UNITED STATES AIR TRANSPORTATION 1980

1969 NASA-WVU Summer Predoctoral Fellowship Program in Engineering Systems Design
Langley Research Center and West Virginia University
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UNITED STATES AIR TRANSPORTATION 1980

NASA LANGLEY RESEARCH CENTER
WEST VIRGINIA UNIVERSITY

Summer Predoctoral Fellowship Program
In Engineering Systems Design
1969

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PREFACE

The continued development of air transportation is of major importance to the United States. If present transportation problems are to be eliminated and future problems prevented, investigations must be made today of desirable systems for future years. The following report considers an "optimum design" for a commercial air transportation system to be used within the United States in the 1980's. It considers, on a national scale, the definition of optimum design, the passenger demand, the passenger routing model, the optimum fleet of aircraft and their characteristics, the effects of the aircraft terminals, and the potential social and economic constraints.

The system is proposed by the eighteen participants of the National Aeronautics and Space Administration - West Virginia University Summer Pre-Doctoral Fellowship Program in Engineering Systems Design as a result of their eleven week study performed at the NASA Langley Research Center. In addition to attaining this design, the purposes of the program were to give the participants a systems design experience and a better awareness of NASA's activities in aeronautics and astronautics.

Engineering Systems Design Programs have become well recognized for the many benefits they give the participants. They obtain an appreciation of and experience with the overall problems which are involved in preparing a preliminary design. At the same time, each participant has the opportunity to investigate in considerable detail and become expert in one or two aspects of the system. A participant learns that he must understand the concepts of other disciplines and how these disciplines relate with his own, he must be able to talk and work with others as a design team, and he must be able to handle systems design problems where often the questions cannot even be properly asked until they are at least partially answered.

The National Aeronautics and Space Administration has encouraged the development of university engineering systems design programs by sponsoring summer faculty training programs at NASA Centers and student pre-doctoral fellowships at selected universities. As a result, the number of institutions offering systems design courses continues to grow; however, the total number remains small. Not all students have the opportunity to take such a course because of the limited curriculum of their institutions. Recognizing this, NASA and West Virginia University agreed to present a summer program in engineering systems design for which all pre-doctoral students in the nation would be eligible to apply The participants would receive academic credit from West Virginia University which could be transferred to their home institution. The eighteen participants who prepared the following air transportation report represent fourteen institutions from across the United States. The NASA and West Virginia University also agreed that there would be added benefit by presenting the program at the Langley Research Center where advantage could be made of the professional staff, facilities, and environment.

Every design team hopes that its design will contribute to the advancement of society. It is felt that the following design, in addition to the experience it has given the participants, is significant in many respects. It approaches the air transportation problem within the United States on a national scale rather than on a regional basis as done in most studies, it seeks to optimize the systems based not only on the costs involved, but also on the waiting time and travel time of the passengers; it determines the passenger demand for specific routes rather than only total demand at a terminal as done in previous studies; it optimizes vehicle characteristic based on the specific demands and routes anticipated in the 1980's, it considers the constraints of present and future airplane terminals, and it considers the needs and desires of society in addition to the purely technical aspects of the system. It is hoped that the following design will aid both the system design engineer looking at the overall air transportation problem in the 1980's and also the component engineer who is looking at a single aspect of the system.

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ORGANIZATION

The participants in the National Aeronautics and Space Administration - West Virginia University Summer Pre-Doctoral Fellowship Program in Engineering Systems Design worked as a team to prepare the air transportation systems design They divided their team into four interrelated working groups, each with an elected group leader and a definite area of responsibility. The groups were:

1. Network Analysis
2. Vehicle Design
3. Terminal Design
4. Social and Economic Considerations

For each phase of the study, the participants elected one of their own as project manager to be in overall charge of the study.

The phases of the program were·

1. Information Gathering - 4 weeks
2. Preliminary Design - 3 weeks
3. Final Design - 4 weeks

During the first phase of the program, the participants were aided by background lectures provided by the staff of the Langley Research Center as well as by other experts from government and industry. By the end of this phase, the participants were able to define the scope of their overall design, its major objectives, and the major alternatives.

During phase two, the team engaged in detailed evaluation of the alternatives and prepared a preliminary design.

Overall system integration and organization of the final report formed the major effort during the final phase. The design was aided by preliminary briefings given at the Langley Research Center and at NASA Headquarters, Washington, D. C., where comments of the audience were reviewed and minor modifications and additions to the design were made whenever necessary.

ACKNOWLEDGMENTS

The successful completion of the United States Air Transportation 1980 Project would not have been possible without the enthusiastic cooperation of the personnel of Langley Research Center. It is a distinct pleasure for the director and participants of the NASA-WVU Summer Program to acknowledge their efforts and support.

The number of persons and organizations deserving recognition would defy any attempt at a listing. We, therefore, wish to thank everyone at Langley Research Center for their guidance and assistance in making this a successful project.

All of us in the Summer Program wish to express our sincere thanks to our secretaries, Miss Barbara Phillips and Mrs. Rhoda Holt for their encouragement and support It is certain that without their encouragement the probability of the projects success would have been small indeed.

LIBRARY CARD ABSTRACT

UNITED STATES AIR TRANSPORTATION 1980

"United States Air Transportation 1980" is a report covering a preliminary design developed by the participants in the NASA Langley Research Center - West Virginia University Summer (1969) Pre-Doctoral Fellowship Program in Engineering Systems Design. The proposed system is designed to minimize passenger cost and time in transit.

Included in this report, in addition to the technical description of the system, are such considerations as passenger demand, costs and funding, vehicle routing, and socioeconomic implications.

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I. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

1.1 TOTAL SYSTEM STUDIES

In order that the United States Air Transportation System may continue as a highly desirable and effective mode of transportation, much care in planning for the future must be taken now. One must plan, or design, the system with emphasis on the interactions among the various components to insure that the result is not a grouping of highly efficient subsystems which do not function together well as a system. This type of planning is called systems design. Approaching a design in this manner introduces a whole new problem in terms of added constraints and trade-offs. The planning is further complicated by the fact that various interest groups are often represented on opposing sides of a tradeoff. The groups involved include airlines, aircraft manufacturers, general public, and users or customers. Tradeoffs may involve pollution (noise and particle), financing, quality of service and innumerable others. The designer must not only be aware of the interactions and trade-offs, but must also attempt to measure their significance and to weigh properly the more significant aspects in a study of the system. This project which investigated a 1980 United States Air Transportation System has accounted for the influences of air pollution, aircraft noise, passenger time delays, air terminal congestion and system economics as well as the technology limitations in a "total system" study.

1.2 APPROACH

The approach taken in this investigation was to represent the United States Air Transportation System in analytic form. Very basically, the form used was a total system operating cost equation consisting of four terms. The four terms are considered to account for all significant cost factors. These terms are as follows: a. Direct Operation Cost (D.O.C.), b. Indirect Operating Cost (I.O.C.), c. Terminal Cost, and d. Waiting Time Cost. Further discussion of these cost considerations is given in the following section.

The object was to minimize this total system operating cost for the United States by manipulating the vehicle characteristics of the system, i.e., the optimum fleet and type of aircraft were determined. This was accomplished by a computer program simulation of the United States Air Transportation System. The simulation represented the 21 major air transportation hubs across the nation and was assumed to be a representative, though not complete, model of the actual system. The results are considered to be valid for the entire United States system in the 1980's.

The results specify the best system for the 1980's in terms of the vehicles required. Knowing the vehicle configurations, one may then determine the necessary terminal facilities required for the expected demands. Care has been taken to determine the passenger and cargo demand for the 1980's. Forecasts are given for the 420 major air routes in the 1975, 1980, 1985, and 1990 time periods.

Terminal saturation is considered, both in passenger handling capacity, and in runway/airway congestion. An investigation of the the social constraints upon the system is also given.

1.3 THE TOTAL SYSTEM OPERATING COST CONCEPT

In any attempt to design a "best" or optimum system one must first answer the question, "Best in terms of what?". That is, one must establish some criteria to weigh the various alternatives One means is to look at an ideal or ultimate system and attempt to determine its desirable characteristics. The ideal transportation system would be one which transports its passengers and cargo instantaneously, and at no cost to anyone. The essence of the ideal system is its low time and cost. These factors are considered in determining the "best" system for the 1980's The total system operating cost equation mentioned accounts for the user's "time spent in the system," as well as the dollar cost to him. The costs to non-users, airlines, and local and federal governments are also included. The terms of the equation are further discussed below:

Direct Operating Cost: (D.O.C.)

Calculated by standard A.T.A. method. (Includes paying off initial investment).

Indirect Operating Cost (I.O.C.)

The method used to calculate I.O.C is a modification of the Research Analysis Corporation method. The items considered are airline ground property, servicing, and administration, along with air traffic control and general airport administration.

Terminal Cost

This is a cost assigned to each passenger enplanement and deplanement in order to pay for terminal facilities not considered in the Indirect Operating Cost.

Waiting Time Cost

Here a dollar value is given for each hour of time spent by the passenger in "using" the system. The typical waiting time between scheduled flights is considered, as is the time in flight.

By manipulating the vehicle configurations the sum of the four above terms are forced to a minimum. It is felt that this defines the best system in terms of cost to society.

1.4 CONCLUSIONS AND RECOMMENDATIONS

Regarding air transportation within the United States in the 1980's, this investigation draws the following principal conclusions and recommendations which are discussed in detail in the following sections:

1. The rapid growth of air transportation will necessitate the accurate prediction of passenger and cargo demand not only for terminal activity, but also for activity on each air route. This report includes, what are believed to be, the first published predictions for the demand by routes in the 1975, 1980, 1985, and 1990 time periods.
2. The large passenger and cargo demands for the 1980's will be best satisfied by the following aircraft

Vehicle	Range (miles)	Capacity (passengers)
A	500	200
B	1500	400
C	3000	800

When this fleet of aircraft is compared to today's aircraft (overestimated as)

Vehicle	Range (miles)	Capacity (passengers)
A	500	200
B	1500	200
C	3000	400

The following daily saving in total system operating cost are anticipated.

Year	Daily Savings
1980	$1,213,000
1985	$3,680,000
1990	$7,603,000

3 The supercritical wing, permitting flight at Mach No. = 1.0, will yield a significant economic advantage For example, in 1980, use of the supercritical wing will yield a saving of $680,000 per day on total system operating cost compared to a system using conventional (Mach No. = 0.8) wings.

4. The supersonic transport will be banned from overland supersonic flight.

5 The maximum allowable community noise level from aircraft in the 1980 time period will not be permitted to exceed 90 decibel.

6 A smoke density reading of 20 percent (based on the Van Brand scale) will be the maximum acceptable level for engines by 1980. This will result in smokeless aircraft operation.

7. The air traffic control should segregate aircraft by approach speeds and assign different runways for different speed aircraft. On-board aircraft control equipment will be used, by 1980, to separate aircraft thus increasing the number of landings per hour.

8. To speed up the passengers travel within the terminal the buildings should be designed to separate the passenger traffic through the ticketing areas from the visitor and greater traffic in the concession areas.
9. Automated and computer-controlled baggage and cargo handling systems must be used to speed the loading and unloading of aircraft at the airport terminals and minimize personnel costs.
10. Ticketing and baggage processing should be handled through a computer-controlled system that will answer queries about schedules and connections, make reservations, compute fares, and issue tickets and baggage checks. Discounts for off-peak hour travel should be incorporated to encourage travelers to level out the traffic flow.
11. Satellite terminals in central business districts should be used to process some passengers and baggage, which could then be taken directly to the plane for boarding.
12. The Nations airways, airports, and terminals will become supersaturated in the next 10 years unless a comprehensive, national planning effort is undertaken by industry, the airlines and government - local, state, and national.
13. Federal aid to the airlines can be expected by the 1980's. This aid will most likely be in the form of an investment tax credit rather than an outright subsidy.
14 Federal involvement in airport financing will require the establishment of a trust fund, similar to the highway trust fund, financial through a system of user charges. Money will be dispensed from this and trust fund by matching

grants and loan subsidization.

15. NASA's role in research and development should expand to involve not only flight vehicles and propulsion systems but all aspects of R & D of importance to the national air transportation system.

II. SYSTEM DESCRIPTION

2.1 INTRODUCTION

Of major importance in the system design of a 1980 air transportation system is the development of an optimal network of routes and flows between terminals within the Continental United States. As such, it was necessary to formulate, design, and analyze various possible system network configurations in order to arrive at an optimum commercial air transportation system. It has been necessary to determine not only the scope and complexity of the proposed transportation system but also the reliability, effectiveness, and optimality of the systems under consideration as a whole.

2.2 PROBLEM DEFINITION AND SOLUTION PROCEDURES

After carefully examining previous efforts in transportation systems design studies, it was decided to subdivide network analysis into five areas of investigation. These areas of analysis are as follows:

a) Selection of a transportation network representative of the Continental United States.

b) Determination of the demand for travel on the system in the 1980-1990 time period.

c) Simulation of a national transportation system.

d) Determination of procedures for optimization of the system.

e) Determination of the factors affecting congestion and scheduling.

2.2.1 Network Selection

Ford and Fulkerson define a directed Network, G=(N,A) as consisting of a "collection N of elements x, y, . . ., together with a subset A of the ordered pairs (x, y) of elements taken from N." The elements of N are variously called nodes, vertices, junction points, or points, members of A are referred to as arcs, links, branches, or edges.[1] With this concept of a network in mind, a real-world network must be selected which fits the above definition yet adequately described the commercial air transportation system as it will exist in the 1980-1990 time period. After considering several possibilities, it was decided that a network consisting of 21 nodes and 420 arcs would satisfactorily describe the system. These nodes and arcs, however, were not chosen haphazardly, nor were they selected randomly. Rather, after careful examination of the air transportation system in the United States today, the 21 largest air traffic hubs were chosen as the system network nodes. The FAA defines a large hub as a metropolitan area which generates one percent (1%) or more of the Nation's scheduled air carrier domestic enplaned passengers. Based on 1965 data, 22 large hubs existed in the United States. However, because of their proximity, the New York and Newark large hubs have been combined into a single large hub for the purposes of this report and in order to keep in line with FAA data collection procedures.

Once the 21 network nodes were determined, 420 arcs connecting these nodes were chosen. That is, each node was linked to every other node by a separate arc, thus generating 420 or (n)(n-1) arcs. On a real-world basis, these arcs represent all possible non-stop routes between the major continental United States air hubs.

Non-stop routes only were considered since it was felt that this type of routing offered the greatest convenience and shortest overall travel time to the potential system users (see Section 2.2).

2.2.2 Demand Determination

Once a system network was chosen it was necessary to develop it, i.e., determine in what manner the network would be utilized. As this investigation was to consider all aspects of commercial air transportation, it was necessary to forecast the potential demand on the system network in terms of both passenger and cargo requirements.

The primary and most obvious reason for forecasting demand upon the system is that it is impossible to plan a national air transportation system for the 1980-1990 time period without a knowledge of how many people and how much cargo will be carried in any given time period. Obviously, one cannot use present data to determine future system requirements. Hence, a measure of this demand is essential for successful planning.

Several of the more important areas in which demand forecasting is a useful and necessary input are as follows:

(1) transportation system simulation efforts

(2) future airport facility requirement planning

(3) personnel, construction, and equipment purchasing requirements planning

(4) financial planning

(5) route potentials and applications

(6) development of comprehensive, long-range airport master planning on a regional and/or national basis

(7) scheduling and congestion requirements

Several possible methods of forecasting demand for the 1980's were examined and considered. Each has been used in the past by the airlines, industry, and government agencies with various degrees of success. Those methods examined include:

(1) surveys of anticipations or expectations

(2) judgment forecasts

(3) correlation and regression analysis

(4) ratio analysis

(5) analogy

(6) fixed percentage extrapolation

(7) modeling-gravity, interactance, etc.

After considering all possible avenues, it was decided to use modified gravity modeling in order to forecast future system demand requirements. Gravity models are the most useful method of forecasting for several reasons:

1 - Modeling is better suited for city-pair demand analysis than other forecasting methods.

2 - Modeling appeared to give the best approximation of the real-world situation.

3 - Social and Economic factors affecting air travel could be considered.

4 - Demand modeling on a nationwide scale is in its infancy, if not in the embroyonic stage, and much work needs to be done in this area.

The demand models are examined in greater detail in Section 2.3.

2.2.3 System Simulation

Given demand requirements, terminal characteristics, and vehicle configuration information, it was necessary to determine the best possible allocation of air vehicles on the network arcs. Several methods of investigation into this problem were examined in the early stages of the program with the eventual result of the use of simulation techniques to describe the system. Early allocation procedures including the simplex algorithm and the classical transportation and transhipment algorithms are described in Appendix A.2.2. The actual simulation model used is described in detail in Section 2.4.

2.2.4 Optimization Procedures

It was decided upon early in the project that the optimum system would be the one that minimized system total operating cost (STOC) while satisfying system demand requirements over each network arc. (The STOC includes a cost penalty assessed because of time delays and travel time for the passenger). The procedures used in minimizing STOC are described in detail in Section 2.6.

2.2.5 Scheduling, Congestion, and Allocation

Some time was spent in attempting to determine solutions to the congestion problem faced in air transportation at most airports in the United States by recommending changes in scheduling procedures. This is examined in greater detail in Section 2.5.

2.3 DIRECT VERSUS INDIRECT ROUTING

The system simulation that was used to find the optimum fleet of vehicles considered all passenger and cargo demands on a direct route basis, that is, enough vehicles were assigned to each city-pair route to satisfy the demands, and no attempt was made to divert some of the traffic to indirect flights. Advantages which could have been gained by indirect routing are higher aircraft (A/C) load factors, more frequent service schedules, and possibly less terminal congestion at some points. The cost analysis, however, shows a high -- $6.50/passenger -- cost of emplaning or deplaning a passenger in terms of baggage handling, air traffic control, ground crews, etc. While this figure may be lower for a stopover in an indirect flight, it is still a dominating factor in the cost analysis and the cost advantages of indirect routing, mainly passenger waiting time, are not enough to offset it. Another obvious disadvantage of indirect routes is the longer distance involved which enters the analysis both as flight time and direct operating cost.

Passenger demands which have been used as inputs to the system simulation must be examined at this point. Since all direct flights are being simulated, one must examine "What happens to that portion of the demand that does travel by an indirect route?" The demand models were calibrated to past data which included people traveling between city pairs whether this was the person's total trip, or just a "leg" in a multistop journey. Since the real-world's portion of indirectly routed passengers are accounted for in the data input, any attempt to account for them in the simulation program would be redundant and indeed erroneous.

In short, it is believed that the 21-hub, direct-route network that was used in this study is truly representative of the actual real-world situation, and thus the results of this study should be applicable to the entire United States.

2.4 PASSENGER DEMAND BETWEEN THE MAJOR HUBS

The purpose of forecasting intercity demand for this study was twofold. First, while studies have been made of passenger demand for specific regions, e.g., the Northeast Corridor and the California Corridor, little information is readily available on nationwide demand predictions. Such information would thus be of interest to those involved in long-range transportation planning. Future air travel demand forecasts are necessary for successfully determining such things as aircraft type and number and terminal size and configuration Second, the information is a necessary input to the aircraft allocation algorithm discussed in detail in a following section.

Among the different methods used for predicting city-pair passenger demand, two methods tend to appear most often. In one method city-pair demand data for previous years is compiled and the fraction of total traffic demand that this city-pair route carried is obtained.[1] Estimates of total traffic demand for the future are then made and these percentages of total traffic demand (or some modification thereof) are used to predict city-pair demand in the future. The other common method is to assume a mathematical form with arbitrary constants (often called a gravity model) and then use previous demand data to determine the constants. These mathematical expressions for predicting city-pair demand are commonly functions of such things as city populations, distances between cities, airport activity, population earning over \$10,000, cost, time, etc., all of which are assumed to have significant effect on traffic demand. Because the first method requires a considerable amount of yearly demand data for which ready access, was not available, the second method was employed. Predictions were made for round trip and one-way demand for 1975, 80, 85, and 90. The following gravity models were studied:

$$T_1(I, J) = a_1 \frac{(E(I) \cdot E(J))^{a_2}}{D(I, J)^{a_3}} \qquad (1)$$

where,

$T_1(I, J)$ = yearly one way airline passenger demand for city I to city J.

$E(I)$ = total domestic enplanements at city (I)

$D(I, J)$ = distance between city I and city J

a_1, a_2, a_3 are constants determined from known city-pair data

$$T_2(I, J) = b_1 \frac{(E(I) \cdot E(J))^{b_2}}{D(I, J)^{b_3}} (1 - e^{-b_4 D(I, J)}) \qquad (2)$$

where

$T_2(I, J)$ = one way yearly airline passenger demand from city I to city J

$D(I, J)$ = distance between city I and city J

b_1, b_2, b_3, b_4 are constants determined from known city-pair

data

$$T_3(I, J) = \frac{c_1}{2} \frac{P(I)P(J)}{D(I, J)^{c_2}} (1 - e^{-(c_3 D(I, J))^2}) \qquad (3)$$

where

$T_3(I, J)$ = number of yearly round trip passengers from city I to city J and return

$P(I)$ = population of city I

c_1, c_2, c_3 are constants to be determined from known city-pair

data

$$T_4(I, J) = \frac{c_1}{2} A(J) \frac{P(I)P(J)}{D(I, J)^{c_2}} (1 - e^{-(c_3 D(I, J))^2}) \qquad (4)$$

where

$T_4(I, J)$ = number of yearly round trip passengers from city I to city J and return

$A(J)$ = attractiveness factor for destination city

c_1, c_2, c_3 are the same as those in equation (3)

$$T_5(I, J) = \frac{c_1}{2} I(I)A(J) \frac{P(I)P(J)}{D(I, J)^{c_2}} \left(1 - e^{-c_3 D(I, J))^2}\right) \qquad (5)$$

where

$T_5(I, J)$ = number of yearly round trip passengers from city I to city J and return

$I(I)$ = income factor for origin city

c_1, c_2, c_3 are the same as those in Equation (3)

$$T_6(I, J) = \frac{d_1}{2} I(I)A(J) \frac{(P(I)P(J))^{d_4}}{D(I, J)^{c_2}} \left(1 - e^{-d_3 D(I, J))^2}\right) \qquad (6)$$

where

$T_6(I, J)$ = number of round trip passengers from city I to city J and return

d_1, d_2, d_3, d_4 are constants determined from known city-pair data.

$$T_7(I, J) = \frac{k_1}{2} I(I)^{k_5} A(J)^{k_6} \frac{(P(I)P(J))^{k_4}}{D(I, J)^{k_2}}$$

$$\left(1 - e^{-(k_3 D(I, J))^2}\right) \qquad (7)$$

where

$T_7(I, J)$ = number of round trip passengers from city I to city J and return

k_1, k_2, k_3, k_4, k_5, k_6 are constants determined from known city-pair demand data

$$T_k(I, J) = \frac{W_k(I, J)}{\sum_k W_k(I, J)} T(I, J) \qquad (8)$$

where

$T_k(I, J)$ = one-way average daily demand from I to J using mode k

$$T(I, J) = b_0 \cdot b_1 \left\{\left[F(I) x 10^{-5}\right] \cdot \left[F(J) x 10^{-5}\right]\right\}^{b_2} \left[\sum_k W_k(I, J)\right]^{b_3}$$

$$W_k(I, J) = a_1 t^{-a_2} c^{-a_3} (f')^{a_4}$$

$F(I)$ = number of families earning more than $10,000 in city I

t = total travel time from I to J including access, egress, and line haul time

c = total travel cost from I to J in current dollars

f' = 1-exp(-kf)

f = average daily frequency of service for mode k on trips from I to J.

b_0 = a scale factor depending on its year for which the cost is normalized

a_1, a_2, a_3, a_4, b_1, b_2, b_3 are constants determined from actual demand data.

Equation (1) is of the type used previously by Belmont in predicting city-pair demand.[2] The FAA publishes yearly hub activity which, along with distances, are used in this gravity model. Since the FAA has predictions for 1980 hub activity,[3] this equation could be used to predict future city-pair demand. Tables 2.4-1 and 2.4-2 show past hub enplanements and airline distances between hubs. In this study, the cities of Baltimore and Washington, D. C. are combined into one hub as are Miami and Fort Lauderdale, Detroit and Ann Arbor; Dallas and Fort Worth, San Francisco and Oakland, and Newark and New York City. The area included in each city is that used by the Bureau of Census in defining Standard Metropolitan Statistical Areas (SMSA). For example, by Chicago it is meant the Chicago SMSA. The counties included in the SMSA's are included in Table 2.4-1.

An equation of the form given by equation (1) has the disadvantage that as distance between cities becomes very small, the demand becomes very large. Intuitively this would not be expected

TABLE 2.4-1*

HUB ENPLANEMENTS

HUB	AREA INCLUDED IN HUB[5]	SCHEDULED PASSENGER ENPLANEMENT 1964[4]	SCHEDULED PASSENGER ENPLANEMENT 1965[4]	SCHEDULED PASSENGER ENPLANEMENT 1966[4]	% INCREASE 1964-1965	% INCREASE 1965-1966
New York/ Newark	Nassau Co. Suffolk Co. Richmond Co Bronx Co. New York Co. Queens Co Rockland Co. Weschester Co. Kings Co. Essex Co. Morris Co. Union Co.	8,764,205	9,947,561	10,850,832	13.50	9.08
Chicago	McHenry Co. Cook Co. Dupage Co. Will Co Kane Co. Lake Co.	7,897,510	9,080,706	10,253, 604	14.98	12.92
Los Angeles/ Long Beach	Los Angeles Co. Orange Co.	4,349,815	5,088,836	5,952,352	16.99	16.97
Atlanta	Clayton Co. Fulton Co. Gwinnett Co. Cobb Co. Dekalb Co.	3,026,662	3,760,891	4,647,706	24.26	23.58
Wash-ington D.C / Balti-more	Washington, D. C. Falls Church City, Va. Fairfax Co. Va. Prince Georges Co., Md. Alexandria City, Va. Arlington Co., Va. Montgomery Co., Md Baltimore City (Cont. next page)					

TABLE 2.4-1* (Continued)

HUB	AREA INCLUDED IN HUB[5]	SCHEDULED PASSENGER ENPLANEMENT 1964[4]	SCHEDULED PASSENGER ENPLANEMENT 1965[4]	SCHEDULED PASSENGER ENPLANEMENT 1966[4]	% INCREASE 1964-1965	% INCREASE 1965-1966
(Cont)	(cont.) Baltimore Co., Md. Howard Co., Md. Anne Arundel Co., Md. Carroll Co., Md.	3,995,345	4,625,986	5,246,527	15.78	13.41
San FRan-cisco/ Oakland	San Mateo Co. Alexandria Co. Maren Co. Soland Co. Contra Costa Co. San Francisco Co.	2,858,764	3,507,644	4,003,189	22.70	14.13
Dallas/ Fort Worth	Collin Co. Denton Co. Dallas Co. Ellis Co. Johnson Co. Tarrant Co.	2,330,931	2,782,010	3,534,651	19.35	27.05
Boston	Suffolk Co Essex Co. (Part) Middlesex Co. Norfolk Co. (Part)	2,321,510	2,621,799	2,944,293	12.94	12.30
Miami/ Fort Lauder-dale	Miami City Outside Central City Fort Lauderdale Hollywood Outside Central Cities	1,903,060	2,343,183	2,568,945	23.13	9.63
Detroit/ Ann Arbor	Wayne Co. Macomb Co. Oakland Co. Ann Arbor City Outside Central City	1,742,723	1,984,466	2,336,970	13.87	17.76
Pitts-burgh	Allegheny Co. Washington Co. Beaver Co. Westmoreland Co.	1,559,832	1,779,944	1,891,310	14.11	6.26

TABLE 2.4-1* (Continued)

HUB	AREA INCLUDED IN HUB[5]	SCHEDULED PASSENGER ENPLANEMENT 1964[4]	SCHEDULED PASSENGER ENPLANEMENT 1965[4]	SCHEDULED PASSENGER ENPLANEMENT 1966[4]	% INCREASE 1964-1965	% INCREASE 1965-1966
Phila-delphia	Buck's Co., Pa. Delaware Co., Pa Chester Co., Pa. Philadelphia Co , Pa. Montgomery Co., Pa. Camden Co., N. J. Burlington Co., N. J. Gloucester Co , N J	1,484,707	1,719,665	1,938,625	15.83	12.73
Denver	Jefferson Co. Denver Co. Arapahoe Co. Boulder Co. Adams Co.	1,426,464	1,674,778	2,014,976	17.41	20.31
St.Louis	St. Louis City Jefferson Co., Mo. St. Charles Co , Mo. St. Louis Co., Mo. Madison Co., Ill. St. Clair Co., Ill.	1,355,448	1,599,706	1,847,772	18.02	15.51
Cleve-land	Cuyahoga Co. Lake Co	1,425,854	1,654,110	1,818,764	16.01	9.95
Minne-apolis/ St. Paul	Anoka Co. Dakota Co. Hennepin Co. Ramsey Co Washington Co.	1,222,052	1,446,005	1,602,029	18.33	10.79
Kansas City	Clay Co., Mo. Jackson Co , Mo. Johnson Co., Kan Wyandotte Co., Kan.	1,134,427	1,295,052	1,494,058	14.16	15.37
Houston	Harris Co.	1,067,106	1,269,658	1,464,134	18.98	15.32
New Orleans	St. Bernard Parish Jefferson Parish Orleans Parish	934,436	1,125,458	1,343,815	20.44	19.40

TABLE 2 4-1* (Continued)

HUB	AREA INCLUDED IN HUB[5]	SCHEDULED PASSENGER ENPLANEMENT 1964[4]	SCHEDULED PASSENGER ENPLANEMENT 1965[4]	SCHEDULED PASSENGER ENPLANEMENT 1966[4]	% INCREASE 1964-1965	% INCREASE 1965-1966
Seattle/ Tacoma	King Co. Snokomish Co. Pierce Co.	863,471	996,813	1,232,021	15.44	23.60
Cincin-nati	Hamilton Co., Ohio Cambell Co., Ky. Kenton Co., Ky.	744,851	904,742	1,074,502	21.47	18.76

*Source of Hub Enplanements: <u>FAA Statistical Handbook of Aviation</u>, 1965,66, 67.

Source of SMSA Information <u>Census of Population 1960</u>.

TABLE 2.4-2

DISTANCES BETWEEN CITY PAIRS
(IN MILES)

	N.Y.	CHI	L.A.	ATL	WASH	S F.	DAL	BOS	MIAMI	DET	PITT	PHIL.	DEN.	CLEV	S.L	MINN	K.C.	HOUS.	N.O.	SEA.	CINN.
N Y.	0	713	2451	748	205	2571	1374	188	1092	482	317	83	1631	405	875	1018	1097	1420	1171	2408	570
CHI	713	0	1475	587	597	1858	803	851	1188	238	410	666	920	308	262	355	414	940	833	1737	252
L A	2451	1745	0	1936	2300	347	1240	2596	2339	1983	2136	2394	831	2049	1589	1524	1356	1374	1673	959	1897
ATL	748	587	1936	0	543	2139	721	937	604	596	521	666	1212	554	467	907	676	701	424	2182	369
W DC	205	597	2300	543	0	2442	1185	393	923	396	192	123	1494	306	712	934	945	1220	966	2329	404
S F	2571	1858	347	2139	2442	0	1483	2699	2594	2091	2264	2523	949	2166	1744	1584	1506	1645	1926	678	2043
DAL	1374	803	1240	721	1185	1483	0	1551	1111	999	1070	1299	663	1025	547	862	451	225	443	1681	814
BOX.	188	851	2596	937	393	2699	1551	0	1255	613	483	271	1769	551	1038	1123	1251	1605	1359	2493	740
MIA	1092	1188	2339	604	923	2594	1111	1255	0	1152	1010	1019	1726	1087	1061	1511	1241	968	669	2934	992
DET	482	238	1983	596	396	2091	999	613	1152	0	205	443	1156	90	455	543	645	1105	939	1938	235
PIT	317	410	2136	521	192	2264	1070	483	1010	205	0	259	1320	115	559	743	781	1137	919	2138	257
PHI	83	666	2394	666	123	2523	1299	271	1019	443	259	0	1579	360	811	985	1038	1341	1089	2380	503
DEN	1631	920	831	1212	1494	949	663	1769	1726	1156	1320	1579	0	1227	796	700	558	879	1082	1021	1094
CLE	405	308	2049	554	306	2166	1025	551	1087	90	115	360	1227	0	492	630	700	1114	924	2026	222
S L	875	262	1589	467	712	1744	547	1038	1061	455	559	811	796	492	0	466	238	679	598	1724	309
MIN	1018	355	1524	907	934	1584	862	1123	1511	543	743	985	700	630	466	0	413	1056	1051	1395	605
K C	1097	414	1356	676	945	1506	451	1251	1241	645	781	1038	558	700	238	413	0	644	680	1506	541
HOU	1420	940	1374	701	1220	1645	225	1605	968	1105	1137	1341	879	1114	679	1056	644	0	318	1891	892
N O	1171	833	1673	424	966	1926	443	1359	669	939	919	1089	1082	924	598	1051	680	318	0	2101	706
SEA	2408	1737	959	2182	2329	678	1681	2493	2934	1938	2138	2380	1021	2026	1724	1395	1506	1891	2101	0	1972
CIN.	570	252	1897	369	404	2043	814	740	992	235	257	503	1094	222	309	605	541	892	706	1972	0

since at very short distances most people travel sooner by auto than by airplane. Equation (2) is a modification to correct this. Since the exponent b_3 in equation (2) turns out to be less than one, after calibration, then $\lim_{D(I, J) \to 0} T_2(I, J) = 0$ rather than infinity as given by equation (1).

Equations (3) - (7) are of the type used by the Lockheed-Georgia Company in their Northeast Corridor study. Equation (4) differs from equation (3) in that it has an additional multiplication factor called an attractiveness factor of the destination The purpose in using this factor is that certain cities, for example, Miami, attract more round trips than other hubs based on more than just a population and distance basis. Cities that have more recreation and entertainment facilities are expected to have more travel demand than those that do not.

Airline passengers tend to earn a higher income than those that use other modes of transportation. Equation (5) - (7) take this into account by assigning more round trip traffic to those cities having a large number of people earning over $10,000. This is reflected in the income factor, I(I).

Equations (6) and (7) have additional modifications by the addition of more constants which provided a better fit to the actual demand data for which they were calibrated. Equation (8) is a model of the type used by the Department of Transportation for the Northeast Corridor which takes into account competition between various modes of transportation This model is discussed in detail in the Appendix.

The first attempt for predicting city-pair demand was to use

TABLE 2 4-3

POPULATION OF MAJOR HUBS*

HUB	1960	1965	% INCREASE 1960-65
New York/Newark	12,384,000	13,217,000	6.7
Chicago	6,221,000	6,689,000	7.5
Los Angeles/Long Beach	6,039,000	6,765,000	12.0
Atlanta	1,017,000	1,216,000	19.6
Washington, D. C./Baltimore	3,716,000	4,262,000	14.7
San Francisco/Oakland	2,649,000	2,918,000	10.2
Dallas/Fort Worth	1,657,000	1,916,000	15.6
Boston	3,110,000	3,205,000	3.1
Miami/Fort Lauderdale	1,269,000	1,502,000	18 4
Detroit/Ann Arbor	3,934,000	4,174,000	6.1
Pittsburgh	2,405,000	2,372,000	-1.4
Philadelphia	4,343,000	4,664,000	7.4
Denver	929,000	1,073,000	15.5
Cleveland	1,909,000	2,000,000	4.7
St Louis	2,105,000	2,249,000	6.8
Minneapolis/St. Paul	1,482,000	1,612,000	8.8
Kansas City	1,093,000	1,183,000	8.3
Houston	1,418,000	1,696,000	19.6
New Orleans	907,000	1,027,000	13.2
Seattle/Tacoma	142,900	1,522,000	6.5
Cincinnati	1,268,000	1,347,000	6.2

*Source· Statistical Abstract of the United States 1967.

equation (5) with the constants c_1, c_2, c_3 derive for the Northeast Corridor study by the Lockheed-Georgia Company. To use this equation it was necessary to determine the income and attractiveness factors for the 21 hubs used in this study. The attractiveness factor, A(J) was found by using the number of people employed in eating and drinking places, hotels and motels, and recreation and entertainment places for each hub. Such information is given in the 1960 Census of Population. This number of employees was divided by the total population of the hub Similarly, the total number of employees in these businesses for all 21 hubs was divided by the total population of the 21 hubs to obtain an average value Each of the previously found 21 quantities was divided by the average number to obtain the attractiveness factor. The income factor was found in a similar fashion using the number of people earning over $10,000. This information is presented in Table 2.4-4. The cities previously studied in the Northeast Corridor have a wide range of populations and relatively short airline distances between cities. However, cities studied in this report all have populations over one million and a wide range of distances between cities (83 miles from New York to Philadelphia and 2934 miles from Miami to Seattle). Thus constants used in the Northeast Corridor might not be expected to accurately predict demand outside the Northeast Corridor. The values of these constants along with others derived later are given in Table 2.4-5. To determine the accuracy of this equation in predicting demand for the 21 hubs, forecasts for 1966 were made and compared to available 1966 demand data. As explained in the Lockheed-Georgia report, equation (5) is calibrated for the year 1960, and to determine the demand six years later, equation (5) is modified to give

TABLE 2.4-4

INCOME AND ATTRACTIVENESS FACTOR DATA[5]

HUB	POPULATION EMPLOYED IN EATING AND DRINKING PLACES	POPULATION EMPLOYED IN ENTERTAINMENT & RECREATION PLACES	POPULATION EMPLOYED IN HOTELS & LODGING PLACES	ATTRACTIVE-NESS FACTOR	POPULATION EARNING OVER $10,000	INCOME FACTOR
New York/Newark	154,168	53,521	46,317	1.128	441,205	1 128
Chicago	64,925	18,511	21,416	.927	210,895	1.073
Los Angeles/ Long Beach	78,946	50,738	18,265	1.206	258,267	1 213
Atlanta	7,105	2,375	2,907	669	26,649	829
Washington, D.C / Baltimore	36,462	10,942	11,509	869	130,760	1 110
San Francisco/ Oakland	34,825	11,284	12,135	1.150	98,799	1.124
Dallas/Forth Worth	17,066	6,174	6,466	986	46,410	887
Boston	27,386	6,871	7,526	.887	75,995	929
Miami/ Fort Lauderdale	20,553	7,695	21,174	2 141	33,686	840
Detroit/Ann Arbor	38,088	10,441	6,799[8]	.773	118,243	951
Pittsburgh	21,118	7,602	5,697	787	55,092	.725
Philadelphia	48,218	10,404	7,505	.837	110,066	802
Denver	10,866	3,293	5,070	1.137	25,963	884
Cleveland	19,149	5,205	4,361	879	54,476	960
St Louis	16,405	4,439	5,860	.713	49,771	765
Minneapolis/ St. Paul	15,876	5,160	5,045	.967	40,245	.860
Kansas City	10,482	3,286	3,874	933	28,313	832
Houston	12,425	3,536	4,050	.885	35,083	893
New Orleans	10,464	2,697	4,166	1 097	18,005	.656
Seattle/Tacoma	15,739	4,470	4,504	951	40,787	.904
Cincinnati	11,716	3,685	3,147	.952	28,789	851

Table 125 of the Census of Population 1960 lists employment in hotels and lodging places only for SMSA's with populations over 250,000 of which Ann Arbor was not in 1960. Ann Arbor was assigned a value of per capita employment in hotels and lodging places equal to the lowest value of all the SMSA's studied.

TABLE 2.4-5

CONSTANTS USED IN DEMAND ANALYSIS

EQUATION	VALUE OF CONSTANTS	STANDARD ERROR OF PREDICTION	ABSOLUTE AVERAGE PERCENTAGE ERROR
$T_5(I,J)=\frac{c_1(n)I(I)A(J)}{2}\frac{P_n(I)P_n(J)}{D(I,J)^{c_2}}(1-e^{-(c_3D(I,J))^2})$	$c_1(0)=1.\times10^{-7}$ (1960) $c_1(6)=1.55\times10^{-7}$ (1966)[10] $c_2=.4$ $c_3=.007$ (Lockheed-Georgia for Northeast Corridor)	420	83.6
$T_1(I,J)=a_1\frac{(E(I)E(J))^{a_2}}{D(I,J)^{a_3}}$	$a_1=4.033\times10^{-6}$ $a_2=.8974$ $a_3=.4747$	345	60.5
$T_2(I,J)=b_1\frac{(E(I)E(J))^{b_2}}{D(I,J)^{b_3}}(1-e^{-b_4D(I,J)})$	$b_1=.007585$ $b_2=.68445$ $b_3=.6070$ $b_4=.01042$	339	----
$T_3(I,J)=\frac{c_1P(I)P(J)}{2\,D(I,J)^{c_2}}(1-e^{-(c_3D(I,J))^2})$	$c_1=2.323\times10^{-7}$ $c_2=.5115$ $c_3=.006478$	316	46.2
$T_4(I,J)=\frac{c_1}{2}A(J)\frac{P(I)P(J)}{D(I,J)^{c_2}}(1-e^{-(c_3D(I,J))^2})$	$c_1=2.323\times10^{-7}$ $c_2=.5115$ $c_3=.006478$	286	43.2
$T_5(I,J)=\frac{c_1I(I)A(J)}{2}\frac{P(I)P(J)}{D(I,J)^{c_2}}(1-e^{-(c_3D(I,J))^2})$	$c_1=2.323\times10^{-7}$ $c_2=.5115$ $c_3=.006478$	276	42.3
$T_6(I,J)=\frac{d_1I(I)A(J)}{2}\frac{(P(I)P(J))^{d_4}}{D(I,J)^{d_2}}(1-e^{-(d_3D(I,J))^2})$	$d_1=1.973\times10^{-4}$ $d_2=.5848$ $d_3=.006289$ $d_4=.8000$	257	----

TABLE 2.4-5 (CONTINUED)

EQUATION	VALUE OF CONSTANTS	STANDARD ERROR OF PREDICTION	ABSOLUTE AVERAGE PERCENTAGE ERROR
$T_7(I,J)=\frac{k_1}{2} I(I)^{k_5} A(J)^{k6} \frac{(P(I)P(J))^{k_4}}{D(I,J)^{k_2}} (1-e^{-(k_3 D(I,J))^2})$	$k_1=3.2024\mathrm{x}10^{-4}$ $k_2=.685$ $k_3=.00625$ $k_4=.8000$ $k_5=2.6368$ $k_6=2.3461$	197	40.3

As shown by equation (9), $c_1(n)$ is different in general for each city pair. The value shown is an average value for three routes for purposes of comparison

$$T_n(I,\ J) = \frac{c_1(n)}{2}\ I(I)A(J)\ \frac{P_n(I)P_n(J)}{D(I,\ J)^{c_2}}\ \left(1 - e^{-(c_3 D(I,\ J))^2}\right)$$

$$= .5 \times 10^{-7} \left[1. + \frac{12.5}{100} - \frac{\Delta P(I)}{100} - \frac{\Delta P(J)}{100}\right]^n$$

$$I(I)A(J)\ \frac{P_n(I)P_n(J)}{D(I,\ J)^{.4}}\ \left(1 - e^{-1.007 D(I,\ J))^2}\right)$$

where

$T_n(I,\ J)$ = yearly round trip passenger demand from city I to city J and return

$$c_1(n) = 1. \times 10^{-7} \left[1. + \frac{12.5}{100} \quad \frac{P(I)}{100} \quad \frac{P(J)}{100}\right]^n$$

12.5 = assumed yearly growth rate of demand in percent

$\Delta P(I)$ = yearly percent change in population of city I

$P_n(I)$ = population of city I, n years after base year

$n = 6$

For purposes of checking results obtained by using Equation (9), actual demand data as given by the Civil Aeronautics Board for the year 1966 was chosen. The demand figures given by the CAB are for yearly passenger demand moving in both directions between the city-pairs on an origin-destination basis, regardless of the number of airlines used and with round trip journeys counted twice This was divided by two and by 365 to obtain average daily one-way demand. (The number of passengers flying from I to J was assumed to be equal to the same number flying from J to I on the average. Assuming all trips were round trips would fulfill this criterion) Equation (9), however, is for round trip demand from city I to city J and return. Again using the above assumptions, the one-way demand from city I to city J, $T_k(I,\ J)$ is given by

$$T_k(I,\ J) = T_n(I,\ J) + T_n(J,\ I) \qquad (10)$$

where

$T_n(I, J)$ is given by Equation (9) and

$$T_n(J, I) = .5 \times 10^{-7} \left[1. + \frac{12.5}{100} - \frac{\Delta P(I)}{100} - \frac{\Delta P(J)}{100}\right]^n$$

$$I(J)A(I) \frac{P_n(I)P_n(J)}{D(I, J)^{.4}} (1 - e^{-(.007D(I, J))}$$

Thus, the one-way demand is the sum of the round trip demand from city I to city J and return, and the round trip demand from city J to city I and return.

To determine the accuracy of these predictions, two criteria were chosen. The first criterion is called the Standard Error of Prediction (SEP) and the second is called the Average Absolute Percentage Error (AAPE). These are defined as

$$SEP = \sqrt{\frac{1}{N} \sum_{I=1}^{21} \sum_{J=1}^{21} (T(I, J) - T_k(I, J))^2} \qquad (11)$$

where

$T(I, J)$ = actual one-way daily passenger demand

$T_k(I, J)$ = predicted daily one-way demand as given by Equation (10)

N = number of data points for which actual demand data could be found. This was 80 routes or 160 data points

$$AAPE = \frac{1}{N} \sum_{I=1}^{21} \sum_{J=1}^{21} \frac{|T(I, J) - T_k(K, J)|}{T(I, J)} \times 100 \qquad (12)$$

For both the SEP and the AAPE the summations were taken only over those city-pairs for which actual data was known, i.e., over 160 data points rather than the whole matrix of 420 data points. The SEP is analogous to the simple standard deviation in statistics where the actual demand is used instead of the mean. As Table 2.4-5 shows the results of these computations give a SEP = 420 and a AAPE = 83.6 percent. In an attempt to reduce these measures of error the constants given in Equations (1) -- (7) were evaluated using the 1966 data. The values of these constants are also given in Table 2.4-5. In the case of Equation (1), the criterion used for minimization was

$$L = \sum_{I=1}^{21} \sum_{J=1}^{21} \left[T(I,\ J) - \frac{a_1 (E(I) \cdot E(J))^{a_2}}{D(I,\ J)^{a_3}} \right]^2 \tag{13}$$

where

T(I, J) = actual 1966 one-way demand

Thus, a search procedure was used to minimize the sum of the square of the difference between the actual data and the gravity model where the summation is over all routes where true demand data was known The search procedure varies the constants a_1, a_2, a_3 in such a manner as to produce a relative minimum for L. The constants b_1, b_2, b_3, b_4 in Equation (2) were determined in a similar manner. The results in Table 2.4-5 show a significant decrease in both measures of error. The constants c_1, c_2, c_3 in Equation (3) were also determined in a similar fashion with the result that both the SEP and the AAPE both decreased. The attractiveness factor as determined previously was then added as shown in Equation (4) and the one-way demand $T_k(I, J)$ was found in a manner similar to that discussed earlier, i.e.

$$T_k(I,\ J) = T_4(I,\ J) + T_4(J,\ I) \tag{14}$$

As shown in Table 2.4-5 some improvement was obtained. The income factor was then added as shown in Equation (5) and resulted in a small reduction in error. Equation (5) corresponds to the model used by the Lockheed-Georgia Company in making their predictions for the Northeast Corridor.

Further refinements in Equation (5) were then tried. The first change as shown by Equation (6) was to have the search procedure determine the best values in d_1, d_2, d_3, d_4, that is, it was no longer assumed that the demand was to be a function of the direct product of the populations In this case the constants were determined with the attractiveness and income factors in place, i.e., the search procedure found a relative minimum for the following expression:

$$L = \sum_{I=1}^{21} \sum_{J=1}^{21} (T(I, J) - T_6(I, J) - T_6(J, I))^2$$

$$= \sum_{I=1}^{21} \sum_{J=1}^{21} \left[T(I, J) - \frac{d_1}{2} (A(J)I(I) + A(I)I(J)) \right.$$

$$\left. \frac{(P(I)P(J))^{d_4}}{D(I, J)^{d_2}} (1 - e^{-(d_2 D(I, J))^2}) \right]^2$$

where

T(I, J) = actual 1966 one-way demand

As shown by the SEP a small reduction in error was obtained. The final refinements as shown by Equation (7) were to add addition constants as exponents to the attractiveness and income factors. The search procedure then determined a new set of constants so as to minimize the following expression.

$$L = \sum_{I=1}^{21} \sum_{J=1}^{21} (T(I, J) - T_7(I, J) - T_7(J, I))^2$$

$$= \sum_{I=1}^{21} \sum_{J=1}^{21} \left[T(I, J) - \frac{k_1}{2} (I(I)^{k_5} A(J)^{k_6}\right.$$

$$+ I(J)^{k_5} A(I)^{k_6}) \cdot \frac{(P(I) \cdot P(J))^{k_4}}{D(I, a)^{k_2}} (1 - e^{-(k_3 D(I, J))^2})]$$

A significant reduction in the standard error of prediction was obtained. The results are shown in Table 2.4-5.

