus the selling price of the old aircraft (see Table 4).

Passenger Traffic Growth Rates – Table 5 shows two submarkets and hence, there are two sets of traffic growth rates. Segment groups 5, 9, 11, 13-17 belong to submarket 2 and the remaining groups belong to submarket 1.

Aircraft Load Factor – Load factors may be input by year for each aircraft type (see Table 6). In this example the domestic fleet is given higher load factors in later years than the international fleet.

Other Input Data – Minimum and/or maximum rates of introduction of aircraft into the fleet can be imposed by aircraft type and year although no such constraints were used in this example. Manufacturers' production rates and available delivery positions may affect the planning process and make it necessary to activate these constraints. Also, there may be limits on the amount of additional long-term debt that the airline can assume in which case replacement of the fleet with new more efficient aircraft may be delayed. The debt limits can be applied to each year of the planning period although this feature was not utilized in the sample problem. Minimum service frequency also can be caused to grow with time. Again, this capability was not used in the sample problem presented here. The cost of capital was assumed to be 7.5 percent in this example.

Output Data

Total Fleet Composition – Table 7 shows total numbers of aircraft actually in the fleet, some of which may be idle or not fully utilized. The number of aircraft are shown as fractional in the table. These figures may be rounded up or down if required. It is also possible to obtain integral numbers of aircraft from the solution process itself provided integer programming techniques are used.

Flight Frequencies by Aircraft Type – Table 8 shows flight frequencies for aircraft Type 4 (similar data for other types are available) on each segment group to which Type 4 aircraft are allocated. Integer values of annual frequencies can be obtained in multiples of quantities based on minima of 5 or 7 flights per week through the use of integer programming techniques.

Scheduled Block Hours and Utilization -- The average utilization (Table 9) expected from an aircraft varies with the ranges flown. Aircraft flying only short flight legs will spend more time on the ground and less time in the air than aircraft assigned to long-range routes. The Fleet Planning Model estimates utilization in terms of block hours per year resulting from the ranges of the flights assigned to an aircraft (see Table 10). These calculations are based on historical data adjusted by the productivity factor determined during the calibration process.

REFERENCES

1. Etschmaier, M. M., "Projects and Implementations in the Schedule Development Process of an Airline," Technical Report No. 17, October 1973, Department of Industrial Engineering, University of Pittsburgh, Pittsburgh, Pennsylvania

2. Simpson, R. W., "A Review of Scheduling and Routing Models for Airline Scheduling," October, 1969, Flight Transportation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

TABLE 1
1970 AIRLINE TRAFFIC MODEL

SEGMENT GROUP	RANGE (ST MI)	DAILY PASSENGERS	MINIMUM DAILY TRIPS	MAXIMUM DAILY TRIPS	SUBMARKET
1	118	497	25	–	1
2	149	589	12	–	1
3	163	205	10	–	1
4	267	956	19	–	1
5	242	119	2	–	2
6	409	11	1	–	1
7	456	862	17	–	1
8	681	167	3	–	1
9	672	198	3	–	2
10	949	128	2	–	1
11	989	119	2	–	2
12	1301	32	1	–	1
13	1369	238	3	–	2
14	2173	178	3	–	2
15	5046	159	2	–	2
16	5692	39	1	–	2
17	6282	79	1	–	2
TOTAL	–	4581	105	–	–

TABLE 2
INITIAL FLEET MINUS RETIREMENTS PLUS FIRM ORDERS

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	3	–	–	–	–	–
2	9	9	9	9	9	9
3	6	8	10	10	10	10
4	8	8	8	8	8	8
5	–	–	–	–	–	–
6	–	–	–	–	–	–