For basis of comparison, Tables 2.4-6, 2.4-7, 2.4-8, and 2.4-9 present demand figures for 1966 based on Equations (1), (3), (7) and actual average daily one-way demand. Comparing tables, one sees that the Philadelphia to New York route and the New York to Miami route are among those that are most poorly predicted by the above equations. The final demand model (Equation (7)) does provide a much better fit on the New York to Miami route but only a slight improvement on the New York to Philadelphia route. The large error in the New York to Philadelphia route is probably caused by the relatively short distances (83 miles) between the cities. At this short distance the automobile would probably be used to a much greater extent.

Predictions for 1975, 1980, 1985 and 1990 were made using a modification of Equation (7). These figures of demand were used as input to the allocation algorithm discussed in a later section. For purposes of making prediction beyond the base year, the following modification of Equation (7) was made:

$$T_n(I, J) = \frac{k_1}{2} \frac{(1 + G(I, J)/100.)^n}{\left[(1 + \frac{P(I)}{100})(1 + \frac{P(J)}{100})\right]^{nk_4}}$$

$$\cdot \frac{A^{k_6}(J) I^{k_5}(I) (P(I) \cdot P(J))^{k_4}}{\cdot D(I, J)^{k_2}}$$

$$\cdot (1 - e^{-(k_3 D(I, J))^2}) \qquad (15)$$

where

TABLE 2.4-6

PREDICTED AVERAGE 1966 DAILY ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (1))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	1976	676	950	1956	463	557	1214	466	631	637	1229	310	547	385	316	286	249	252	166	290
CHI.	1975	0	754	1013	1120	513	683	564	426	838	536	435	387	592	649	494	432	287	282	184	406
L.A.	676	754	0	353	363	698	341	204	190	188	150	146	249	148	169	152	151	147	124	150	96
ATL.	950	1013	353	0	576	236	353	265	288	267	235	214	167	220	242	156	168	162	191	81	167
W.DC	1956	1120	363	576	0	247	311	446	263	361	421	531	168	326	221	171	160	139	144	88	178
S.F.	463	513	698	236	247	0	219	140	126	129	102	100	164	101	114	105	101	95	81	124	65
DAL.	557	683	341	353	311	219	0	163	169	163	131	122	174	129	176	125	159	218	146	72	90
BOS.	1214	564	204	265	446	140	163	0	135	175	162	218	93	147	110	93	83	73	73	51	80
MIA.	466	426	190	288	263	126	169	135	0	115	101	103	83	94	97	72	74	82	90	43	62
DET.	631	838	188	267	361	129	163	175	115	0	197	140	92	282	132	107	93	71	71	46	111
PIT.	637	536	150	235	421	102	131	162	101	197	0	149	71	207	99	76	70	58	59	37	88
PHI.	1229	435	146	214	531	100	122	218	103	140	149	0	67	123	85	68	63	54	56	35	66
DEN.	310	387	249	167	168	164	174	93	83	92	71	67	0	71	89	83	87	59	58	53	47
CLE.	547	592	148	220	326	101	129	147	94	282	207	123	71	0	102	80	71	56	57	36	91
S.L.	385	649	169	242	221	114	176	110	97	132	99	85	89	102	0	93	121	72	71	40	79
MIN.	316	494	152	156	171	105	123	93	72	107	76	68	83	80	93	0	82	51	48	39	51
K.C.	286	432	151	168	160	101	159	83	74	93	70	63	87	71	121	82	0	61	55	35	50
HOU.	249	287	147	162	139	95	218	73	82	71	58	54	69	56	72	51	61	0	78	31	39
N.O.	252	282	124	191	144	81	146	73	90	71	59	56	58	57	71	48	55	78	0	27	40
SEA.	166	184	150	81	88	124	72	51	43	46	37	36	55	36	40	39	35	31	27	0	23
CIN.	290	406	96	167	178	65	90	80	62	111	88	66	47	91	79	51	50	39	40	23	0

TABLE 2.4-7

PREDICTED AVERAGE 1966 ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (3))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	2009	1090	365	2036	457	419	1459	371	1527	1047	1056	214	797	607	405	285	367	242	245	452
CHI.	2009	0	658	209	721	274	280	442	180	1008	472	735	146	457	539	350	238	230	146	147	324
L.A.	1090	658	0	116	369	655	228	255	130	383	207	390	157	180	232	170	133	193	104	203	127
ATL.	365	209	116	0	141	47	55	78	47	129	78	137	24	64	79	41	35	50	38	24	53
W.DC	2036	721	369	141	0	154	148	424	132	553	354	530	74	296	221	139	101	130	88	82	177
S.F.	457	274	655	47	154	0	90	107	53	160	86	163	63	75	95	72	54	76	42	104	52
DAL.	419	280	228	55	148	90	0	95	54	156	84	152	50	73	114	65	67	122	59	44	56
BOS.	1459	442	255	78	424	107	95	0	83	325	206	528	50	164	134	93	64	83	54	58	95
MIA.	371	180	130	47	132	53	54	83	0	114	68	136	24	56	64	38	31	52	38	27	41
DET.	1527	1008	383	129	553	160	156	325	114	0	347	564	81	157	268	176	118	132	85	86	203
PIT.	1047	472	207	78	354	86	84	205	68	347	0	392	42	115	135	84	60	73	49	46	113
PHI.	1056	735	390	137	530	163	152	528	136	564	392	0	77	298	223	145	104	133	89	87	171
DEN.	214	145	157	24	74	63	50	50	24	81	42	77	0	37	53	40	33	39	21	31	27
CLE.	797	457	180	64	296	75	73	164	56	157	115	298	37	0	123	78	54	63	41	40	97
S.L.	607	539	232	79	221	95	114	134	64	268	135	223	53	123	0	103	96	91	58	49	103
MIN.	405	350	170	41	139	72	65	93	38	176	84	145	40	78	103	0	58	52	31	40	54
K.C.	285	238	133	35	101	54	67	64	31	118	60	104	33	54	96	58	0	49	29	28	42
HOU.	367	230	193	50	130	76	122	83	52	132	73	133	39	63	91	52	49	0	61	36	47
N.O.	242	146	104	38	88	42	59	54	38	85	49	89	21	41	58	31	29	61	0	21	32
SEA.	245	147	203	24	82	104	44	58	27	86	46	87	31	40	49	40	28	36	21	0	28
CIN.	452	324	127	53	177	52	56	95	41	203	113	171	27	97	103	54	42	47	32	28	0

TABLE 2.4-8

PREDICTED 1966 AVERAGE AIRLINE PASSENGER DEMAND (USING EQUATION (7))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	1966	1354	242	2518	571	391	1567	1487	1224	712	909	268	880	331	389	265	306	246	212	483
CHI.	1966	0	746	121	623	313	254	324	696	747	273	412	182	448	307	358	232	178	149	118	348
L.A.	1354	746	0	89	417	1567	296	243	629	325	139	271	300	204	155	208	161	220	137	281	149
ATL.	242	121	89	0	83	36	35	39	[illegible]	56	30	53	19	39	28	24	21	28	31	13	37
W.DC	2518	623	417	83	0	177	135	370	626	385	243	401	93	300	112	129	92	101	99	66	191
S.F.	571	313	1567	36	177	0	113	103	246	138	58	113	118	86	63	87	65	85	53	155	61
DAL.	391	254	296	35	135	113	0	68	175	105	42	79	64	65	63	58	65	127	59	37	50
BOS.	1567	324	243	39	370	103	68	0	258	193	102	303	48	133	53	68	45	53	42	39	76
MIA.	1487	696	629	[illegible]	626	246	175	258	0	351	127	282	85	212	132	113	92	173	83	80	130
DET.	1224	747	325	56	385	138	105	193	351	0	170	260	76	137	108	129	82	76	67	52	169
PIT.	712	273	139	30	243	58	42	102	127	170	0	150	27	79	42	44	30	33	24	21	70
PHI.	909	412	271	53	401	113	79	303	282	260	150	0	52	188	69	77	53	62	48	42	102
DEN.	268	182	300	19	93	118	64	48	85	76	27	52	0	44	37	50	42	44	22	39	31
CLE.	880	448	204	39	300	86	65	133	212	137	79	188	44	0	65	73	49	48	40	32	106
S.L.	331	307	155	28	112	63	63	53	132	108	42	69	37	65	0	57	57	43	34	23	61
MIN.	389	358	208	24	129	87	58	68	113	129	44	77	50	73	57	0	55	41	26	34	50
K.C.	265	232	161	21	92	65	65	45	92	82	30	53	42	49	57	55	0	41	25	23	38
HOU.	306	178	220	28	101	85	127	53	173	76	33	62	44	48	43	41	41	0	63	27	39
N.O.	246	149	137	31	99	53	59	42	83	67	24	48	22	40	34	26	25	63	0	17	29
SEA.	212	118	281	13	66	155	37	39	80	52	21	42	39	32	23	34	23	27	17	0	22
CIN.	483	348	149	37	191	61	50	76	130	169	70	102	31	106	61	50	38	39	29	22	0

TABLE 2 4-9

ACTUAL AVERAGE 1966 DAILY ONE-WAY AIRLINE PASSENGER DEMAND

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	1923	1089	368	2318	793	315	2596	1727	914	734	164	212	734	375	270	188	230	210	173	296
CHI.	1923	0	763	182	605	464	212	381	538	589	289	395	247	414	459	563	318	126	-	134	219
L.A.	1089	763	0	78	390	2033	249	225	116	247	100	201	311	152	160	158	155	175	84	456	-
ATL.	368	182	78	0	-	63	-	-	195	-	-	-	-	-	-	-	-	-	-	-	-
W.DC	2318	605	390	-	0	303	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S.F.	793	464	2033	63	303	0	123	163	60	129	68	149	201	70	93	105	81	-	-	571	-
DAL.	315	212	249	-	-	123	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BOS.	2596	381	225	-	-	163	-	0	296	-	-	400	-	-	-	-	-	-	-	-	-
MIA.	1727	538	116	195	-	60	-	296	0	253	159	289	-	-	-	-	-	-	-	-	-
DET.	914	589	247	-	-	129	-	-	253	0	-	205	-	-	-	-	-	-	-	-	-
PIT.	734	289	100	-	-	68	-	-	159	-	0	341	-	-	-	-	-	-	-	-	-
PHI.	164	395	201	-	-	149	-	400	289	205	341	0	-	175	-	-	-	-	-	-	-
DEN.	212	247	311	-	-	201	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-
CLE.	734	414	152	-	-	70	-	-	-	-	-	175	-	0	-	-	-	-	-	-	-
S.L.	375	459	160	-	-	93	-	-	-	-	-	-	-	-	0	-	182	-	-	-	-
MIN.	270	563	158	-	-	105	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-
K.C.	188	318	155	-	-	81	-	-	-	-	-	-	-	-	182	-	0	-	-	-	-
HOU.	230	126	175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	221	-	-
N.O.	210	-	84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	221	0	-	-
SEA.	173	134	456	-	-	571	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
CIN.	296	219	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

n = number of years beyond the base year (1966)

$T_n(I, J)$ = yearly round trip demand for city I to city J and return

$G(I, J)$ = annual growth rate of demand from city I to city J in percent

$P(I)$ = yearly population growth rate of city I in percent

The one-way demand is given by

$$T(I, J) = T_n(I, J) + T_n(J, I) \tag{16}$$

Thus, $T_n(I, J)$ is a nonsymmetrical demand while $T(I, J)$ is symmetrical. This says that the number of round trip passengers from New York to Miami is not the same as the number of round trip passengers from Miami to New York, but the total number of passengers flying from New York to Miami is the same as that flying from Miami to New York over a one-year period. The modification of Equation (7) is essentially a modification of the constant k_1 for increasing time. It is obtained by assuming a constant growth rate for airline traffic, that is

$$T_n(I, J) = T_o(I, J) \cdot (1 + G(I, J)/100)^n \tag{17}$$

where

$T_o(I, J)$ = round trip demand at base year $n = 0$

$T_n(I, J)$ = round trip demand n years past base year

$G(I, J)$ = annual growth rate in demand on route I-J

It is then assumed that Equation (7) can be written as

$$T_n(I, J) = \frac{k_1(n)}{2}\left[I(I)^{k_5} \cdot A(J)^{k_6} \frac{(P_n(I) \cdot P_n(J))^{k_4}}{D(I, J)^{k_2}} \right.$$

$$\left. (1 - e^{-(k_3 D(I, J))^2}) \right] \tag{18}$$

Where k_1 is now a function of time

Thus

$$T_n(I, J) = \frac{k_1(n)}{k_1(o)} \frac{(P_n(I)P_n(J))^{k_4}}{(P_o(I)P_o(J))^{k}} T_o(I, J) \tag{19}$$

Where $P_o(I)$ is the population of hub I at the base year. Using Equations (17) and (19), we obtain

$$k_1(n) = \frac{(P_o(I)P_o(J))^{k_4}}{(P_n(I)P_n(J))^{k_4}} (1 + G(I, J)/100)^n$$

Using

$$P_n(I) = P_o(I)(1 + \Delta P(I)/100)^n$$

$$P_n(J) = P_o(J)(1 + \Delta P(J)/100)^n$$

we obtain

$$k_1(n) = \frac{(P_o(I) \cdot P_o(J))^{k_4}}{\left[P_o(I)(1 + \frac{\Delta P(I)}{100})^n P_o(J)(1 + \frac{\Delta P(J)}{100})^n\right]^{k_4}}$$

$$(1 + G(I, J)/100)^n$$

or

$$k_1(n) = \frac{(1 + G(I, J)/100)^n}{\left[(1 + \frac{\Delta P(I)}{100}) \cdot (1 + \frac{\Delta P(J)}{100})\right]^{nk_4}} \tag{20}$$

Substituting Equation (20) into Equation (18) we obtain Equation (15) as desired

Since information for determining the route growth rate G(I, J) for all routes was not available, the following approximation was used The yearly growth rates of each of the 21 hubs were found for the years 1964-66, and the yearly average growth for each hub computed For each route the origin and destination growth rates were averaged to give the route growth rate G(I, J). The data used for these computations is given in Table 2.4-1 and the values of G(I, J) are given in Table 2.4-10. Populations of the hubs for the years

TABLE 2.4-10

ESTIMATED AVERAGE CITY-PAIR PERCENTAGE GROWTH RATES FOR 1964-66

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	11.3	12.6	14.1	17.6	12.9	14.9	17.2	12.0	13.8	13.6	10.7	12.8	15.1	12.1	14.0	12.9	13.0	14.2	15.6	15.4	15.7
CHI.	12.6	13.9	15.5	18.9	14.3	16.2	18.6	13.3	15.2	14.9	12.1	14.1	16.4	13.5	15.4	14.3	14.4	15.5	16.9	16.7	17.0
L.A.	14.1	15.5	17.0	20.4	15.8	17.7	20.1	14.8	16.7	16.4	13.6	15.6	17.9	15.0	16.9	15.8	15.9	17.1	18.5	18.2	18.5
ATL.	17.6	18.9	20.4	23.9	19.3	21.2	23.6	18.3	20.2	19.9	17.1	19.1	21.4	18.5	20.3	19.2	19.3	20.5	21.9	21.7	22.0
W.DC	12.9	14.3	15.8	19.3	14.6	16.5	18.9	13.6	15.5	15.2	12.4	14.4	16.7	13.8	15.7	14.6	14.7	15.9	17.3	17.1	17.4
S.F.	14.9	16.2	17.7	21.2	16.5	18.4	20.8	15.5	17.4	17.1	14.3	16.3	18.6	15.7	17.6	16.5	16.6	17.8	19.2	19.0	19.3
DAL.	17.2	18.6	20.1	23.6	18.9	20.8	23.2	17.9	19.8	19.5	16.7	18.7	21.0	18.1	20.0	18.9	19.0	20.2	21.6	21.4	21.7
BOS.	12.0	13.3	14.8	18.3	13.6	15.5	17.9	12.6	14.5	14.2	11.4	13.4	15.7	12.8	14.7	13.6	13.7	14.9	16.3	16.1	16.4
MIA.	13.8	15.2	15.7	20.2	16.5	17.4	19.8	14.5	16.4	16.1	13.3	15.3	17.6	14.7	16.6	15.5	15.6	16.8	18.2	18.0	18.2
DET.	13.6	14.9	16.4	19.9	15.2	17.1	19.5	14.2	16.1	15.8	13.0	15.0	17.3	14.4	16.3	15.2	15.3	16.5	17.9	17.7	18.0
PIT.	10.7	12.1	13.6	17.1	12.4	14.3	16.7	11.4	13.3	13.0	10.2	12.2	14.5	11.6	13.5	12.4	12.5	13.7	15.1	14.9	15.1
PHI.	12.8	14.1	15.6	19.1	14.4	16.3	18.7	13.4	15.3	15.0	12.2	14.3	16.6	13.6	15.5	14.4	14.5	15.7	17.1	16.9	17.2
DEN.	15.1	16.4	17.9	21.4	16.7	18.6	21.0	15.7	17.6	17.3	14.5	16.5	18.9	15.9	17.8	16.7	16.8	18.0	19.4	19.2	19.5
CLE.	12.1	13.5	15.0	18.5	13.8	15.7	18.1	12.8	14.7	14.4	11.6	13.6	15.9	13.0	14.9	13.8	13.9	15.1	16.5	16.3	16.5
S.L.	14.0	15.4	16.9	20.3	15.7	17.6	20.0	14.7	16.6	16.3	13.5	15.5	17.8	14.9	16.8	15.7	15.8	17.0	18.3	18.1	18.4
MIN.	12.9	14.3	15.8	19.2	14.6	16.5	18.9	13.6	15.5	15.2	12.4	14.4	16.7	13.8	15.7	14.6	14.7	15.9	17.2	17.0	17.3
K.C.	13.0	14.4	15.9	19.3	14.7	16.6	19.0	13.7	15.6	15.3	12.5	14.5	16.8	13.9	15.8	14.7	14.8	16.0	17.3	17.1	17.4
HOU.	14.2	15.5	17.1	20.5	15.9	17.8	20.2	14.9	16.8	16.5	13.7	15.7	18.0	15.1	17.0	15.9	16.0	17.1	18.5	18.3	18.6
N.O.	15.6	16.9	18.5	21.9	17.3	19.2	21.6	16.3	18.2	17.9	15.1	17.1	19.4	16.5	18.3	17.2	17.3	18.5	19.9	19.7	20.0
SEA.	15.4	16.7	18.2	21.7	17.1	19.0	21.4	16.1	18.0	17.7	14.9	16.9	19.2	16.3	18.1	17.0	17.1	18.3	19.7	19.5	19.8
CIN.	15.7	17.0	18.5	22.0	17.4	19.3	21.7	16.4	18.2	18.0	15.1	17.2	19.5	16.5	18.4	17.3	17.4	18.6	20.0	19.8	20.1

TABLE 2.4-11

PREDICTED 1975 DAILY ROUND TRIP AIRLINE PASSENGER DEMAND (USING EQUATION (15))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	CAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	2231	1989	364	2273	935	842	2005	3806	1413	1000	1373	558	1072	491	630	434	453	653	394	984
CHI.	3099	0	1410	240	762	656	682	526	2020	1148	481	786	464	711	588	725	476	338	463	276	885
L.A.	2059	1051	0	163	468	3166	779	387	1960	466	241	506	767	308	283	416	327	402	442	640	374
ATL.	550	262	239	0	148	108	132	92	583	125	75	143	70	89	77	70	62	75	133	43	134
W.DC	4474	1080	889	193	0	415	397	693	1829	692	471	850	253	544	242	287	206	215	318	172	532
S.F.	885	447	2895	68	199	0	305	167	811	200	103	217	311	132	118	180	135	158	178	360	157
DAL.	612	357	547	63	147	235	0	110	650	148	77	153	178	99	117	123	138	238	219	86	132
BOS.	2113	407	393	64	371	186	159	0	712	247	157	503	109	179	90	121	82	86	121	79	169
MIA.	389	149	193	39	95	88	91	69	0	73	44	99	51	52	41	45	38	56	90	34	65
DLT.	2187	1279	697	128	544	326	316	363	1112	0	338	561	214	248	233	294	190	163	230	138	483
PIT.	725	251	169	36	174	79	77	108	310	158	0	191	59	79	52	60	42	41	60	33	121
PHI.	1125	464	400	78	354	188	173	391	791	297	216	0	113	229	102	128	89	93	136	79	212
DEN.	288	172	382	24	66	169	126	53	255	71	35	71	0	46	48	75	63	98	63	65	57
CLE.	1257	601	349	69	324	163	159	199	592	188	128	329	105	0	113	136	92	83	119	69	249
S.L.	517	446	288	54	130	231	169	90	418	159	75	132	98	101	0	116	119	81	111	53	157
MIN.	442	366	282	32	102	133	118	81	312	134	58	110	102	81	77	0	87	57	72	59	97
K.C.	304	240	221	29	73	100	133	54	258	86	41	76	86	55	79	87	0	58	70	41	75
HOU.	432	232	370	47	104	159	312	78	519	101	54	179	107	68	73	77	79	0	196	58	90
N.O.	167	85	109	22	41	48	77	29	225	38	21	42	31	26	27	26	26	52	0	18	36
SEA.	328	166	515	24	73	317	95	62	276	74	38	80	104	49	42	69	48	51	59	0	57
CIN.	697	451	256	63	191	118	129	114	451	221	118	183	79	150	105	97	76	67	99	48	0

TABLE 2.4-12

PREDICTED 1980 AVERAGE DAILY ROUND TRIP AIRLINE PASSENGER DEMAND (USING EQUATION (15))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SFA.	CINN.
N.Y.	0	3931	3715	777	4005	1908	1782	3460	6923	2602	1643	2439	1079	1858	922	1123	778	837	1298	786	1989
CHI.	5460	0	2784	542	1420	1341	1524	980	3887	2236	839	1477	947	1306	1167	1366	902	660	972	583	1891
L.A.	3846	2075	0	389	923	6845	1838	748	3989	961	445	1006	1656	598	595	830	655	830	982	1427	844
ATL.	1175	590	568	0	334	266	354	203	1355	294	159	326	171	198	185	160	142	177	335	109	344
W.DC	7883	2013	1755	435	0	847	887	1265	3515	1347	821	1597	517	997	480	540	391	420	668	363	1135
S.F.	1711	914	6259	167	407	0	745	335	2798	426	197	446	694	265	256	372	280	337	469	831	368
DAL.	1297	798	1292	170	328	573	0	241	1494	346	162	345	433	218	278	277	314	556	545	217	337
BOS.	3645	743	761	142	677	373	349	0	1342	471	268	925	217	322	175	224	152	164	250	163	355
MIA.	708	286	394	92	183	184	210	130	0	148	79	191	106	98	83	88	74	112	195	74	143
DET.	4026	2491	1436	301	1059	696	736	692	2233	0	614	1100	456	475	483	580	375	332	503	304	1076
PIT.	1192	438	312	76	302	151	162	185	558	288	0	335	95	136	96	106	75	74	117	65	243
PHI.	1998	871	796	177	665	386	389	719	1532	583	379	0	232	424	205	243	171	184	287	167	450
DEN.	557	352	826	58	136	378	367	107	1537	152	68	146	0	93	104	155	132	123	144	149	134
CLE.	2181	1103	678	154	594	328	351	358	1122	360	219	608	212	0	221	252	171	160	246	143	523
S.L.	972	885	605	129	257	285	402	175	856	329	139	264	213	198	0	233	240	168	248	119	356
MIN.	788	699	563	74	193	276	267	149	607	263	103	208	210	151	155	0	166	112	153	125	209
K.C.	544	454	443	66	139	207	302	101	504	170	72	146	178	102	159	164	0	114	149	86	163
HOU.	799	453	765	111	204	340	729	149	1044	205	98	214	228	130	152	152	156	0	429	128	202
N.O.	332	179	242	57	87	110	192	61	487	83	41	90	71	54	60	56	55	115	0	43	86
SFA.	654	349	1147	61	153	730	249	129	600	164	75	169	241	101	94	148	102	112	141	0	137
CIN.	1408	964	577	161	408	275	328	238	993	493	237	395	184	316	239	210	165	150	238	117	0

TABLE 2.4-13

PREDICTED 1985 AVERAGE DAILY ROUND TRIP AIRLINE PASSENGER DEMAND (USING EQUATION (15))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	6926	6938	1661	7056	3494	3772	5968	12594	4791	2702	4330	2085	3223	1731	1999	1394	1545	2578	1568	4020
CHI.	9620	0	5496	1223	2647	2741	3407	1790	7479	4355	1461	2774	1934	2398	2317	2574	1711	1289	2041	1228	4029
L.A.	7183	4096	0	927	1821	14757	4338	1448	8120	1981	821	2002	3577	1163	1249	1657	1315	1715	2178	3180	1966
ATL.	2512	1332	1354	0	753	655	949	450	3146	693	336	741	421	440	442	364	326	416	847	275	884
W.DC	13889	3752	3463	981	0	1730	1981	2310	6758	2022	1429	2999	1056	1830	953	1018	740	819	1401	754	2423
S.F.	3309	1868	13531	410	832	0	1819	672	3597	909	376	919	1551	534	557	768	582	721	939	1915	858
DAL.	2745	1784	3049	457	732	1398	0	528	3430	807	349	777	1056	479	659	625	713	1297	1365	547	858
BOS.	6288	1357	1473	313	1236	747	765	0	2530	900	458	1702	435	579	340	414	282	314	513	338	743
MIA.	1287	551	802	213	351	388	483	245	0	296	141	370	224	185	170	172	144	225	421	160	315
DET.	7413	4852	2961	709	2061	1485	1715	1321	4486	0	1118	2160	971	912	1000	1142	743	677	1102	669	[illegible]
PIT.	1961	763	575	161	526	288	339	315	1002	524	0	588	182	232	178	187	133	136	230	128	485
PHI.	3547	1636	1584	401	1248	795	875	1324	2969	1143	664	0	478	785	410	462	326	351	607	354	982
DEN.	1076	719	1783	144	277	846	749	213	1130	324	129	301	0	187	226	319	273	263	331	343	313
CLE.	3782	2926	1319	342	1091	661	772	645	2125	691	376	1124	425	0	432	468	319	307	509	296	1101
S.L.	1824	1757	1271	308	510	620	954	340	1751	691	258	527	462	388	0	468	484	349	553	267	809
MIN.	1403	1301	1123	169	363	565	603	276	1180	518	181	395	434	280	312	0	319	221	323	266	450
K.C.	973	862	888	151	263	431	685	187	985	336	128	279	370	190	321	318	0	227	318	184	355
HOU.	1475	885	1581	262	397	726	1702	284	2102	418	179	421	486	250	316	301	310	0	942	292	451
N.O.	659	376	538	143	182	253	480	125	1053	182	81	189	164	111	134	118	116	252	0	102	206
SEA.	1305	736	2557	152	323	1684	626	267	1304	360	147	360	554	210	211	315	219	246	332	0	331
CIN.	2847	2060	1304	414	872	642	835	499	2185	1098	474	849	430	665	544	454	359	335	570	281	0

TABLE 2.4-14

PREDICTED 1990 AVERAGE DAILY ROUND TRIP AIRLINE PASSENGER DEMAND (USING EQUATION (15))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	12204	12957	3551	12431	6755	7986	10296	22908	8819	4442	7689	4029	5590	3251	3561	2498	2854	5120	3128	8128
CHI.	16951	0	10850	2759	4933	5602	7615	3269	14389	8482	2544	5210	3948	4402	4601	4852	3243	2517	4284	2588	9633
L.A.	13414	8087	0	2209	3594	31987	10240	2832	16528	4084	1516	3982	7725	2262	2624	3306	2637	3542	4831	7089	4334
ATL.	5369	3004	3226	0	1698	1614	2545	996	7304	1629	710	1683	1035	979	1060	829	746	980	2139	699	2273
W.DC	24472	6992	6834	2211	0	3534	4422	4218	12992	5104	2487	5632	2154	3358	1891	1919	1402	1599	2937	1619	5174
S.F.	6396	3818	29252	1010	1699	0	4439	1346	7577	1939	720	1893	3465	1074	1211	1586	1209	1540	2154	4475	2095
DAL.	5810	3989	7195	1224	1634	3411	0	1157	7908	1880	711	1749	2574	1054	1564	1411	1617	3028	3416	1375	2186
BOS.	10847	2479	2851	694	2257	1497	1676	0	4769	1717	780	3133	871	1040	662	765	522	601	1056	698	1566
MIA.	2341	1059	1632	494	675	818	1111	463	0	595	254	718	471	350	348	334	281	453	910	348	694
DET.	13647	9449	6104	1667	4012	3169	3998	2522	9009	0	2035	4238	2070	1748	2073	2248	1471	1380	2412	1471	5359
PIT.	3272	1329	1062	340	917	551	709	537	1802	954	0	1032	348	398	330	330	235	248	451	253	970
PHI.	6299	3073	3151	912	2344	1638	1970	2437	5753	2244	1166	0	983	1451	820	876	623	710	1283	752	2115
DEN.	2080	1467	3851	353	565	1889	1826	427	2377	691	247	620	0	376	492	659	567	561	758	791	731
CLE.	6559	3719	2564	759	2002	1331	1700	1159	4024	1326	644	2079	856	0	844	869	596	591	1052	615	2317
S.L.	3425	3490	2670	738	1012	1348	2265	662	3584	1412	479	1054	1004	758	0	939	976	726	1234	599	1838
MIN.	2500	2452	2242	385	684	1176	1361	510	2293	1020	319	751	896	520	625	0	611	437	686	566	972
K.C.	1747	1633	1782	345	498	893	1555	347	1926	665	226	532	768	355	648	609	0	451	678	394	770
HOU.	2724	1729	3265	618	775	1552	3972	544	4233	851	327	827	1038	481	657	594	615	0	2067	622	1039
N.O.	1309	788	1193	362	384	582	1200	256	2277	399	159	400	376	229	299	250	248	554	0	241	493
SEA.	2604	1551	5700	385	681	3882	1574	552	2832	792	291	764	1276	436	473	671	469	542	785	0	766
CIN.	5756	4400	2944	1065	1861	1499	2128	1046	4809	2449	947	1828	1002	1399	1235	981	780	748	1365	677	0

TABLE 2.4-15

PREDICTED 1975 AVERAGE DAILY ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (16))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	5330	4048	913	6747	1820	1454	4118	4195	3600	1725	2498	846	2329	1009	1073	738	886	820	722	1680
CHI.	5330	0	2451	502	1842	1104	1039	943	2169	2427	733	1250	636	1312	1033	1091	716	570	548	442	1336
L.A.	4048	2451	0	402	1357	6062	1326	780	2154	1163	410	906	1149	657	571	698	547	772	552	1155	629
ATL.	913	502	402	0	341	176	195	156	623	253	111	221	93	158	131	103	91	122	155	66	196
W.DC.	6747	1842	1357	341	0	614	544	1063	1923	1235	645	1204	320	858	372	389	279	320	360	245	723
S.F.	1820	1104	6062	176	614	0	540	323	899	526	182	404	480	295	249	313	235	317	226	677	275
DAL.	1454	1039	1326	195	544	540	0	269	741	464	155	326	304	258	285	241	271	550	293	185	261
BOS.	4118	943	780	156	1063	323	269	0	781	610	256	893	162	378	180	202	136	163	151	142	283
MIA.	4195	2169	2154	623	1923	893	741	781	0	1185	374	889	306	644	459	358	296	574	315	310	516
DET.	3600	2427	1163	253	1235	526	464	610	1185	0	496	858	285	436	391	428	275	263	268	212	704
PITT.	1725	733	410	111	645	182	155	256	374	496	0	407	85	207	126	119	83	94	81	71	240
PHI.	2498	1250	906	221	1204	404	326	893	889	858	407	0	184	558	234	238	166	202	178	158	395
DEN.	846	636	1149	93	320	480	304	162	306	285	85	184	0	151	145	177	149	164	94	169	136
CLEV.	2329	1312	657	158	858	295	258	378	644	436	207	558	151	0	214	217	146	151	145	117	399
S.L.	1009	1033	571	131	372	249	285	180	459	391	126	234	145	214	0	194	198	154	138	95	262
MIN.	1073	1091	698	103	389	313	241	202	358	428	119	238	177	217	194	0	173	134	98	128	194
K.C.	738	716	547	91	279	235	271	136	296	275	83	166	149	146	198	173	0	136	96	88	152
HOU.	886	570	772	122	320	317	550	163	574	263	94	202	164	151	154	134	136	0	248	109	158
N.O.	820	548	552	155	360	226	293	151	315	268	81	178	94	145	138	98	96	248	0	78	135
SEA.	722	442	1155	66	245	677	185	142	310	212	71	158	169	117	95	128	88	109	78	0	105
CIN.	1680	1336	629	196	723	275	261	283	516	704	240	395	136	399	262	194	152	158	135	105	0

TABLE 2.4-16

PREDICTED 1980 AVERAGE DAILY ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (16))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	9391	7561	1952	11888	3519	3079	7104	7631	6629	2835	4436	1636	4039	1894	1911	1323	1635	1629	1440	3397
CHI.	9391	0	4859	1133	3434	2255	2323	1723	4173	4727	1277	2348	1299	2409	2052	2056	1357	1113	1151	932	2855
L.A.	7561	4859	0	957	2678	13104	3130	1510	4383	2397	756	1803	2482	1277	1200	1393	1098	1595	1224	2574	1421
ATL.	1952	1133	957	0	769	433	524	345	1446	596	235	503	229	352	313	234	208	288	392	168	505
W.DC	11888	3434	2678	769	0	1254	1215	1942	3698	2405	1123	2262	653	1592	737	733	529	623	755	516	1543
S.F.	3519	2255	13104	433	1254	0	1318	708	1892	1122	348	833	1073	594	542	647	487	677	519	1561	642
DAL.	3079	2323	3130	524	1215	1318	0	590	1704	1082	324	734	741	568	679	544	616	1285	737	466	665
BOS.	7104	1723	1510	345	1942	708	590	0	1472	1164	453	1644	324	680	350	374	253	313	310	293	593
MIA.	7631	4173	4383	1446	3698	1892	1704	1472	0	2381	636	1723	643	1220	939	695	578	1156	682	674	1136
DET.	6629	4727	2397	596	2405	1122	1082	1164	2381	0	902	1683	608	836	811	843	545	537	586	468	1569
PIT.	2835	1277	756	235	1123	348	324	453	636	902	0	714	163	355	235	209	147	172	158	140	430
PHI.	4436	2348	1803	503	2262	833	734	1644	1723	1683	714	0	379	1032	469	451	317	397	377	336	851
DEN.	1636	1299	2482	229	653	1073	741	324	643	608	163	379	0	305	317	365	310	351	216	390	318
CLE.	4039	2409	1277	352	1592	594	569	680	1220	836	355	1032	305	0	419	403	273	290	300	244	839
S.L.	1894	2052	1200	313	737	542	679	350	939	811	235	469	317	419	0	388	399	320	308	213	596
MIN.	1911	2056	1393	234	733	647	544	374	695	843	209	451	365	403	388	0	332	265	208	273	419
K.C.	1323	1357	1098	208	529	487	616	253	578	545	147	317	310	273	399	332	0	270	204	188	329
HOU.	1635	1113	1595	288	623	677	1285	313	1156	537	172	397	351	290	320	265	270	0	544	240	352
N.O.	1629	1151	1224	392	755	519	737	310	682	586	158	377	216	300	308	208	204	544	0	183	323
SEA.	1440	932	2574	168	516	1561	466	293	674	468	140	336	390	244	213	273	188	240	183	0	254
CIN.	3397	2855	1421	505	1543	642	665	599	1136	1569	480	851	318	839	596	419	329	352	323	294	0

TABLE 2.4-17

PREDICTED 1985 AVERAGE DAILY ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (16))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	16576	14120	4173	20945	6803	6517	12256	13881	12203	4661	7878	3161	7005	3556	3403	2370	3020	3237	2873	6868
CHI.	16546	0	9592	2555	6399	4509	5191	3147	8029	9207	2223	4410	2652	4423	4074	3875	2572	2174	2416	1964	6099
L.A.	14120	9592	0	2281	5284	28328	7387	2921	8922	4942	1396	3586	5360	2482	2520	2780	2203	3295	2716	5738	3209
ATL.	4173	2555	2281	0	1734	1065	1405	763	3358	1401	497	1142	564	782	751	533	476	678	990	427	1298
W.DC	20945	6399	5284	1734	0	2662	2713	3546	7109	4683	1955	4247	1332	2921	1463	1381	1003	1217	1582	1087	3295
S.F.	6803	4509	28328	1065	2662	0	3217	1419	3985	2394	665	1715	2397	1195	1177	1337	1012	1447	1192	3598	1500
DAL.	6517	5191	7387	1405	2713	3217	0	1293	3921	2522	678	1652	1805	1251	1613	1227	1398	2999	1845	1173	1694
BOS.	12256	3147	2921	763	3546	1419	1293	0	2775	2221	773	3026	648	1223	681	690	469	598	638	605	1242
MIA.	13881	8029	8922	3358	7109	3985	3921	2775	0	4782	1144	3339	1353	2310	1921	1351	1129	2327	1474	1464	2500
DET.	12203	9207	4942	1401	4683	2394	2522	2221	4782	0	1643	3303	1295	1603	1681	1659	1079	1095	1284	1029	3498
PIT.	4661	2223	1396	497	1955	665	678	773	1144	1643	0	1253	311	608	436	369	261	315	311	276	959
PHI.	7878	4410	3586	1142	4247	1715	1652	3026	3339	3303	1253	0	779	1909	937	857	605	782	796	714	1832
DEN.	3161	2652	5360	564	1332	2397	1805	648	1353	1295	311	779	0	613	689	753	643	749	495	897	743
CLE.	7005	4423	2482	782	2921	1195	1251	1223	2310	1603	608	1909	613	0	820	749	510	557	620	506	1766
S.L.	3556	4074	2520	751	1463	1177	1613	681	1921	1681	436	937	689	820	0	780	805	666	687	478	1353
MIN.	3403	3875	2780	533	1381	1337	1227	690	1351	1659	369	857	753	749	780	0	636	522	441	581	905
K.C.	2370	2572	2203	476	1003	1012	1398	469	1129	1079	261	605	643	510	805	636	0	537	434	403	714
HOU.	3020	2174	3295	678	1217	1447	2999	598	2327	1095	315	782	749	557	666	522	537	0	1194	528	786
N.O.	3237	2416	2716	990	1582	1192	1845	638	1474	1284	311	796	495	620	687	441	434	1194	0	434	775
SEA.	2873	1964	5738	427	1087	3598	1173	605	1464	1029	276	714	897	506	478	581	403	528	434	0	612
CIN.	6868	6099	3209	1298	3295	1500	1694	1242	2500	3498	959	1832	743	1766	1353	905	714	786	775	612	0

TABLE 2.4-18

PREDICTED 1990 AVERAGE DAILY ONE-WAY AIRLINE PASSENGER DEMAND (USING EQUATION (16))

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	29175	26371	8920	34903	13151	13795	21143	27250	22467	7663	13988	6108	12149	6676	6061	4245	5578	6429	5732	13884
CHI.	29175	0	18937	5713	11920	9420	11604	5768	17447	17931	3873	8283	5410	8121	8091	7303	4876	4246	5072	4140	13029
L.A.	26371	18937	0	5434	19428	51239	17455	5533	18159	10188	2577	7133	11576	4826	5294	7548	4419	6807	6024	12789	7249
ATL.	8920	5713	5434	0	3909	2424	3759	1039	7798	3297	1050	2595	1389	1738	1798	1214	1092	1598	2500	1084	3338
W.DC	34903	11920	19428	3909	0	233	6957	6176	13655	9117	3604	7976	2719	5360	2904	2603	1900	2374	3318	2291	7035
S.F.	13151	9420	51239	2424	1233	0	7850	2843	8393	5107	1271	3531	5355	2405	2559	2762	2102	3092	2736	8297	3504
DAL.	13795	11524	17435	3759	6957	7350	0	2834	9019	5878	1420	3719	4400	2755	3828	2771	3172	7001	4616	2949	4315
BOS.	21143	5768	5533	1039	6176	2843	2834	0	5231	4239	1313	5570	1298	2199	1324	1274	871	1145	1313	1250	2602
MIA.	27250	17447	18159	7799	13656	8393	9019	5231	0	9605	2056	6471	2949	4374	3931	2027	2209	7685	3187	3180	5504
DET.	22467	17931	10188	3297	9117	5107	5878	4239	9605	0	2990	6482	2761	3074	3485	3267	2136	2232	2811	2263	7800
PIT.	7663	3873	2577	1050	3604	1271	1420	1313	2055	2990	0	2198	595	1043	808	649	461	575	611	544	1918
PHI.	13988	8283	7133	2595	7976	3531	3719	5570	6471	6482	2198	0	1603	3530	1874	1627	1155	1537	1683	1516	3942
DEN.	6103	5410	11576	1389	2719	5355	4400	1298	2949	2761	595	1603	0	1232	1496	1555	1335	1599	1134	2067	1733
CLE.	12149	8121	4826	1738	5360	2405	2755	2199	4374	3074	1043	3530	1232	0	1602	1389	951	1072	1281	1051	3716
S.L.	6675	8091	5294	1798	2904	2559	3328	1324	3931	3485	808	1874	1496	1602	0	1564	1624	1383	1533	1072	3073
MIN.	6051	7303	7548	1214	2603	2762	2771	1274	2627	3267	649	1627	1555	1389	1564	0	1219	1030	936	1237	1954
K.C.	4245	4876	4419	1092	1900	2102	3172	871	2208	2136	461	1155	1335	951	1624	1219	0	1065	926	863	1550
HOU.	5578	4246	6807	1598	2374	3092	7001	1145	7685	2232	575	1537	1599	1072	1383	1030	1065	0	2621	1164	1755
N.O.	6429	5072	6024	2500	3318	2736	4616	1313	3187	2811	611	1683	1134	1281	1533	936	926	2621	0	1026	1858
SEA.	5732	4140	12789	1084	2291	8297	2949	1250	3180	2263	544	1516	2067	1051	1072	1237	863	1164	1026	0	1473
CIN.	13884	13029	7249	3338	7035	3504	4315	2602	5504	7800	1918	3942	1733	3716	3073	1954	1550	1755	1859	1473	0

1960 and 1965 and growth rates are given in Table 2.4-3. Using this information and Equations (15) and (16) predictions for round trip and one-way demand were made for 1975, 1980, 1985 and 1990. This data is given in Tables 2.4-11 to 2.4-18.

A general indication of the increased passenger demand for air transportation is shown in Table 2.4-18. Based on the demands predicted by this investigation, the total passenger demand and the percentage demand, as a function of distance are shown. It is noted that the total demand doubles approximately each five years, but that the percentage demand over a fixed distance remains relatively constant.

TABLE 2.4-18

PASSENGER DEMAND FOR AIR TRANSPORTATION

	1966	1975	1980	1985	Typical
Total Passenger Demand Per Day	85,770	275,063	518,908	1,042,445	-------
Distance (miles)			Percentage Demand		
0 - 500	36.7	36.3	35.9	38.2	36.8
500 - 1000	28.4	24.4	26.0	26.0	26.2
1000 - 1500	17.9	18.1	18.3	17.6	18.0
1500 - 2000	7.8	9.0	9.7	9.0	8.9
2000 - 2500	9.0	11.8	9.8	8.8	9.9
2500 - 3000	.3	.3	.3	.3	.3

2.5 CARGO DEMAND

2.5.1 Model Used

Perhaps the most difficult problem one faces when making city-pair cargo projections is the lack of past data to evaluate the results. There is also a lack of data about specific factors influencing cargo demand. This leads to questions as to what are the factors influencing cargo demand, what data are available, and how can it be used to predict city-pair cargo demand?

As to the factors that influence air cargo demand; the most obvious factor is the cost of shipping. Presently the cost of air cargo is too high to be competitive with ground transportation except for high value cargo.[7] The advent of the jumbo jet will enable the airline to reduce the cost of air cargo, but the industry will be reluctant to invest in cargo aircraft unless their return on investment is essentially equal to that of similar new passenger aircraft.[7] Nevertheless, the air cargo demand is increasing more rapidly than the air passenger demand.

The problem with including cost in a cargo demand model is that it is difficult to get a uniform charge per unit of measure. With the lack of a variety of data, a simple approach to cargo demand was decided upon In any model formulation some assumptions have to be made. First, it was assumed that the cargo demand between any two hubs is a percentage of the total cargo and that the percentage would remain relatively constant with time Second, the cargo demand is related to the manufacturing activity of the hub. Third, the manufacturing activity is directly proportional to the number of people employed in manufacturing in the hub. Fourth, the cargo demand between any city-pair is symmetrical.

The reasons for relating cargo demand to manufacturing was twofold. First, the number of people employed in manufacturing is readily available on both the nationwide scale and on a metropolitan basis. Second, there appears to be a logical relation between manufacturing and cargo. The relationship derived was

$$D_{ij} = \frac{(M_i \times M_j)}{M} \text{ (Total Air Cargo)}$$

where

M_i = the number of people employed in manufacturing in city i

M_j = the number of people employed in manufacturing in city j

M = the total number of people employed in manufacturing in the United States

D_{ij} = the two-way air cargo between city i and city j

2.5.2 Conclusion

Although there was a lack of city-pair data to prove that the correct model was correct, the model is considered to provide a good first approximation as to the city-pair air cargo demand. Hopefully, as more agencies become aware of the importance of air cargo a greater attempt will be made to collect the valuable data needed to formulate and evaluate more sophisticated models.

A quick look at the cargo projections reveals that the New York-Newark hub handles over 6 6 percent of the total United States domestic air cargo and that Chicago handles approximately 2.6 percent.

Lower costs for air cargo will greatly increase the demand. This could be brought about by a better handling system or larger airplanes. There is also an advantage to customers of air cargo since quicker air cargo service reduces the necessary inventory and storage space.

The projected cargo demand obtained from this investigation is given in Appendix A.2.3.

2.6 ALLOCATION, SCHEDULING AND CONGESTION

2.6.1 Introduction

Along with the allocation of aircraft over a system network, a necessary and often simultaneous procedure is the scheduling of flights between network nodes in such a way as to satisfy demand requirements over each network arc As detailed in Appendix A.2.2, allocation is the process of assigning the various types of aircraft available in the system to the 420 routes in order to minimize total system operating cost. Scheduling, then, can be defined as the sequencing of flights for each aircraft over a definite route structure to provide an optimum load-factor/frequency-mix which will either minimize costs or maximize earnings or profits.

In this transportation system design, a comprehensive scheduling model for the proposed system has not been developed. Such a model was not undertaken for several reasons First, the complexity and size of a model of this type were considered to be beyond the capability of the investigation in such a short period of time. Secondly, since the proposed system does not take competition among airlines into consideration and since competition will undoubtedly exist in the 1980-1990 time period, a scheduling model did not appear to be realistic enough to be worked on. And, thirdly, one of the main problems faced by the United States is not the airline scheduling procedures, per se, but rather the effect of this scheduling on the passengers, the airports, and the areas around the airports It was felt that suggestions concerning the alleviation of the problems partially, if not wholly, caused by scheduling-traffic tie-ups, airport terminal congestion, equipment and manpower overlaoding, and airplane delays--would be more beneficial than a general scheduling model. Thus, Section 2.6.2 will discuss in greater detail the problems arising from scheduling and the possible methods of attacking these problems.

2.6.2 Scheduling Problems

At the present, the prime factor in the airlines' determination of aircraft schedules is the public's demand for convenient, and oftentimes, frequent service. The air passenger expects, and almost always gets, both convenient departure and arrival times for most flights. Hence, the airlines, in their attempt to win the public's dollar, have kowtowed to this demand. As a result, there is usually a bimodal demand distribution for service with one peak occurring in the morning and the second peak occurring in the late afternoon. Using surveys of passenger's time-of-day preference Warren Hyman and Larry Gordon of Lockheed-California[8] have determined a Combined Route Preference (CRP) function. "This function weighs a combination of convenient arrival and departure times more heavily than either a convenient arrival time with an undesirable departure time or a convenient departure time with an undesirable arrival time."[8] Each network route has a different CRP function which varies for different days of the week. The curve represents the density function of the total potential passenger market which would patronize a flight at a specific time. The problems arising from scheduling procedures are primarily caused by these two daily buildups. If they could be eliminated, i.e., flattened out somewhat, several important results would occur. One, since terminals must be built for some peak time capacity, the lowering of all peaks would bring about a considerable reduction in terminal space required and, hence in terminal construction costs. Two, in terms of access to and egress from the terminals, a much smoother and more even flow of traffic would result if the peak were flattened. As it is now, airport flight demand coincides almost perfectly with rush-hour traffic. The mixing of these two types of traffic slows everyone concerned up and causes great system cost both to the user and non-user. Third, the peak daily travel demand causes congestion problems in the air as well as on the ground. The even spacing of flights throughout the day would greatly reduce both the time spent in holding patterns, and taxiing and take-off time. Thus, if these peaks could be eliminated, the benefits that would accrue to the system would indeed be substantial.

Although, an equal or nearly equal distribution of flights over the day would greatly reduce congestion and lower system cost, the system is then faced with the problem of user acceptance--will the traveler fly at 6:00 in the morning instead of at 9:00? This is presently the major obstacle that must be overcome in striving for a rectangular distribution of flights per day. This problem, however, can be overcome by the 1980-1990 time period by a thorough education of the system user as to the benefits of flying at odd hours and through a system of penalties and incentives. That is, charge substantially lower fares for early morning and late evening arrival and departures. Make it cost the user more to fly during present peak hours. In this way, the system can attempt to alleviate peak hour congestion in the skies, at the airports, and on the highways to the airports.

2.7 SYSTEM SIMULATION

2.7.1 Purpose

In the context of this design study, system simulation is the process of determining the behavior of the transportation system when a given set of vehicles are allocated to a given network of routes in order to satisfy a given passenger demand. Behavior of the system is measured by the through-flow requirements imposed on the nodes of the network (i.e., terminals), the size of the fleet required, and the dollar cost to the individuals using and operating the system. Knowing the behavior of the system to various vehicle configurations and demand levels, one could determine the "best" system.

2.7.2 General Approach

As discussed in previous sections, Continental United States interurban transportation may be represented by a network connecting the major urban areas. As a matter of convenience to potential users, it was decided that non-stop travel should be offered between each city-pair as the primary traffic mode, furthermore, it was decided that air would be the principle travel medium.

The resulting air transportation system can thus be viewed as one national air-carrier attempting to offer non-stop travel between each major city. This concept of "one national" transportation service does not eliminate individual competitive carriers; on the contrary, it extracts the essence of the system from the citizen-user's point of view and leads to a system which is best for the nation as a whole. The assignment of routes to competing carriers by the CAB or ICC will continue as in the past.

Finally, the specifications and availability of the air vehicles used in the system are not considered to be initially given, rather they are to be determined as part of system optimization; thus, the approach to simulation usually taken in the literature is not directly applicable and is in fact too specific [9,10] In this design project arbitrary vehicles in unlimited quantities were considered.

The most representative measure of the dollar cost of a national air transportation system is its operating cost per unit time. The following operating costs are distinguished·

DOC = Direct Operating Cost to all air-carriers operating the system.

IOC = Indirect Operating Cost to all air-carriers operating the system.

COC = Citizens Operating Cost - the cost to the general public for facilities and services not paid for from the operating revenues of the air-carriers.

UTC = Users Time Cost - the dollar value of time to users for time lost while waiting for aircraft and while flying on aircraft.

The System Total Operating Cost is defined as:

$$STOC = DOC + IOC + COC + UTC.$$

For the purpose of system simulation, an aircraft vehicle is considered to be the composite concept consisting of a passenger capacity, a maximum range and a vehicle type: VTOL, STOL, or CTOL. Given these two parameters and the type, both the DOC and IOC are considered uniquely determined. This information and estimates for UTC and COC were determined as required

Any reasonable system simulation requires the following input and should produce the following output:

System Simulation

INPUT:
1. Route Network
2. City-pair travel demand forecasts per unit time for a given time period.
3. A mix of aircraft specified by capacity, range, and type.
4. Cost estimates for DOC, IOC, COC, UTC as functions of their required input parameters.

OUTPUT:
1. Per Route - Types and numbers of vehicles used; Route operating costs.
2. Per Vehicle - Route usage, numbers required
3. Per Terminal - Passengers to be handled; Aircraft to be handled.
4 Overall

System Total Operating Cost

Schematically the data flow required shown in Figure 2.7.2.1.

2.7.3 Simulation Algorithms

All that remains to determine a simulation algorithm is a criterion for assigning particular vehicles to specific routes. In this design project, it was considered sufficient to simply assign only one type of vehicle to each route Based on this, two algorithms were developed.

An algorithm called ALOCAT (for Allocate) was first devised which, given a mix of aircraft, assigns each type to a route based on the aircraft's design range only. A second algorithm called NTSS (for National Transportation System Simulation) was then developed which takes a more realistic view and assigns that vehicle to a

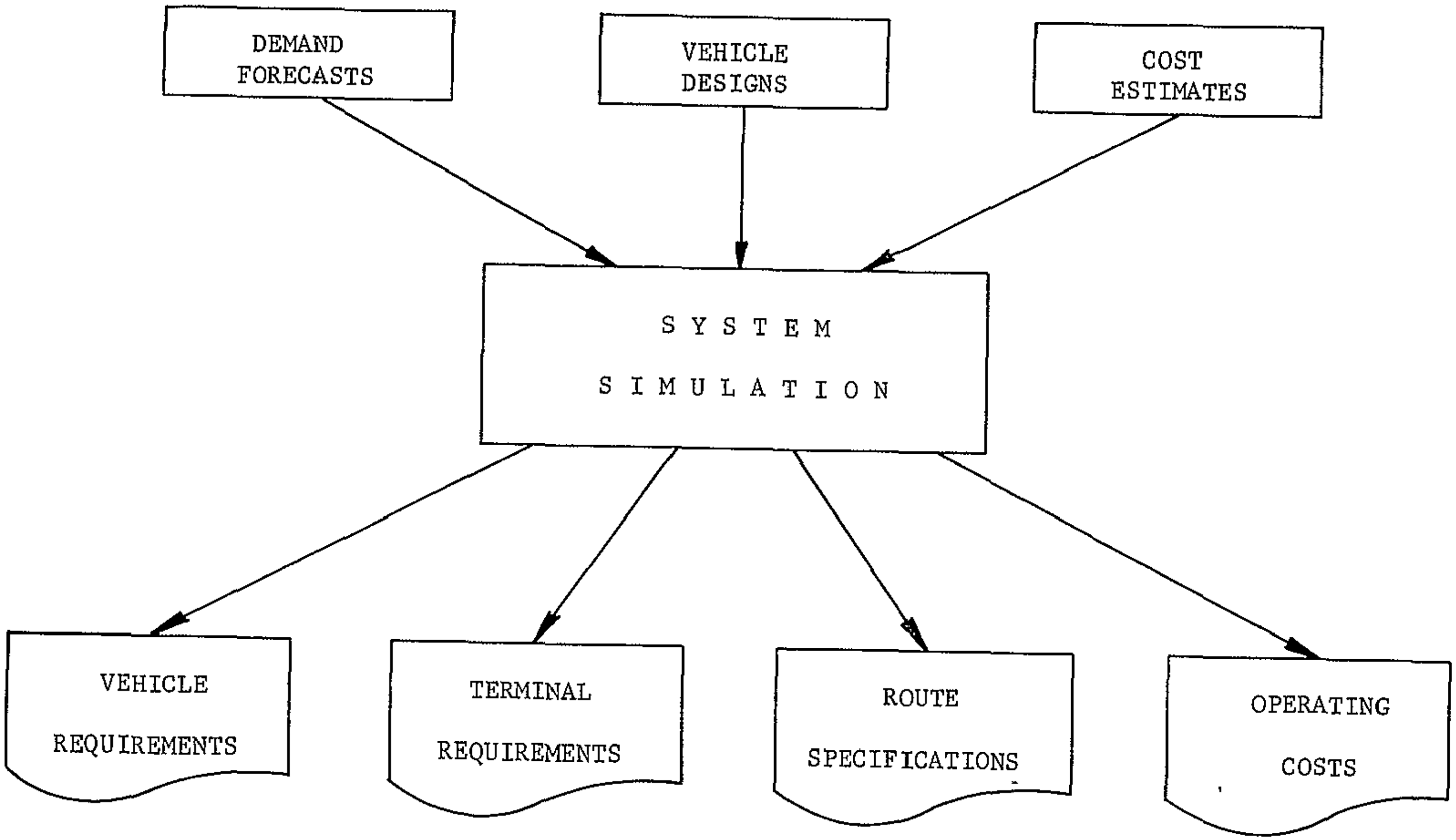

FIGURE 2 7.2-1

SYSTEM SIMULATION

route which has the lowest STOC. The flow chart in Figure 2.7.3-1 describes NTSS, the flow of data for ALOCAT is identical except for the vehicle choice criterion.

Both algorithms require a vehicle design routine for determining DOC and flight characteristics This was supplied in the form of a parametric aircraft design program and is described in Section 3 0.

ALOCAT and NTSS perform the same computations based on the following relations For each route, say from i to j, using the vehicle k

Block Time = Computed by ATC method

Block Speed = Distance (i to j)/Block Time

$$\text{Number of Flights Required} = \frac{\text{Demand (i to j)}}{\text{Capacity}_k \times \text{Load Factor}}$$

Hours of Vehicle k Required = Block Time x Number of flights

$$\text{Number of vehicles required in fleet} = \frac{\text{Number of Vehicle Hours Required}}{\text{Utilization (hrs /day)}}$$

DOC per flight = Determined from a function of distance via the vehicle design routine based on ATA standard method.

IOC per flight = Determined by estimation formulas (see Section 4)

COC = Estimated (see Section 3.) to be \$1 00 for STOL and \$1.50 for CTOL for each enplaned or deplaned passenger.

UTC = Estimated (see Section 4.6.3) to be \$11.5/(Number of flights) + \$.96 x Block Time.

$$\text{Theoretical Fare} = \frac{\text{total (DOC + IOC) x (1.11) x Distance (i to j)}}{\text{total seat miles flown x load factor}}$$

For any route, the number of flights is that integral number which allows a certain load factor while, satisfying demand. A load factor of 60 percent was chosen to allow for peak demand loadings. The

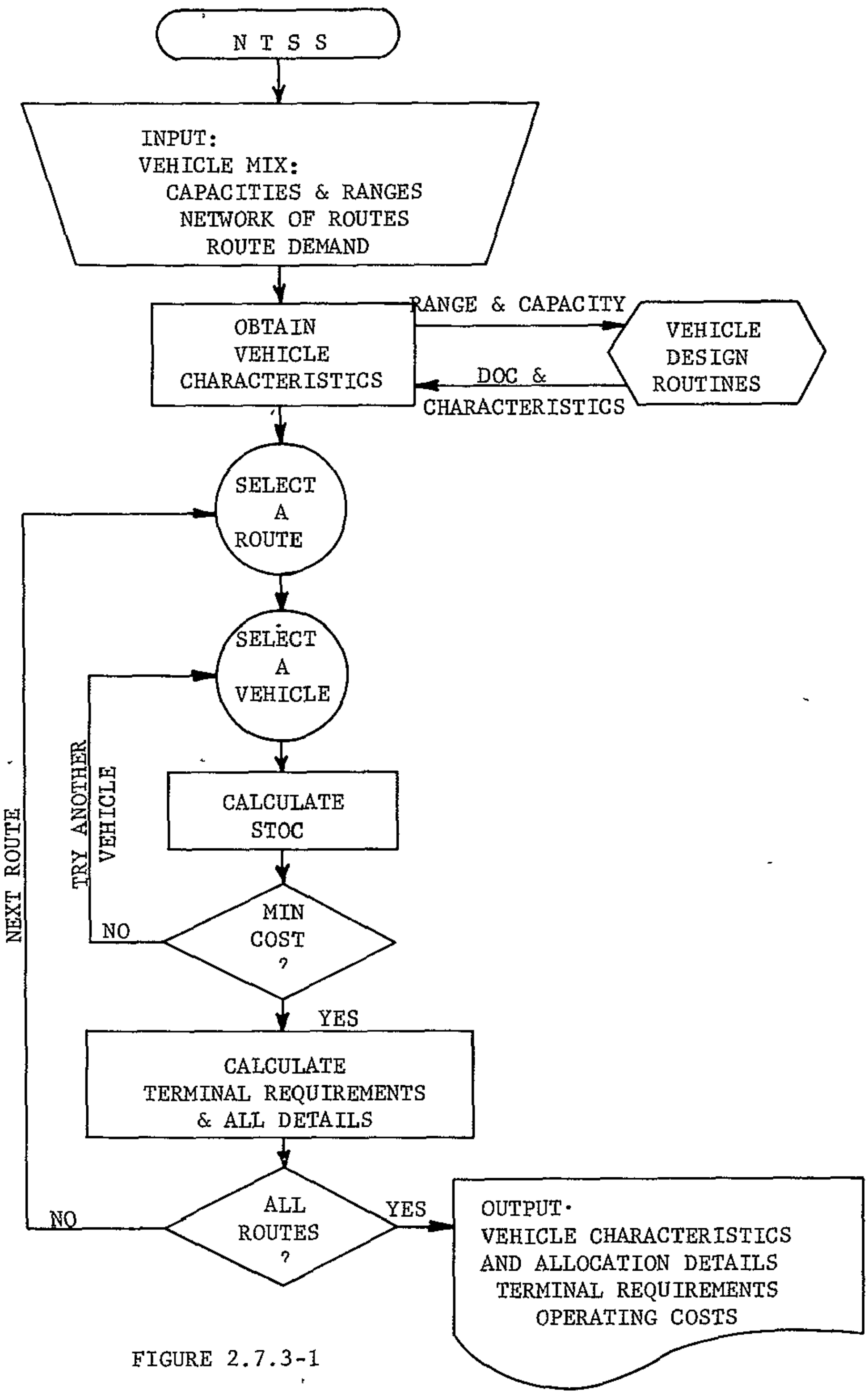

FIGURE 2.7.3-1

NTSS FLOW DIAGRAM

number of hours of each aircraft required is accumulated to indicate the size of the fleet required; this number divided by a Utilization factor (12 hrs./day for CTOL) gives a rough idea of the number of aircraft required. The Theoretical Fare is simply an indicator which allows the operating air carriers a 10 percent operating margin of profit (i.e., operating profit/sales). In the past the Big Four in domestic operations have managed just under 9 percent (3). Fares were included as a check on the effect of UTC during system optimization (see Section 1 6).

Finally, the remark that two simulation algorithms were provided to allow different approaches to various problems in the design effort. ALOCAT was used in preliminary studies while NTSS was used exclusively to produce final results

2.7.4 Computer Implementation

The algorithms ALOCAT and NTSS were both programmed as subroutines in FORTRAN. Subroutines have been discussed elsewhere in this study (see Section 2 7.2) which supply all dependent vehicle specifications and DOC's as required for the parametric design of VTOL, STOL and CTOL.

This approach of designing each vehicle as required was chosen for local reasons· these programs were run on a bank of CDC 6000 series computers which are extremely fast but with moderate storage capability. Thus, it was "cheaper" to repeatedly compute everything rather than store large quantities of data.

2.7 5 Conclusions

Both simulation algorithms fail to take into account indirect routing and rely heavily on supplied cost estimates, however, it is felt that the output of ALOCAT and NTSS was sufficiently representative of the total system. More importantly, the simulator NTSS was used successfully to determine STOC for system optimization and to judge the cost effectiveness of various vehicle mixes. The results of these efforts are discussed in Section 2.8.

2.8 SYSTEM OPTIMIZATION

2.8.1 The Optimization Problem

The optimum system is considered to be that system which has the minimum total system operating cost (defined in Section 2.7 -- on which this section relies heavily) yet satisfies the system constraint: passenger demand. The only variables that one has the ability to adjust are the vehicle or aircraft specifications themselves and the only independent aircraft parameters are capacity, design range and type Hence, the optimization problem is: given several types of aircraft, find the capacity and design range of each type so that the total operating cost of the entire system is a minimum.

2.8.2 System Cost Functions

The system's total operating cost is considered to be STOC = DOC + IOC + COC + UTC. For a given set of aircraft, STOC may be calculated using either of the system simulation algorithms or one may attempt to formulate an analytical expression. This requires a great deal of approximation and estimation, and, in the case of this transportation system analysis, found little success. It was decided to use direct simulation to compute STOC.

2.8.3 Minimization Technique

In order to better envision the optimization problem it may be expressed in a more abstract form. Given N types of vehicles, let c_i and r_i denote, respectively, the capacity and design range of vehicle type i. Essentially, there is a vehicle vector v = $(c_1, r_1, c_2, r_2, \ldots c_N, r_N) \in R^{2N}$ *. The function $f: R^{2N} \rightarrow R$ with values f(v = STOC is well defined (e.g., by the algorithms of Section 2.5).

Because of physical limitations, the parameters v are constrained to belong to a constraint set $A \subset R^{2N}$ consisting of realizable seating capacities and design ranges, i.e., a set of admissible vehicles.

The Optimization Problem is then, find a vehicle vector $\hat{v} \in R^{2N}$ such that:

a. $\hat{v} \in A$

b. for all $v \in A$, $f(\hat{v}) \leq f(v)$.

A vehicle vector satisfying a and b will be called the optimum vehicles.

Under certain continuity conditions on the cost function f, this problem is simply the "Basic Problem" of nonlinear programming with no constraint equation.[12,13] However, for a given vehicle vector v, the value of STOC is only computable by one of the simulation algorithms: no analytical expression is known Thus, the standard indirect methods known from the nonlinear programming literature are not applicable and a direct approach must be

*We denote by R^n the usual Euclidean space of real n-tuples which we represent for typographical ease as row vectors.

attempted.[12,13,14,15]

The well known Method of Steepest Decent was chosen based on the fact that the gradient of a function at any point, "points" in the direction of greatest increase of the function from that point. Thus, following the negative direction of the gradient leads to a point where the function is a minimum. More specifically, let $f : R^n \rightarrow R$ and denote the gradient of f at $x^o \in R^n$ by

$$\frac{\partial f}{\partial x}(x^o) = \left(\left.\frac{\partial f}{\partial x_1}\right|_{x_o}, \left.\frac{\partial f}{\partial x_2}\right|_{x_o}, \dots, \left.\frac{\partial f}{\partial x_n}\right|_{x_o} \right)$$

where $(\partial f / \partial x_i)\, x_o$ denotes the i^{th} partial derivative of $f(x_1, x_2, \cdot\cdot\cdot, x_n)$ evaluated at $x^o = (x_1^o, x_2^o, \cdot\cdot\cdot, x_n^o)$. Then, if f has a minimum value at a point in a region $C \subset R^n$ and $x^o \in C$; the sequence:

$$x^{k+1} = x^k - \lambda_k \frac{\partial f}{\partial x}(x^k), \quad \lambda_k > 0$$
$$k = 0, 1, 2, \cdot$$

has the property that it converges to the point $x^* \in C$ where f has its minimum.[5,6]

The magnitude assigned to the step size λ_k is critical for rapid convergence, any value for which $f(x^{k+1}) < f(x^k)$ is sufficient. The optimum value is given by:

$$\lambda_k = \left(\frac{\partial f}{\partial x} \frac{\partial f}{\partial x}^T \right) \Big/ \left(\frac{\partial f}{\partial x} H \cdot \frac{\partial f}{\partial x}^T \right).$$

where T denotes transpose and H is the so-called Hessian Matrix of f evaluated at x^k:

$$H = \left[\left(\frac{\partial^2 f}{\partial x_i \partial x_j} \Big|_{x^k} \right) \right]$$

In practice, because of computational difficulties, a less sophisticated method for computing λ_k must be employed.

Finally, the set of admissible vehicles "A" could be represented as a set of linear inequalities and the Optimization Problem solved using the Gradient Projection Method,[13,14] however, the exact nature of A was not known initially and in fact was dependent on the engineering judgment of the anticipated vehicles. Furthermore, the important question of the existence of optimal vehicles was unanswerable; the same situation prevailed as to the continuity properties of the cost function. Therefore, the Optimization Problem was attacked by applying the method of Steepest Descent guided by human internal and external control. An algorithm called MINTOC was devised to solve the problem, a flow chart is shown in Figure 2.8.3-1.

In order to compute the gradient we claim the approximation:

$$\frac{\partial f}{\partial x_i}\Big|_{x^k} \simeq \frac{f(x_1^k, x_2^k \cdots, x_i^k + \Delta x_i, \cdots, x_n^k - f(x^k))}{\Delta x_i}$$

for some "sufficiently" small x_i.

At each step the norm of the gradient is calculated as:

$$\left\| \frac{\partial f}{\partial x}(x^k) \right\| = \sum_{i=1}^{n} \left| \left(\frac{\partial f}{\partial x_i}\Big|_{x_k} \right) \right|$$

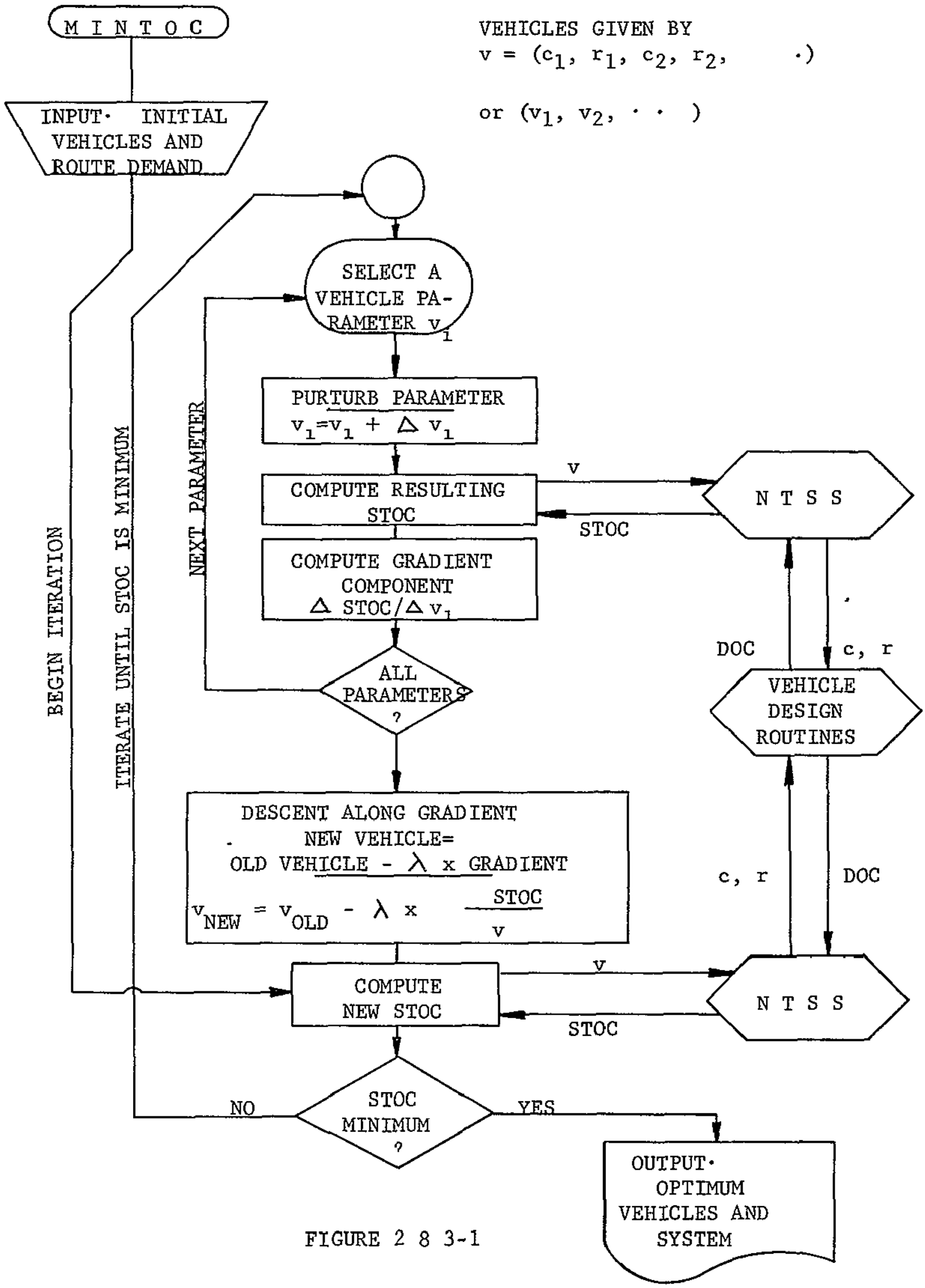

FIGURE 2 8 3-1

MINTOC FLOW DIAGRAM

the step size is then computed to be:

$$\lambda_K = c_K \Big/ \left\| \frac{\partial f}{\partial x}(x^K) \right\|$$

where c_k is a positive number whose value is determined from "computational experience." The remaining details are discussed below.

2.8.4 Computer Implementation

The algorithm MINTOC was programmed in FORTRAN in conjunction with the subroutine NTSS described in Section 2.7.3.

After some computational experience had been gained, perturbations of 100 for range and 100 for capacity were found to give sufficiently consistent gradient values. (Perturbations of as low as 20 were tried for capacity; however, too many "local minimums" occurred which prevented attainment of a true minimum.) In addition, the scheme shown in Figure 2.8.2 was found to properly guide the process to an optimal value. At various stages in the program, logical statements were inserted to insure that at each step the vehicles were admissible (i.e., X   A). As shown in Figure 2.8.4-1, iteration was terminated when the gradients norm was small.

Sample runs and final results may be found below.

2.9 COMPUTATIONAL RESULTS

Several schemes were employed in order to search for an optimum set of vehicles. A series of computations of System Total Operating Cost (STOC) as a function of the vehicle parameters was first run in order to determine the nature of the cost surface. It was found to

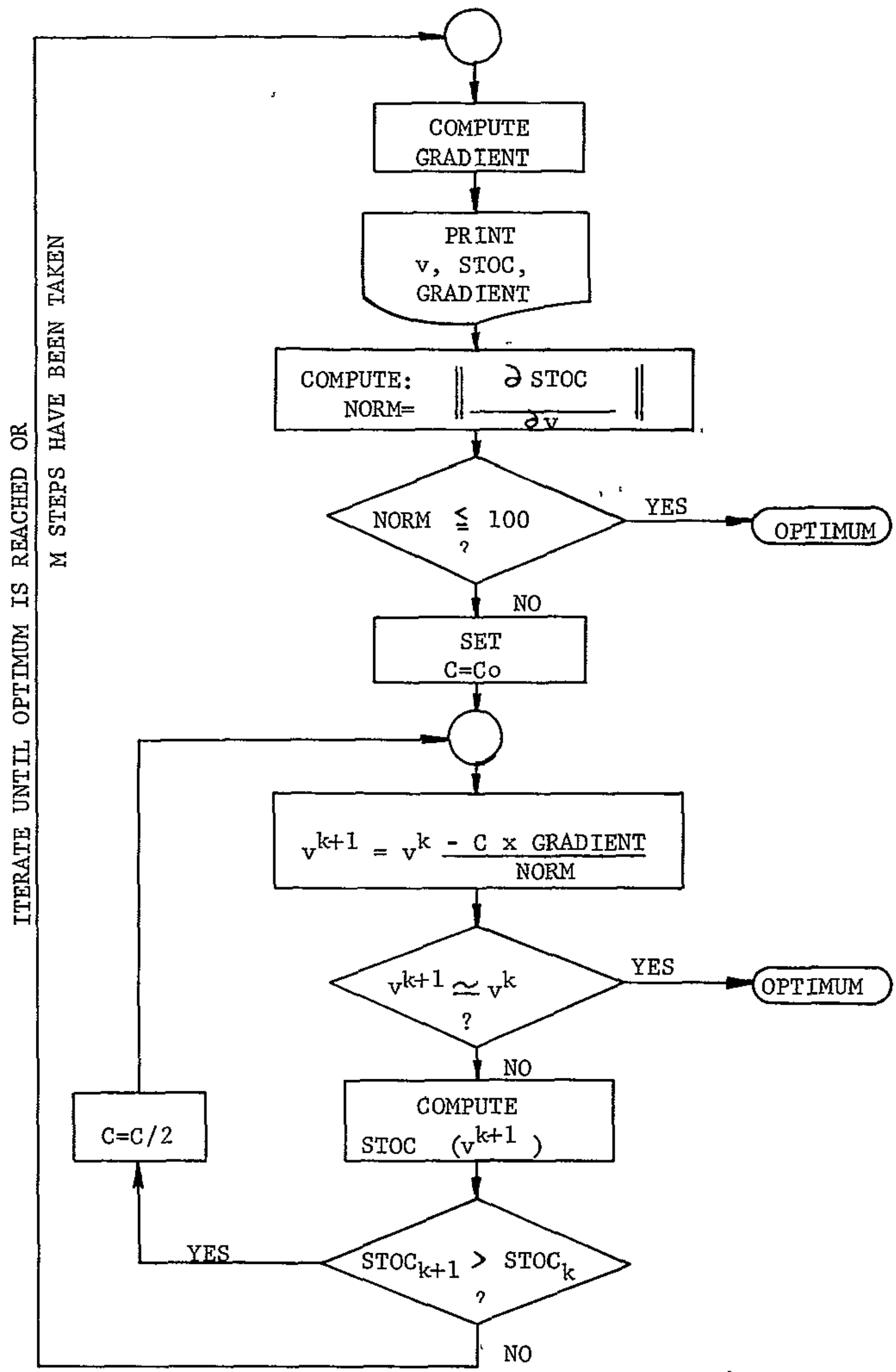

FIGURE 2 8 4-1

ITERATION PROCEDURE TO DETERMINE
MINIMUM SYSTEM TOTAL OPERATING COST

be sufficiently well behaved to justify using a gradient search. These computations also indicated that a mix of three aircraft with short, medium, and long design ranges was sufficient to obtain a low STOC. As the cost function was found to be rather insensitive to design range and more dependent upon design capacity, the vehicles were arbitrarily assigned the following design ranges:

short range : 500 miles
medium range: 1500 miles
long range : 3000 miles

Using MINTOC (see Section 2.8) with three CTOL vehicles of the above ranges, the vehicle capacities were determined which would best satisfy the passenger demands of 1975, 1980, 1985, and 1990. The final results are summarized in Table 2.9-1.

The 1975, 1980, 1985, and 1990 time periods were investigated so that a judgment could be made as to the phasing out of present day (1969) aircraft, the initiation and use of the proposed 1980 aircraft, and the possible phasing out of the 1980 aircraft in the 1990's.

TABLE 2.9-1

VEHICLE SELECTION YIELDING MINIMUM TOTAL SYSTEM OPERATING COST

Aircraft	Range
A	500 miles
B	1500 miles
C	3000 miles

Year	Capacity (Seats) Aircraft A	Aircraft B	Aircraft C	Daily Total System Operating Cost ($ x 10^6)
1975	400	200	400	11.855
1980	600	400	800	21.362
1985	1000	1000	800	40.436
1990	1000	1000	1000	79 140

Although, for each time period investigated, a specific set of vehicles was found that produced the lowest STOC, the variation in STOC with capacity was not drastic It was felt that a final selection made by society would consider additional factors. The effect of passenger capacity upon STOC is shown in Table 2.9-2a, b, c, d.

The vehicles selected for use in the 1980's as a result of this investigation, are

Vehicle	Range (miles)	Capacity (seats)
A	500	200
B	1500	400
C	3000	800

A capacity of 200 for the short range aircraft was selected because the TSOC was least sensitive to the capacity of the short range aircraft. It was observed that this plane is essentially forced out of the system (few are required), in the mid 1980's. It was felt this aircraft could be a carry over from today's aircraft.

A capacity of 400 was selected for the middle range aircraft. It was anticipated that the newly introduced long range aircraft of today (1969) with capacities of 400 would be used. This would be caused by their availability and also the necessity of introducing a new long range, very high capacity aircraft in order to reduce anticipated 1980 TSOC.

A capacity of 800 was selected for the long range aircraft. It was felt that its lower direct operating cost and STOC compared to present day aircraft would make it attractive to airlines and society. It was also noted that the TSOC, as defined, has a bias to increase the frequency of service through a passenger waiting cost penalty. In spite of this penalty, the higher capacity aircraft, which decreases the frequency of service, was determined as the

TABLE 2.9-2a

EFFECT OF AIRCRAFT CAPACITY UPON
TOTAL SYSTEM OPERATING COST

1975

	Short Range Aircraft Capacity (seats)	Medium Range Aircraft Capacity (seats)	Long Range Aircraft Capacity (seats)	TSOC ($)	Rank*
Minimum Cost System	400	200	400	11,854,813	1
Alternate Systems	400	200	200	12,666,905	13
	"	"	400	11,854,813	1
	"	"	600	11,872,785	3
	"	"	800	12,101,018	11
	"	"	1000	12,458,422	12
	400	200	400	11,854,813	1
	"	400	"	11,928,557	6
	"	600	"	11,962,761	8
	"	800	"	12,063,742	10
	"	1000	"	12,023,160	9
	200	200	400	11,930,544	7
	400	"	"	11,854,813	1
	600	"	"	11,867,611	2
	800	"	"	11,909,266	5
	1000	"	"	11,884,930	4

*The lower the "rank", the lower the cost of the system. Rank 5 implies the fifth lowest system in total system operating cost.

TABLE 2.9-2b

EFFECT OF AIRCRAFT CAPACITY UPON
TOTAL SYSTEM OPERATING COST

1980

	Short Range Aircraft Capacity (seats)	Medium Range Aircraft Capacity (seats)	Long Range Aircraft Capacity (seats)	TSOC ($)	Rank*
Minimum System	600	400	800	21,361,831	1
Alternate Systems	600	400	200	23,482,200	13
	"	"	400	21,938,576	12
	"	"	600	21,467,300	6
	"	"	800	21,361,831	1
	"	"	1000	21,504,264	7
	600	200	800	21,832,881	9
	"	400	"	21,361,831	1
	"	600	"	21,559,003	8
	"	800	"	21,932,532	11
	"	1000	"	21,920,569	10
	200	400	800	21,464,538	5
	400	"	"	21,408,214	4
	600	"	"	21,361,831	1
	800	"	"	21,368,699	3
	1000	"	"	21,366,906	2

*The lower the "rank", the lower the cost of the system. Rank 5 implies the fifth lowest system in total system operating cost.

TABLE 2.9-2c

EFFECT OF AIRCRAFT CAPACITY UPON
TOTAL SYSTEM OPERATING COST

1985

	Short Range Aircraft Capacity (seats)	Medium Range Aircraft Capacity (seats)	Long Range Aircraft Capacity (seats)	TSOC ($)	Rank*
Minimum Cost System	1000	1000	800	40,435,594	1
Alternate Systems	1000	1000	200	45,624,991	13
	"	"	400	42,302,796	12
	"	"	600	41,163,526	10
	"	"	800	40,435,594	1
	"	"	1000	40,534,705	6
	1000	200	800	41,732,132	11
	"	400	"	40,841,788	9
	"	600	"	40,470,857	3
	"	800	"	40,771,929	8
	"	1000	"	40,435,594	1
	200	1000	800	40,605,284	7
	400	"	"	40,487,870	4
	600	"	"	40,469,892	2
	800	"	"	40,508,892	5
	1000	"	"	40,435,594	1

*The lower the "rank", the lower the cost of the system. Rank 5 implies the fifth lowest system in total system operating cost.

TABLE 2.9-2d

EFFECT OF AIRCRAFT CAPACITY UPON
TOTAL SYSTEM OPERATING COST

1990

	Short Range Aircraft Capacity (seats)	Medium Range Aircraft Capacity (seats)	Long Range Aircraft Capacity (seats)	TSOC ($)	Rank*
Minimum Cost System	1000	1000	1000	79,140,445	1
Alternate Systems	1000	1000	200	90,495,346	13
	"	"	400	83,423,454	12
	"	"	600	80,920,582	10
	"	"	800	79,549,116	5
	"	"	1000	79,140,445	1
	1000	200	1000	81,918,085	11
	"	400	"	80,746,380	9
	"	600	"	79,829,413	8
	"	800	"	79,616,088	6
	"	1000	"	79,140,445	1
	200	1000	1000	79,619,600	7
	400	"	"	79,464,925	4
	600	"	"	79,375,782	3
	800	"	"	79,306,339	2
	1000	"	"	79,140,445	1

*The lower the "rank", the lower the cost of the system. Rank 5 implies the fifth lowest system in total system operating cost.

optimum

As the TSOC was most sensitive to the capacity of the long range aircraft, the recommendation of an 800 passenger capacity, long range aircraft is considered a principle result of this investigation.

The advantages of initiating the proposed vehicles and the schedule of their initiation may be obtained for the proposed system, an optimum system, and a system using today's aircraft. For purposes of comparison, today's aircraft are defined to be capacities of 200 (short range), 200 (medium range) and 400 (long range), however, the costs presented are those obtained using the vehicle design method of this investigation and may not, necessarily, represent true present day aircraft The costs are shown in Table 2-9.3.

It is noted that the proposed system, when compared to the present system, would have a daily TSOC savings of $1.21 million in 1980, $3 68 million in 1985, and $7 54 million in 1990. It is also noted that the present system would be better than the proposed system in 1975; consequently, the proposed system is suggested for initiation between 1975 and 1980. Although in the early 1990's the proposed system would be losing $3.1 million per day, compared to an ideal system, it is difficult to make a judgment that the proposed system will need to be altered

The number of vehicles needed and the number of routes they use is shown in Table 2.9-4 Results are given for a system using present day vehicles and for a system using the proposed vehicles. Direct and indirect operating costs for each aircraft are also shown. A comparison of direct operating costs, indirect operating costs, user time costs, terminal costs, and total system operating

TABLE 2.9-3

COST ESTIMATES FOR 1980 UNITED STATES AIR TRANSPORTATION SYSTEM

	1975	1980	1985	1990
IDEAL SYSTEM				
Capacity (Short, medium, long range aircraft)	400,200,400	600,400,800	1000,1000,800	1000,1000,1000
Daily Total System Operating Cost (TSOC)	$ 11,855,000	$ 21,362,000	$ 40,436,000	$ 79,140,000
PRESENT SYSTEM				
Capacities: 200,200,400				
TSOC	$ 11,931,000	$ 22,677,000	$ 44,903,000	$ 89,831,000
Δ $ from IDEAL	$ 76,000	$ 1,315,000	$ 4,467,000	$ 10,691,000
PROPOSED SYSTEM				
Capacities: 200,400,800				
TSOC	$ 12,086,000	$ 21,465,000	$ 41,223,000	$ 82,288,000
Δ $ from IDEAL	$ 231,000	$ 103,000	$ 787,000	$ 3,148,000
Δ $ from PRESENT	$ 155,000	$ 1,212,000	$ 3,680,000	$ 7,543,000

TABLE 2.9-4

VEHICLE AND ROUTE ALLOCATIONS
DIRECT AND INDIRECT OPERATING COSTS

YEAR	PRESENT SYSTEM			PROPOSED SYSTEM		
Range (miles)	500	1500	3000	500	1500	3000
Capacity (seats)	200	200	400	200	400	800
Design DOC (cents/seat-mile)	1.01	.78	69	1 01	.61	.62
1975						
Hours Required	609	711	1641	246	1141	644
Vehicles Required	51	59	137	21	95	54
Routes Used On	41	80	89	31	118	61
Average Route Length (miles)	318	882	1590	332	856	1867
Daily DOC ($\$10^6$)	0 66	0 61	2 71	0.24	1.64	1.91
Daily IOC ($\$10^6$)	1 06	0 88	3.81	0.39	2 76	2.59
1980						
Hours Required	1178	1059	3404	224	2044	1219
Vehicles Required	98	88	284	19	170	101
Routes Used On	38	57	115	18	119	73
Average Route Length (miles)	307	893	1414	331	769	1748
Daily DOC ($\$10^6$)	1.27	0 91	5.63	0.23	3.01	3 61
Daily IOC ($\$10^6$)	2 03	1.31	7 86	0.37	5.06	4.91
1985						
Hours Required	2449	1239	7395	259	4464	2281
Vehicles Required	204	103	616	21	372	190
Routes Used On	41	42	127	13	119	78
Average Route Length (miles)	311	832	1397	322	758	1676
Daily DOC ($\$10^6$)	2.57	1 07	12.25	0.28	6 50	6.76
Daily IOC ($\$10^6$)	4 11	1 53	17 01	0.45	10 93	9.20
1990						
Hours Required	4870	853	15927	68	9709	4536
Vehicles Required	406	71	1327	6	809	378
Routes Used On	42	17	151	2	138	70
Average Route Length (miles)	313	841	1309	479	733	1756
Daily DOC ($\$10^6$)	5 04	.74	26 44	0.05	14.14	13.42
Daily IOC ($\$10^6$)	8.06	1.04	36.53	0 08	23.77	18.25

costs for the proposed system and the "present" system is shown in Table 2.9-5

All of the vehicles investigation, including "present day aircraft", were considered to have the "supercritical wing" by 1975, permitting Mach No. = 1.0 operation. The economic impact of this airfoil is shown in Table 2 9-6 where comparison is made to a similar system using conventional airfoils (Mach No. = 0.8). It is observed that for the proposed system a daily STOC savings of approximately $0 5 million is obtained.

For the proposed system, the daily terminal requirements in the year 1980 are contained in Appendix A-2.9. Examples of the vehicle allocation by terminal and route are also given for New York, Chicago, and Los Angeles. As a result of this investigation these data are available for 1975, 1980, 1985, and 1990 for all twenty-one major hubs.

As a matter of interest, the total system operating cost for a STOL vehicle or a VTOL vehicle operating on routes less than 500 miles was investigated. The results are shown in Table 2.9-7 and Table 2.9-8

TABLE 2.9-5

COST COMPARISON: PROPOSED SYSTEM - "PRESENT SYSTEM"

YEAR	COST	PRESENT SYSTEM $\$10^6$/day	PROPOSED SYSTEM $\$10^6$/day
1975	DOC	3.982	3.795
	IOC	5.750	5.741
	UTC	1 361	1.712
	TC	837	837
	TSOC	11.931	12.086
1980	DOC	7 811	6.854
	IOC	11 200	10.339
	UTC	2.013	2.618
	TC	1 654	1.654
	TSOC	22.677	21.465
1985	DOC	15 890	13.548
	IOC	22.639	20.581
	UTC	3.078	3 798
	TC	3.296	3.296
	TSOC	44 903	41.223
1990	DOC	32.221	27 613
	IOC	45 635	42.106
	UTC	5 347	5 941
	TC	6.628	6 628
	TSOC	89.831	82 288

DOC - Direct Operating Costs
IOC - Indirect Operating Costs
UTC - User Time Costs
TC - Terminal Costs
TSOC - Total System Operating Costs

TABLE 2.9-6

ECONOMIC IMPACT OF SUPERCRITICAL WING

Year	Mach No.	Capacities	Daily STOC	Daily Savings Using Supercritical Wing
1975	0.8	200,200,400	$12,586,000	
	1.0	200,200,400	$11,930,000	$656,000
	0.8	200,400,800	$12,494,000	
	1.0	200,400,800	$12,086,000	$408,000
1980	0 8	200,200,400	$23,915,000	
	1.0	200,200,400	$22,677,000	$1,238,000
	0.8	200,400,800	$22,148,000	
	1 0	200,400,800	$21,465,000	$683,000

TABLE 2.9-7

TOTAL SYSTEM OPERATING COSTS
STOL VEHICLE - 1985

Range: 500 miles
Number of Routes: 44
Average Route: 320 miles

Capacity (Seats)	Daily TSOC ($\$10^6$)
50	14.725
70	12.637
90	11.440
110	10 721
130	10 466
150	10.031
170	9.910
190	9.692
210	9.638
230	9.484
250	9.264
270	9 160
290	9.250

TABLE 2.9-8

TOTAL SYSTEM OPERATING COSTS
VTOL - 1990

Range. 500 miles
Number of Routes: 44
Average Route: 320 miles

Capacity (Seats)	Daily STOC ($\$10^6$)
50	30.282
70	26.602
90	24 827
110	23.452
130	23.266
150	22.332
170	22.100
190	21.693
210	21.890
230	21.677
250	21 148
270	20.964
290	21.247

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III. VEHICLE DESIGN

3.1 INTRODUCTION

The systems design approach was followed in attacking the problem of designing vehicles suitable for the 1980-1990 time period. The desired output was not a detailed vehicle design, but rather a set of feasible vehicles which could be analyzed and optimized. Thus, this investigation's primary effort was a vehicle feasibility study. This feasibility study was conducted in four steps.

The first step in the feasibility study was the need analysis. That there is a need for a study of a 1980 air transportation system has been established in a preceding part of the report. That the transportation system of the 1980's shall be air is dictated by the prohibitive expense of acquiring right of way or of tunneling for necessary expansion of ground systems. Also, sufficient need does not presently exist to justify the tremendous expenditure necessary for the research and development of a high speed ground transportation system which would be competitive with air transportation over similar routes in the 1980's.

The second step in the feasibility study was the identification of the design problem. The system to be analyzed was chosen to be the network of 21 major hubs across the United States. Proposed vehicles must service this network.

The third step in the feasibility study involved the synthesis of design concepts. The 1980 technology and innovations had to be predicted. Evolutionary trends can be extrapolated from the present whereas revolutionary changes may be impossible to predict or at best predicted on the basis of an educated guess. Considering the magnitude of the system under study and the time needed to put revolutionary concepts into production, it was assumed that unless the concept existed presently, it would not be a part of the vehicles of the 1980's. The vehicles flying in the 1980's will not appear very different from those flying or on drawing boards now. At present the state of the art suggestions for 1980 aircraft include supercritical wings, variable bypass ratio turbofans, and high lift blown flaps. After establishing the 1980 levels of technology, the new concepts were synthesized into vehicles. The choice of vehicles was the result of considering a wide variety of proposed vehicles and eliminating all but the most practical from a technical and economic standpoint. This was done after a broad literature survey with the state of the art. A description of the vehicles will be given in the actual Vehicle Design Section (3.4). After establishing the configuration of the aircraft it was necessary to formulate a computer program to design the aircraft caused by the complexity of the weight, lift, drag, thrust, and capacity relationships. Sufficient design criteria were specified to parametrically design an aircraft. This is covered in the Parametric Design Program Section (3.3).

The fourth step of the feasibility study was the economic analysis. The system was optimized with respect to the cost and time. By varying parameters of the design program the optimum system could be found.

3.2 TECHNOLOGY FORECAST

Realistic results for a 1980 air transportation system will be obtained only if the vehicles reflect a 1980 technology. The technology available from 1975 to 1990 was predicted in increments of five years. The estimated technological levels arrived at are presented as follows:

1975:

CTOL

maximum weight = 800,000 lbs.
SFC = 0.70

1980:

STOL

first generation
wing loading = 90 lb/ft^2
maximum passengers = 175
cruise Mach number = 0.60
blown flap system

CTOL

maximum weight = 1,000,000 lbs.
supercritical wing
5% improvement in structural efficiency
SFC = 0.65

1985:

STOL

wing loading = 100 lb/ft^2
maximum passengers = 225
cruise Mach number = 0.70

CTOL

maximum weight = 1,100,000 lbs.
SFC = 0.60
5% improvement in structural efficiency

1990:

VTOL

first generation
wing loading = 95 lb/ft^2
cruise Mach number = 0.60

STOL

wing loading = 110 lb/ft^2
maximum passengers = 300
cruise Mach number = 0.80

CTOL

maximum weight = 1,200,000 lbs.
SFC = 0.55
5% increase in structural efficiency

The technological projection made was based on extrapolation of existing technologies, expected improvement trends, and judgments on future vehicular types (VTOL, STOL).

CTOL technology in the period 1980-1990 will not differ appreciably from CTOL technology of the 1970's. This is true in light of projected developments if no startling technological breakthroughs, a new type of engine, for example, occur.