TABLE 3
AIRCRAFT CHARACTERISTICS

	AIRCRAFT 1	AIRCRAFT 2	AIRCRAFT 3	AIRCRAFT 4	AIRCRAFT 5	AIRCRAFT 6
BLOCK TIME	0.002 RANGE +0.200	0.004 RANGE +0.250	0.002 RANGE +0.300	0.002 RANGE +0.250	0.002 RANGE +0.280	0.002 RANGE +0.350
COST	1.03 RANGE +184.00	0.85 RANGE +76.00	1.43 RANGE +194.00	2.02 RANGE +273.00	2.02 RANGE +500.00	3.86 RANGE +655.00
INTRODUCTION DATE (YR OF TRAFFIC MODEL)	0.	0.	0.	0.	2.	2.
FINAL YEAR OF PRODUCTION	0.	0.	11.	0.	11.	11.
PRODUCTIVITY ADJUSTMENT FACTOR	0.66	0.38	0.71	0.81	0.81	0.81
COST OF INTRODUCTION ($ PER ACFT)	0.0	0.0	500000.	0.0	4500000.	5000000.
COST OF IDLE AIRCRAFT ($ PER ACFT PER YR)	0.0	0.0	414000.	877000.	1746000.	2124000.
UNIT PRICE ($ MILLIONS)	0.0	0.0	4.10	0.0	19.40	23.60
DESIGN RANGE (N MI)	1550.00	800.00	1320.00	5500.00	5140.00	5650.00
RANGE AT ZERO PAYLOAD (N MI)	1800.00	1560.00	1670.00	6200.00	6000.00	6800.00
NUMBER OF SEATS	83.	40.	112.	139.	255.	366.

TABLE 4
ESTIMATED AVERAGE SELLING PRICE

$ MILLIONS

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	—	0.28	0.28	0.28	0.28	0.28
2	—	0.06	0.06	0.06	0.06	0.06
3	—	3.84	3.42	3.01	2.60	2.18
4	—	2.19	1.31	1.08	1.08	1.08
5	—	—	—	17.65	15.91	14.16
6	—	21.48	19.35	17.23	15.10	12.98

TABLE 5
PASSENGER TRAFFIC GROWTH RATES

SUBMARKET	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	0.015	0.105	0.103	0.100	0.098	0.095
2	0.200	0.135	0.130	0.125	0.120	0.115

TABLE 6
AIRCRAFT LOAD FACTORS

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	0.50	0.54	0.58	0.60	0.62	0.64
2	0.50	0.54	0.58	0.60	0.62	0.64
3	0.50	0.54	0.58	0.60	0.62	0.64
4	0.50	0.52	0.54	0.55	0.56	0.57
5	0.50	0.52	0.54	0.55	0.56	0.57
6	0.50	0.52	0.54	0.55	0.56	0.57

TABLE 7
TOTAL FLEET COMPOSITION

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	3.00	—	—	—	—	—
2	9.00	9.00	9.00	9.00	8.73	8.27
3	6.00	8.73	8.73	8.76	9.07	9.68
4	8.00	8.00	8.00	8.00	8.00	8.00
5	—	0.38	0.80	1.38	1.94	2.60
6	—	—	—	—	—	—

TABLE 8
FLIGHT FREQUENCIES
(AIRCRAFT TYPE 4)

SEGMENT GROUP	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
5	629	723	788	879	963	1065
9	1050	1207	1316	1467	1608	1778
11	630	724	789	880	964	1066
13	1262	1451	1581	1763	1932	2137
14	944	1086	1183	1186	1157	1108
15	841	762	597	433	293	132
16	212	179	153	117	82	42
17	421	484	527	588	644	712

TABLE 9
UTILIZATION
(HOURS/AIRCRAFT/YEAR)

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	1927	—	—	—	—	—
2	1110	1103	1104	1104	1111	1111
3	2213	2204	2204	2205	2203	2199
4	3231	3386	3359	3327	3298	3265
5	—	3690	3689	3669	3658	3650
6	—	—	—	—	—	—

TABLE 10
SCHEDULED BLOCK HOURS

AIRCRAFT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6
1	5,781	—	—	—	—	—
2	9,988	9,925	9,939	9,935	9,699	9182
3	13,280	19,235	19,234	19,316	19,970	21288
4	25,845	27,087	26,869	26,614	26,385	26116
5	—	1,391	2,944	5,078	7,099	9492
6	—	—	—	—	—	—