A review of current and past commercial aircraft indicates increased weight with time. Figure 3.2-1 illustrates dramatically the established trend of increased aircraft weight. The dashed line in the figure represents the allowable gross aircraft weight for the time period of interest. This figure does not indicate the weight that the post 1980 aircraft must have but merely the maximum weight that an air vehicle of the time period can logically have.

Jet engine technology has shown dramatic and significant increases since the end of World War II. Turbojet technology has progressed from the expensive, troublesome, and relatively low

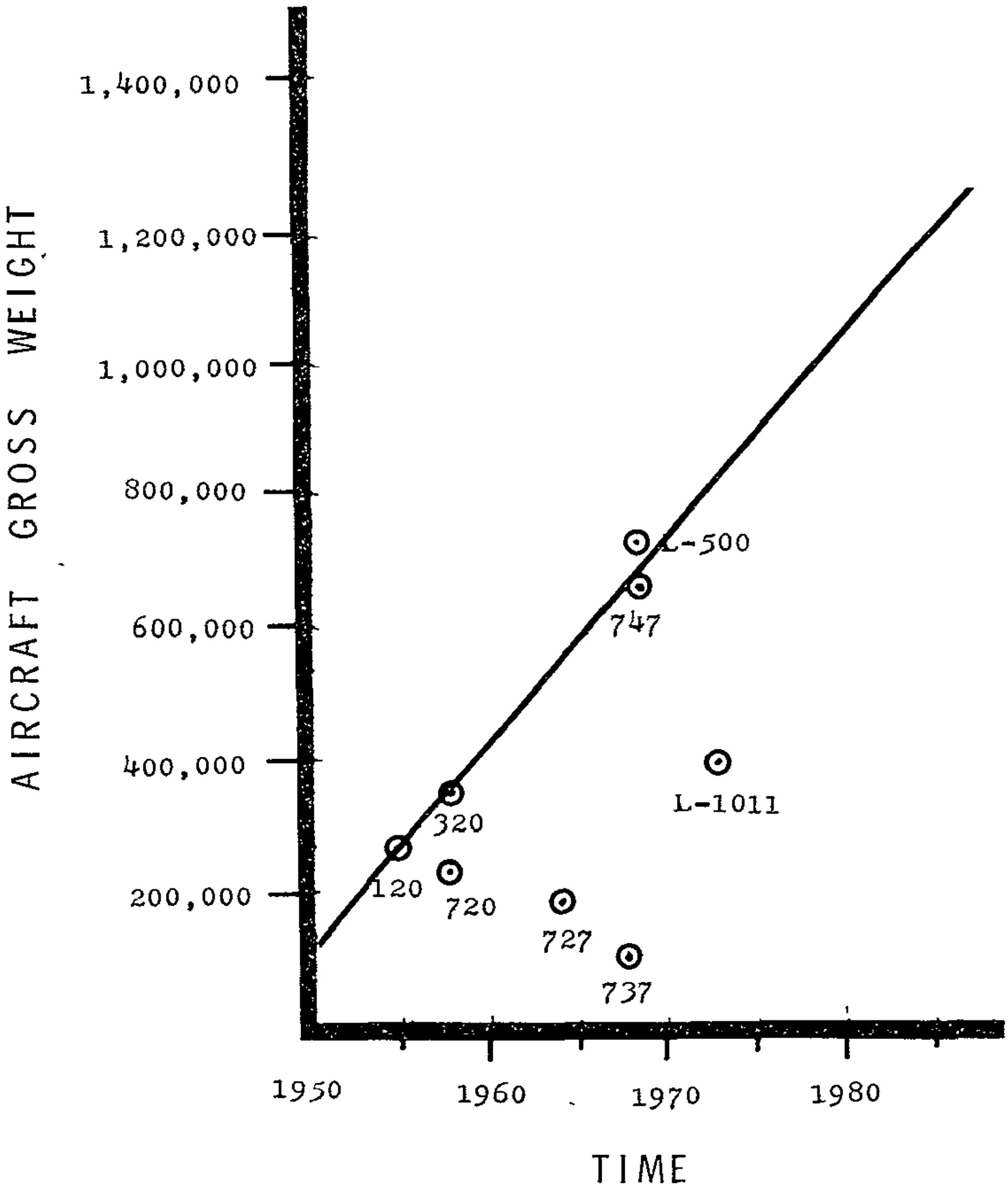


FIGURE 3.2-1

AIRCRAFT GROSS WEIGHT HISTORY

thrust of the early 1940's to the economical, troublefree, high thrust engines of today. Engine weight per pound of thrust and engine specific fuel consumption (SFC) has shown marked decreases, especially since the introduction of the turbofan engines. However, it was felt that this progress could not continue and that with the exception of the variable bypass turbofan engine, the performance increases of the engines would not be as great. Even the introduction of the variable bypass engine would not be revolutionary in the performance sense. Thus, specific fuel consumption is projected to show a slow but steady decrease throughout the 1980's. Figure 3.2-2 graphically depicts the decrease in SFC.[2] This figure is in general agreement with other projections.

In addition to specific fuel consumption the engine specific weight is also of interest. Figure 3.2-5 indicates 1969 technology levels for engine thrust and engine weight.[3] The crosshatched portion of the figure indicates expected technology improvements through the period of interest.

Structural technology is expected to show slow but significant gains throughout the 1980's. Figure 3.2-3 best represents the magnitude and sources of increased technology in aircraft structures (as taken from Schriever and Seifert).[2] A five percent improvement every five years in structural efficiency was forecast. Although Figure 3.2-3 indicates somewhat more improvement to be available, the combined problems of development and certification preclude realizing all of the potential by the 1980's.

With one exception aerodynamic efficiencies are not expected to increase appreciably. The one exception is the supercritical wing.[4,5] Drag considerations limit the subsonic cruise velocity of

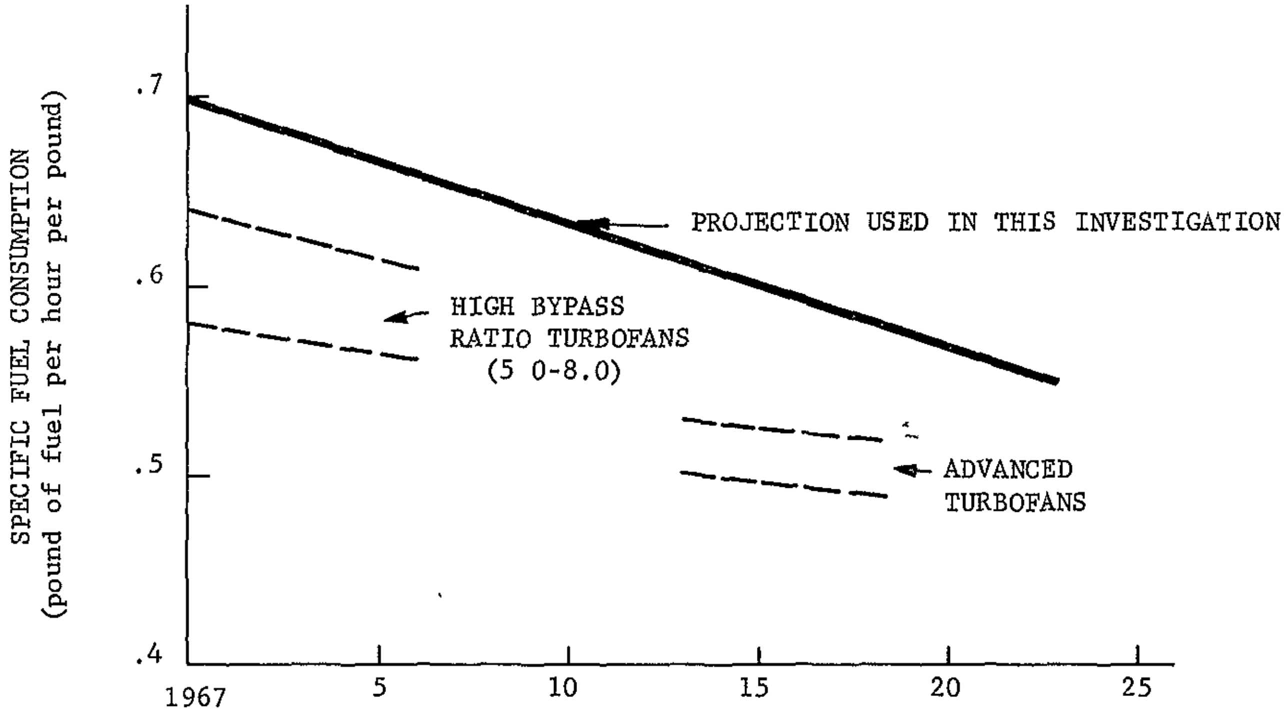


FIGURE 3 2-2

ENGINE PERFORMANCE PROJECTIONS[2]

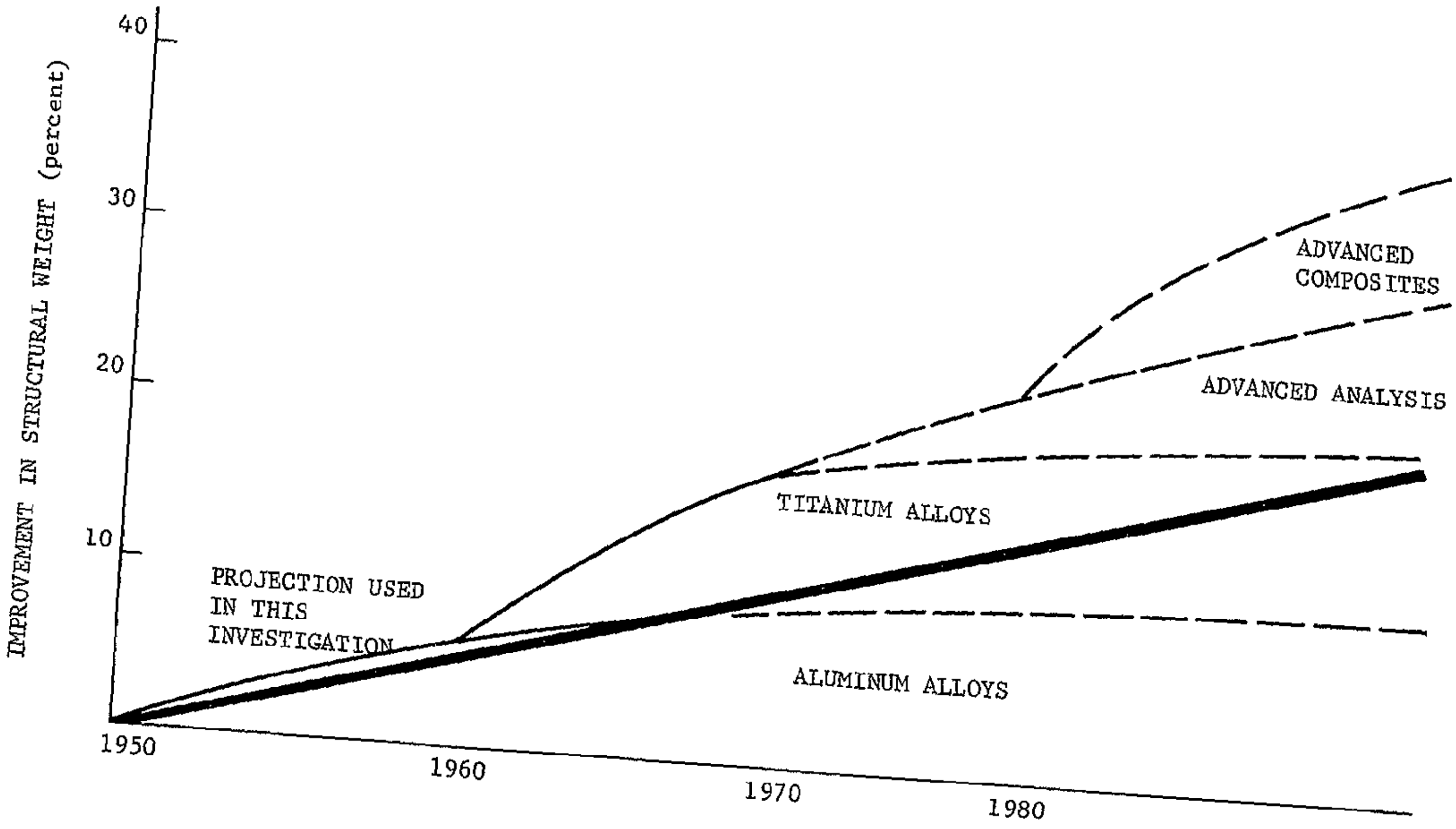


FIGURE 3.2-3

STRUCTURAL WEIGHT IMPROVEMENT[2]

a vehicle equipped with conventional wings to a nominal Mach number = 0.85. By proper wing design the cruise Mach number can be raised to unity. An airfoil with a cruise Mach number near unity is called supercritical airfoil or wing (the supercritical wing is discussed in detail in the Aerodynamics Section of CTOL, Section 3.4.1.1). The higher cruise Mach number permits a greater productivity at relatively little cost. Hence, it is postulated that the supercritical wing will be in general use on long range aircraft of the 1980's.

The introduction of STOL and VTOL aircraft is anticipated in the 1980's. This investigation predicted that a commercial STOL vehicle will be available in the early 1980's and a commercial VTOL will become available in the later 1980's. This seemingly arbitrary judgment was prompted by several factors· (1) The lack of an adequate technological base for commercial VTOL's by 1980, (2) The need for short and/or vertical takeoff and landing aircraft in the 1980's, (3) The existence of the McDonnell/Douglas 188, the first feasible (but not acceptable) STOL or VTOL vehicle, and (4) No acceptable STOL will be available by 1975.

Numerous propulsion schemes are available for STOL and VTOL. Figure 3.2-4 illustrates a number of lift/thrust concepts. It is felt that the blown flap system--not illustrated in Figure 3.2-4--will be the most likely lift/thrust scheme, especially for the early 1980's. Because of structural and aeroelastic problems, the rotor designs appear in a very unfavorable light. Deflected thrust or fan-in-wing designs represent a relatively expensive means of obtaining STOL lift capability. The turboprop deflected thrust scheme represented a cheap, simple means of obtaining high lift. But, because of the proclivity of the traveling public for jet powered

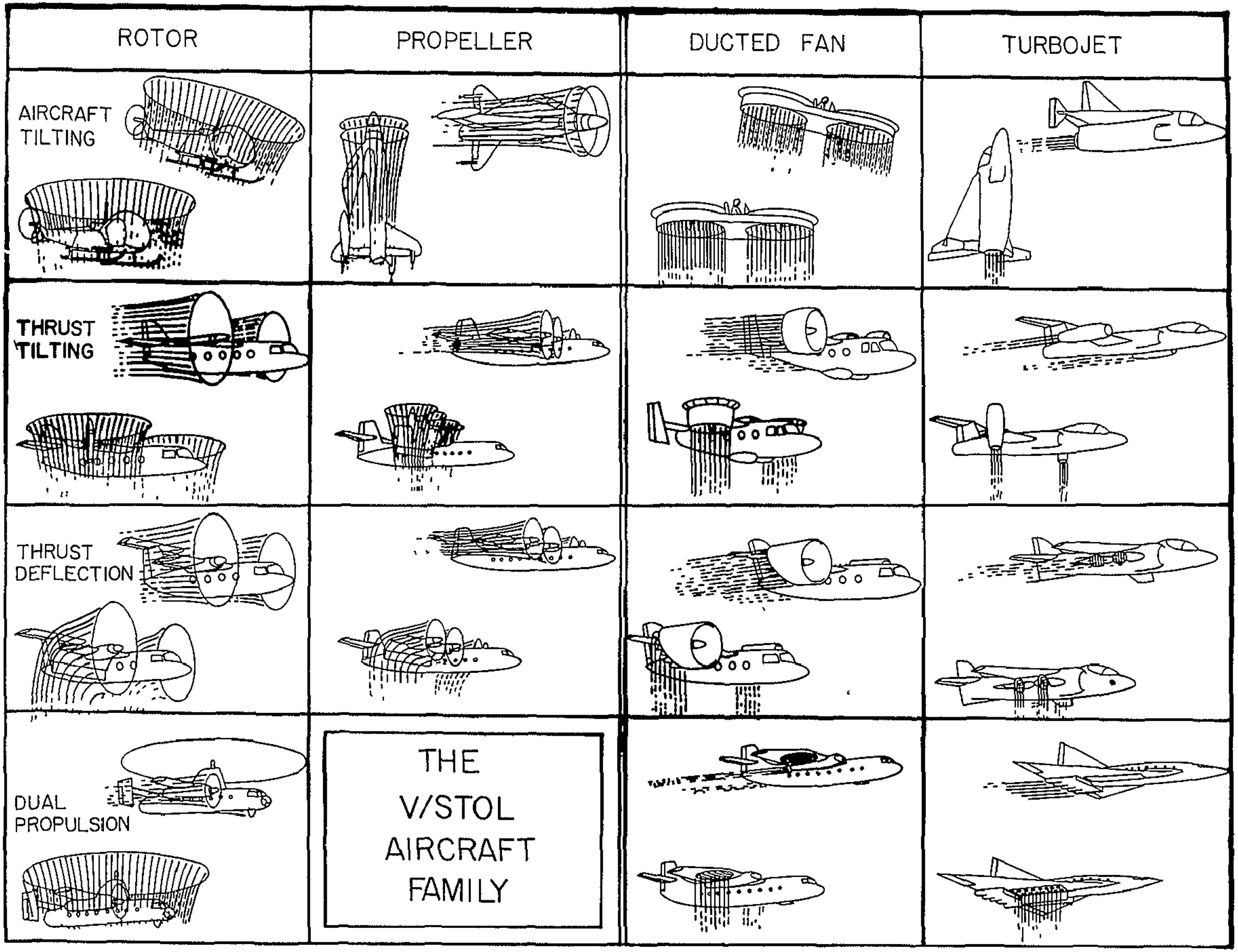
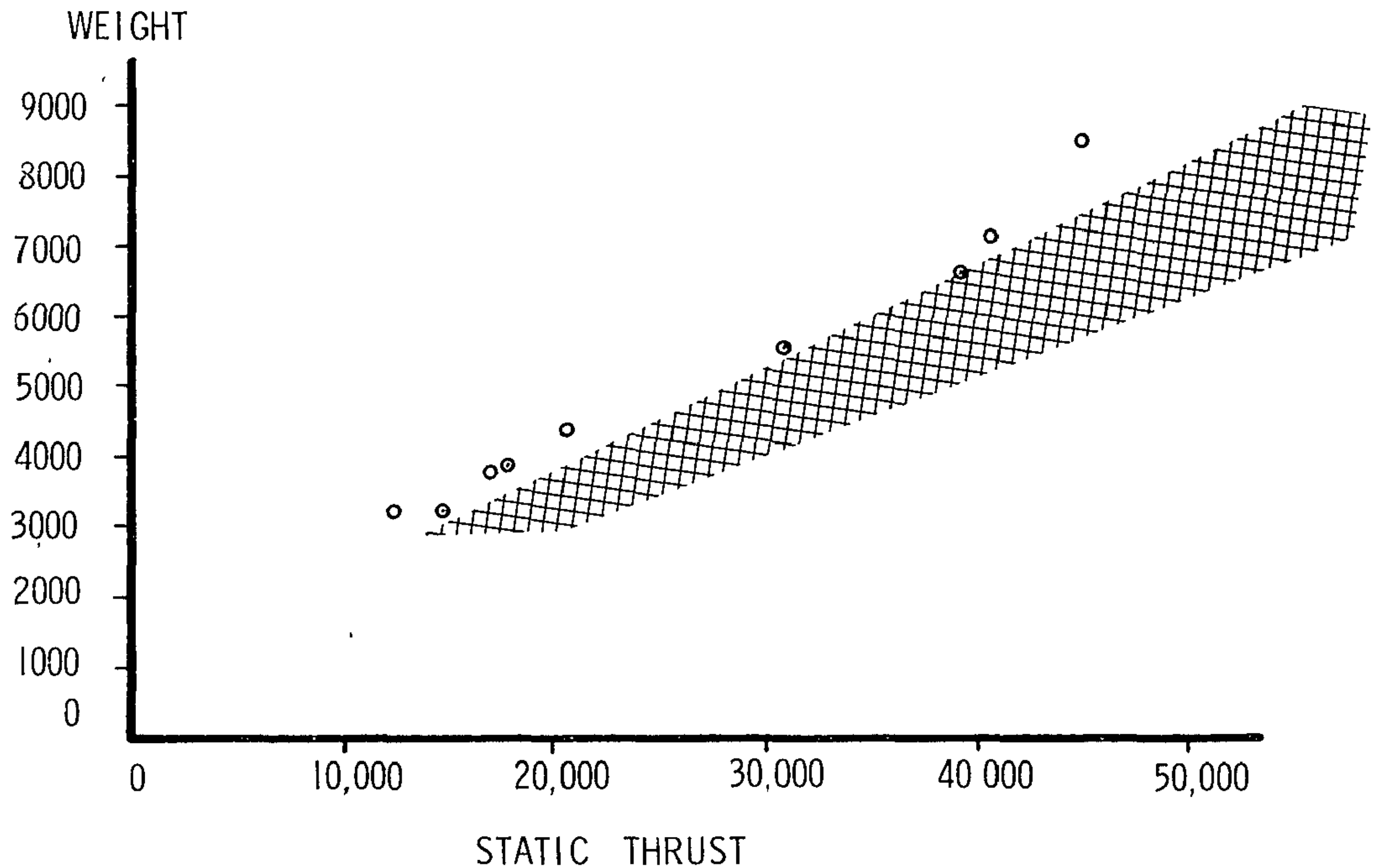

ROTOR
PROPELLER
DUCTED FAN
TURBOJET
AIRCRAFT TILTING
THRUST TILTING
THRUST DEFLECTION
DUAL PROPULSION
THE V/STOL AIRCRAFT FAMILY

FIGURE 3.2-4



ENGINE WEIGHT AS A FUNCTION OF SEA LEVEL STATIC THRUST

FIGURE 3.2-5

aircraft and because of the ease of construction this investigation chose the blown flap system for the STOL vehicle. The blown flap system is examined in detail in the Aerodynamic Section of the STOL program development.

Documents by leading aircraft companies tend to limit the passenger capacity of STOLs. Thus, a maximum load limit of 176 passengers was chosen for 1980 with a gradual increase to 300 by 1985.[6,7,8] Wing loadings for first generation blown flap STOLs are expected to be around 90 psf with a slight increase as operational experience is gained. This accounts for the gradual increase in wing loading through the 1980's.

VTOL will be available and needed by 1990. At this point in time the lift/thrust scheme that will be used for the first generation VTOL is not evident. With the exception of the XC-142A, a turboprop tilt-wing aircraft, no experience with large VTOLs is available. A fan-in-wing vehicle was used for the VTOL simulation program used in this investigation but only to generate cost figures.[9] No hypothesis was made as to the thrust/lift. The VTOL program was used for comparative purposes only and represented a cost simulation rather than a design program.

3.3 PARAMETRIC DESIGN PROGRAM

The parametric design program was a computer design of the aircraft to be used in the system From design data inputs the physical dimensions, thrust, weight, performance, and direct operating costs were generated for the vehicles. A block diagram of the computer program and a synopsis of the direct operating costs are contained in this section.

The Parametric Design Program is shown in Figure 3.3-1 as a simplified flow diagram. In reality, there were three programs; one each for CTOL, STOL, and VTOL vehicles. The flow diagram applies to all three with the individual differences discussed in the respective sections.

Inputs to the program were the cruise speed, cruise altitude, design range, and the number of passengers. For the CTOL vehicle, the cruise altitude was 36,000 feet and cruise Mach number ranged from 0.8 to 1.0 The STOL and VTOL vehicles were flown at 15,000 feet and at a Mach number of 0.6. Many different vehicles were designed by varying design ranges and passenger capacities. For the different vehicles, the ranges and capacities were:

	Range (mi)	Capacity
CTOL	50 - 3,000	50 - 1,000
STOL	50 - 500	50 - 500
VTOL	50 - 500	50 - 500

The second step was to calculate the number of lavatories, doors, and galleys required for the number of passengers. Then, the number of seats across the aisles are set equal to one. The seats across are incremented by one and the fuselage dimensions calculated. In these calculations, a circular fuselage was used with the seats positioned in the most efficient way and at least eight feet headroom maintained at the center. On the CTOL vehicle, provision is made for double decking If the seats across are more than ten, a double deck is used and a vehicle with more than twenty seats across is not considered. For this number of seats across, a triple deck should be used for more efficiency. The V/STOL vehicles were not

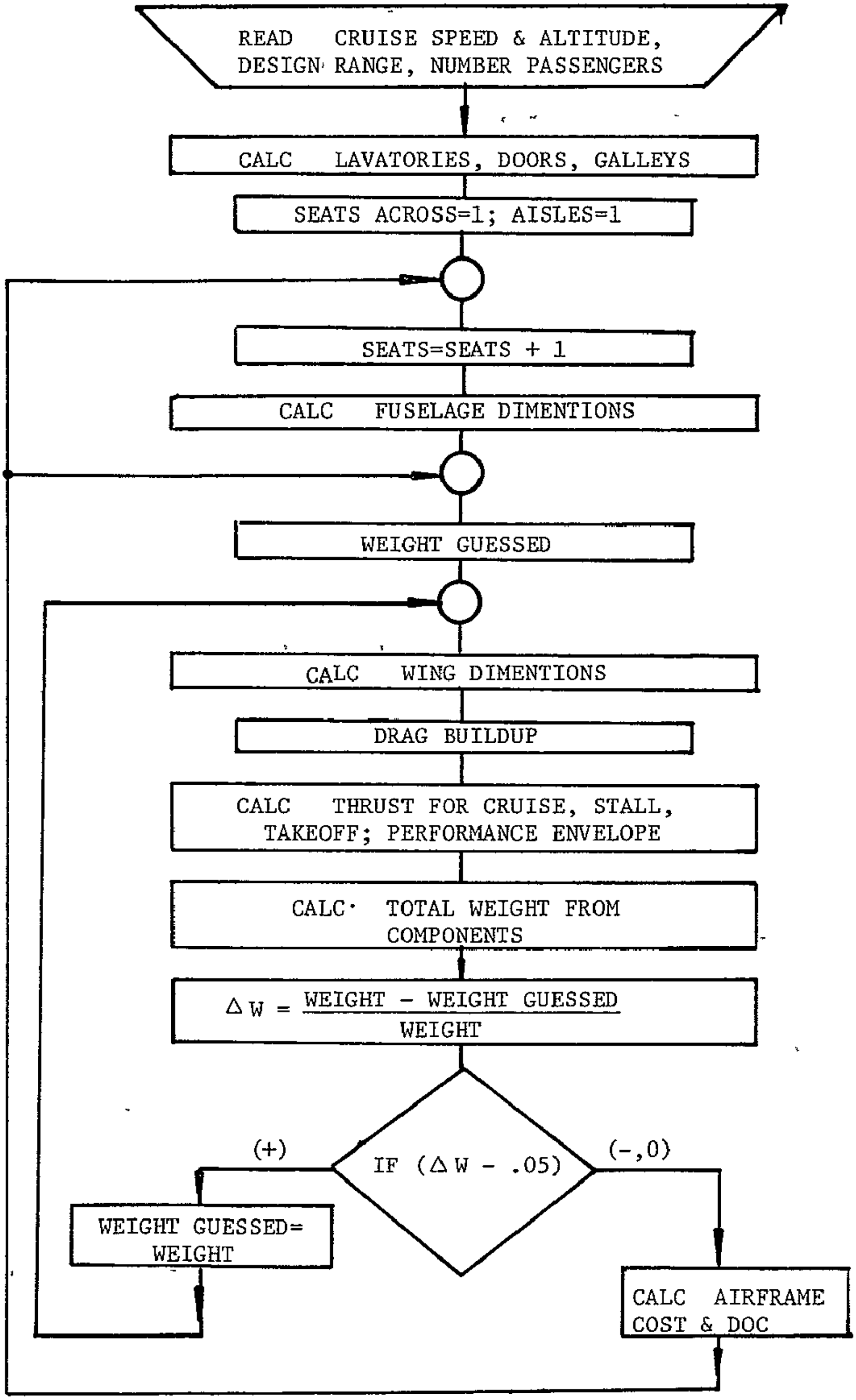


FIGURE 3.3.1-1

FLOW CHART - PARAMETRIC DESIGN PROGRAM

double decked and more than ten seats across was not considered.

Consideration of cargo was limited in the program to calculating available volume leftover when the airplane is designed for maximum passengers. The passenger compartment was considered rectangular and any extra space above, below, or on the sides was calculated and considered available for cargo. In calculating the volume for cargo, the total extra volume was divided by two since all volume cannot be used. The circular fuselage was used for simplicity and ease in calculating aerodynamics. The actual fuselage design, particularly for double decked vehicles, may be improved by using another cross section. The best cross section should not have appreciable differences in aerodynamics but would adapt to cargo more efficiently.

From the fuselage dimensions, the ratio of length to diameter was calculated. The program was made to consider only vehicles with a fuselage length to diameter ratio between eight and fifteen. These numbers were selected from data on existing and projected aircraft. The ratio starts high with a configuration of two seats across and a design capacity of 50 passengers or more. If the ratio is above fifteen, the program loops and adds one seat across, then continues through the fuselage dimensions again. When the ratio becomes less than fifteen, the program continues to the next step.

A total vehicle weight was estimated from a simple linear expression obtained by plotting weight versus passenger capacity for existing airplanes. The wing area was calculated from the weight using a wing loading or 120 psf for CTOL and 90 pounds per square foot for STOL and VTOL. The other wing dimensions were calculated using an aspect ratio of eight for CTOL and seven for STOL and VTOL. Next, the drag buildup, thrust calculations, performance envelope, and total weight were calculated. These are discussed in later sections.

The total weight and estimated weight, on which the calculations were made, were compared. If there was no more than five percent error, the calculations were assumed reasonable and the vehicle designed. If the weights had more than five percent error, the calculated weight was taken as a new estimate and the vehicle redesigned. This continues until the error is less than five percent. When the error is five percent or less, the program continues and calculates airframe costs and direct operating costs.

After the costs are calculated, the program loops and increments the number of seats across by one. The entire calculations are repeated for the new arrangement and then seats are incremented again. This will continue until either the length to diameter ratio becomes less than eight or the number of seats across becomes more than twenty for CTOL or ten for STOL and VTOL. The procedure for designing vehicles with different numbers of seats across allows the best interior configuration to be selected in terms of costs.

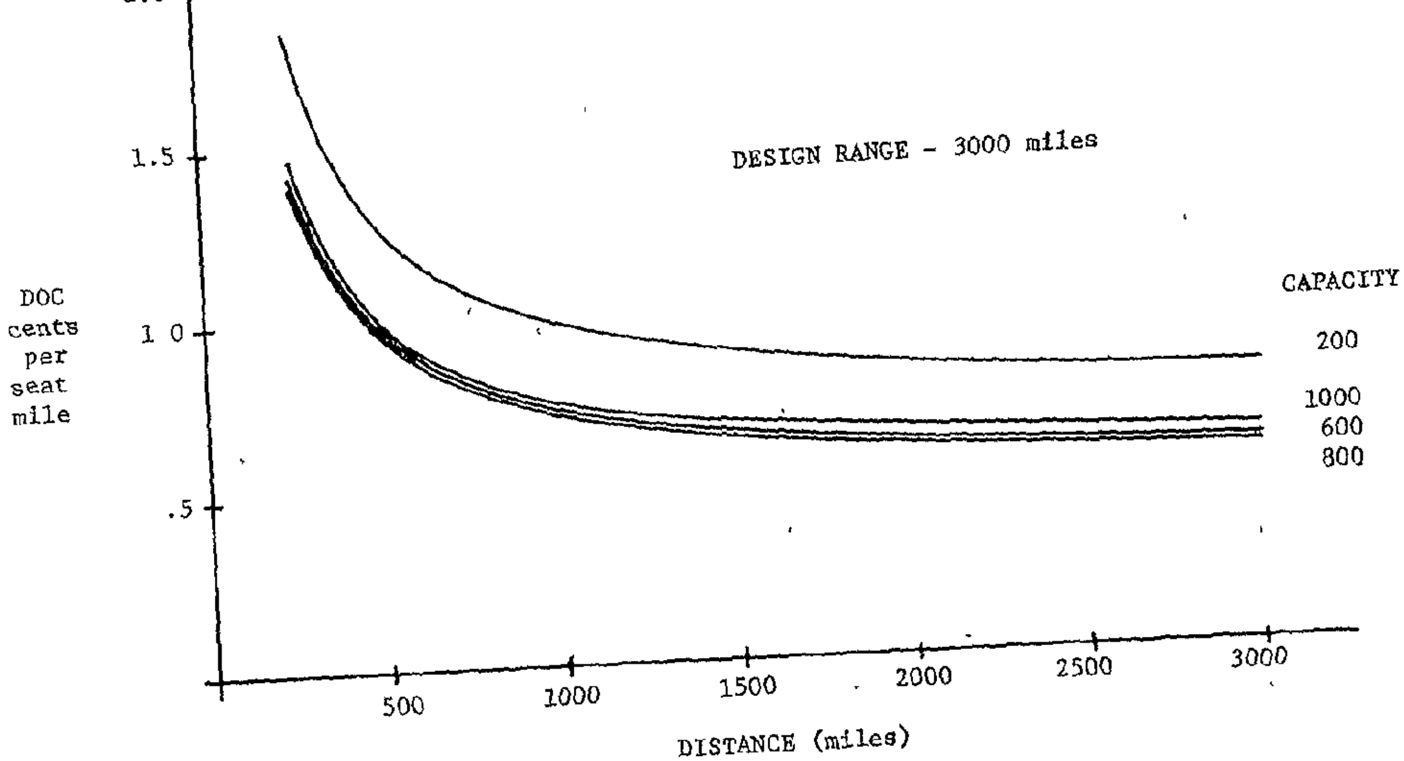
3.3.1 Cost Results

The results presented in this section represent the cost analysis of the parametric vehicles. Cost data is shown for four basic types of aircraft: long range conventional (CTOL), medium range conventional (CTOL), short takeoff or landing (STOL), and vertical takeoff or landing (VTOL). Design ranges for the long range conventional and the medium range conventional were arbitrarily chosen for the data presented here as 3000 miles and 1500 miles, respectively.

Figure 3.3.1-1 represents direct operating cost (DOC) as it varies with distance flown for a 3000 mile design range CTOL

FIGURE 3.3.2-1

CTOL. DIRECT OPERATING COST vs. DISTANCE FLOWN



aircraft. There are two main points of interest shown in the figure. First, as the passenger capacity is increased from 600 to 800 passengers, the reduction of DOC is very small compared to that of the 200 to 600 passenger aircraft. This indicates a possible disadvantage of using an 800 passenger aircraft where one carrying 600 travelers is almost as cheap. Also, the initial cost for an 800 passenger aircraft is much greater than for a plane that carries 600. Secondly, the curve for the 1000 passenger plane is markedly above those curves for the 600 and 800 capacity planes. The somewhat startling conclusion results from a fuselage weight-fuselage drag interaction. A 1000 passenger aircraft will be designed double-decked. Structural weight per passenger for large aircraft will exhibit a downward trend with increasing passenger loads, fuselage weight is proportional to fuselage length/diameter ratio. But drag is essentially proportional to the square of the cross-sectional area. Thus the drag of the fuselage for double-decked aircraft can become so severe that any advantage gained by increased passenger capacity is lost. This point is seen to occur at about 800 passengers for the current design parameters.

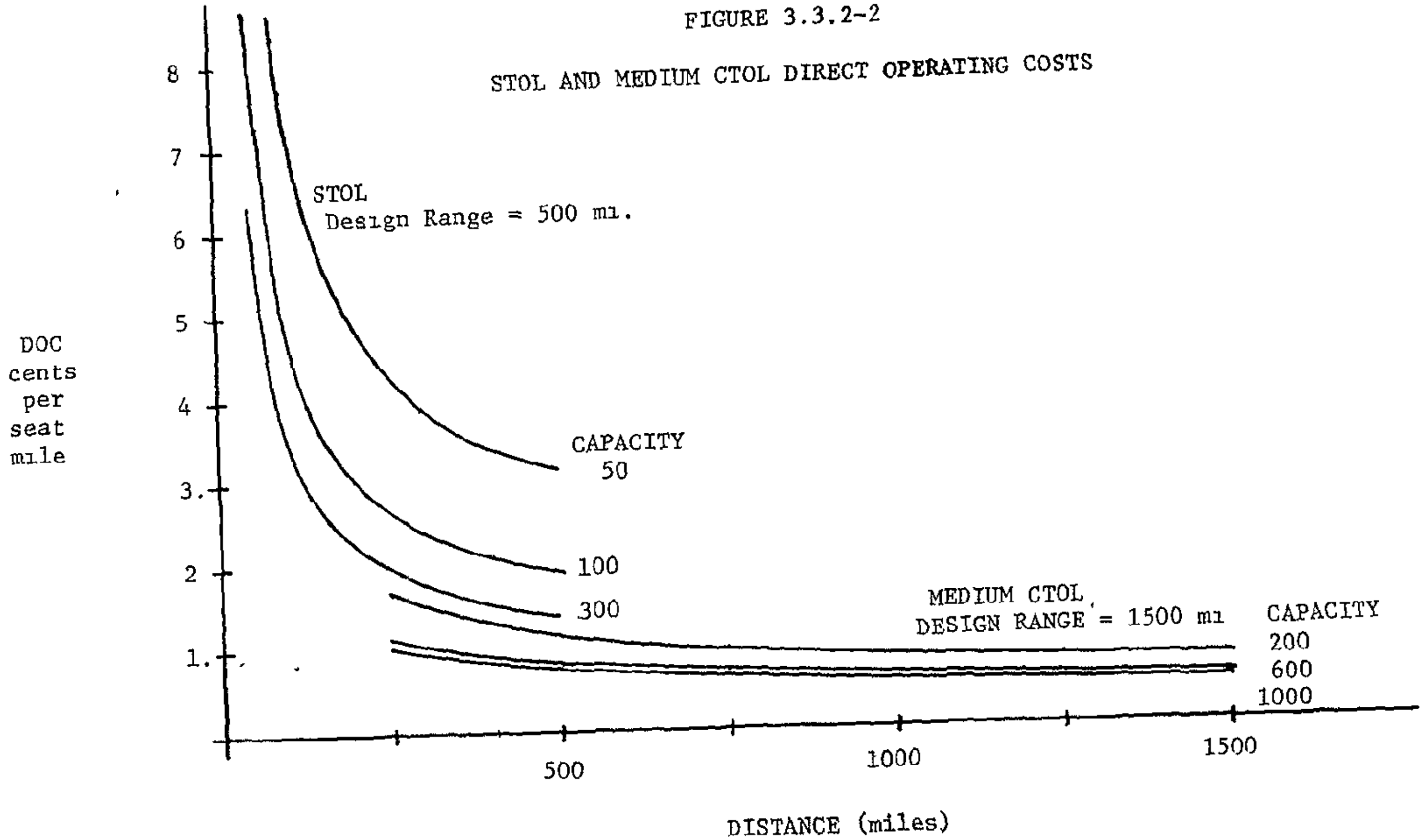
Direct operating cost versus distance flown for the medium range CTOL aircraft and the STOL aircraft is shown in Figure 3.3.1-2. The STOL aircraft has a maximum design range of 500 miles

The STOL aircraft has higher DOC's than the CTOL aircraft for the same distance flown. Higher STOL DOC's are the result of increased engine requirements for short takeoffs and landings. However, lower terminal costs and increased passenger convenience may cause the STOL to be more desirable than the CTOL aircraft.

Cost data shown for the medium range CTOL shows, as in Figure

FIGURE 3.3.2-2

STOL AND MEDIUM CTOL DIRECT OPERATING COSTS



3.3.1-2, that the reduction in DOC between a 600 and 1000 passenger aircraft is very small. In the medium range CTOL, it may be less costly to use a 600 passenger aircraft than those having higher seating capacities.

The family of curves presented in Figure 3.3.1-3 shows DOC versus distance flown for aircraft of different design ranges.

A different method of presenting direct operating cost is shown in Figure 3.3.1-4. Here DOC in dollars per trip versus aircraft design range is plotted. The three curves represent different passenger capacities. As would be expected, the larger the aircraft, the more it costs to operate over a given distance. Even though it costs more to fly a 1000 passenger plane 3000 miles than to fly a 200 passenger craft the same distance, the operating cost per seat will be less on the larger capacity vehicle.

Figure 3.3.1-5 is a non-dimensionalized form of the DOC versus distance flown curves. The curves represent different design ranges. As is shown in the figure, it is cheaper to fly a 3000 mile design range aircraft over a fraction of its range than to do so for the shorter design range vehicles. The shape of these curves is sensitive to design range.

A similar non-dimensionalized curve is shown in Figure 3.3.1-6 for STOL aircraft. In this case the two curves shown represent different passenger capacities and a fixed design range. Seating capacity variation was found to have a small influence on the shape of these curves.

As would be expected, VTOL aircraft are more expensive to operate over a given distance than either CTOL or STOL vehicles. Figure 3.3.1-7 demonstrates this difference in cost. Caused by the added

FIGURE 3.3.2-3

CTOL: DIRECT OPERATING COSTS AT VARIOUS DESIGN RANGES

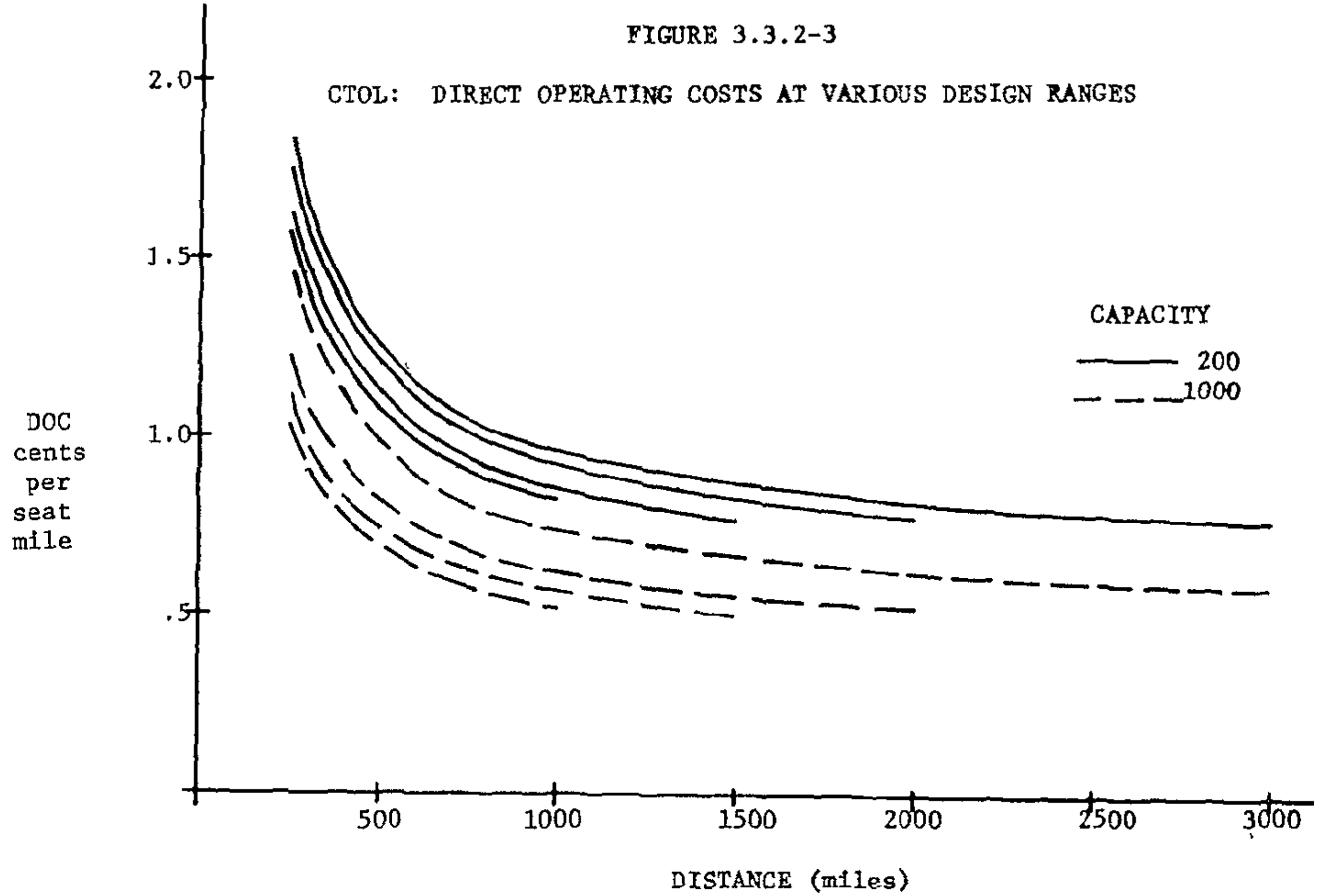
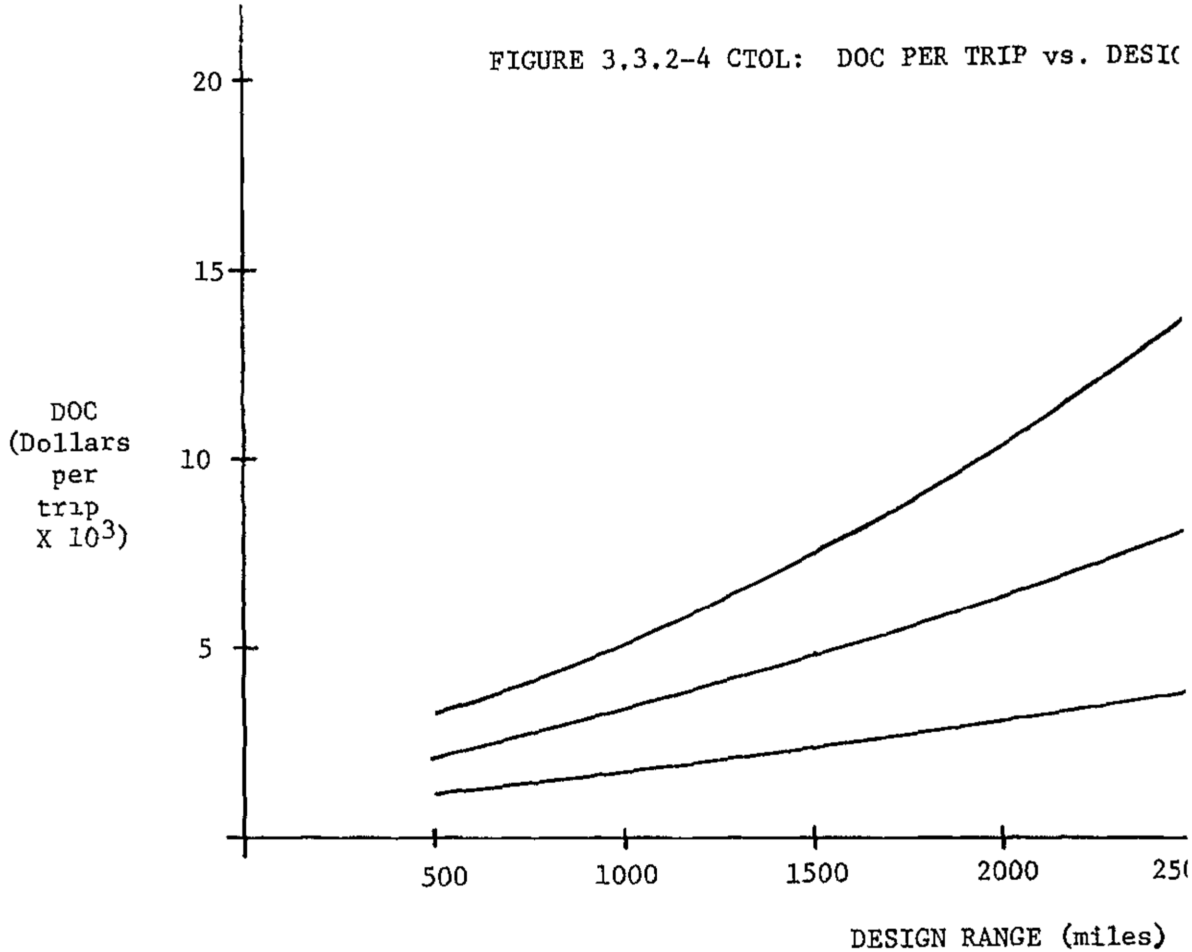


FIGURE 3.3.2-4 CTOL: DOC PER TRIP vs. DESI(



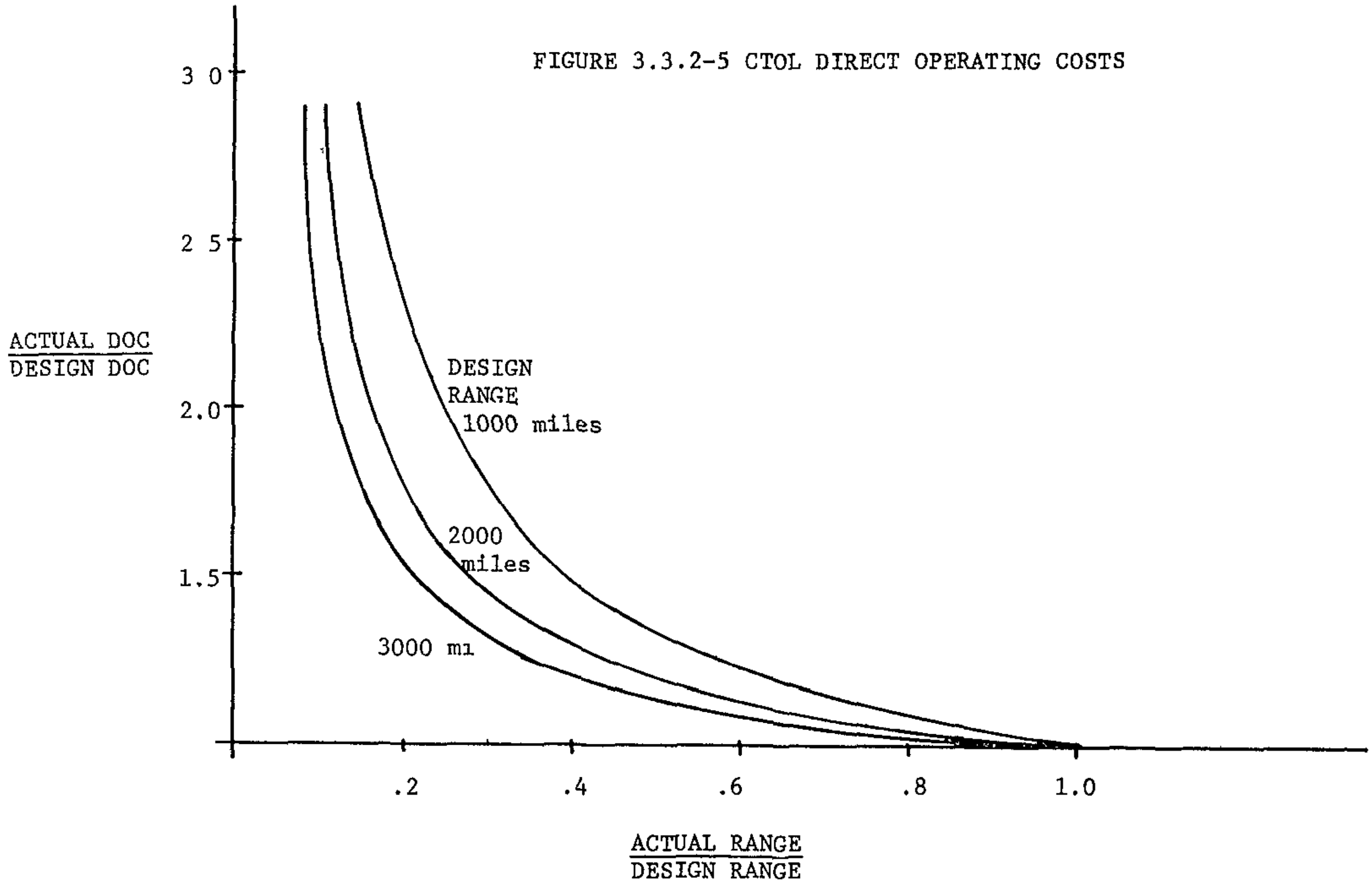


FIGURE 3.3.2-5 CTOL DIRECT OPERATING COSTS

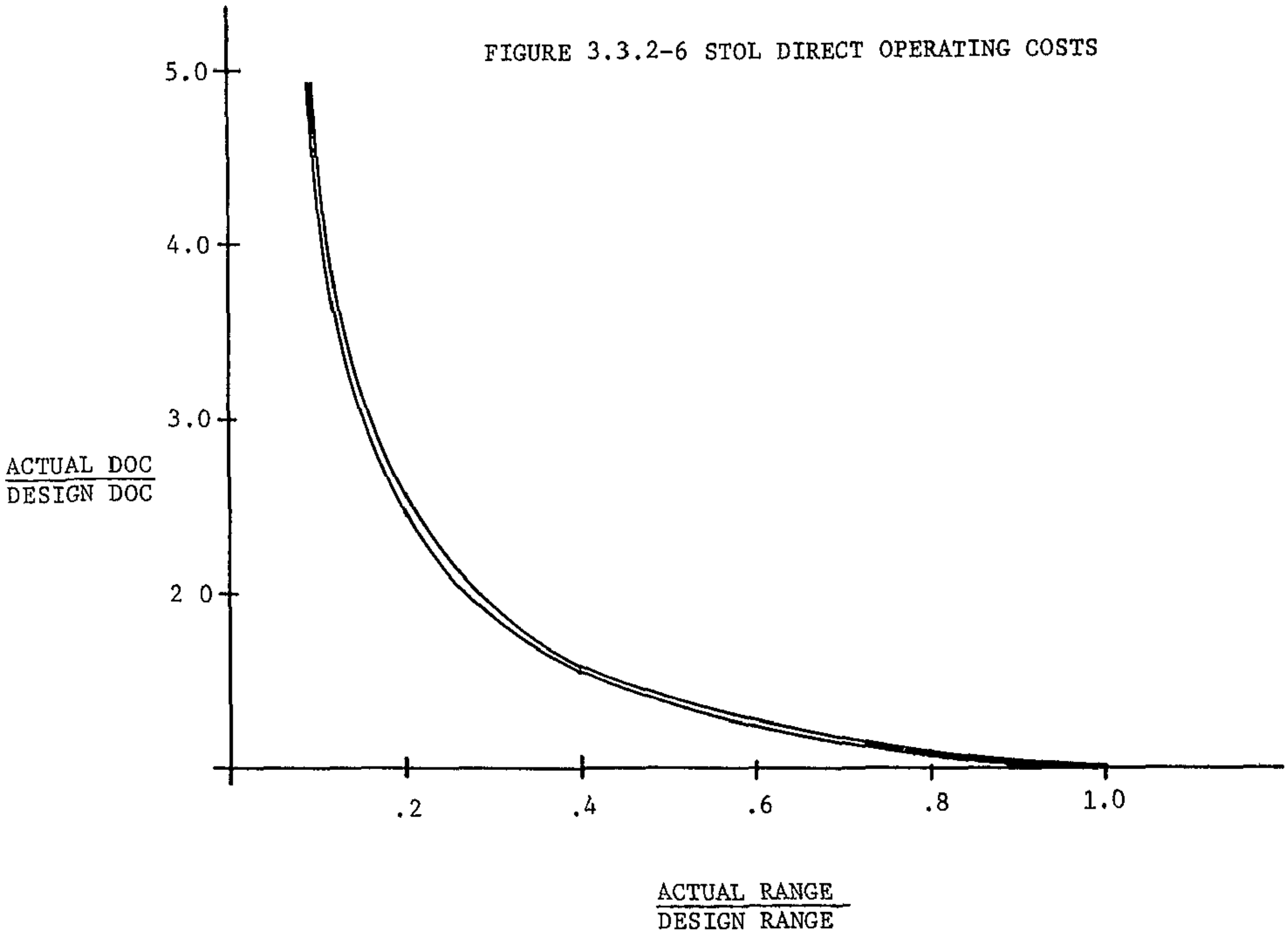
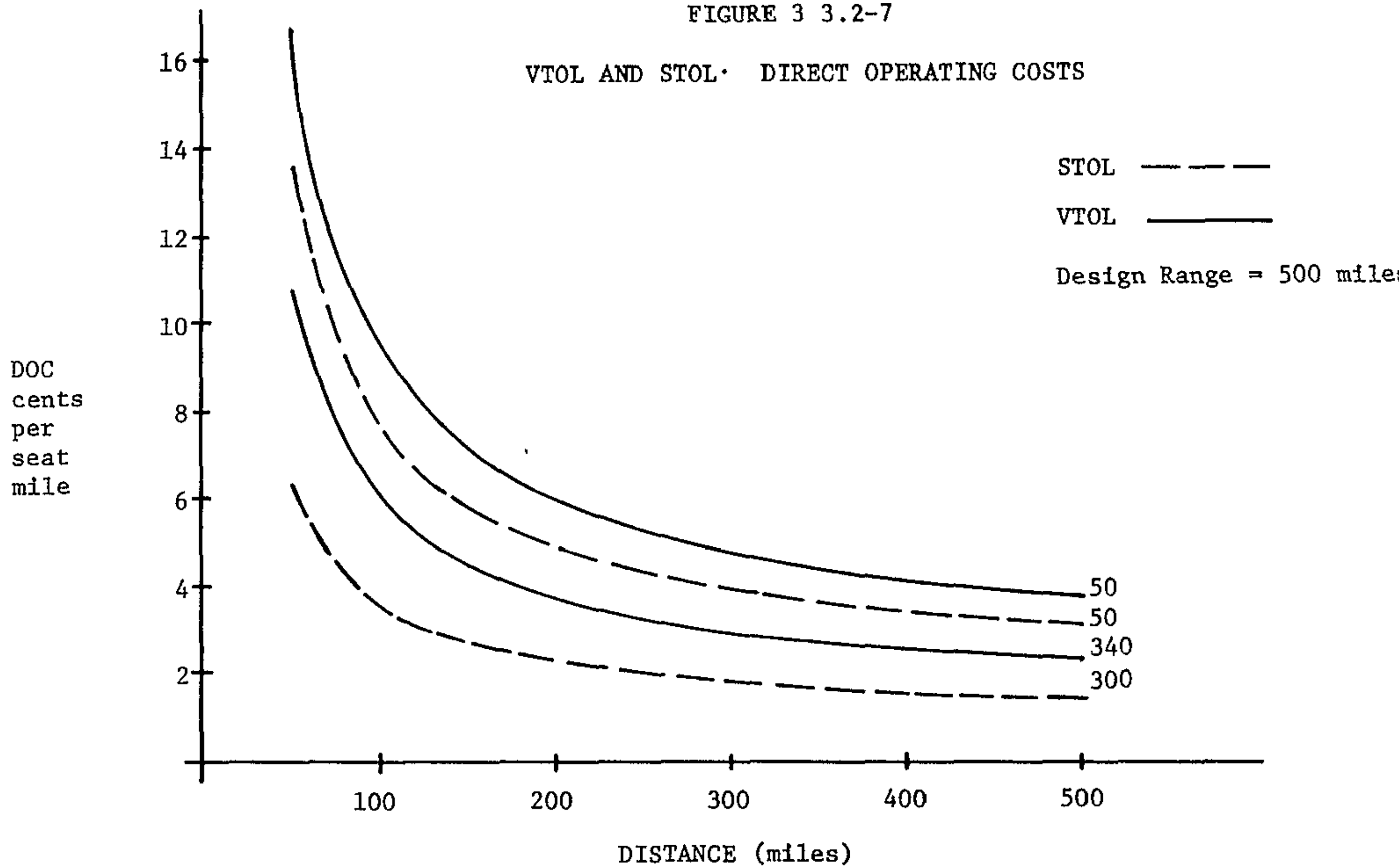


FIGURE 3.3.2-6 STOL DIRECT OPERATING COSTS

FIGURE 3 3.2-7

VTOL AND STOL· DIRECT OPERATING COSTS



engine performance and weight required, the VTOL is noticeably more expensive to run than the STOL. However, VTOL aircraft have many advantages that cannot be reflected in direct operating costs. Lower terminal costs and close-in operation are only two of these.

Total vehicle cost versus gross vehicle weight is shown in Figure 3.3.1-8. After the parametric design program calculates the weight of an aircraft, the cost analysis module calculates the total vehicle cost using the gross weight and maximum aircraft speed as inputs. This figure shows the results of these computations. As an example, a Boeing 747 weighs approximately 680,000 pounds. Figure 3.3.1-8 shows that the total production vehicle cost would be $22 million dollars. The actual cost of the Boeing 747 is about $20 million dollars.

Figure 3.3.1-9 shows direct operating cost for a CTOL long range aircraft with the supercritical wing. When compared to the CTOL long range vehicle with conventional wings the cost is shown to be less. For the 200 passenger vehicle, the cost savings with the Mach one aircraft is shown to be as high as three to four percent. The savings decreased as passenger capacity was increased. Drag due to the cylindrical fuselage for high capacity aircraft had a detrimental effect on DOC. A more refined fuselage may prove the supercritical wing configuration to be even more economical than shown in this analysis.

3.4 VEHICLE DESIGN

Design programs were written for two categories of vehicles, CTOL and STOL, and a simulation program was written for a VTOL type aircraft. The CTOL and STOL programs contained relatively detailed

FIGURE 3.3.2-8

TOTAL AIRCRAFT COST vs. GROSS VEHICLE WEIGHT

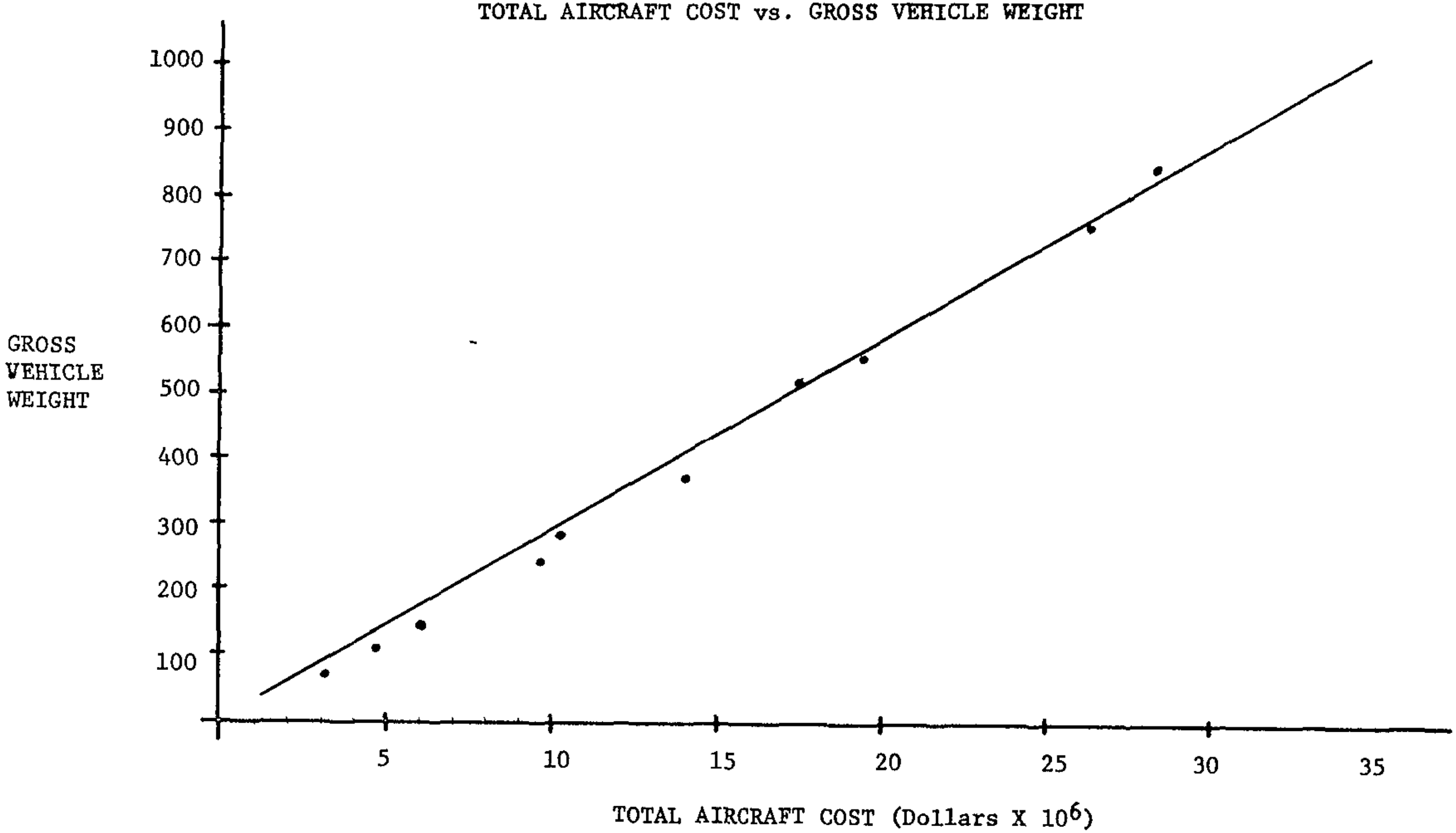
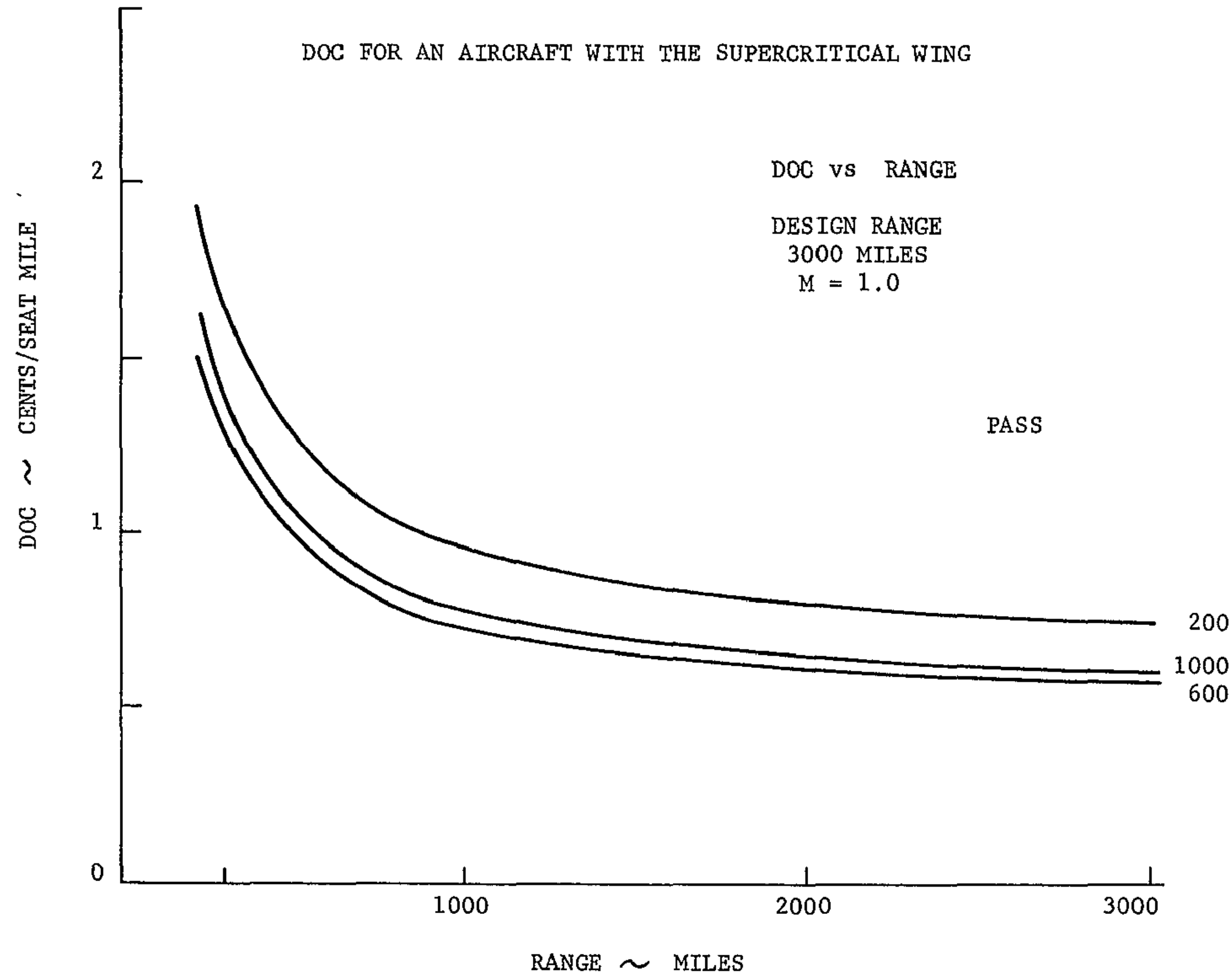


FIGURE 3.3 2-9



DOC FOR AN AIRCRAFT WITH THE SUPERCRITICAL WING
DOC vs RANGE
DESIGN RANGE
3000 MILES
M = 1.0
PASS
200
1000
600
DOC ~ CENTS/SEAT MILE
0
1
2
1000
2000
3000
RANGE ~ MILES

information concerning aerodynamics, structures, performance, and propulsion. Each of the topics is discussed in detail in the following sections. The VTOL simulation program used characteristics typical of VTOL aircraft.

3.4.1 CTOL Aircraft

CTOL aircraft of the 1980's will differ only slightly from the CTOL aircraft currently being used by common commercial carriers. The aircrafts will utilize turbofan engines: the Mach 0 8 aircraft is projected to have a 12 1 bypass ratio engine while Mach 1.0 aircraft are expected to possess 4:1 bypass ratio engines. All CTOL aircraft designs were low wing--the conventional wing was swept 30°, the supercritical wing had a 45° sweep. The number of engines each different design utilized was based upon aircraft gross weight:

Aircraft gross weight	
0 - 200,000	2 engines
200,000 - 500,000	3 engines
above - 500,000	4 engines

Double-decked passenger seating was used if a lower overall vehicle cost was achieved using a double-decked arrangement. Figure 3.4.1-1 illustrates schematically the external appearance of the intermediate range CTOL aircraft equipped with a supercritical wing planform.

3.4.1.1 Aerodynamics

The aerodynamic characteristics of the conventional vehicle were estimated using a drag buildup for the profile drag coefficient and a parabolic drag polar for the vehicle in a lifting condition. A survey of contemporary passenger aircraft was made and the coarse

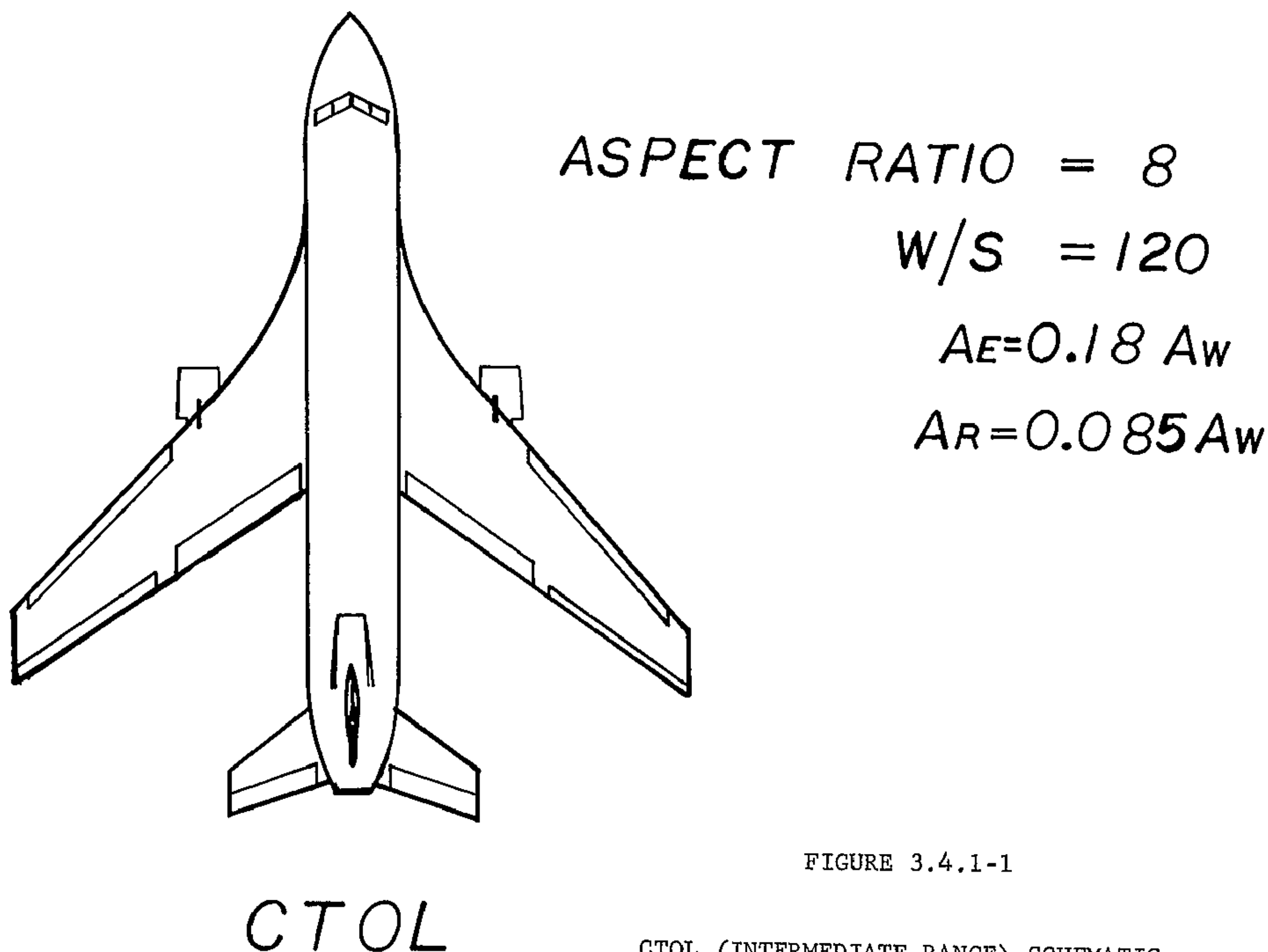


FIGURE 3.4.1-1

CTOL (INTERMEDIATE RANGE) SCHEMATIC

physical characteristics (wing loading, aspect ratio, sweep angle, taper ratio, fuselage fineness ratio, control surface areas, etc.) were noted for each vehicle.[5] Typical values of these characteristics were then chosen and used throughout the study in parametrically designing CTOL vehicles. The values typifying turbofan passenger CTOL aircraft are:

Wing loading	120 lb./ft^2
Aspect ratio, wing	8
Sweep angle	30°
Taper ratio	1/2
Fuselage fineness ratio	$8 \leqq$ ratio $\leqq 15$
A_{ele}/A_{wing}	.085
A_{rud}/A_{wing}	.180
Aspect ratio, rudder	2.5
Aspect ratio, elevator	6.0

LOW WINGS

The assumption of a parabolic drag polar, while not entirely correct, is consistent with the usual performance analysis of subsonic aircraft operating below the drag divergence Mach number.[10] Following accepted procedures the lift and drag coefficient are defined respectively as:

$$C_D = \frac{D}{1/2\ \rho v^2 S}$$

$$C_L = \frac{L}{1/2\ \rho v^2 S}$$

The drag coefficient for a lifting vehicle can then be written as:

$$C_D = C_{D_o} + \frac{C_L^{\ 2}}{AR \quad e}$$

where:

C_{Do} = profile drag coefficient

AR = aspect ratio = $\frac{\text{span}}{\text{chord}}$

e = wing efficiency factor, 0.90 nominally

The above equation provides a reasonable functional relation between lift and drag Another parameter, L/D ratio, is also of interest. The lift-to-drag ratio represents the aerodynamic efficiency of the aircraft--a high ratio (15-18 for commercial aircraft) denoting a relatively efficient vehicle. For an aircraft with a parabolic polar the (L/D) max is given by:

$$\left(\frac{L}{M}\right)_{max} = 1/2 \sqrt{\frac{AR \ e}{C_{D_o}}}$$

The drag coefficient of an object (in a subsonic flow completely immersed in a fluid) is often envisioned to consist of two components· pressure drag, the drag resulting from the body shape, and friction drag, the drag resulting from the shear at the surface/fluid interface. The profile drag coefficient of the aircraft was constructed by summing the contributions of the vehicle components and estimating the skin friction drag coefficients.

In addition to the aforementioned pressure and skin friction components of drag, a new contribution is found when two aircraft components, such as the wings and fuselage, are joined so as to affect each other's flow field. This new contribution has been labeled interference drag. Interference drag can either increase or decrease the drag of individual items, but generally a small increase is noted. In computing the drag coefficient buildup the interference drag was included in the drag coefficient of the individual components. The fuselage, wings, engine nacelles, and empennage were the components of the aircraft included in the drag buildup.

FUSELAGE:

Pressure Drag Coefficient

1) fuselage nose[11]

C_D = 0.1 based on fuselage cross-sectional area

2) fuselage aft closure[11]

C_D = 0.02 based on fuselage cross-sectional area

Skin Friction Drag

1) Laminar

Transition to turbulent flow was assumed to occur at a Reynolds number (based on length) of 13000. For the portion of the nose in laminar flow the skin friction coefficient is:

$$C_f = 0.01164 \text{ (based on areas in laminar flow)}$$

2) Turbulent

Transition location was computed on the basis of a transition Reynold's number of 13000. Aft of the transition point the entire fuselage was considered to be in turbulent flow. The turbulent skin friction coefficient (after reference[12]) was given by

$$C_f = \frac{0.074}{Rn]_{fus}^{0.2} \; (T/T_o)^{0.348}}$$

where·

$$\frac{T}{T_o} = 1 + \frac{\gamma - 1}{2} M^2$$

$R_n]_{fus}$ = Reynold's number evaluated using the fuselage length.

WINGS:

Pressure Drag

Conventional

Any aircraft flying in the high subsonic regime requires a thin airfoil for efficient cruise flight. The NASA airfoil section 66-208 is typical of the airfoils on high subsonic aircraft.[13] Because the CTOL aircraft will possess high wing loading and since low landing speeds are necessary for commercial operations, the projected wing design is equipped with both leading edge slats and triple slotted flaps. The pressure and interference drag coefficient for the projected airfoil was estimated to be:[13]

$$C_D]_{wing} = 0.0055$$

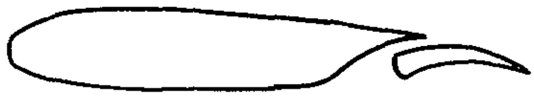
The combination of leading edge slots and slotted flaps permits a maximum lift coefficient of three to be attained from the wings.[14]

A conventional airfoil section possesses good drag characteristics up to the drag divergence Mach number (see Figure 3.4.1.1-1a).[5] Sweeping the wing allows some increase in the drag divergence Mach number but structural considerations limit the sweep to about 30 degrees. This degree of sweep allows a Mach number of 0.85 to be reached before drag divergence. This Mach number represents the highest economic cruise velocity available for conventional airfoil sections.

Supercritical

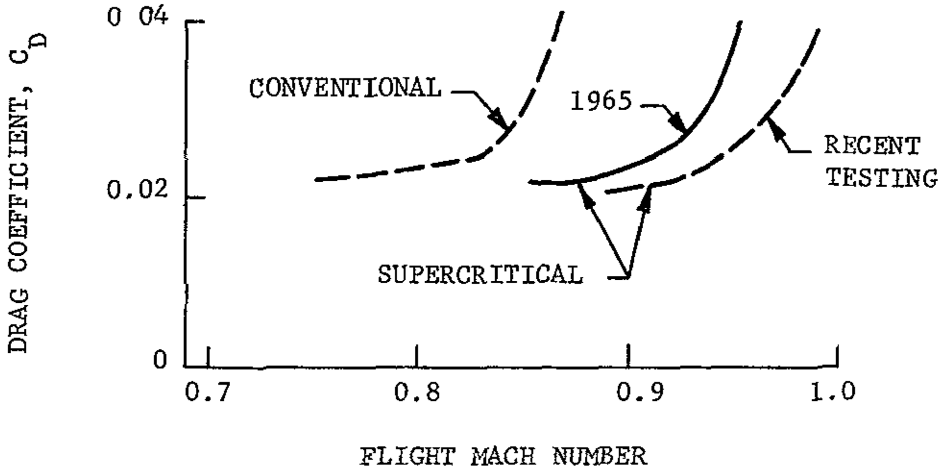
Recent research in aerodynamics has led to the supercritical wing. This wing through three-dimensional contouring can increase the drag divergence Mach number to a Mach number of near unity. Figure 3.4.1.1-1a illustrates the section geometry of a supercritical airfoil and graphically indicates the increase in Mach number at drag divergence.[5] Figure 3.4.1.1-1b illustrates a typical planform for a supercritical wing.

In conventional airfoil sections the drag rise results from the formation of shock waves on the wing surface as the Mach number increases. The shock waves, which are located at about the 0.5 chord position, induce flow separation at a position on the wing considerably ahead of the usual separation point. This shock wave induced separation results in two performance degrading effect: the earlier separation point results in a larger drag coefficient due to the increased wake and the earlier separation point



SUPERCRITICAL AIRFOIL

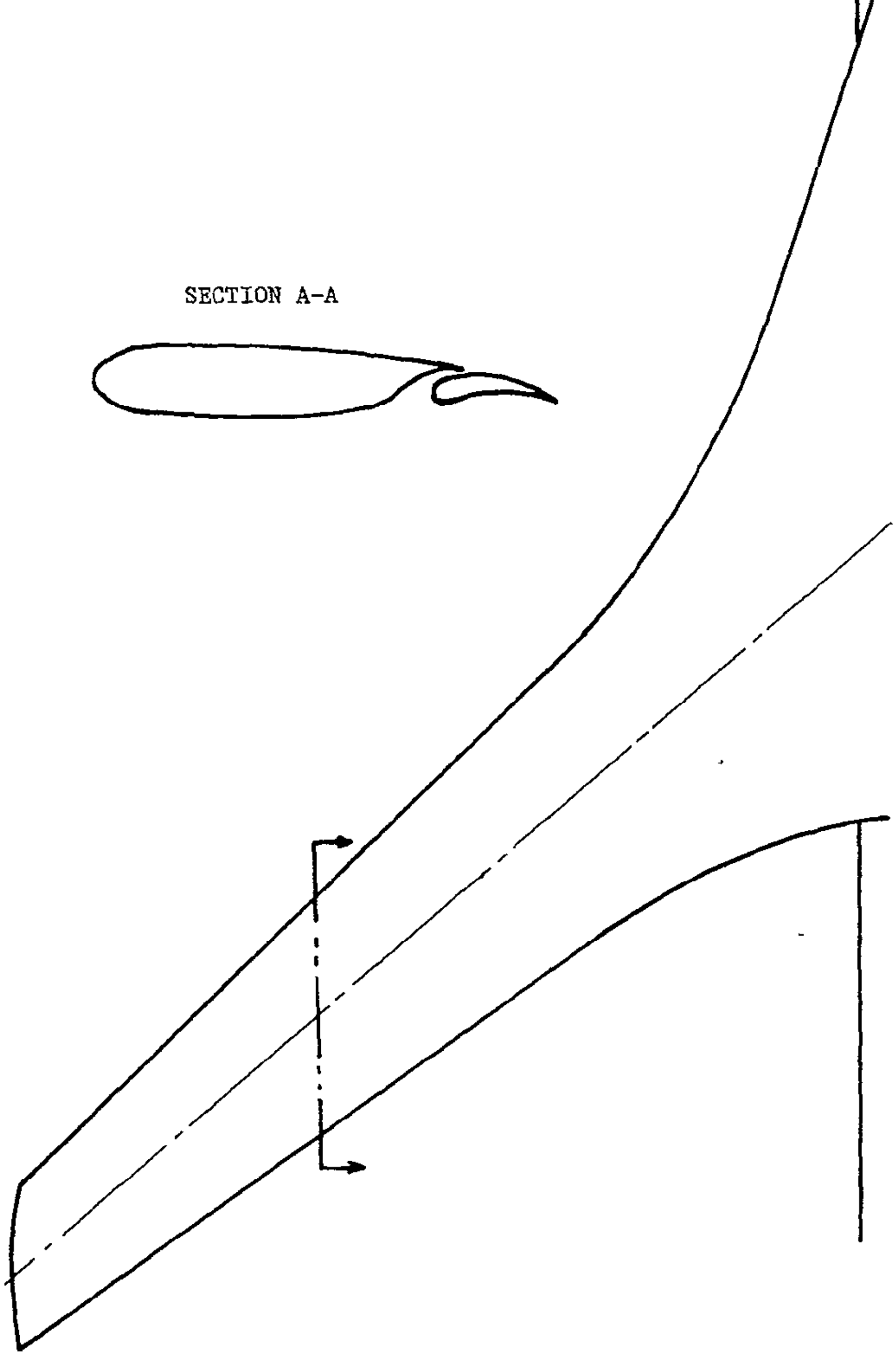
WING-BODY MODEL DRAG TESTS
(35^o WING SWEEP ANGLE)



SUPERCRITICAL WING TECHNOLOGY

FIGURE 3.4.1.1-1a

FIGURE 3.4.1.1-1b SUPERCRITICAL WING PLANFORM



drastically reduces the lift, thus giving rise to an increased drag coefficient, i.e., drag divergence, at some high subsonic Mach number. The effects combine to preclude economically cruising at Mach numbers above the drag divergence Mach number.

Figure 3.4.1.1-1a infers that no appreciable increase in profile drag coefficient is expected from the supercritical wing over the conventional wing.[5] Therefore, the lift-drag ratio of an aircraft equipped with the supercritical wing should be approximately the same as the lift-drag ratio of a conventionally equipped aircraft. Whence, the Breguet range equation indicates a higher productivity for the supercritical airfoil than for the conventional airfoil.

As with any mechanical system, improvement will cost. The supercritical wing exacts its toll in increased structural weight and a higher sweep angle. Current estimates are for an increase in wing weight of about 10%. The supercritical wing does not impede the installation of high lift devices (slots, flaps, etc.).

All of the above combine to make the concept appear favorable. Thus this investigation postulated the use of the supercritical wing on aircraft of the 1980's.

Skin Friction Drag

The wing flow was considered as turbulent over the entire wing surface. The Reynolds number of the wing was computed using the average wing chord. The skin friction coefficient was calculated using:

$$C_f = \frac{0.074}{R_n]_{wing}^{0.2} \; (T/T_o)^{0.348}}$$

Empennage

Pressure Drag

The profile and interference drag for the empennage was estimated on the assumption that both the vertical and horizontal surfaces were NACA 66-208 airfoil sections. To a good approximation the drag coefficient used for the wing can also be used for the empennage.

Normally in the course of aircraft design the areas of the two empennage components are "sized" so as to result in a stable aircraft. This technique, however, requires a rather extensive structural and air loads analysis. It was felt that time was not available for such a detailed analysis. Hence, the simple expedient of sizing the empennage surfaces according to some fixed percentages of wing area was used. The vertical stabilizer area (rudder) was taken as 0.085 of the wing area while the horizontal stabilizer area (elevator) was taken as 0.18 of the wing area. These numbers reflect current CTOL technology. For the empennage components the reference area for the drag coefficient was taken as the rudder or elevator area.

Skin Friction Drag

The skin friction drag coefficients for the empennage were computed using Reynold's number based upon the average chords of the rudder and elevator. Once again, the flow around both empennage components was considered to be in a totally turbulent state. The skin friction then becomes:

$$C_f\Big]_{\substack{rud\\or\\ele}} = \frac{0.074}{R_n\Big]_{\substack{rud\\or\\ele}}^{0.2} (T/T_o)^{0.348}}$$

Nacelle

The engines were considered to be contained in nacelles, mounted below the wings. The pressure and interference drag coefficient (based on engine frontal area) was taken as:

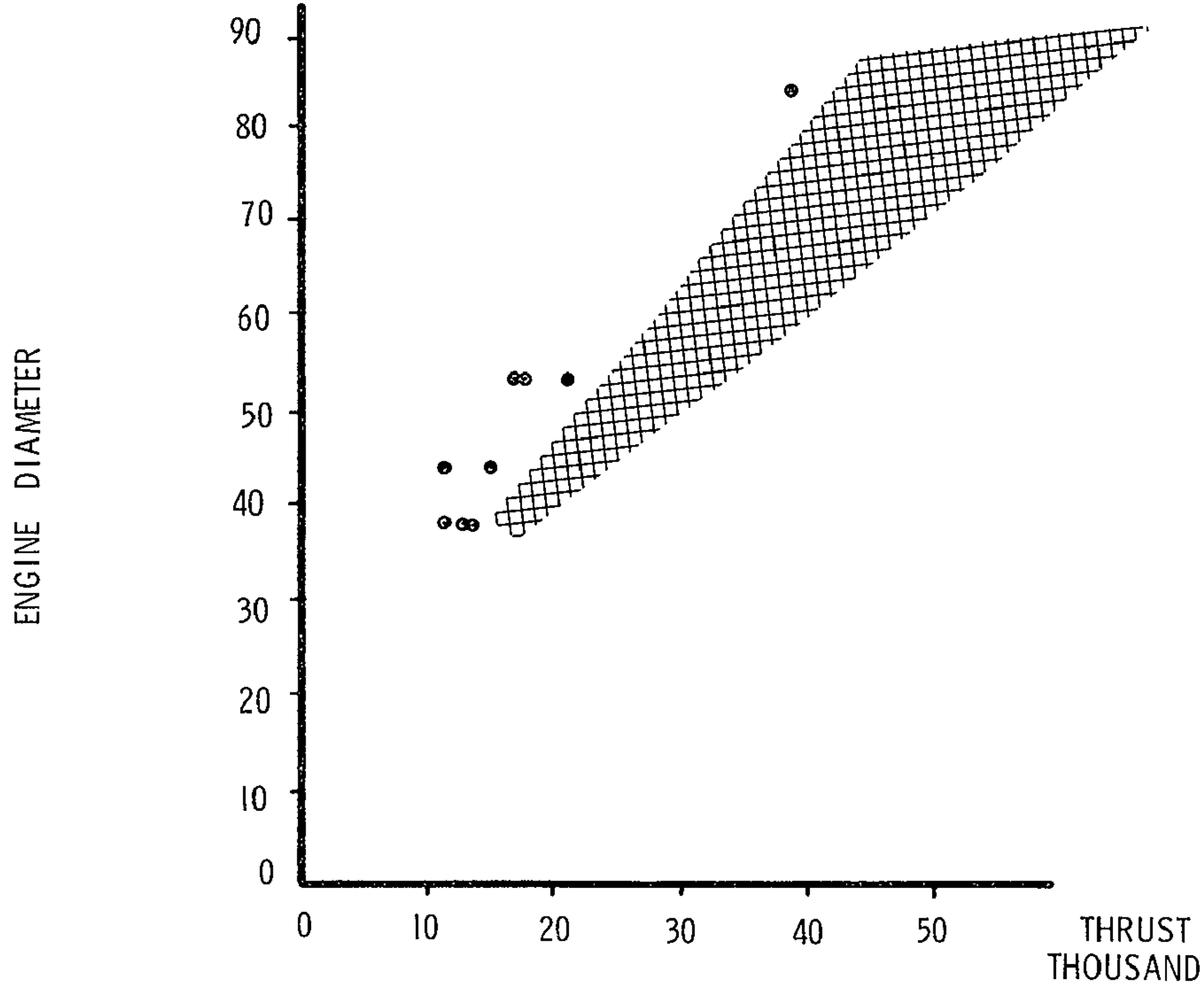
$$C_D\Big]_{nacelle} = 0.1$$

Engine frontal area was estimated using Figure 3.4.1.1-2. The crosshatched area represents the projected technological developments for the post 1980 time period

The flow around the engine nacelle was assumed to be turbulent and the Reynold's number computed on the basis of nacelle diameter, and the skin friction coefficient estimated using.

$$C_f = \frac{0.074}{R_n\Big]_{NAC}^{0.2} (T/T_o)^{0.348}}$$

The profile drag coefficient of the aircraft is obtained by adding the drag coefficients of the individual components. However, before adding the coefficients they must be referenced to the same area. For a given component, c, the drag coefficient C_D c is referenced to the A_c. Then:



ENGINE DIAMETER AS A FUNCTION OF SEA LEVEL STATIC THRUST

FIGURE 3 4.1.1-2

$$C_{D_c} = C_D\Big]_c \frac{A_c}{A_{wing}}$$

references the drag coefficient to the wing area.

3.4.1.2 Weights

The total weights of the aircraft were calculated in the design programs from individual component weights. For the component weights, simplified equations were used. These were selected from the various references shown at the end of the weight section. In the simplified design used, only a few parameters were known for a certain vehicle and therefore, the weight equation had to be of the simplified form.

Component weights included were:

Fuselage	Hydraulics
Wing	Electronics
Tail	Electrical
Landing Gear	Controls
Oil	Payload
Furnishings	Fuel
Floor	Fuel Tank
Air Conditioning	Engines

The equations used for the individual weights are as follows:

<u>Fuselage Weight</u>

$$W_f = CK_{co} \left(\frac{L_f}{D_{eq}}\right)^{0.5} (L_f D_{eq})^{0.75} (N_{ult} W_g)^{0.40} \left(\frac{M_o}{0.45}\right)^{0.30}$$

L_f - fuselage length

D_{eq} - equivalent fuselage diameter

N_{ult} - ultimate design load factor

$\overline{W}_g$ - aircraft gross weight

M_o - Mach number at sea level

K_{co} - cutout factor

C - constant

For the program designing a commercial type vehicle, an ultimate design load factor (N_{ult}) of 4.0 and a constant factor (K_{co}) of 1.0 were used. The constant (C) was calibrated from existing vehicles to be 0.090. The equation was taken from reference 15 in the list of weight references. In the fuselage weight equation, the weight effects caused by Mach number and size are accounted for, the Mach number is to the 0.30 power and size is to the 1 15 power. The size exponent for a dimensional increase is theoretically 1.5; but with increased size, the structure can be made more efficiently thus lowering non-optimum weight and the effect of size increase.

Wing Weight

$$W_w = 0.009\ B^{0.656}$$

$$B = W_g N_{ult} S\ (AR)^{1.5}(1.1 + 0.5r)\ f_r\ (f_q)^{1.5}/f_T \cos^{1.5}\Lambda$$

W_g - aircraft design gross weight

N_{ult} - ultimate design load factor

S - wing area

AR - aspect ratio

r - planform tapes ratio

f_R - bending relief factor

f_q - $1 + 68.5 \frac{\dot{M}_o^{\ 4}}{N_{ult}^{\ 3}}$ stiffness factor

f_T - wing section thickness factor

Λ - sweep angle

For the program, a bending relief factor (f_R) of 1.0, a wing section thickness factor (f_T) of 15.0, approximately equal to thickness divided by cord, and sweep angle of 40^o, were used. The equation was taken from reference 16 in the weight references. The effect of size increase using this equation is to the 1.312 power, again less than the 1.5 theoretical. When adapted to conventional vehicles with Mach numbers more than .8 and therefore the supercritical wing, the wing weight was increased by 10 percent. On the V/STOL vehicles the wing weight was multiplied by 1 2 to compensate for the extra equipment required

Tail Weight

The weight of the tail section was calculated as 2.5 percent of the gross weight for the conventional aircraft. For V/STOL vehicles, this was multiplied by 3.0 because of much higher control surface requirements.

Landing Gear Weight

The landing gear weight was calculated as 3.0 percent of the gross weight.

Oil Weight

The oil weight was assumed constant.

Furnishings Weight

The weight of the furnishings (seats, galleys, lavatories, etc.) was calculated using:

$$W_{FURN} = 550 + 40 \text{ (number passengers)}$$

Floor Weight

To calculate the weight of the floors, the width was calculated and multiplied by the fuselage length to give the area. The floor area was multiplied by a density of 2.0 lb per square ft. to give the weight. Reference 17 suggests 1.6 - 1.8 lb. per square ft. for density of passenger vehicles.

Air Conditioning Weight

Air conditioning equipment weight was calculated using:

$$W_{ac} = 500 + 13 \text{ (number passengers)}$$

Hydraulics Weight

The weight of the hydraulics was calculated using:

$$W_{HYDR} = 0.0005 \text{ (gross weight)}^{1.28}$$

Electronics Weight

The electronics weight was assumed constant.

Electrical Weight

The electrical systems and components weight was calculated as one percent of the gross weight.

Controls Weight

The weight of the controls was calculated as two percent of the gross weight. This was raised 10 percent for V/STOL vehicles.

Payload Weight

Payload weight was calculated using:

$$W_{load} = 200 \text{ (number passenger + 3) + 3 "volume"}$$

Where "volume" is half of the volume in the fuselage not taken up by passengers, etc. It was taken as half since all of the volume is not usable, particularly with containerized cargo. The cargo density used was 3.0 lb/ft^3.

Fuel Weight

The fuel weight was calculated by summing the various parts (fuel for climb, fuel for cruise, etc.) calculated in the performance part of the program.

Fuel Tank Weight

The fuel tank weight was assumed constant.

Engine Weight

The engine weight was calculated by multiplying the number of engines by an empirical expression derived from data on existing engine. The expression is:

$$W_{ENG} = 1500 + 1333 \text{ THRUST}$$

The program has been run inputing data equivalent to a Boeing 707 and 747. The resulting weights calculated compared well (less than 10 percent error) with data for these planes. It is felt that the program gives a good indication of the trends in the vehicles used.

3.4.1.3 Propulsion

The parameter which relates aerodynamics to engine characteristics of an aircraft is thrust. Supplied with information pertaining to the vehicle flight envelope, the propulsion data module generated information concerning engine weight, specific fuel consumption, and engine diameter.

Two figures illustrating parametric propulsion relationships are incorporated in the computer program. The first (Figure 3.2-5), a plot of existing engines, shows correspondence of engine weight to engine thrust; the second (Figure 3.4.1.1-2) correlates current engine diameter to thrust. These graphs both contain projections predicting 1980 technology.

Conclusions in propulsion were obtained through the following procedure:

1. Obtain information concerning turbofan essentials.
2. Develop relationships that parametrically size the engine for diameter, weight, and specific fuel consumption.

Figure 3.4.1.3-1 shows lines which closely approximate present-day JT90 performance characteristics--these relationships are used in the computer program. They are obtained from the following equation:[10]

$$\frac{F_{nt}}{F_{nt*}} = (P/P*)^x \quad \frac{SFC}{SFC*} = (P/P*)^y$$

where:

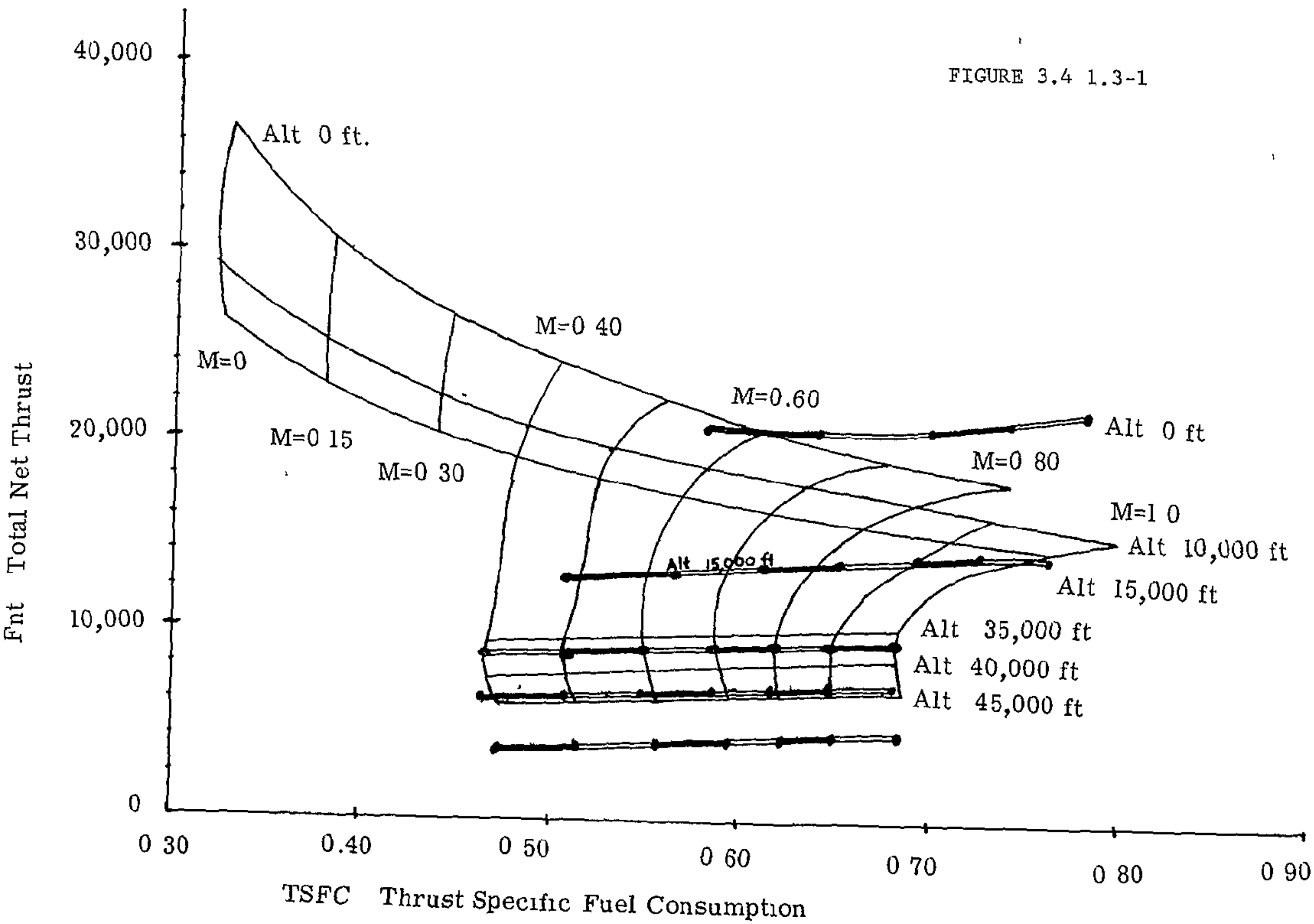
x and y are dimensionless exponents

* represents values at the tropopause

F_{nt} = total net thrust

MAXIMUM CONTINUOUS RATING CHART
FOR JT9D-3 ENGINE OF BOEING 747

FIGURE 3.4 1.3-1



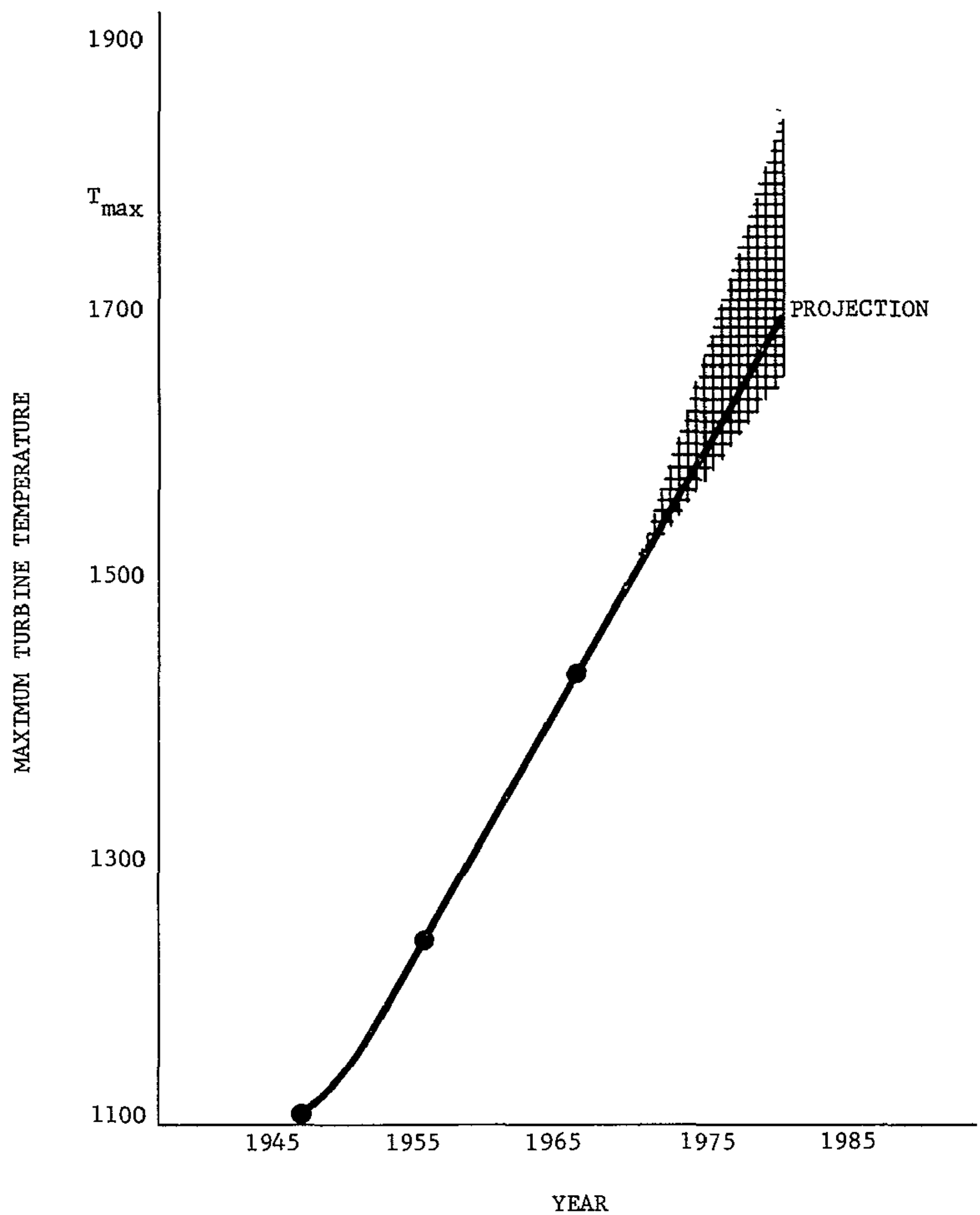


FIGURE 3 4 1 3-2

TURBINE ENTRY TEMPERATURE HISTORY

SFC = specific fuel consumption

	Tropospheric Flight	Stratospheric Flight
x	0.7	1.0
y	0.2	0

Theoretical engine design involves a complex, iterative analysis of many parameters. Many less important engine parameters can be neglected and very good approximations can result. The six most important parameters are:

(1) Maximum Turbine Inlet Temperature (T_{max})

(2) Bypass Ratio (μ)--flow of air through fan/mass flow through basic gas generator

(3) Specific Fuel Consumption (SFC)--fuel flow/unit thrust

(4) Specific Thrust (s.t.)--thrust/unit mass flow

(5) Total Overall Engine Efficiency (η)

(6) Compressor Pressure Ratio (r)

Technological innovation will give rise to materials capable of attaining greater temperature extremes As a result, the maximum possible turbine entry temperature will increase in future engines. Figure 3.4.1.3-2 is a graph showing the relationship of this turbine maximum inlet temperature for engines representing various technologies.

Certain technological improvements are also forecasted in engine compressors. This will be accomplished, not by adding on additional "stages", but by increasing the compression of each individual stage.

The higher bypass turbofans of the future will employ relatively smaller specific thrusts, this implies a bulkier engine;

however, the portion of the engine which accommodates the higher bypass ratio is substantially lighter than the basic gas generator. The net result is that future engines will deliver a small upward drift in specific weight (engine weight/thrust).[21]

Since future compressors will produce relatively greater compression and since maximum entry turbine temperatures will attain higher values, 1980 engines of approximately the same diameter and length of those representing 1968 technology will deliver relatively greater thrusts. The small upward drift in specific weight is indicative of the total increase in engine weight.

Variable bypass ratio will probably not be employed by 1980. Strong competition and requests for this type of an engine might accelerate its development, but technical problems preclude realizing the advantages of these engines by the 1990's.

3.4.1.4 Performance

An aircraft, or any other transportation mode, is physically determined by three factors: (1) the payload and the range over which it is to be carried, (2) the path the vehicle describes in delivering the payload, and (3) constraints imposed by cargo, economics, society, etc. This section delineates the effects of the path the vehicle describes in delivering the payload on the design of the vehicle.

Since this study is concerned with air transportation in the common carrier as opposed to the military sense, climb rates, descent rates and accelerations must lie within tolerances determined by acceptable standards of passenger ride comfort. Additionally, sufficient reserve fuel must be carried to meet current FAA requirements.

The flight path used in this design program consisted of four segments: (1) takeoff, (2) ascent (climb-out), (3) cruise, and (4) descent.

In order to insure sufficient engine thrust the power required for takeoff in less than 12,000 feet was computed as was power required for cruise, and power required for stall with a maximum lift coefficient of 3.0. The maximum of the three conditions was taken as the design thrust. Tacit to all the performance calculations is the assumption that thrust is variable and, hence, can assume any value less than design thrust.

Takeoff distance for CTOL aircraft was computed assuming a constant lift coefficient during the takeoff roll. Since a short takeoff roll is desirable, the lift coefficient selected for takeoff represents the shortest roll for a constant lift coefficient constant thrust mode. Analytically this was determined to be:[12]

$$C_{L\ T.O.} = \frac{\mu \pi e\ AR}{2}$$

where:

μ = coefficient of friction, nominally 0.02

An iteration scheme in the computer program augmented sea level thrust until sufficient thrust was available for takeoff in less than 12,000 feet.

After determining that a conventional (CTOL) aircraft design program was needed, it was recognized that the design program would be realistic only if it reflected reasonable flight characteristics and typical flight paths. Thus, information about actual flight paths was needed. A flight recorder which had been placed on board a turbofan passenger aircraft was obtained from FMTD Airworthiness Branch, NASA/Langley Research Center.

Altitude and indicated airspeed, both recorded with respect to time, were recovered from the recorder. Indicated airspeed was converted to true airspeed by the equation:

$$V_{true} = V_{indicated} \; \rho_{sea\ level} / \rho_{at\ altitude}^{1/2}$$

Discrete integration of true airspeed with respect to time gave altitude and velocity as a function of distance.

Several climb-out profiles were examined and plotted. The profiles were then used to define an ascent corridor that was taken as typical aircraft. Figure 3.4.1.4-1 represents the defined ascent corridor used in this study.

Since economy is one of the prime criterion of commercial carriers the aircraft was assumed to use the most economic climb flight mode. For turbojet powered aircraft the most economical climb and the fastest climb modes are very nearly the same. As presented by Miele[10] the fastest climb is given by·

$$\frac{V}{V_{Rei}} = \frac{1}{\sqrt{3}} \sqrt{Z + \sqrt{Z^2 + 3}}$$

where:

$$V_{Rei} = \sqrt{\frac{2W}{\rho s}} \; \sqrt[4]{\frac{1}{C_{Do} \; AR \; e}}$$

$$Z = \frac{T \; (L/D)_{max}}{W}$$

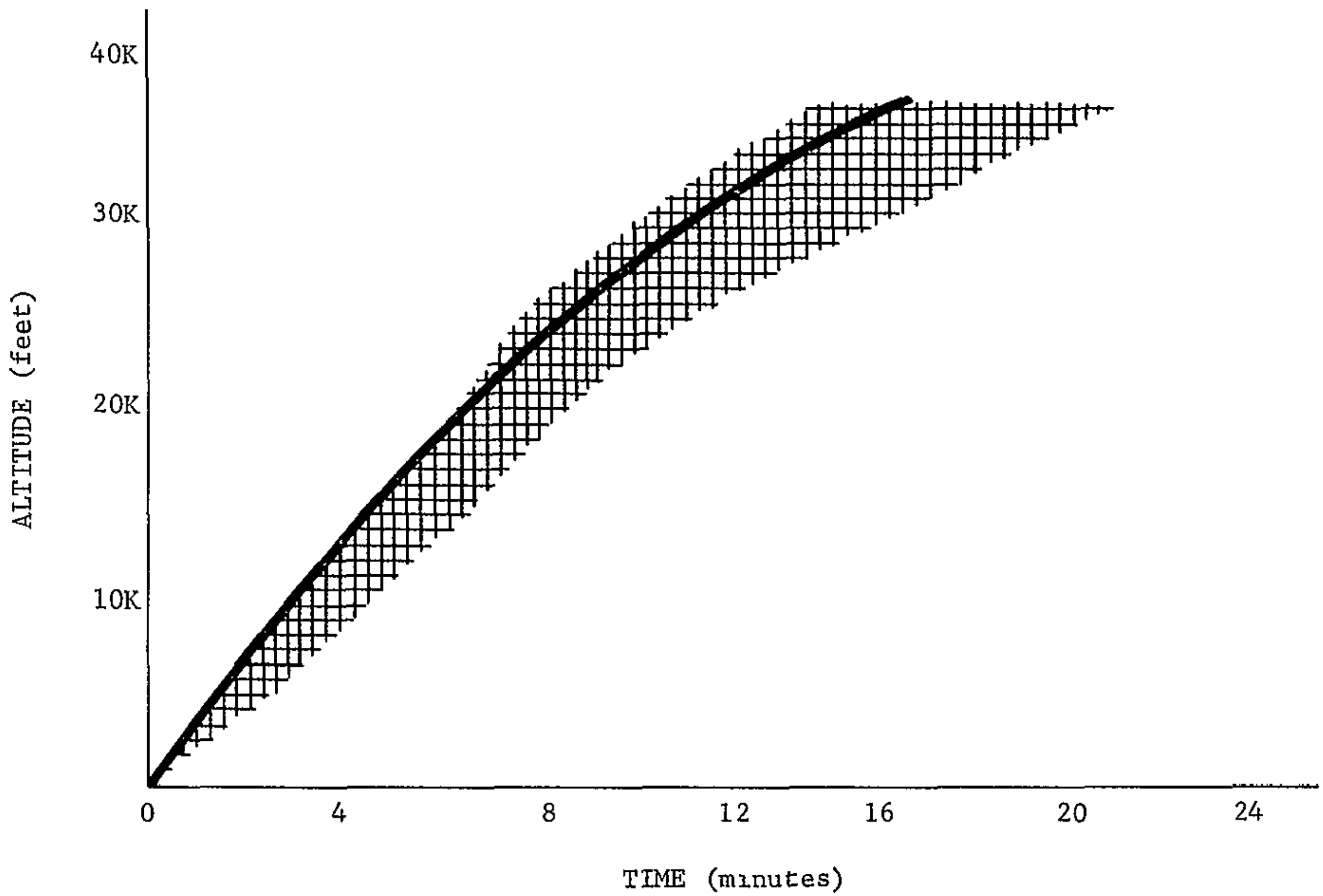


FIGURE 3.4.1 4-1

ASCENT CORRIDOR FOR A TYPICAL FOUR-TURBOFAN
PASSENGER AIRCRAFT

and corresponding to the fastest climb is the climb angle Ψ which is defined by:

$$\Psi = \arcsin\left\{ \frac{2}{(L/D)_{max}^{3}\sqrt{3}} \sqrt{Z + \sqrt{Z^2 + 3}} \left[2Z - \sqrt{Z^2 + 3}\right] \right\}$$

The above equations are sufficient to permit the time, fuel consumption, and range for ascent to be computed. The thrust level, T, however, must be specified as thrust determines the shape of the profile for ascending flight. For the fastest climb mode it was found that 0.667 of the available thrust yielded an ascent profile which approximated the profile corridors obtained from the flight recorder data. Figure 3.4.1.4-1 illustrates an ascent profile obtained from the design program. A realistic climb-out is thus obtained.

The cruise portion of flight represents the next portion of the flight path to be examined. An analysis of the data from the flight recorder indicated that constant airspeed and constant altitude are characteristic of cruise flight for turbofan passenger aircraft. As with the ascent computational procedure, cruise flight was computed using the development of Miele.[10] Within the framework of Miele's assumptions range at cruise is given by

$$\text{Range} = \frac{V_{Ri}\ (L/D)_{max}}{SFC}\ 2u_i \arctan \frac{f\ u_i^2}{1 - f + u_i^2}$$

where:

$V_{ei} = V_{Rei}$ at beginning of climb-out

$u_i = V/V_{Ri}$

and f represents the fraction of vehicle weight, at the beginning of cruise, allocated to fuel. Thus for a given range a simple iteration will yield the fraction of fuel that must be carried. For commercial carriers, however, the FAA specifies the fuel reserve which must be carried. Currently the FAA specified fuel reserves are:

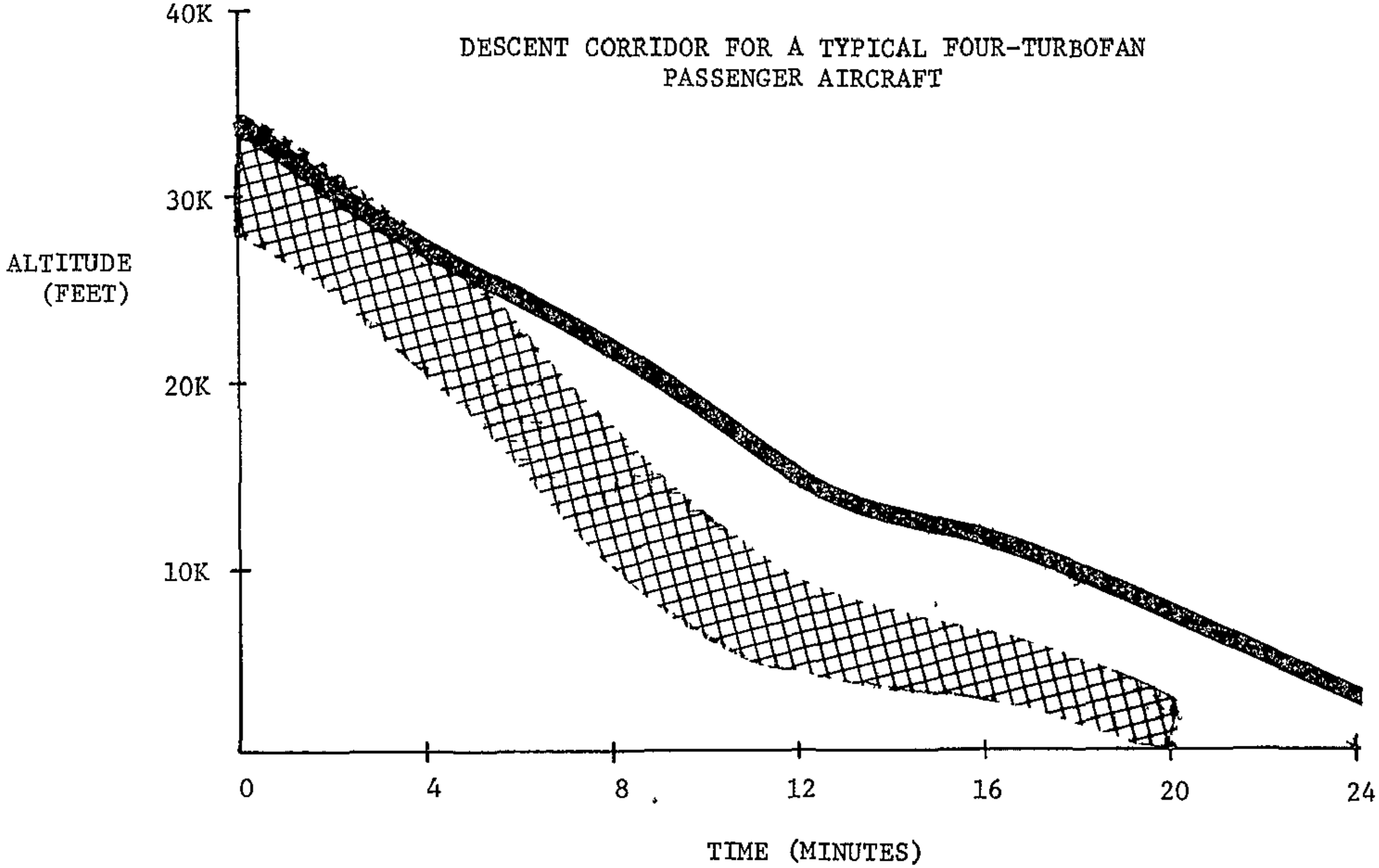
1) fuel for an additional hour of flying at cruise velocity and altitude.
2) sufficient fuel for descent from cruise altitude, execution of a missed approach at the original terminal, climb-out and landing at a terminal 200 miles from the original destination.

The FAA requirements were approximated by allotting sufficient fuel for one hour at cruise plus an additional 200 miles at cruise, two ascents to cruise altitude, and a descent from cruise altitude. The above requirements were used in computing the fuel requirements for an aircraft with a given design range.

As with the previous flight regimes examined, flight recorder data was inspected in an effort to ascertain a realistic descent profile. Figure 3.4.1.4-2 represents a descent corridor compiled from several flights. Further examination of flight data showed a constant indicated airspeed during an appreciable portion of the vehicle descent. Moreover, examination of descent profile suggested that a constant descent angle was maintained (see Figure 3.4.1.4-2). Thus, it was felt that little error would be introduced by descending in a constant indicated airspeed/constant descent angle mode. A summation of forces on a free body diagram yields two equations, the equations are sufficient, in conjunction with the airspeed, to define the thrust required for a constant descent flight path. An integration

FIGURE 3.4.1.4.-2

DESCENT CORRIDOR FOR A TYPICAL FOUR-TURBOFAN
PASSENGER AIRCRAFT



with respect to time yields the pertinent descent parameters, time and fuel consumed during descent.

Fuel consumed during ground handling, taxi, and other non-flying engine-operation activities was estimated as 0.25 hours at 10 percent engine power.

3.4.2 STOL Aircraft

The STOL aircraft of the 1980 was visualized as being a high wing, blown flap STOL. All STOL aircraft designed utilized four engines, clustered in pods of two and mounted relatively close to the fuselage. As with the CTOL aircraft, the STOL vehicle was powered by turbofan engines. Because of the high thrust-to-weight ratios necessary in a STOL aircraft, the aircraft seating capacity was maintained at less than 300. All STOL aircraft designed possessed sufficient power for a 1500 foot takeoff roll. A schematic of the STOL vehicle is illustrated in Figure 3.4.2-1.

3.4.2.1 Aerodynamics

With the exception of the high lift system--a blown flap--and the empennage surfaces the aerodynamic considerations for the STOL aircraft differ very little from the aerodynamic consideration of the CTOL vehicle. The blown flap was selected as the most likely high lift system for a first generation STOL aircraft. The large tail structure is a result of insuring sufficient static and dynamic stability, particularly in roll and yaw, during an engine out situation.[22]

Figure 3.4.2.1-1 schematically illustrates the cross section of a blown flap wing. Because high lift is required a double, or perhaps triple, slotted flap will be used. A high lift coefficient

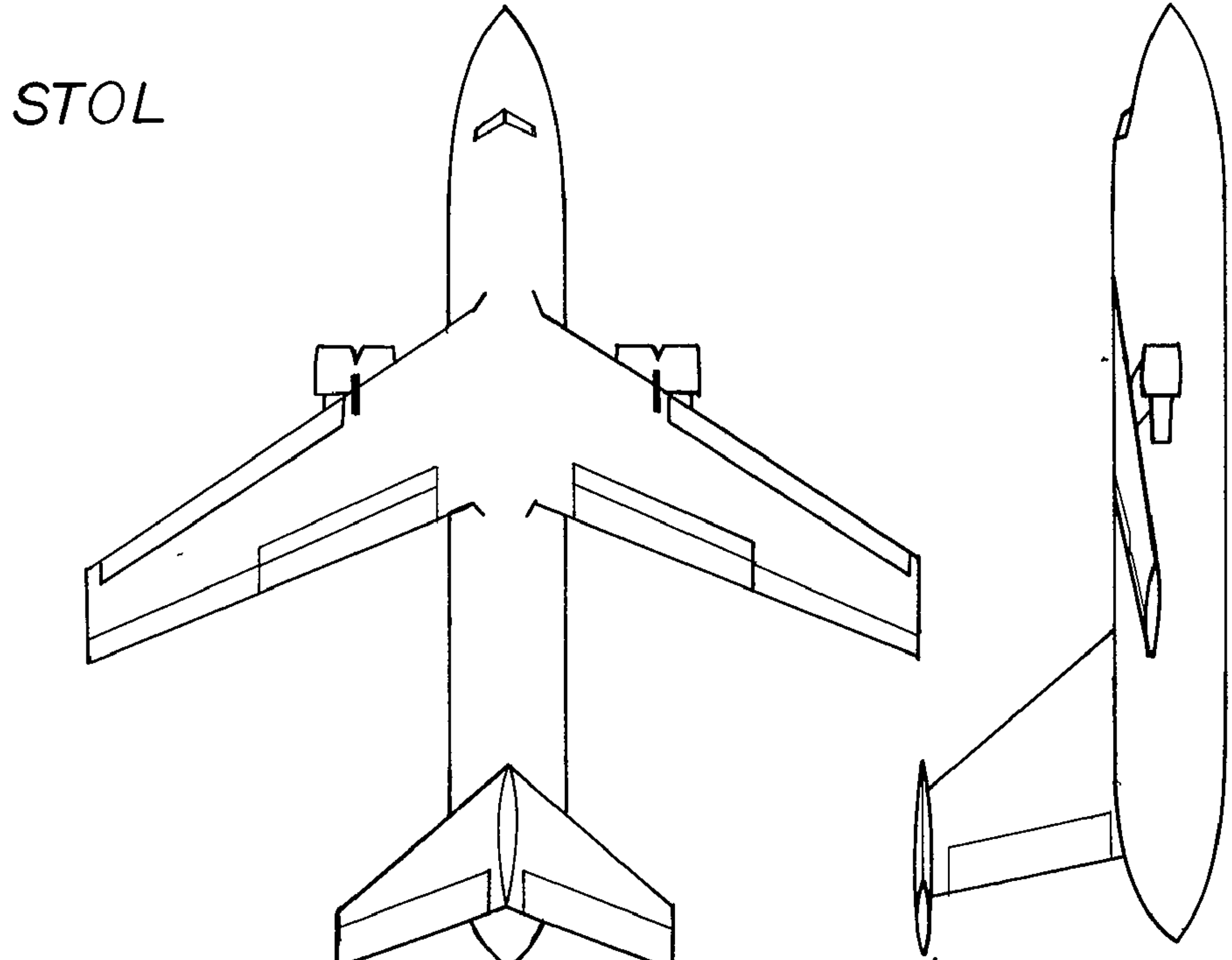
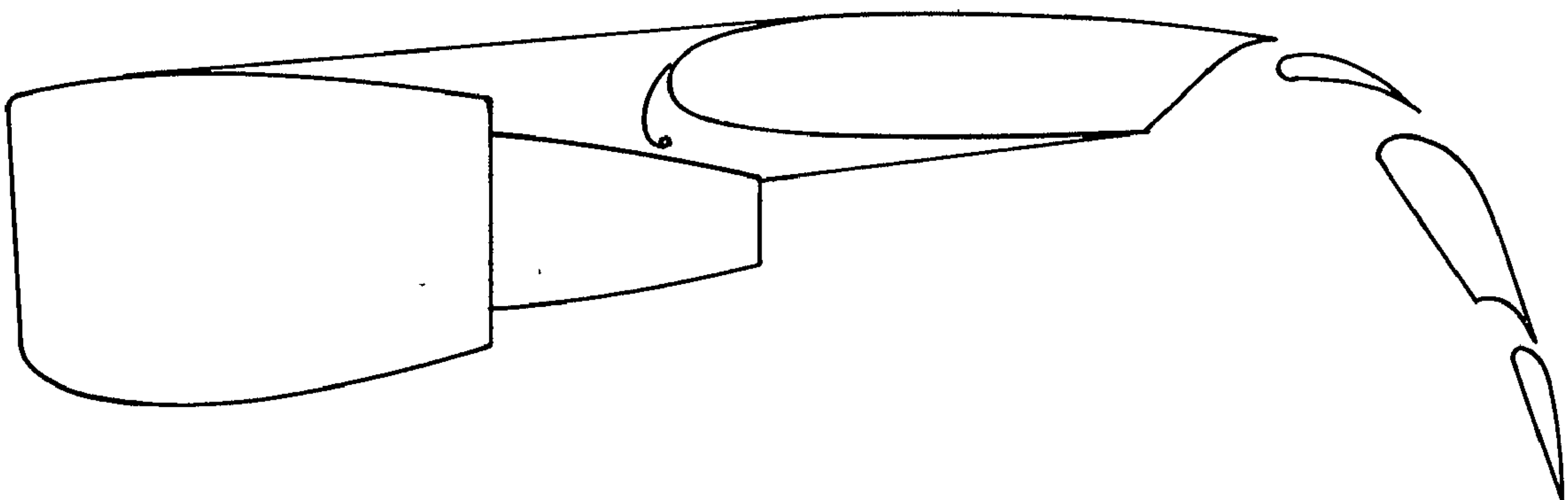


FIGURE 3.4.2-1

STOL AIRCRAFT SCHEMATIC

FIGURE 3.4.2.1-1   BLOWN FLAP SCHEMATIC



in the absence of blowing is desired--hence, the leading edge slots. An airfoil with slotted flaps and leading edge slots is capable of producing a maximum unblown lift coefficient of 3.[14] But the blowing generates more lift, primarily by momentum deflection and increased circulation.

Figure 3.4.2.1-2 illustrates the origin and relative magnitude of the constituents of lift.[23] The component $(C_L)\ c_\mu = 0$ represents the lift generation available from a flapped but unblown airfoil. Conventional airfoil data or conventional airfoil theory may be used to compute the lift coefficient obtained in the absence of blowing the flap. Since air is blown over the flap system and since the air stream is deflected through an angle δ, the momentum of the air stream is also deflected. The reaction to this deflection is a lift component, $C_\mu \sin \delta$. C_μ is a dimensionless coefficient characteristic of the momentum of the air acting on the flap and is defined as:

$$C_\mu = \frac{m_j\ v_j}{q\ S}$$

where·

m_j - mass flow rate of blown air

v_j - velocity of the jet

A two-to-five degree upward cant to the engine has been suggested in order to insure as much interception of the engine exhaust by the flap system as possible. Assuming 90 percent momentum interception by the flap system and an engine thrust coefficient of C_T the blowing coefficient C_μ becomes:

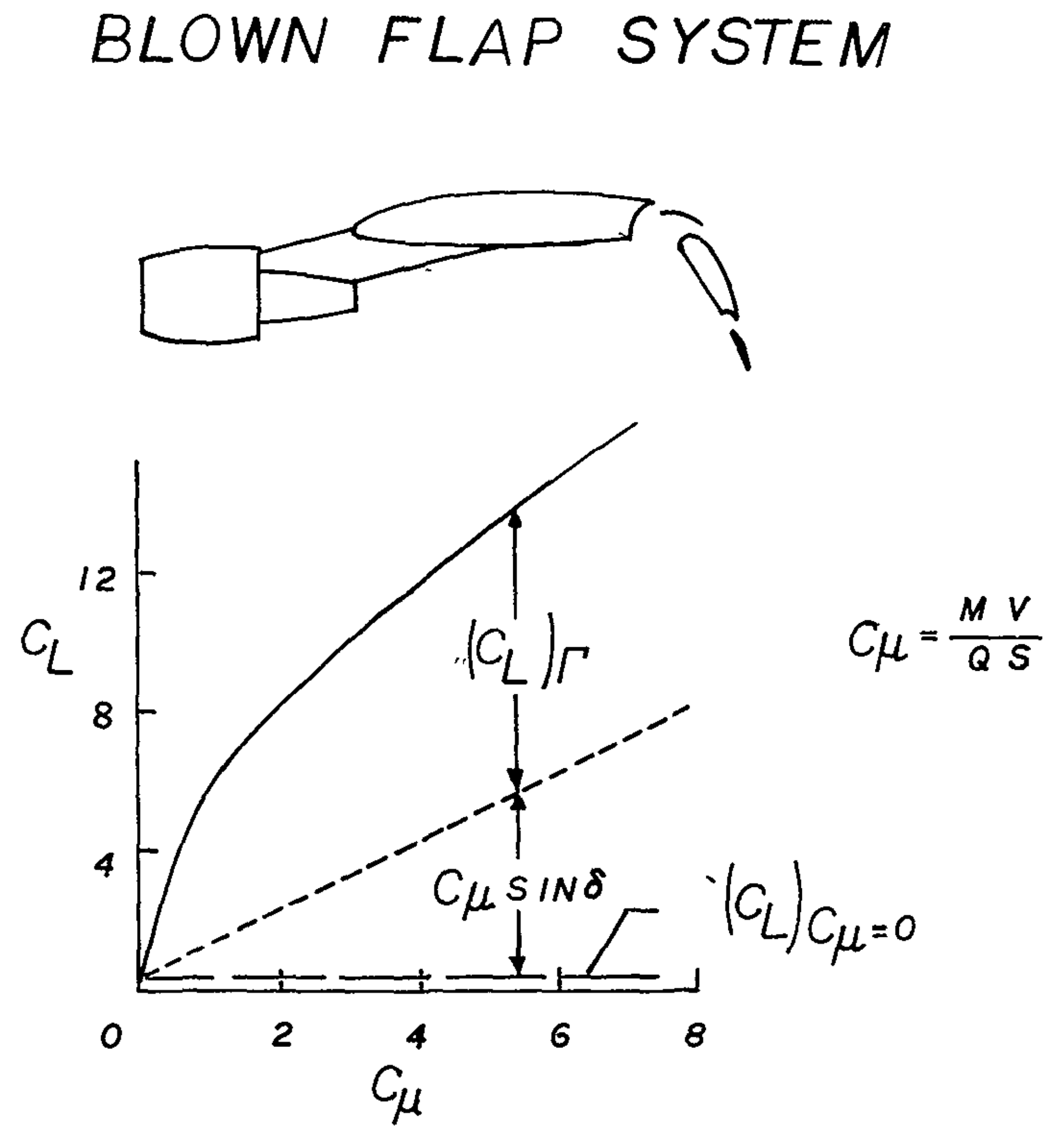


FIGURE 3 4 2.1-2

LIFT COEFFICIENT CONTRIBUTIONS
FOR BLOWN FLAP AIRFOIL
(FROM REFERENCE 23)

$$C_\mu = 0.90\ C_T \text{ (per engine)}$$

The essential results of this effect is hence seen to be merely a thrust deflection through an angle δ

The massive afflux of air (momentum) across the flap system induces an additional circulation around the airfoil. Since lift is proportional to circulation, the added circulation results in an additional lift term, $(C_L)_\Gamma$. Then for a blown flap system the lift coefficient becomes:

$$C_L = (C_L)_{C_\mu=0} + C_\mu \sin \delta + (C_L)_\Gamma$$

The effect of a wing configuration and thrust coefficient are relatively simple to evaluate. Thus $(C_L)_\Gamma$ remains the only unknown. Figure 3.4.2.1-3 a and b[23] contain sufficient information to evaluate $(\partial C_L/\partial \delta)_{\Gamma;AR}$ from which $(C_L)_\Gamma$ can be evaluated (since the relationship between S and C_L is linear):

$$(C_L)_\Gamma = \left(\frac{\partial C_L}{\partial \delta}\right)_{\Gamma,AR} \delta$$

The lift coefficient for a blown flap system can, therefore, be evaluated.

The induced drag for a blown flap system differs slightly from the induced drag of a conventional wing. The blown flap induced drag term is.[24]

$$C_{Di} = \frac{C_L^{\ 2}}{\pi\, AR\ e + 2\ C_\mu}$$

The formulation of the induced drag term for the blown flap system

FIGURE 3 4.2.1-3a

VARIATION OF JET CIRCULATION LIFT COEFFICIENT WITH ASPECT RATIO AND MOMENTUM COEFFICIENT[23]

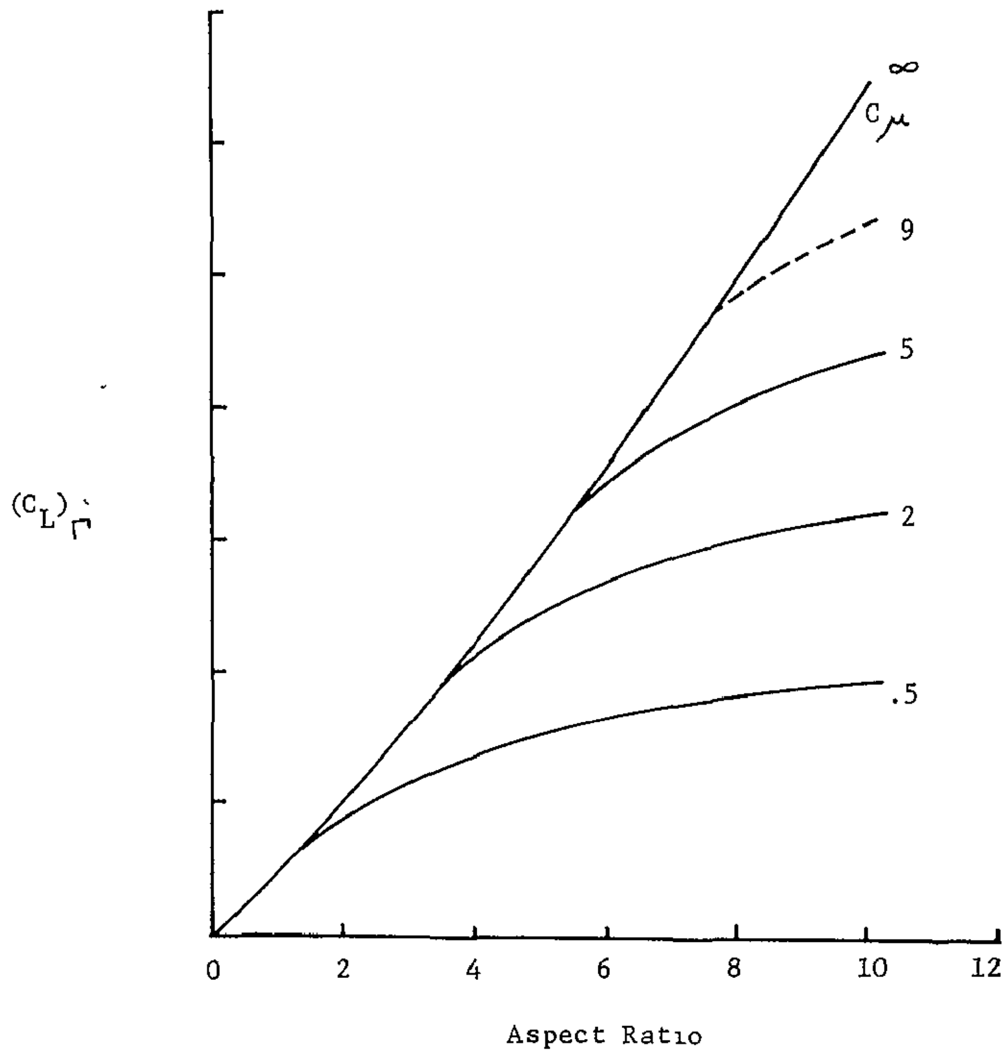
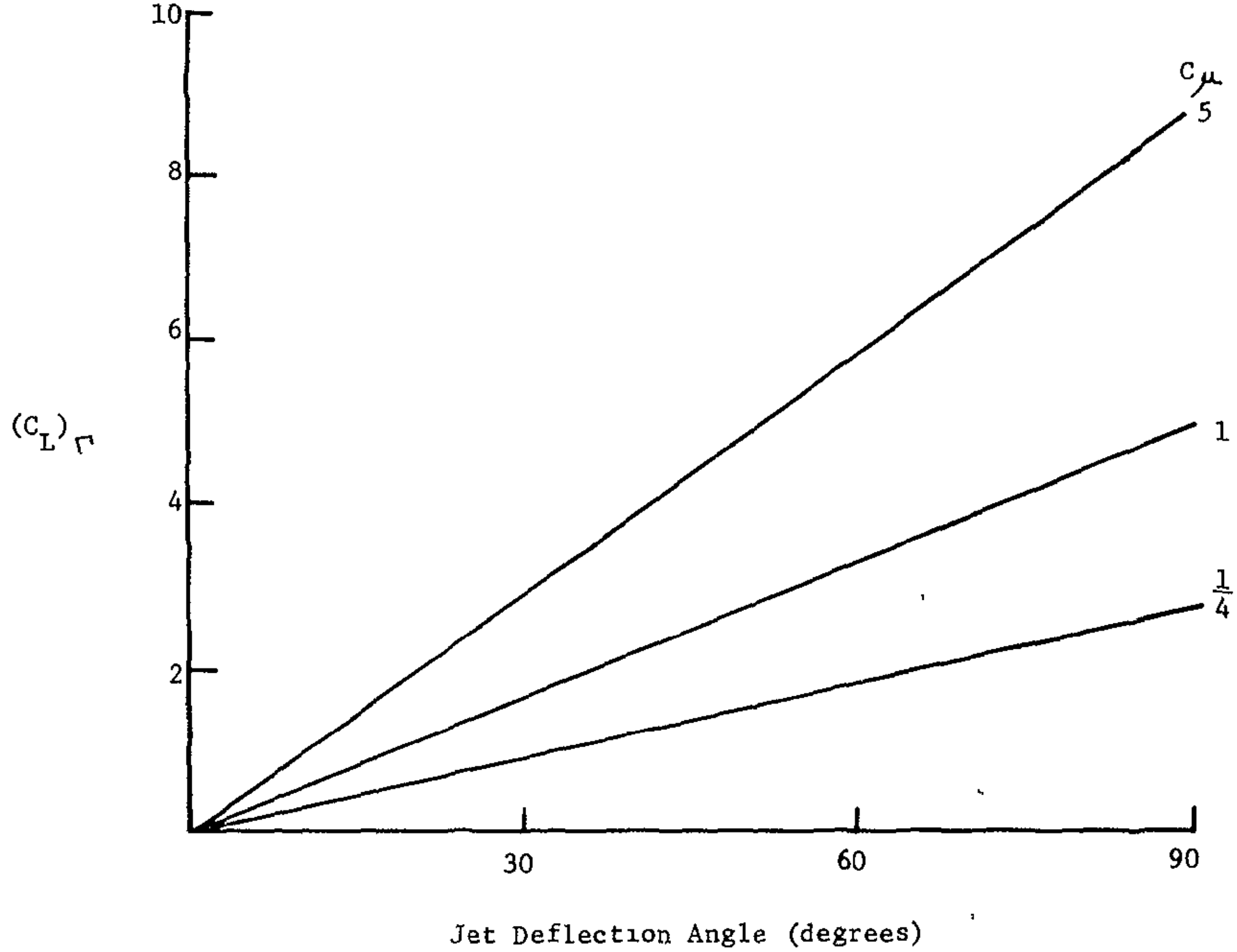


FIGURE 3.4.2.1-3b

VARIATION OF JET CIRCULATION LIFT COEFFICIENT WITH JET DEFLECTION ANGLE
A=8.4;   =0.23



reflects the effects of the thrust deflect lift term for which the induced drag is small--i.e., blown flap lift is relatively cheap in terms of induced drag.

From an aerodynamic standpoint, the blown flap system is now defined, but the effect of the flap on the recoverable engine thrust has not been evaluated. Several thrust degradation schemes were examined and evaluated but none were used since anomalies between the various procedures were large. Instead the results of NACA TN 3898 were used.[25] Their observation was that thrust losses were never more than 25 percent and usually much less. A thrust loss of 12.5 percent was considered to be a representative number and was used throughout the design program. The coefficient of the recovered thrust per engine then becomes:

$$(C_T)_R = (0.9)\ (C_T)\ (.875) + 0.1\ C_T$$

The thrust per engine after traversing a blown flap system can thus be computed.

Empennage:

Because of the large yaw and roll moments that would be experienced by a blown flap STOL operating under engine out condition, the horizontal and vertical tail surfaces must be large in order to insure a stable aircraft.

Typical STOL blown flap aircraft possess a vertical stabilizer and horizontal stabilizer area of approximately 30 percent of the wing area. These areas were used in the STOL design program.

3.4.2.2 Weight analysis

The weight analysis used in the STOL design-program was the same as the weight analysis used in the CTOL design program.

3.4.2.3 Propulsion

The propulsion analysis used in the STOL design program was the same as the propulsion analysis used in the CTOL design program.

3.4.2.4 Performance

The STOL aircraft's operating envelope differs drastically from the CTOL's operating envelope in only one respect--the short takeoff and landing capability. Except for minor changes in climb-out and descent profiles the typical STOL flight is expected to differ very little from the typical CTOL flight. Thus takeoff, approach, and landing are the only portions of the flight envelope of the STOL that will be considered different than CTOL.

It was considered that a STOL capable of a 1500 foot takeoff represented in a realistic first generation STOL. The same takeoff routing was used for STOL as for CTOL except that sufficient thrust was provided the STOL for a 1500 foot takeoff roll.

The same climb-out, cruise, and descent routines were used for STOL as for CTOL.

FAA engine-out approach requirements were checked in order to insure enough power. The FAA requires on an engine-out approach sufficient power and lift to climb at 1.5° with a velocity not more than 1.5 times the full-power stall speed.

The design thrust of the STOL was chosen as the maximum of takeoff, sea-level stall, cruise, or engine-out approach as described above.

3.4.3 VTOL Aircraft

The long period of time from 1969 to 1990 and the lack of definitive VTOL technology precluded choosing a specific lift/thrust mode for the VTOL vehicle. As a result the computer program written for VTOL is a simulation program rather than a design program.

A thrust to weight ratio of 1.1, characteristic of vehicles with VTOL capabilities, was utilized in specifying engine design thrust at sea level.[26] A turbofan-powered fan-in-wing lift/thrust mode was used for coarse physical characteristics--aspect ratio, wing loading, etc. A summary of the pertinent physical characteristics used in the VTOL simulation program is presented below:

Aspect ratio	-	5
Wing loading	-	90
T/W ratio	-	1.1
No. of engines	-	4
Cruise Mach number	-	0.6
Design Range	-	500

The STOL aircraft performance computation procedures were used to compute the performance envelope of the VTOL aircraft.

3.5 COST ANALYSIS

3.5.1 Estimation of Airframe Costs

After reviewing the literature for methods of airframe cost analysis, an analysis using airframe weight and maximum speed was found to give realistic airframe costs.

The method described in reference 27 shows the computation of labor costs, material costs, engineering costs, tooling costs, overhead costs, general administrative and engineering costs per airframe in a lot of 100 aircraft. Originally these equations were used to generate costs for military vehicles, however, after applying the equations using modern commercial transport input data, it was found that the cost calculated agreed reasonably well with the actual costs.

The airframe cost equations used in this analysis are as follows:

1) Direct Labor Cost (millions of dollars)

$$\log DL = -0.9346 + 0.6435 \log VMAX + .77811 \log WTC$$

where: DL is the direct labor in thousands of man-hours for the 100th unit

VMAX is the maximum aircraft speed in knots

WTG is the airframe weight in thousands of pounds.

$$DLC = (DL)\ (HC)$$

where: DLC is the direct labor cost.

HC is the 1967 hourly labor rate.

$$CAC = DLC/.6781$$

where: CAC is the cumulative average cost per airframe based on an 80 percent learning curve.

2) Overhead Costs (millions of dollars)

Overhead costs shown in reference (1) can vary from 85 percent up to 234 percent. An average value of 175 percent is used in this analysis.

$$OHC - 1.75\ CAC$$

3) <u>Materials Cost</u> (millions of dollars)

$$MC = .1082 \left(\frac{WTG}{10.}\right)^{1.012}$$

$$CAMC = MC/.9260$$

where: CAMC is the cumulative average materials cost based on a 95 percent cost reduction curve.

4) <u>Engineering Costs</u> (millions of dollars)

$$\log ENGC = -4.35530 + 1.74831 \log VMAX + 0.83263 \log WTG$$

ENGC is the total engineering costs for the first 100 airframes. Out of the total cost 60 percent is used in the initial engineering and 40 percent is used as sustaining engineering.

$$SENGC = (ENGC)\ (.4)$$

Engineering cost per airframe produced is then:

$$USENGC = SENGC/100$$

5) <u>ECP = Engineering Charges</u> (millions of dollars)

ECP's are estimated to be approximately 10 percent of labor, overhead and material costs.

$$ECPC = .1\ (CAC + CAMC + OHC)$$

6) <u>Tooling Costs</u> (millions of dollars)

$$\log TC = -2.78057 + 1.09854 \log VMAX + 0.997 \log WTG$$

TC is the total tooling costs for the first 100 airframes. The total is split up into 67 percent for initial tooling and 33 percent for sustaining costs

$$STC = .33\ TC$$

Tooling cost per airframe produced is:

$$USTC = STC/100$$

7) <u>General and Administrative Costs</u> (millions of dollars)

This cost is estimated to be six percent of all other recurring costs.

$$GAC = .06\ (CAMC + CAC + OHC + USENGC + USTC + ECPC)$$

The total cost then becomes the sum of all the recurring costs and the GAC.

This represents the total airframe cost. The total aircraft cost also includes the cost of engines, avionics and furnishing equipment.

In most modern transport planes both commercial and military the airframe cost is approximately 69 percent of the total cost of the aircraft. This was shown in reference 27 for military transports.

Engine costs amount to 15 percent of the total aircraft cost for many commercial turbofan aircraft such as the Boeing 747, 707, and 737.

This leaves 16 percent of the aircraft cost which is spent for in avionics and furnishing equipment.

As a result, the total aircraft cost will be approximately 1.43 times the airframe cost.

Sample Calculation of Airframe Cost Estimation

The airframe cost of the Boeing 737-200 will be estimated in this example.

Maximum Speed = 518. knots

Airframe Weight = 46500. lbs.

Direct Labor Man-hours

log DL = -.93496 + .6435 log 518. + .77811 log 46.5

log DL = 2.102

or DL = 126.5 thousands of man-hours

Cumulative Average Cost

$CAC = DL/.6781 = 186.5$ (man-hours x 10^3)

DLC = (HC) (CAC)

DLC = 3.49 (186.5) = \$.651 (millions of dollars)

Overhead Cost

OHC - 1.75 (.651) = \$1.14 (millions of dollars)

Materials Cost

$$MC = .1082 \left(\frac{46.5}{10}\right)^{1.012} = \$.515 \text{ (millions)}$$

Cumulative Average Materials Cost

log Engc = -4 3553 + 1.74831 log 518. + .83263 log 46.5

log Engc = 1.7727

Engc = \$59.4 (millions of dollars)

Sustaining Engineering Costs

SENGC = (.4) (59.4) = \$23.75 (millions)

Engineering Charges Cost

Labor	\$ .651	
OHC	1 140	
MC	.540	
	\$ 2.331	(million)

ECPC = (.1) (2.331) = $.2331 million

Tooling Costs

log TC = -2.78057 + 1.09854 log 518 + .997 log 46.5

log TC = $72.3 (millions)

Sustaining Tool Costs

STC = (.33) (72.3) = $23.82 (millions)

General and Administrative Costs

DLC, DHC, MC	=	$ 2 3310	
ECPC	=	.2331	
USENGC	=	.2375	
USTC	=	2382	costs at the 100th production unit
		$ 3.0398	(millions)

GAC = (.06) (3.0398) = $.1821 million

Total Airframe Cost

TOTC = 3.0398 + .1821 = $3.2219 millions

The total aircraft cost is as follows:

Airframe	$ 3.2219	69%
Engines	.675	15%
Avionics	.350	16%
Furnishings	.353	
TOTM	$ 4.6000	(millions of dollars)

In general the airframe cost for commercial aircraft and for military transports and cargo planes is 69 percent of the total aircraft cost. Actual cost of a 737-200 is approximately $4.5 million.

3.5.2 Direct Operating Costs

The standard version of computing direct operating costs published by the Air Transport Association of America in 1967 was used to compute costs for the parametric vehicles.[30]

Block speed and block fuel are calculated within the DOC program. An average fuel consumption is computed in the vehicle design portion of the program in addition to time to climb and descend and distance to climb and descend.

The formula to compute block time is as follows:

$$T_{bl} = T_{gm} + T_{cl} + T_{d} + T_{cr} + T_{am}$$

where

T_{gm} = .25 hours (ground maneuver time at both ends of the trip)

T_{cl} = time to reach cruise altitude from lift-off

T_{d} = time from cruise altitude to touchdown

T_{am} = .1 hours air maneuver time

if D 1400 mi: $T_{cr} = \dfrac{(1.015D + 27) - (D_c + D_d)}{V_{cr}}$

if D 1400 mi: $T_{cr} = \dfrac{(1.02D + 20) - (D_c \pm D_d)}{V_{cr}}$

D = trip distance (mi.)

D_c = climb distance (mi.)

D_d = descend distance (mi.)

V_{cr} = cruise speed (mph)

Block speed is then:

$$V_{bl} = {}^{D}/T_{bl}$$

Block fuel required for a given trip of distance D is given by:

$$F_{bl} = F_{gm} + F_{am} + F_{cl} + F_{d} + F_{cr}$$

where: $F_{gm} = (.2)F_{con}T_{gm} = .05F_{con}$ (lbs)

F_{con} = avg. fuel consumption (lb/hr)

Here it is assumed that the fuel consumption on the ground will be 20 percent of that at cruise altitude and speed.

$F_{am} = T_{am}F_{con}$ (lbs)

F_{cl} = Fuel to climb (lbs)

F_{d} = Fuel to descend (lbs)

$F_{cr} = F_{con}T_{cr}$ (lbs)

Flight Crew Costs

All parametric aircraft are assumed to have three members in their flight crew. The cost per airplane mile then becomes:

$$FCC = (.05(WTC/1000.) + 135.)\ \frac{1}{V_{bl}}$$

Where, FCC = Flight crew costs/airplane mile($)

WTC = Maximum gross takeoff weight.

The cost of additional crew members such as stewardesses is included with the use of the formula shown below.

$$ACC = (35.00)\ \frac{1}{V_{bi}}$$

where, ACC = additional crew costs ($/airplane mile)

Fuel and Oil Costs

The fuel used in the parametric vehicles is to be JP-4 at 6.4 at 6.4 lbs./gallon and at a cost of \$.01493/lb. The fuel and oil costs are given by:

$$FOC = 1.02 \frac{F_{b1}C_{ft} + N_{e}(.135)\ C_{ot}T_{b1}}{D}$$

where, FOC = Fuel and oil costs (R/airplane mile)

C_{ft} = Cost of fuel or \$.01493/lb

C_{ot} = Cost of oil or \$.926/lb

N_e = Number of engines

Hull Insurance Costs

The insurance costs will be a maximum when a new aircraft is introduced but will go down as the aircraft is used The average rate will be approximately two percent per year of the initial price of each aircraft. The insurance will cover all of the initial price of the airplane.

$$HIC = \frac{IR_a C_t}{U\ V_{b1}}$$

Where HIC = hull insurance costs (\$/airplane mile)

IR_a = insurance rate two percent

C_t = total cost of one airplane (\$)

U = annual utilization (Block hours/year)

Utilization per year was assumed to be 4000. hours per year.

Direct Maintenance on Flight Equipment

Maintenance on flight equipment will include the following items: labor and material costs for inspection, servicing, and overhaul of the airframe and its accessories, engines, instruments, radio, etc. This method also included a two percent non-revenue flying factor.

Labor on the Airplane (Excluding Engines)

$$LAC = \frac{K_{FHA}\ T_f = K_{FCA}}{V_{bl}T_{bl}}\ R_L M^{1/2}$$

Where: LAC = Airframe Labor Costs ($/airplane mile)

K_{FHA} = .59 K_{FCA} Labor man-hours per flight hour

$$K_{FCA} = .05\ \frac{W_a}{1000.} + 6.\ \frac{630}{\frac{W_a}{1000} + 120.}$$

W_a = Basic empty weight lbs. of the airplane less the engine

T_f = Flight time (hours) or T_{bl} - T_{gm}

R_L = $4.00 labor rate ($/hr.)

M = cruise Mach number

Airplane Material Costs (Excluding Engines)

$$AMC = \frac{C_{FHA}\ T_f + C_{FCA}}{V_{bl}T_{bl}}$$

Where, AMC = Airplane Material Cost ($/airplane mile)

C_{FHA} = 3.08 $C_A/10^6$ = Material Cost ($/flight hour)

C_{FCA} = 6.24 $C_A/10^6$ = Material Cost ($/flight cycle)

C_A = Total cost of airplane (excluding engines)

Engine Labor Costs

The only type of engine considered was the turbojet.

$$LEC = \frac{K_{FHE}\ T_f + K_{FCE}\ R_L}{V_{bl}T_{bl}}$$

Where LEC = Engine labor costs

K_{FHE} = $(0.6 + .027\ T/10^3)Ne$ = Labor man-hours per flight hour

K_{FCE} = $(013 + 0103T/10^3)NE$ = Labor man-hours per flight

T = Maximum certified takeoff thrust

R_L = Labor rate = \$4.00/hr.

Engine labor costs cover the following items: bare engine, engine fuel control, thrust reverses, exhaust nozzle systems and augmenter systems.

Engine Material Costs

These formulas will predict engine material costs on the same items which are serviced under engine labor costs.

$$MEC = \frac{C_{FHE}\ T_f + C_{FCE}}{V_{b1}T_{b1}}$$

Where, MEC = Engine materials cost (\$/airplane mile)

C_{FHE} = $2.5\ N_E(C_E/10^5)$ = Material Cost (\$/airplane mile)

C_{FCE} = $2.0\ N_E(C_E/10^5)$ = Material Cost (\$/flight cycle)

C_E = Cost of one engine (\$)

Maintenance Burden Cost

The maintenance burden is described as 1.8 times the direct airplane and engine labor cost.

MBC = 1.8 (LEC + LAC) = Maintenance Burden Cost (\$/Airplane mile)

Depreciation of Flight Equipment

Depreciation of the airplane is assumed to be straight line with the residual value of the airplane to be zero after 12 years. This formula also includes apare parts depreciation.

$$DC = \frac{1}{V_{bl}} \frac{C_t + .10(C_t - N_eC_e) + .40\ N_eC_e}{D_AU}$$

where DC = Depreciation Cost ($/airplane mile)

C_t = Total cost of one airplane including engines ($)

D_A = Depreciation period = 12 years

U = Annual utilization (block hours/year)

Total Direct Operating Cost

The total DOC is simply the sum of the flight crew costs, fuel and oil costs, hull insurance costs, direct maintenance on flight equipment including labor and materials, and depreciation costs.

TDOC = DC + MBC + MEC = LEC + AMC + LAC + HIC + FOC + ACC + FCC ($/airplane mile)

Sample Cost Calculation For DOC

Aircraft Characteristics

Design Range = 3000. mile

Capacity = 500. passengers

Fuel required to climb = 4525. lbs.

Gross Weight = 340161. lbs.

Engine Cost = $1.599 millions

Aircraft Cost = $10.654 millions

Total Fuel = 92945. lbs.

Distance to Climb = 55.43 mi.

Distance to Descend = 150. mi.

Cruise speed = 549 m.p.h.

Time to descent = .25 hrs.

Time to climb = .12 hrs.

The direct operating cost will be computed at design range.

Cruise time: $TCR \frac{((3000. + 60. + 20.) - 55.43 - 150)}{549.}$

$TCR = 5.24$ hours

Block Time: $TBL = .25 + .12 + .1 + .25 + 5.24 = 5.96$ hours.

Flight Time: $TF = 5.96 - .25 + 5.71$ hours.

Fuel Consumption: $\frac{(92945. - 2.(4525.))(549.)}{(3000. + 200. + 549 + 55.4)} = 11900$ lbs/hr.

Block Speed: $VBL = 3000.5/5.96 = 503$ m.p.h.

Air Maneuver Fuel: $F_{AM} = (.1)\ 11900. = 1190.$ lbs.

Cruise Fuel: $FCR = (5.24\ (11900.) = 62300.$ lbs.

Ground Maneuver Fuel: $F_{GN} = (.05)\ (11900) = 595$ lbs.

Block Fuel: $FB = 1190. + 4525. + 62300. + 4250. + 595$

$FB = 72860.$ lbs.

Sample DOC Calculations

Flight Crew Costs:

$$FCC = \frac{(.05)(340.161) + 135.}{503} = \$0.302/\text{mi.}$$

Additional Crew Costs:

$ACC = 35./503. = \$.0696/\text{mi.}$

Fuel and Oil Costs:

$$FOC = 1.02\ \frac{(72860.)(\ 01493) + (3.)(.135)(.926)(5.96)}{3000.}$$

$FOC = \$.3715/\text{mi.}$

Aircraft Labor Costs:

Empty A/C weight less engines $WTE = 340161. - (92945. + 100600. + 19839)$

$WTE = 126777$ lbs.

$$XKFCA = (.05)(126.777) + 6.\ \frac{-630.}{126.777 + 120.} = \frac{9.79 \text{ Labor man-hrs.}}{\text{flight cycle}}$$

$$XKFHA = (.59)(9.79) = 5.76 \frac{\text{Labor man-hrs.}}{\text{flight hour}}$$

$$XLAC = \frac{(5.76)(5.71) + 9.79}{(5.96)(503)} (4.) = \$.057/mi$$

Aircraft Material Costs:

$$AMC = \frac{(3.08)(10.6511)(5.71) + (6.25)(10.6511)}{3000.} = \$.0846/mi$$

Engine Labor Costs:

Engine Thrust = 28370. lbs.

$$XKFHE = (.6 + (.027)(28.37)(3.) = 4.1 \frac{\text{Labor man-hrs.}}{\text{Flight hour}}$$

$$XKFCE = (.3 + (.03)(28.37) \; 3. = 3.45 \frac{\text{Labor man-hrs.}}{\text{Flight hour}}$$

$$XLEC = \frac{(4.1)(5.71) + 3.45}{3000.} 4. = \$.0358/mi.$$

Engine Materials Cost:

Cost of one engine = $532,000.

CFHE = (2.5)(3.)(.532)(10.) = $40./Flight hour

CFCE = 2.(3.)(.532)(10.) = $31.99/Flight cycle

$$XMEC = \frac{(40.)(5.71) + 31.99}{3000.} = \$.1087/mi.$$

Depreciation Cost:

$$DC = \frac{10651100. + .1(10651100. - (3.)(532000.)) + (.4)(3.)(532000.)}{(503.)(12.)(4000.)}$$

DC = $.505/mi

Hull Insurance Costs:

$$XHIC = \frac{(.02)(10651100.)}{(4000.)(503.)} = \$.106/mi$$

Maintenance Burden Costs:

$$MBC = 1.8(.0358 + .0509) = \$.156/mi.$$

Total Direct Operating Cost at Design Range

	Amount ($/mi)	% of Total
Flight Crew Costs	$.3020	17.00
Additional Crew Costs	.0696	3.92
Fuel & Oil Cost	.3715	21.00
Aircraft Labor Cost	.0570	3.21
A/C Material Costs	.0846	4.77
Engine Labor Cost	.0358	2.02
Engine Material Cost	.0870	4.90
Depreciation Cost	.5050	28.45
Hull Insurance Cost	.1060	5.97
Maintenance Burden Cost	.1560	8.79
TOTAL	$1.7745	100.00

As is shown above, the biggest single cost is depreciation, second is fuel and oil costs and third is flight crew costs.

3.6 VEHICLES SELECTED

As stated in Section 2, the optimum air transportation vehicles for the 1980's are those which produce the minimum total system operating cost. Total system operating cost includes direct operating costs, indirect operating costs, added terminal costs not included in the indirect operating costs, and penalty costs associated with the value of the passengers' time while flying and waiting for his flight to leave.

Based upon a minimum total system operating cost the aircraft selected for the 1980's are

Aircraft	Range (miles)	Capacity (seats)
A	500	200
B	1500	400
C	3000	800

The physical characteristics of these aircraft are shown in Table 3.6-1.

As a matter of curiosity, a separate investigation was made regarding STOL vehicles and VTOL vehicles being used on the major routes having lengths less than 500 miles. As indicated in Section 2, the total system operating costs over these routes was relatively insensitive to the capacity of the aircrafts. Based on this fact and the technology forecasts for the 1980's, the characteristics for a STOL to be used in 1980 and a VTOL to be used in 1990 are given in Table 3.6-2 (It is emphasized that these vehicles would have a larger total system operating cost than the 500 mile CTOL aircraft selected in this investigation).

TABLE 3.6-2

CHARACTERISTICS OF STOL AND VTOL WHICH COULD BE USED ON ROUTES LESS THAN 500 MILES

Characteristic	STOL	VTOL
Year Used	1985	1990
Range (miles)	500	500
Capacity (seats)	100	100
Cruise Velocity (Mach No.)	0.6	0.6
Length (ft.)	149.25	128.85
Span (ft.)	90.17	101.57
Fuselage Diameter (ft.)	10.76	11.82
Weight (lbs.)	104,000	140,000
Number of Engines	4	4
Thrust/Engine (lbs.)	15,033	38,500
Fuel (lbs.)	25,000	29,590
Cost ($\$10^6$)	4.52	5.23
Seating Arrangement		
decks	1	1
aisles	1	1
seats abreast	3	4

TABLE 3.6-1

CHARACTERISTICS OF AIR TRANSPORTATION VEHICLES
SELECTED FOR 1980's

Characteristic	Aircraft A	Aircraft B	Aircraft C
Range (miles)	500	1500	3000
Capacity (seats)	200	400	800
Cruise Velocity (Mach No.)	1.0	1.0	1 0
Length (ft.)	159.62	174.34	260.8
Span (ft.)	108.22	157.79	255.96
Fuselage Diameter (ft.)	15.08	21.68	24.17
Weight (lbs.)	175,683	373,970	982,738
Number of Engines	2	3	4
Thrust/Engine (lbs)	29,000	42,000	82,000
Fuel (lbs.)	24,775	81,785	299,389
Cost ($$10^6$)	7.93	14.03	31.95
Seating Arrangement			
decks	1	2	2
aisles	1	2	2
seats abreast	6	12	14
Time to Climb and Descend (hr.)	.60	.62	.63
Distance to Climb and Descend (miles)	279.4	283.3	286.3
Design Direct Operating Cost (cents/seat-mile)	1.01	.61	.62

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IV. TERMINAL PLANNING

The terminals for the 1980's must optimize the entire air transport system by optimizing the flow of passengers and cargo to and from the aircraft at a minimum cost and optimizing the aircraft movement in the airport vicinity The indirect operating cost of aircraft is affected by passenger traffic flow, cargo, and air traffic control, therefore these three areas are investigated The flow of passengers, cargo, and aircraft needs to be increased in and around terminals to accommodate the predicted traffic flow in the 1980's.

The cost of the terminal and the time required for a passenger to pass through the terminal are studied. The indirect operating cost is estimated by three methods and an airport terminal cross-section is suggested.

The time required for a passenger to obtain a ticket, check baggage and board the aircraft under present-day procedures is a significant portion of the customer's total travel time A centralized computerized reservation system is investigated to provide faster service to the customer. A mechanized baggage checking and handling process is proposed that will code-mark baggage for automatic sorting to delivery points.

The air traffic control procedures in the local vicinity of the airport are analyzed using simple kinematic equations of motion. The effect of the aircraft approach speed, aircraft deceleration while on the runway, minimum ATC separation between aircraft, mixing of aircraft with different approach speeds, and new landing and taking off procedures utilizing the "Brandt Drift-off Runway" are investigated to determine their effect on the possible number of landings per hour per runway

4.1 DOOR TO AIRPLANE

The airports and associated terminal facilities at a large air travel hub affect the total time required for a trip involving air travel. The time required for obtaining a ticket, checking baggage, and boarding the plane at the origin of the air trip together with the time required to claim baggage at the end of the trip make up a substantial portion of the total time required for a point-to-point trip which includes surface transport to the airport and from the final airport

Figure 4 1-1 showing the pony traveling from the central business district (CBD) to the airport, the turtle traveling through the airport terminal, the goose flying from airport to airport, the turtle through the second airport, and the pony traveling from the airport of arrival to the CBD of the destination city can be considered representative of current 1969 travel times and distances covered This figure gives approximate proportions for airline distances of 200 to 300 miles. The average vehicle speeds in large metropolitan areas approach 17-20 miles per hour or approximately the same as the pony. The turtle analogy applies to the passenger's arrival at the airport 30 minutes to one hour before departure of the flight in order to purchase or confirm passage, check in baggage and board the aircraft.[1] The average aircraft flight speed is slowed down by takeoff and landing delays. The claiming of baggage at the destination airport

PRESENT AIR TRAVEL SYSTEM

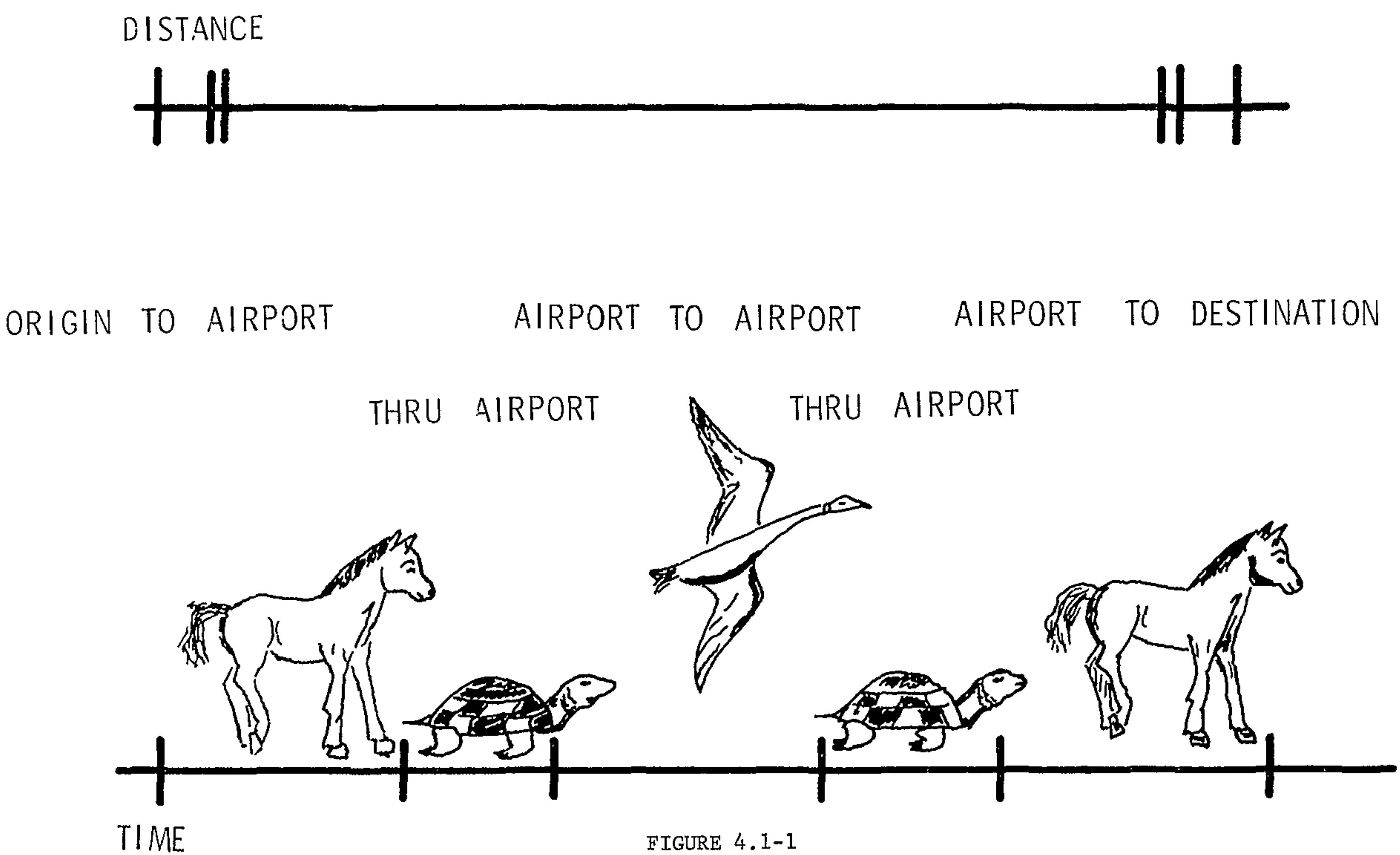


FIGURE 4.1-1

requires considerable time at the large hubs and the turtle analogy is repeated.

The lack of urban mass transportation systems in most areas and the congested auto traffic problems cause the relatively low average speeds from central business districts to airports. The accessibility of the airports needs to be improved in each individual hub area. The access to the airports can be improved by additional mass transit systems and by increased highway capacity.

Two airports that currently have mass transit links connecting them with the central business district are the Cleveland-Hopkins airport (using an interurban line) and the Newark airport (using buses). The local interurban transport problems are complex with many political and economic problems beyond the scope of this study

The cost of furnishing services and processing the passenger at the airport and terminal is difficult to determine, however the cost can be estimated from data available to the general public

This study will suggest the improvement of terminal and airport layout and procedures to speed up the processing of passengers and cargo as well as reducing the current costs associated with airport and terminal activities. More efficient methods should reduce the cost of processing passengers and cargo and the passenger time should be reduced by speedier processing

The terminal arrangement must be improved. The problem of the slow motion process through the terminal to the aircraft is a major problem at the present time and the future terminal must be streamlined to permit the passenger to move more easily and rapidly through the terminal.

Currently the passenger is required to arrive at the airport at least 30 minutes before flight departure time for some airports and up to one hour for other airports. This period is used for traveling from the parking or unloading area, purchasing or confirming tickets, checking baggage, and walking or traveling to the plane. The passenger has enough time to get processed with very slight chance of causing a costly delay in departure of the aircraft

The period before flight departure should be minimized by reducing the distance the passenger must walk and reducing the queueing for ticketing and other services. According to Lee, about three minutes is the maximum time that should be required to obtain a ticket and about eight minutes of time is required for a checked bag to get aboard the plane after it is passed into the check-in process.[2]

The passenger also requires some time to walk or travel from the point of arrival to the ticketing area. A person walking two miles per hour or slightly faster covers about three feet per second or about 175 to 200 feet per minute The average person can be expected to require a minimum of about five minutes of walking and ten minutes of waiting in ticket and restroom areas for a compact and well-organized terminal If the person is in a larger terminal, the person will require more time to travel greater distances within the terminal. The average person will also be slowed somewhat by the confusion caused by the larger number of people

A terminal can be made more compact, without sacrificing its utility, in several ways. One way is to separate the ticket sales and baggage check-in area from the concession, general office, and restaurant area thus discouraging visitor and well-wisher traffic in the ticketing area This separation of facilities could be arranged such that the ticket sales area would be on a different floor level than the concession floor level, or levels. The public transportation access should be at the ticket sales floor with the private auto passengers having access at the concession floor level.

Another way of making the airport terminal compact could be accomplished by having one or more downtown terminals. In these downtown terminals the passengers could complete the ticketing process and then board buses which go directly to planeside bypassing the airport terminal ticket facilities. Their baggage would be placed aboard special buses that would go directly to a baggage compartmentalization area.

The downtown terminal facilities could be used together with a three-level airport terminal where the buses from the downtown terminals pass through the airport terminal and discharge the passengers at the apron and then travel to the cargo and baggage containerization area on the ground floor Covered ramps could be used to speed loading during windy and inclement weather. Long sloping ramps would permit the passengers to walk rapidly and easily from the bus to the plane.

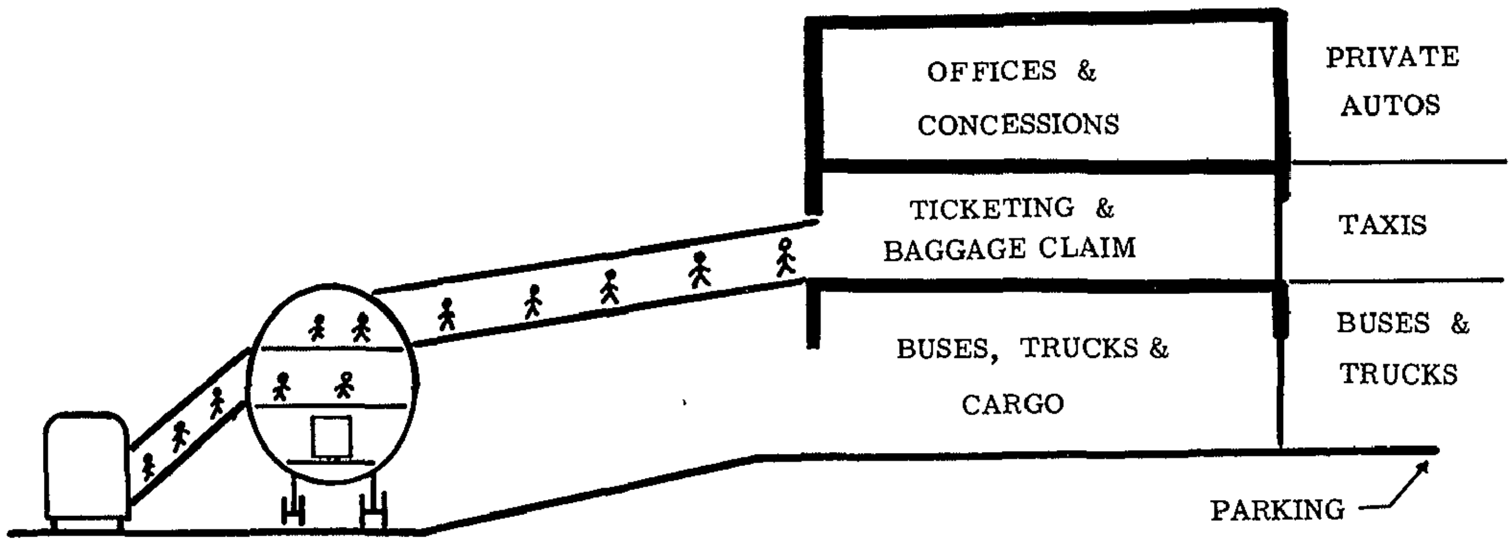
The airport terminal could have the cargo and baggage processing facilities on the ground level, accessible to trucks and buses, with the ticket sales and baggage check-in and claim areas on the second floor. The concessions such as restaurants, gift shops, car rental booths and the general offices could be placed on the third and higher floors. The additional warehousing required could be on the ground level with auto parking on several levels above it to connect to the terminal building. The airport terminal building could be constructed in modular form in either rectangular or circular shape.

The airport terminal would be compact only if the aircraft could be unloaded and loaded quickly. The unloading and loading can be expedited if the passengers are unloaded through several doors and are directed such that they can go to the downtown terminal if desired The baggage for the passengers going through the airport terminal should be unloaded from its aircraft cargo containers to the baggage claim system for the airport terminal while the baggage belonging to the persons going to downtown terminals should be placed aboard the correct buses The baggage destination within a terminal could be color-coded or otherwise identified for the passenger so that the passenger could be easily and clearly directed to the proper baggage carousel or other claim device This method has been suggested by Heinemann for current improvement of baggage handling [3]

The cargo and baggage placed in containers to fit in the cargo compartments of the aircraft could be used to speed the unloading and loading process. The minimum number of planes should be unloading and loading, with simultaneous servicing, at one time in order to minimize the length of the terminal and thus minimize the distance the passengers have to walk. The longer distances within the terminal may have to be served by a multi-stop bus service with a bus departing every five minutes, or more often at busy times

Figure 4.1-2 shows the cross-section outline of a terminal with capability of serving either a two- or three-deck aircraft.

Computer-assisted ticket sales and baggage checking procedures should be used to expedite passenger processing but the passenger should be tactfully and clearly directed into an easy and direct path from the moment he steps out of his auto or other ground transport to



SUGGESTED TERMINAL

FIGURE 4.1-2

the plane door. The people should be able to walk quickly and easily between floor levels on ramps. The ramps would be reliable and economical to construct and maintain

4.2 COSTS

The total cost of air transportation consists of the direct cost of operation (DOC) such as fuel and oil, cockpit crew, and maintenance of the aircraft together with the indirect cost of operation (IOC) which includes airport services, ground facilities, selling expenses and other expenses not associated with a particular aircraft but required to furnish air travel service to passengers. The direct cost of operation is, in a sense, proportional to the time that the individual aircraft is in flight, and can be assigned to the specific craft It does not include any services to passengers or expenses associated with landing the aircraft.

The role of the federal government in supplying air traffic control, both personnel and ground equipment, is expected to remain the same as at present, however, the government financing of airports, runways and lighting systems currently used may be changed. The local state, community, and city financial role may also change

At the present time, the costs of air transportation are borne by several groups of people: the passengers or shippers, the federal government, the state in which the airport is located, and the local community which often operates the airport through an airport commission or other official body. The passenger pays for the direct operating expense and part or all of the indirect operating expense through the ticket. Excise taxes on the ticket pay for a portion of the federal government air traffic control (ATC) expense and airport financing. The federal government, from excise tax receipts and other tax income, pays for the air traffic control personnel and ground equipment as well as other air safety personnel. The state and local community furnish most or all of the capital for the construction of the airport and related facilities. The property owned by the official airport operating body is usually not on the tax rolls, however, the local business generated by the airport activities contributes to the community income so the overall result is considered a benefit to the community. As a consequence, the actual costs of airports are difficult to determine accurately and are estimated.

Three different sources were compared to see if the estimates could be considered valid The Research Analysis Corporation, McLean, Virginia, (RAC) made a detailed breakdown of the direct operating cost and the indirect operating cost as estimated from the CAB required accounts.[4] A second breakdown of costs for an airline was given in Holiday magazine, July 1969 [5] A third estimate was prepared from data presented by the Committee on Transportation To and From Airports of the Technical Council on Urban Transportation (ASCE).[6]

The RAC estimate of indirect operating costs is very detailed and gives an insight to the changes in costs for different lengths of flights.

4 3 INDIRECT OPERATION COST

4.3.1 Passengers

The formulas and coefficients developed by the Research Analysis Corporation (RAC) were used in calculating the indirect operating cost for the air transportation system. The use of the RAC method for determining the indirect operating costs is representative of the user's cost for the system. Block time, flight distance and passenger load factor are used for determining the user's cost of the airport terminal ground facilities. The portion of the terminal ground facilities that is not taken into account in the indirect operating cost is assigned as a non-user cost The non-user cost for the system is taken as $1 50 per passenger for conventional type of airport terminal facilities and as $1.00 per passenger for STOL ports.

The indirect cost items are divided among (a) ground property and equipment, (b) aircraft servicing, (c) aircraft control, (d) cabin attendants, (e) passenger food, (f) traffic servicing, (g) servicing and administrative, (h) reservations and sales, and (i) general and administration. The indirect operating cost and the non-user's terminal cost are used in the allocation algorithm for determining total systems cost.

The formulas and coefficients used in evaluating the indirect operating cost are shown below:

Indirect Operating Cost

(a) Ground Property and Equipment--Direct maintenance, maintenance burden and depreciation·

$/block-hour=0.597K

where $K = \left(\frac{\text{aircraft direct maintenance labor}}{\text{block hour}} \right)$ and

for block-hour = 0 00-1.38,	K = 131.50
for block-hour = 1 39-2.31,	K = 324 00
for block-hour = 2.32-3.24,	K = 595.00
for block-hour = 3.25-4.16,	K = 944.00
for block-hour = 4.17-5 09,	K =1,370.00
for block-hour = 5.10-6.02	K =1,880.00

(b) Aircraft Servicing--Aircraft servicing and service administration

$/departure=0.00064 (maximum take off weight)

or $/departure=0.96 (number of seats)

(c) Aircraft Control--Aircraft control and service administration

$/departure=16 13

(d) Cabin Attendants--Passenger service

$$\$/\text{block-hour}=7\ 65\ \left(\frac{\text{number of seats}}{29}\right)$$

(e) Passenger Food--Passenger service-food expense

$/departure = 0.00191 ((number of seats x .8 x L.F.) +
(2 06 x number of seals x 2 x L.F.)) x
(flight distance) x H

where H = 1 when block-time 5.5 hours

H = 2 when block-time 5.5-9 0 hours

H = 3 when block-time 9 0 hours

(f) Passenger Handling--Traffic servicing, service administration and reservations and sales

$/departure = 4.09 x (number of seats x L F.)

(g) Baggage Handling--Traffic servicing and service administration

$$\$/\text{departure} = 58.71\ \left(\left(\frac{\text{number of seats x L.F. x 30}}{2000}\right)\right)$$

(h) Passenger Service--Passenger service, reservation and sales, advertising and publicity

$/departure = 0.00468 (number of seats x L.F.) (flight distance)

(i) General and Administrative

$$\$/\text{departure} = 0.12 \times \sum_{8} (\text{IOC's of 8 items})$$

Non-Users Costs for Terminals

$1 50 per passenger for conventional airport terminals
$1.00 per passenger for STOL ports

For the air transportation system, the cargo handling charges and the freight expenses including freight commissions and freight advertising are not included in the indirect operating cost The general and administrative costs were computed by taking twelve percent of the total general services and administration. This value was determined from the Income Statement from the Big Four Domestic Carrier Operations for Years 1957-1966.[7]

4.3.2 Cargo

The RAC method for calculating indirect operating costs was modified to reflect the indirect operating cost for the 1980 air cargo demand The indirect operating cost is representative of the user's cost for the system. Block time, flight distance and tons of freight are used to determine the user's cost of the airport terminal ground facilities. The portion of the terminal ground facilities that is not taken into account in the indirect operating cost is assigned as a non-user's cost. The non-user's cost takes into account the local funding and cost which is paid by the local community. The non-user's cost for the system is taken as \$500 per flight for conventional type of airport terminal facilities and as \$400 per flight for STOL ports.

The indirect cost items are divided among (a) ground property and equipment, (b) aircraft servicing, (c) aircraft control, (d) cargo handling, (e) freight expenses, and (f) general and administrative The indirect operating cost for air cargo and the non-user's cost for terminal ground facilities are used in the allocation algorithm for determining the total systems cost.

The formulas and coefficients used in evaluating the indirect operating costs are shown below:

Indirect Operating Cost - Cargo

(a) Ground Property and Equipment

$$\$/\text{block-hour} = \frac{0.597 \times K}{\text{block-hour}}$$

for block-hour = 0.00-1.38 hrs., K = 131 50

for block-hour = 1 39-2 31 hrs , K = 324.00

for block-hour = 2.32-3 24 hrs., K = 595.00

for block-hour = 3 25-4.16 hrs., K = 944.00

for block-hour = 4 17-5 09 hrs., K =1,370.00

for block-hour = 5.10-6.02 hrs., K =1,880 00

(b) Aircraft Servicing

\$/departure = 0.00064 x (maximum gross takeoff weight)

(c) Aircraft Control

\$/departure = K=16.13

(d) Cargo Handling

\$/departure = 58.71 x tons of air cargo

(e) Freight Expenses

\$/departure = 0 0095 x (tons of air cargo) x (flight distance)

(f) General and Administrative

$$\$/\text{departure} = 0\ 12 \times \sum_{5} (\text{IOC's of 5 items})$$

Non-User's Cost for Air Terminal Ground Facilities

\$500 per flight for conventional airport terminals
\$400 per flight for STOL ports

The allocation algorithm will optimize the best routing system selecting the most efficient air vehicle to satisfy the cargo demand. The optimum air cargo transportation system will result from the minimization of the direct and indirect operating costs.

4.3.3 Total Indirect Operating Cost

The RAC method was used in calculating the total indirect operating cost for the air transportation system. The formulas and coefficients of the RAC method were modified to reflect only the passenger demand and service and does not include cargo handling charge, freight expense including freight commission and freight advertising The modified method contains nine items of indirect operating costs, while the RAC method includes ten items The modified RAC method for calculating indirect operating costs was incorporated into the allocation algorithm from which the passenger demand and the air vehicle design required to satisfy the passenger demand is used to determine the minimum costs (direct and indirect) for the air transportation system

Table 4.3.3-1 indicates the total indirect operating costs computed by the RAC and the modified RAC method used in the optimization model The total indirect operating costs is a function of block-time, flight distance, the number of passengers and the passenger load factor The largest items of the total indirect operating costs are aircraft servicing, passenger handling and passenger service. These three items are 60 percent of the total indirect operating costs. The table indicates the total indirect operating costs and the indirect operating cost per passenger

4.4 COMPARISON OF DIRECT AND INDIRECT OPERATING COST

Table 4.4-1 illustrates the relationship between direct and indirect operating costs for commercial airlines Over a period of ten years, the indirect costs have been increasing while the direct operating costs of the airlines have been decreasing. Projecting the

TABLE 4.3.3-1

COMPARISON OF TOTAL INDIRECT OPERATING COSTS

Block-Time (Hrs.)	1 38		2.31		3.24		4.16		5 09	
Number of Seats	248		248		248		248		248	
first class	30		30		30		30		30	
coach	119		119		119		119		119	
Load Factor (%)	60%		60%		60%		60%		60%	
Flight Distance (miles)	500		1000		1500		2000		2500	
ITEM	RAC	RAC*	RAC	RAC*	RAC	RAC*	RAC	RAC*	RAC	RAC*
1	58.30	56.50	84.13	84.00	109.96	110.00	135.52	135.70	161.35	161.90
2	208 64	232.00	208.64	232.00	208.64	232.00	208.64	232.00	208.64	232 00
3	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13
4	55.87	55.87	93.52	93.52	131.17	131.17	168.41	168.41	206.07	206 07
5	100.15	100.15	200.00	200.00	300.44	300.44	400.58	400.58	500.73	500 73
6	353.16	354.00	353.46	354.00	353.46	354.00	353.46	354.00	353.46	354 00
7	171.80	76.00	171.80	76.00	161.80	76.00	171.80	76.00	171.80	76.00
8	202.22	202.00	404.45	404.00	606.67	606.00	808.89	808.00	1011.11	1000 00
9	6.27	----	12.54	----	18.81	----	25.09	----	31.36	----
10	98.03	122.00	139.49	163.00	181.76	224.00	223.45	274.00	265.74	325.00
Total Cost ($)	1270.84	1214.65	1684.75	1622.65	2098.86	2050.74	2511.97	2464.82	2926.38	2871.83
Cost/Passenger	8.54	8.16	11.31	10.90	14.05	13.76	16.85	16.60	19.60	19.25

*Modified RAC Method (RAC Method excluding freight expense, freight commission and freight advertising)

TABLE 4.4-1

DIRECT AND INDIRECT OPERATING COST OF DOMESTIC OPERATIONS OF THE BIG FOUR
(In thousands)

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
DOC'S	530,357	512,509	596,759	663,117	745,047	780,459	828,758	857,189	961,654	1,031,426
IOC'S	446,887	465,751	552,100	627,894	706,807	781,139	836,335	928,440	1,072,855	1,199,959
TOTALS	977,244	978,260	1,148,800	1,291,011	1,451,854	1,561,597	1,665,094	1,785,627	2,034,509	2,231,385
DOC (%)	54.4	52.2	51 9	51.4	51.3	49 8	49 7	47.7	47.4	46.4
IOC (%)	45 6	47.6	48.1	48.6	48.7	50.2	50.3	52.3	52.6	53.6

DOC's and IOC's into the 1980 time period, the allocation algorithm indicates that the IOC's will be three times as great as the DOC's when cost of living and 1969 dollars are taken into account. The variables used in computing the IOC's are block time, route distance and passenger load factor. When using the routes between paired cities, the distances remain constant. Also assuming a passenger load factor of 60 percent the tendency when optimizing the system would be to use the largest vehicle possible having the greatest passenger capacity and using these air vehicles to obtain the smallest block time between city pairs

It has been suggested in Section 4.1 that small satellite terminals be located throughout the city so that passengers may make reservations, ticketing and baggage arrangements. Passengers may board a ground vehicle and be transported directly to the runway for enplaning. In this way the main terminal may be bypassed thereby alleviating passenger traffic congestion through the terminal and reduce the penalty factor of time and inconvenience to the passenger With the reluctance of the local communities to enlarge and expand terminal facilities, a better and more efficient use of the terminal facilities must be developed. Figure 4 4-1 indicates the trend between IOC and DOC for a ten-year period.

Comparison of indirect operating costs using three methods shown in Table 4.4-2 below indicates the air carrier's method to be the lowest cost The RAC method and the RAC* (modified method) are respectively higher than that indicated from airline carriers calculations [5] The expected tendency as shown in another section of the report is for indirect operating costs to increase while the direct operating costs will decrease. The RAC and the RAC* method lists the

DIRECT AND INDIRECT OPERATING COSTS

FIGURE 4.4-1

TABLE 4.4-2

COMPARISON OF INDIRECT OPERATING COST

	Airlines		RAC	RAC* (Modified)
Airport	$ 294.00	(a)	$ 71.32	$ 105.50
Inflight Service	215.00	(b)	208.64	232.00
A/C Operating Costs	117.00	(c)	16.13	16.13
Selling Expense	70.00	(d)	74.65	74.65
Advertising & Reservations	131 00	(e)	150.00	150.00
Depreciation & Insurance	246 00	(f)	353 00	353.00
General & Administrative	180.00	(g)	171.50	76.00
TOTALS	$ 1,252.00	(h)	303.00	303.00
Cost per passenger	$ 22.60	(i)	9.40	----
		(j)	119 00	111.50
		TOTALS	$ 1,476.64	$ 1,421.78
		Cost per passenger	$ 26.60	$ 25.80

various operating costs making up the total indirect operating costs.

The cargo handling expense has been omitted from the RAC* since the air transportation system will be used to carry only passengers and their accompanying baggage. A direct comparison of the IOC's is difficult to make since the methods of accounting by various groups of aircraft manufacturers, airline carriers and governmental agencies differ in classifying the operating costs The total indirect operating costs may be compared however, as well as the cost per passenger The RAC and RAC* method indicates 17 7 and 16 8 percent higher operating costs than the airline carrier method for computing the IOC's. In estimating the indirect operating costs for the proposed 1980 air transportation system, the costs as computed by the RAC and the RAC* would more nearly reflect the actual values for the IOC's. Wage labor costs comprise 60 percent of the total IOC's which is required for direct maintenance of aircraft servicing and passenger handling and service. The trend of increased labor costs will increase the IOC's to the 1980 period.

4 5 TICKETING PROCEDURES

The heart of the ticketing scheme is the central data bank (CDB). In order to make the system versatile on a national basis, all major airlines should be parties to the central data bank. The CDB has on file the status of all flights scheduled by the participant airlines in addition to pertinent information on aircraft The CDB informs the appropriate agencies of service they will be called upon to perform and supplies the necessary data to these agencies concerning those services

The most important product of the system is its output, which includes the passenger's ticket It assigns the passenger to a flight and informs the CDB of the fact It establishes the procedure for handling the passenger's baggage. Additionally it makes arrangements for certain ground transportation at both ends of the flight as desired by the passenger The passenger's fare is computed and presented to him before he approves the reservation. The passenger may alter the reservation and get a new output When the passenger is completely satisfied, he makes final approval and hard copy is printed Baggage handling information is disseminated to the agencies that will be handling it. In order to level out peaks in the daily demand, lower fares can be offered in slack hours

Hopefully, the customer should be able to get his complete reservation within two minutes.

The hardware components most important from the customer's point of view are the cathode ray tube and the keyboard. Through these two devices, the customer or his ticket agent interact with the system to produce a reservation for a flight and to select options on ground and inflight service

The first step an operator takes at the keyboard is to input the airport of origin, the airport destination, and desired times of departure and arrival. The CRT then displays, by calling on the CDB, the flights from origin to destination, including connections, status of the flights, costs, and available services.

The customer selects a flight number and service options. The CRT displays any transfer options, if applicable, and the customer makes his selection as before. He has now made his flight reservations and selected in flight service options

The next step is to outline ground service options. The customer must decide whether or not he desires ground transportation from the plane to his final destination. If he is taking care of himself after leaving the aircraft, he must select one of several baggage handling options. For example, he may elect to have his baggage loaded on a bus going to a predetermined hotel, at a carousel, or put on a "hold until called" basis. After these have been completed, the "reserve" button is selected and all reservations are completed. At this time the CDB makes a record of the fact.

After the reservation has been made, the CDB receives the reservation information, it changes the status of the flight according to the reservation The CDB informs the agencies handling the passenger and his baggage with the details of service which the person has selected For example, if a person selected the limousine service, the agency responsible for the limousine would be informed by the CDB when and where to pick up the passenger

The central data bank is the heart of the ticketing scheme. In it is contained all scheduled airline flight information required for handling passengers and baggage Changes in the CDB are occurring continually as reservations are being made, flights change or are rescheduled. The CDB must have the capability to take the information provided by the ticket purchaser and give output to many different people besides the purchaser. It must inform the limousine service if the passenger desires door to plane service. It must inform the airport of the number of passengers using their facilities at any given time It must provide detailed baggage handling information to both the airline and the passenger.

Physically, the data links could be rented phone lines or private lines The high demand for channels in the air space requires that any large system in the future must be occupied by older systems which are made obsolete by the new system.

Provisions for persons purchasing tickets after the latest time for reservations are handled by eliminating some of the options available. The limousine service is difficult to provide after four hours before flight time However, tickets can still be purchased and baggage checked at remote terminals providing direct access to the aircraft up to an hour before flight time. Between one hour and eight minutes before flight time, baggage options remain open, but the direct access option is closed Between eight minutes and four minutes before flight time, baggage options are closed, and the passenger must carry his bags through the terminal and onto the plane. Presumably, the passenger arriving at this time is making a "commuter" type flight and is carrying only one small bag. After four minutes, ticket sales should be closed, as the plane is now ready to commence pre-flight operations

4.6 CARGO AND BAGGAGE HANDLING

The object of an efficient baggage handling system is to keep it moving, allowing no bottlenecks to form. Ideally, the baggage should not stop moving until it is loaded on an aircraft or it reaches its final destination Actually, it must stop several times in various sub-staging areas, be loaded or unloaded in bins, be placed in the aircraft or retrieved by the passenger

A modern system, using an on-line computer in conjunction with coded strips on the bags, should have the capability of handling large volumes of baggage Systems of belts and separators have a large active storage. Baggage arrives at a predetermined location after being "stored" on a moving belt. At either end of the system is a passive storage system of sufficient capability to keep the active storage from backing up.

As demonstrated by the ZIP Code system, a numerical code can be used by separate items of diverse sizes destined for a variety of locations. A coded system, operating electronically, can separate a plane load of baggage, and, in conjunction with an error detecting back up system, distribute the payload to predetermined locations. The tickets on the bags can be scanned to provide the necessary information available, the system makes the appropriate switches operate to shift the piece on its proper route

The revenue generating potential of the giant jets depend largely on being able "to turn the jet around" in a very short time (to shorten the ground time between flights). However, the cost of purchasing and operating the equipment required to turn the aircraft around swiftly increases as turn around time decreases. Somewhere, an optimum turn around time may be found.

The cost of the handling equipment is a function of the amount of cargo handled, the amount of time required to handle it, and the amount of cargo actually in the system at one time. The variables refer to the maximum amount of cargo to be handled by the system.

The first theory is based on pricing of industrial equipment. The assumption is that equipment costs two dollars per pound of material handled per hour:

$$C = (2) \frac{P}{T} (60)$$

where C is the cost, P is the payload in pounds, and T is the time required to handle one payload in minutes The model predicts what one would intuitively expect, that is, it has zero cost for infinite turn around time, and infinite cost for zero turn around time.

Although this neglects research and development (R & D) costs, it is a reasonable estimate of the cost of industrial equipment. Obviously, the R & D costs will increase as more sophisticated equipment is called for Therefore, judgment must be used when applying the formula in the low turn-around time region.

4.7 AIR TRAFFIC CONTROL

The terminal area is considered to be the biggest bottleneck to the flow of traffic in the entire Air Traffic Control system Because of this feeling, the ATC analysis is limited to IFR traffic in the airport control zone. While no actual equipment is designed, the final conclusions and recommendations are based upon a realistic advancement in the state of the art of electronic developments in radar, aircraft collision avoidance equipment, and navigational equipment.

The ATC analysis considered three types of single runway operations alternation of take-off and landing operations, only landings, and only take-offs. Whenever more than one active runway is in use at a single instant, it is assumed that each runway could operate independently, without interference from other runways.

AIRPORT CONTROL ZONE

The airport control zone is defined by the Airman's Information Manual as "Airspace extending upward from the surface of the earth which may include one or more airports and is normally a circular area of five statute miles in radius with extentions where necessary to include instrument approach and departure paths."[17]

INSTRUMENT LANDING SYSTEM (ILS)

The ILS currently used consists of two highly directional, ground based, transmitters that give a visual display to the pilot of the aircraft so that he may fly the aircraft to the runway One transmitter gives lateral direction while the other transmitter emits a vertical glide slope signal. Three or less marker beacons (low powered directional transmitters, aimed vertically upward) are located on the glide slope to indicate horizontal distance from the end of the runway.

4.7.2 Single Operation Runway Landing Analysis

4.7.2.1 Runway capacity constraint

The runway capacity or landing rate versus aircraft (A/C) final approach speed as a function of two separate capacity constraints is shown in Figure 4 7.2-1

The first constraint is imposed by the ATC minimum separation regulation while on the ILS. It is assumed that the A/C maintains a constant approach speed after entering the ILS, until it touches down on the runway.

The second constraint is imposed by the time the A/C actually spends on the runway. This time begins at the A/C touchdown point and lasts until it exits from the runway. It is assumed that a constant deceleration equal to 9 fps^2 would be maintained The A/C's touchdown point is 2500 feet past the runway threshold and the A/C

RUNWAY CAPACITY CONSTRAINT

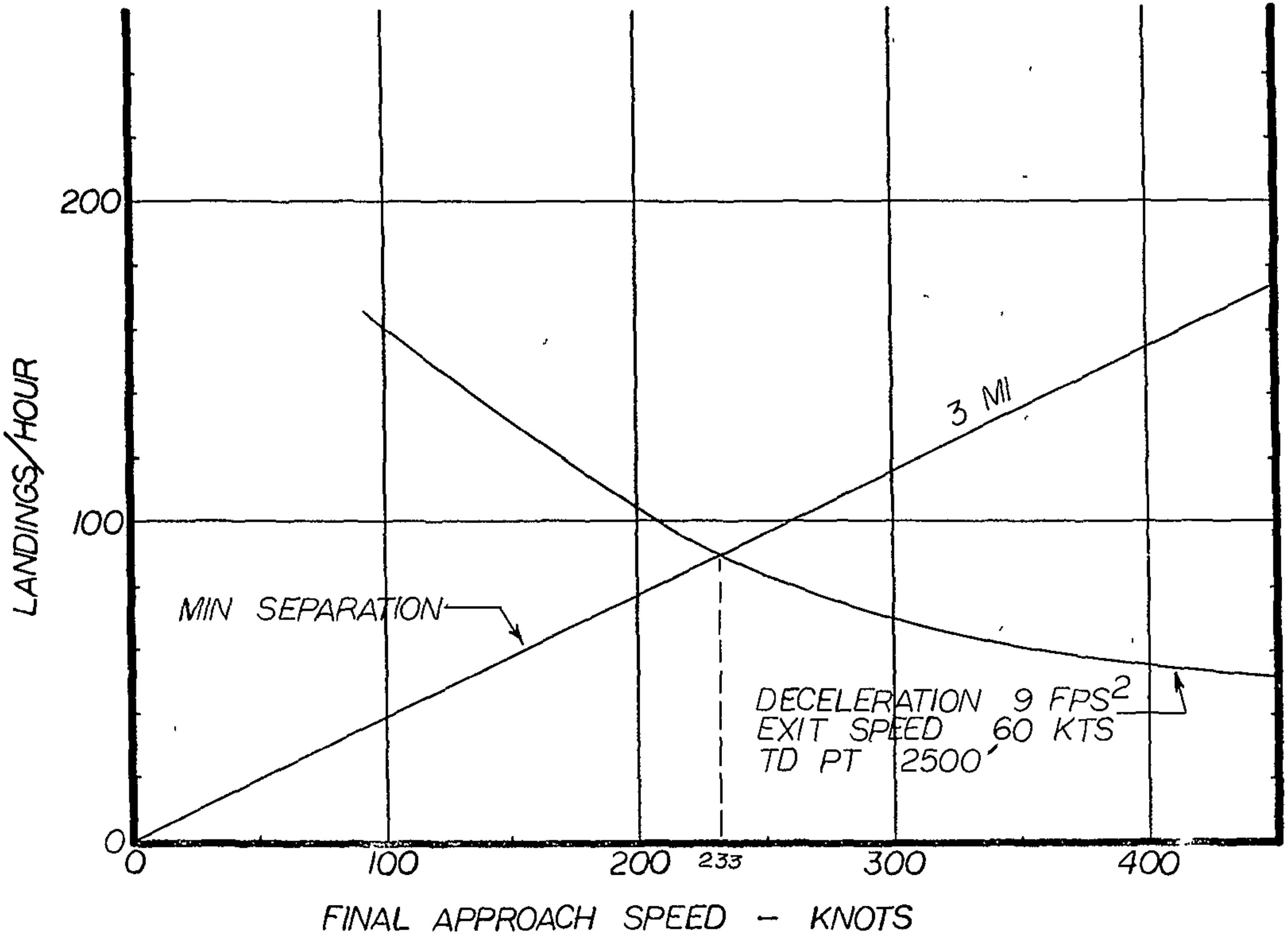


FIGURE 4.7.2-1

exits from the active runway at a speed of 60 kts. onto a high-speed exit or taxiway.

It can be seen that at approach speeds below 233 kts., the minimum A/C spacing or approach regulation is the active constraint. Aircraft deceleration is the active constraint at speeds above 233 kts.

Today's large commercial A/C have an approach speed of approximately 130 kts. This approach speed is well below 233 kts., which indicates that under the present ATC 3-mile minimum separation, A/C deceleration will not affect the runway landing rate

It can also be seen that, if 20 kts were added to the approach speed, the landing rate would not be substantially increased. However, an increase in approach speed would create much greater wear on the A/C's tires and brakes In addition, the A/C roll on the active runway would increase

4.7.2.2 Variation of ATC minimum separation

Figure 4.7 2.2-1 shows the effects on the landing rate as a function of the ATC minimum A/C approach separation.

At an approach speed of 130 kts it can be seen that with the three mile separation, 50 landings per hour (LPH) may be obtained; at two miles, 75 LPH may be obtained, and at one mile, 150 LPH may be obtained

VARIATION OF THE TOUCHDOWN POINT

The touchdown point is measured from the runway threshold to the point where the landing A/C contacts the runway. Figure 4.7.2.2-2 shows the effect of the variation of the touchdown point on the landing rate. It can be seen that the touchdown point has no effect

VARIATION OF ATC MINIMUM SEPARATION

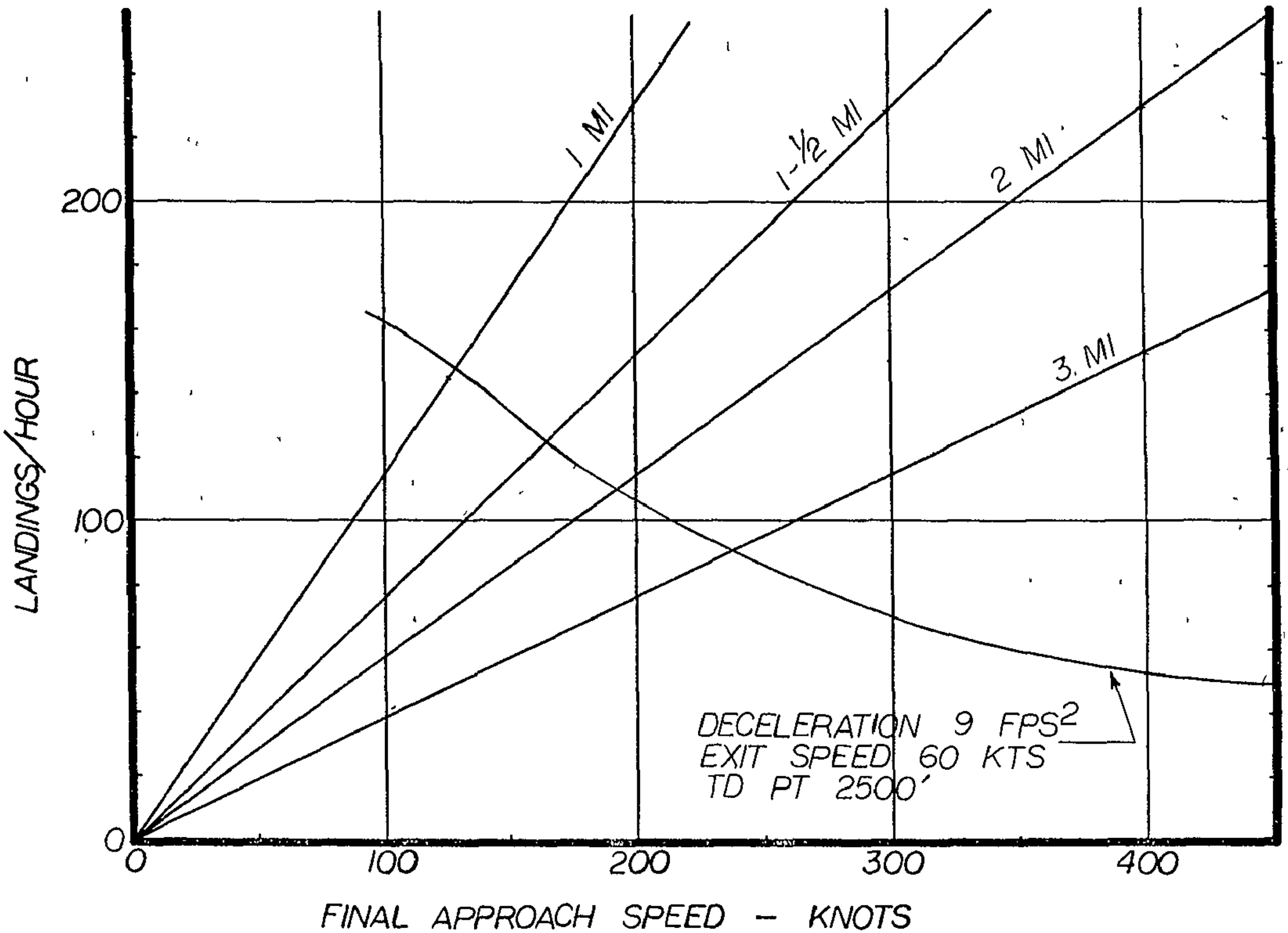


FIGURE 4.7.2.2-1

VARIATION OF TOUCHDOWN POINT

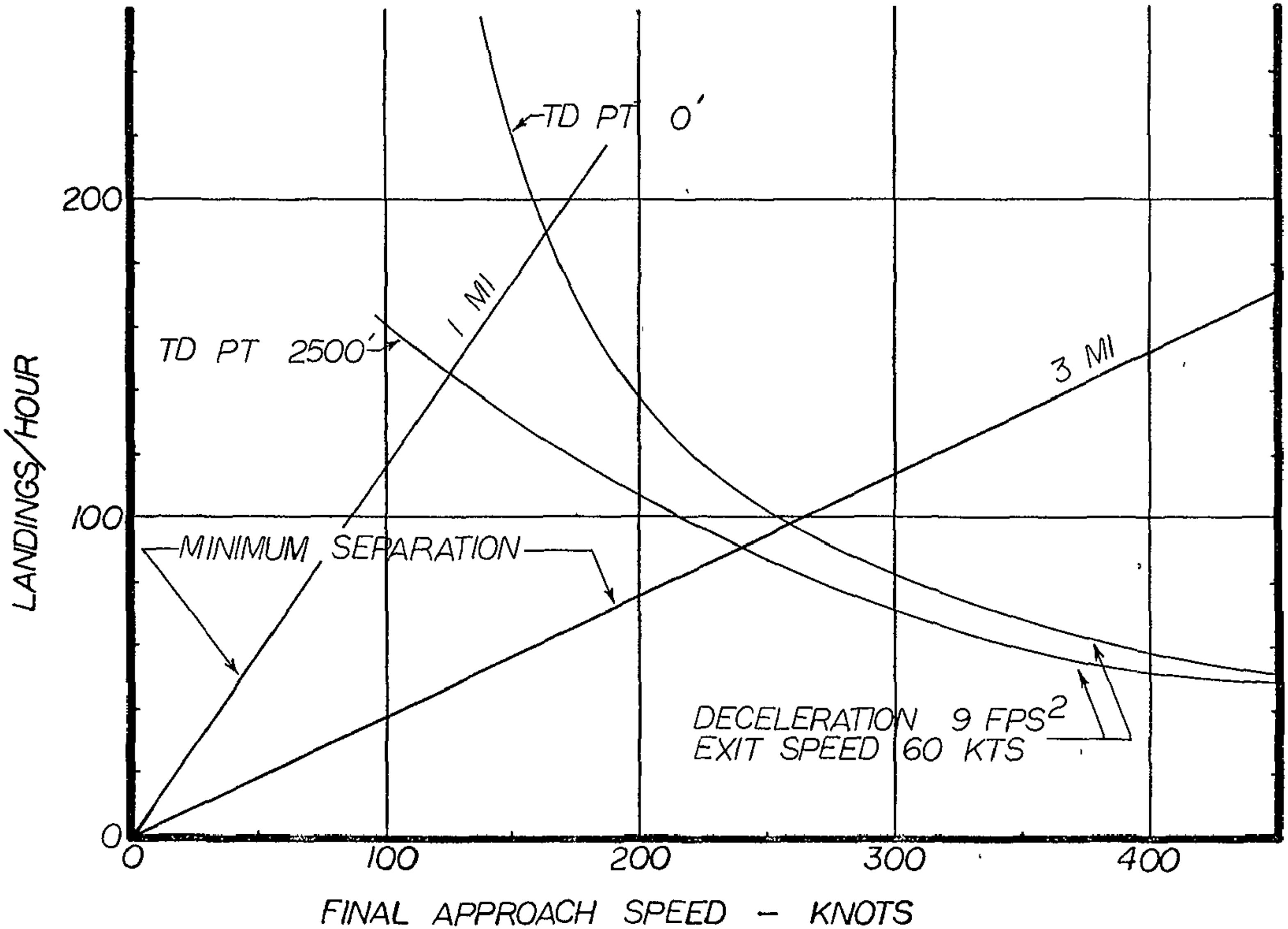


FIGURE 4.7.2.2-2

upon the landing rate unless very high approach speeds are used and/or the ATC minimum separation is reduced.

VARIATION OF DECELERATION

Figure 4 7 2 2-3 shows the effects of variation of deceleration upon A/C exit location and the runway landing rate As would be expected, actual time spent on the runway and exit location is decreased when deceleration rate is increased. However, under the three mile ATC separation minimum, and unless very high approach speeds are used, variation of deceleration has no effect upon the runway landing rate.

4.7.2.3 Landing only analysis--SUMMARY

It has been shown that the variation of deceleration and touchdown point would have no effect on the runway landing rate under the present ATC minimum separation of three miles. However, it is recommended that the current ATC minimum be reduced

It is felt that the ATC minimums could be reduced to as close as one mile with an improvement in air surveillance radar on the ground and with the introduction of a reliable, onboard, A/C collision avoidance system It should be realized, however, that pilot and ATC ground control personnel must psychologically accept these reduced minimums. Because of this reason, the separation minimums must be reduced incrementally

4.7 2.4 Take-off analysis

The ATC separation rules that were used in the take-off analysis are as follows:

VARIATION OF DECELERATION

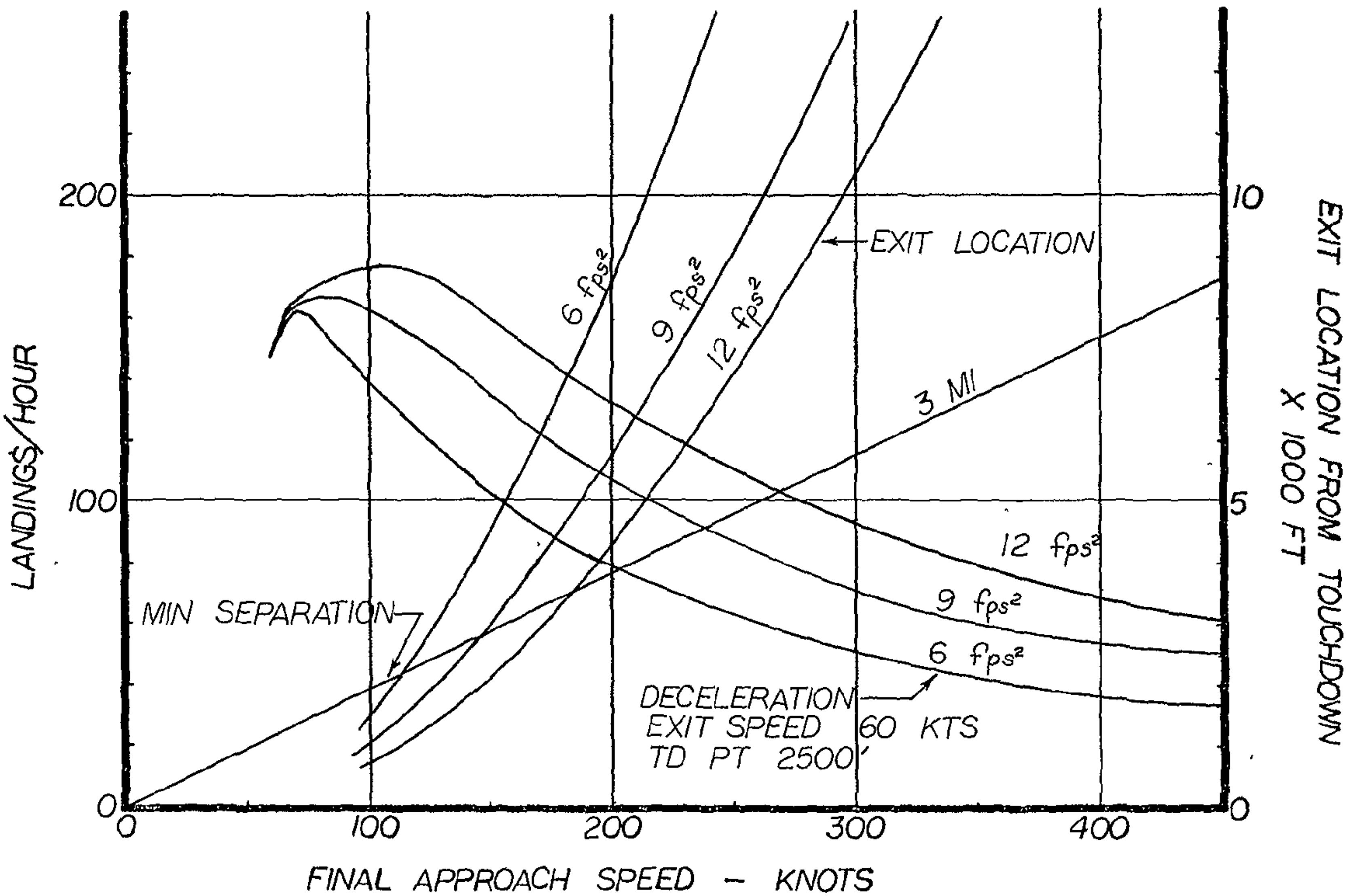


FIGURE 4 7.2.2-3

1. An A/C waiting for departure is given an OK for brake release after the preceding A/C has no further contact with the active runway, and has·

2. Crossed the end of the runway, or

3. Turned away from the runway to avoid conflicts, or

4. Has a separation of at least 6000 feet

Characteristics of heavy commercial A/C, such as the Boeing 707-320B, were used in the take-off analysis A liftoff speed of 160 kts. and an average, constant, acceleration of 0.12 g or 3.86 fps^2 were assumed The A/C will lift off in 9500 feet and will take approximately 70 seconds to do so.

Rules 1 and 4 have automatically been satisfied under the above assumptions If an A/C were cleared for take-off every 70 seconds, a take-off rate of 51.5 take-offs per hour and a horizontal separation of 2 91 miles may be obtained.

It is believed that with an improvement in air surveillance radar and with the introduction of an onboard A/C collision avoidance system, the minimum ATC separations could be reduced with both pilot and ATC personnel acceptance However, pilots would not accept the risk of initiating a take-off with another A/C on the runway Since the time to accelerate to lift-off speed is the governing constraint on the take-off rate, only an increase in A/C acceleration or a decrease in lift-off speed will raise the runway take-off rate.

4 7.3 Mixed Runway Operation Analysis

The mixed runway operation analysis required that the runway would be used alternately for taking off and landing A/C.

Characteristics of heavy, commercial A/C, such as the Boeing 707-320B, were used in the analysis The following assumptions were used in this analysis:

LANDING A/C

1 A/C approach speed is 130 kts.

2 A/C deceleration is 9 fps^2.

3. The touchdown point is 2500 feet from the runway threshold.

4. Exit speed onto a high-speed taxiway is 60 kts.

TAKING OFF A/C

1. A/C acceleration is 0.12g or 3.86 fps^2

2 Lift-off speed is 160 kts

3. Time from brake release to lift-off is 70 seconds.

4 Distance from the runway threshold to lift-off point is 9500 feet.

In this analysis, at no time were two A/C allowed to conduct operations simultaneously on the active runway. Departing A/C were given clearance to taxi into take-off position, but not to take-off, after the preceding landing A/C had past the runway threshold. After the preceding landing A/C exited from the runway, the waiting A/C was cleared for take-off.

The governing constraint on the runway operations rate was the time for the taking off A/C to accelerate to lift-off speed The runway operation rate is indirectly proportional to the time it takes the taking off A/C to accelerate to lift-off speed. The runway operation rate can be increased by decreasing the A/C lift-off speed or increasing A/C acceleration. This constraint limited the runway operation rate to 86.5 OP/HR or 43.25 LPH and 43 25 take-offs per hour.

To conduct the mixed operations on one runway, it is recommended that the Brandt drift-off runway be adopted. The Brandt Drift-off Runway was patented in 1962 by Captain Jay E Brandt of Trans World Airlines.

The drift-off runway consists of a drift-off area, approximately the width of the active runway, attached to one side of the active runway The drift-off area would start from 500 feet to 1000 feet from the ends of the runway as shown in Figure 4 7.3-1

The purpose of the drift-off runway is to allow a landing A/C to exit from the active runway at a high-speed roll, thus allowing the runway to be used for a departure. When a landing A/C crosses the runway threshold, the A/C waiting for take-off is given "clearance for departure " This clearance for take-off means the waiting A/C should taxi into position and hold until the landing A/C has rolled clear of the active runway. When the landing A/C has exited from the runway, the departing A/C releases its brakes and starts its take-off roll No further communication with the tower is necessary after the initial clearance for departure, thus reducing radio congestion. At no time are there more than one A/C conducting a take-off or landing operation simultaneously on the active runway.

The Brandt Drift-Off Runway offers several advantages·

1 This type of runway is readily adaptable to airports now in operation without large costs in additional land acquisitioning

2 Active runway occupancy time will be reduced substantially.

3. Wave-offs would be extremely rare.

4 Pilots' confidence in a successful completion of a Category II and Category III landing would be greater due to the wider runway drift-off area.

BRANDT DRIFT-OFF RUNWAY

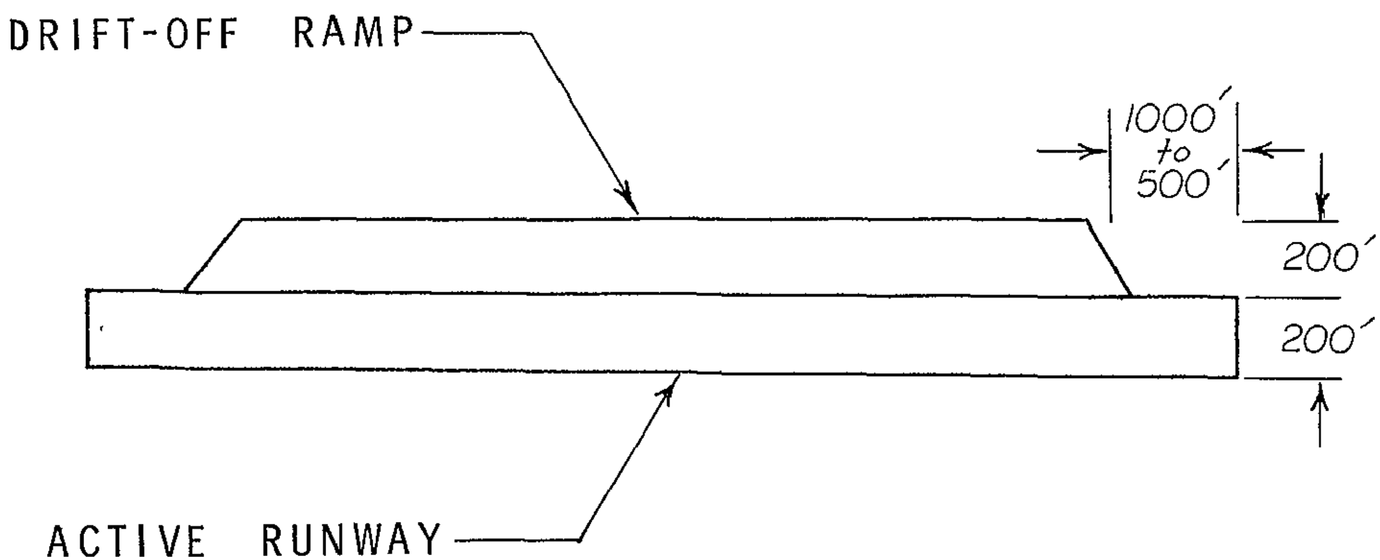


FIGURE 4.7.3-1

5. No additional pilot skill would be required by the average private pilot to use the runway.

An analytical study initiated by the Federal Aviation Administration, in 1961, arrived at the following conclusions:[18]

1. "The Brandt Drift-Off Runway will increase practical VFR runway operating rates substantially beyond those obtainable with other accepted turnoff layouts when the runway is used for mixed operations."

2. "The drift-off technique permits a considerable reduction in effective runway occupancy time--even over a runway with four high-speed turnoffs "

An actual flight test conducted by the University of Kansas,[19] has shown that active runway occupancy time was reduced by 50 percent. Even though the test was conducted by A/C with an approach speed less than 110 kts., it was felt that the results would be the same with faster and larger A/C.

4.7.4 Recommendations

The single operation runway offers the advantage of being more flexible than the mixed operation runway If an A/C is delayed 30 seconds from its scheduled departure or arrival time, it is relatively easy to resequence the A/C. If a delay is incurred on the mixed operation runway, it will cause a delay to at least one of the following A/C.

The mixed operation runway is more efficient than the single operations runway. An average of 86.5 OP/HR may be obtained utilizing only one runway. The single operations runway, conforming to our present ATC minimum separations, will handle 51.5 TOPH and 50 LPH for a total of 101.5 OP/HR. The average OP/HR for each runway is 50.75 OP/HR, which is far below the OP/HR of the mixed operations runway. Substantial improvement in LPH will occur with the improvement of air surveillance radar and onboard collision avoidance equipment. This will increase the average OP/HR. However, the airport could become saturated to the point where no parking area would be available for landing A/C.

The following recommendations are suggested to ensure that the future traffic projected by this report can be accommodated:

1. Utilize the mixed operations runway procedures.
2. Utilize the Brandt Drift-Off Runway or high-speed taxiways and exits.
3. Where traffic demands it, use multiple runways, preferably separating the runways such that their operations can be conducted independently.
4. Segregate A/C according to approach speed (i.e., do not mix slow and fast A/C).
5. Provide shorter runways for A/C that can land on runways under 4500 feet.

4.8 RESULTS AND CONCLUSIONS

The terminal planning should separate the various traffic flows to minimize interference between passengers and visitors or shoppers, between people and cargo, between passengers using local transportation and those using mass transit connecting to central business districts, and between high-speed and lower-speed aircraft in the aircraft areas. The use of satellite terminals in the central business districts, with transportation directly to the boarding ramp from the satellite terminal will reduce the area required at the terminal for ticketing and related procedures

The ticketing procedures could be speeded through the use of a central data bank containing pertinent information on all flights. (This would require more cooperation among the airlines or might be possible through mergers.) A passenger should also have the option of access to the aircraft via an airline limousine service which would pick up the passenger at any predetermined location. The passenger's baggage would be code-marked at the time the ticket was purchased. Computed discounts could be used to encourage off-peak traveling.

The cost of the passenger being processed through the terminal and airport is estimated to be in the range of thirteen to nineteen dollars. The cost in the 1980's should be reduced through more efficient terminal plans, more efficient use of computer-aided ticket machines and careful traffic separation.

Cargo and baggage handling cost may be approximated by the relation:

$$C = (2) \frac{P}{T} (60)$$

where C is the cost, P is the payload in pounds to be handled, and T is the time in minutes required to handle the payload. Automated baggage handling equipment utilizing an on-line computer and precoded strips identify the baggage for sorting. A tilting conveyor used by Braniff Air Lines in 1969, at Dallas, Texas, is an example of such a system designed for cargo.

The ATC analysis indicates that the approach to landing or while on the Instrument Landing System is the major restriction to traffic flow and runway utilization in the airport control zone, the number of runway operations per hour can be increased by decreasing the ATC minimums for aircraft separation. Segregation of aircraft by approach speeds yields some increase in the number of runway operations per hour. The "Brandt Drift-Off Runway" may also be used to substantially increase the rate of runway operations. An increase in approach speed does not substantially increase the number of landings per hour and an increase in the rate of aircraft deceleration while on the runway does not have any effect on landings per hour unless very high approach speeds (in excess of 200 nautical miles per hour) are used.

The development of on-board collision avoidance equipment and better resolution for ATC equipment is expected to reduce the minimum aircraft separation to less than the present three-mile requirement.

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V. IMPACT OF SOCIOECONOMIC TRENDS ON AIR TRANSPORTATION

5.1 INTRODUCTION

An air transportation system operates in a dynamic environment consisting of people and their inherent social, economic, and political concerns. This environment influences and shapes the demands that are made on the system, simultaneously offering both opportunities and constraints. On the one hand, the rapid growth of population, industry, leisure time, education, and disposable income creates new and expanding markets for the air transportation industry. On the other hand, limitations on noise, and pollution as well as legal, financial, and jurisdictional problems act to restrain its growth. Thus the socioeconomic environment acts on the transportation industry as both an expanding and a limiting factor.

The socioeconomic study begins with a consideration of demographic trends and economic growth, followed by an investigation of government financing. Trends in governmental powers, policies and practices are analyzed and possible impacts considered An analysis of the governmental system for regulation and projection of limitations on the air transportation system follows. The study is concluded with an investigation of cost penalty to the system for the passenger having to wait or be delayed in the system

5.2 SOCIETY CONSTRAINT MODEL

The Society Constraint Model (SCM) is essentially a theoretical and analytical effort to show the relationship of the social and economic factors to the other aspects of the system and identify the approach for considering general or abstract principles of transportation functions. Mathematical models have been developed that present transportation in a systematic picture, however, this is the first time that such a comprehensive systems analysis of air transportation has been undertaken.

The air transportation system analysis consists of three parts -- determination of requirements which the system must meet, formulation of the system physical characteristics and definition of system constraints. All of these serve as inputs into evaluating the system performance and formulating a general system concept.

There is a wide gap between a conceptual model and a transportation system in reality. It is important, however, to identify the set of alternatives to be used from the universe of alternatives in order to provide a reasonable base from which the transportation decision-maker can order his choices. The concern then, is to develop an analytical tool not only to describe the demand for air transportation, but also the manner in which transportation shall be supplied and the satisfaction that will be gained by the use of it.

When people hear the phrase "air transportation for the 1980's" many think about a fully automated system. Fully automated systems require heavy public and private investments and it would be far too costly to convert hundreds of already existing airports and thousands of vehicles to automatic control overnight. Any new system involving millions of people will have to evolve step-by-step. Because new ideas in transportation must be integrated into our existing system it is necessary that changes be compatible with what already exists.

In order to justify the expenditure of billions of dollars, any radical changes must offer radical improvements over our present system. Just a little bit better will not be enough.

Even though it now seems like a long time until 1980, the length of time required to complete studies, to acquire financial backing, to carry out development programs and build prototypes makes it necessary that a model be developed to provide short cuts in conceptualizing future systems. The SCM is in the form of four subsystems of operations and information generation. This is shown in Figure 5.2-1.

The functional analysis for transportation, regardless of its description as a derived activity, can be set into a socioeconomic framework for the purpose of <u>devising the price that any society must pay for a given system</u>. The price is an aggregation of:

(1) the capital cost to the investor, whether public or private;

(2) the fare or outlay cost to the user as he travels or ships his goods, and

(3) the added cost that the public must pay in order to make certain that the system continues in existence and provide reliable minimal services.

The physical system within this kind of functional analysis is not the full and complete description of exotic new vehicles or automatic airports, but a weighing of the feasibility of many advanced ideas to determine which would be most practical to develop and test. Because the expenditures for advanced technology are so high, the expense would be prohibitive to develop and test every proposed system Preliminary research is necessary to weed out "duds" before too much is invested in them. The new devices incorporated into future transportation must be flexible enough during their useful life spans to grow and adapt both to unforeseen technical innovation and to

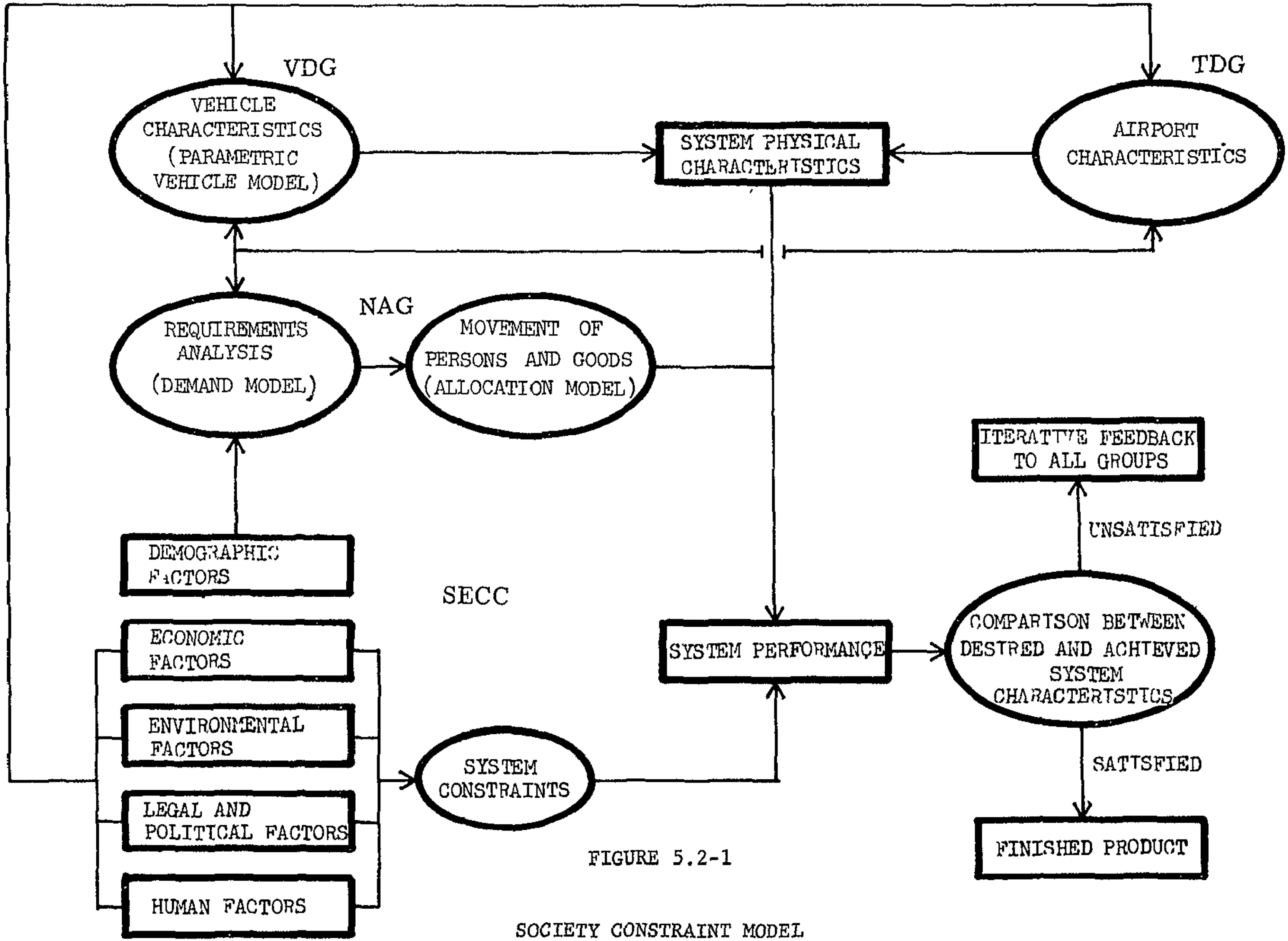


FIGURE 5.2-1

SOCIETY CONSTRAINT MODEL

changes in the living patterns of the people who use them

The operational environment, of human, legal, political, economic, and other man-made constraints, coupled with the natural environmental constraints set the limitations within which a desired system shall perform. At the same time, the demand for transportation must be developed through the use of quantitative descriptions of the society.

Societal descriptions are divided into two categories. First, the geographic and physical locations are enumerated. Second, it is necessary to interject the actual or proposed economic conditions in terms of basic activities, population size and distribution factors, industrial production, goods distribution, and agricultural activities. These requirement characteristics in turn are mathematically converted, along with those of the constraints limits, into a narrow bank of statistics that will interact with a mathematically converted description of the physical transportation system These constitute the necessary demographic variables for analyzing the system.

Because accurate data are not available, it was decided early in the stages of this investigation that the SCM be a deterministic model system For the purpose of this analysis, deterministic is construed to mean deductive rather than inductive The two near-term expectations for the SCM system are (1) outputs of technological aid and (2) information expected to assist the public administrators in their decision-making The SCM cannot be considered the panacea for solving transportation problems It is a foundation tool using systems analysis that will provide the logic which will result in better knowledge and understanding of the physical process of movement within the total social structure. It is not a substitute for the decision-maker, nor does it take the place of the ingenious inventor. In fact, SCM and those who use it must rely upon both the inventive and decision processes in order that viable alternatives may be analyzed. Ultimately this system will reveal broader choices and greater number of alternatives from which administrators can select and judge the best solution to current and future problems

5.3 DEMOGRAPHIC TRENDS AND ECONOMIC GROWTH

5.3.1 Population

The size of the population has so noticeable an effect on the volume of travel performed that it is usually given initial consideration in any attempt to develop quantitative descriptions of travel behavior. It is logical to assume that larger numbers of people generate more occasions for social and economic travel as well as greater desires for recreational and vacation travel.

While it is clear that the influence of population is an important force in determining the volume of intercity travel, the precise relationship between population and travel is not intuitively evident. Travel that is the result of social and economic interaction would appear to be closely related by cross-products of population. Whereas, the population of the destination point has little or no bearing on the volume of vacation and sightseeing travel. Rather than speculate as to the exact relationship between population and travel, a direct proportion has been assumed and several models have been tested in this investigation.

The population of the United States has already exceeded 200 million people and is growing rapidly. The estimated rate of growth for 1967 was 1.01%.[5] Growth projections in judgment models imply an average annual growth rate of 1.53% per year through the year 2000.[6]

5

The population of the U.S. by the year 2000 is estimated to be between 295 and 384 million.

A logical question might be how this affects the growth of air travel? The domestic revenue passengers enplanements will go from 74.4 million passengers to an estimated 420.0 million in 1980.[7] The Federal Aviation Administration projects an 11% per year increase in revenue passenger miles from 1970 through 1980. This will be an increase from 81.6 billion in 1968 to 288 billion in 1980.[7] One can readily include from this that although population has a large influence on air travel there are other things to consider.

5.3.2 Disposable Income and Leisure Time

The effects of disposable income and leisure time on air travel is not as discernable as the effect of population. It becomes more obvious when we look at the people who fly. "The 1963-1964 domestic survey (conducted by the Port of New York Authority) revealed that almost eight out of ten passengers had attended college, that 63 percent of all passengers were in professional, technical, managerial or official occupations, and that 63 percent of all passengers were traveling for business purposes. The median family income of the 1963-1964 air passengers was $15,000 (as compared to $6,190 for the population as a whole)."[8] The average disposable income per household will increase from $5,661 per year in 1948 to an estimated $10,350 per year in 1976 in constant 1959 dollars.[6] Although there has been a marked increase in disposable income since 1948, there has also been a marked increase in household expenditures. Income, therefore, has an affect on demand and is used as an input in the demand models.

The average workweek will go from about 41 hours in 1965 to an estimated 35.4 hours in 1976 and 30.7 hours in 2000.[6] This reduction in work hours may be offset by increased commuting time. The major effect will come from a change in the use of one's leisure time. The rising level of educational attainment produces an awareness of cultural opportunities which could create a desire for travel. "It has been estimated that by 1980 approximately 80 percent of the total at-home free time will be occupied by activities such as games or sports, politics, or cultural self-improvement."[8] The trend in the reduction of retirement age and the improved retirement plans being offered by many companies coupled with the advent of the jumbo jets and reduced airline fares will greatly increase the demand for air travel.

5.4 THE ROLE OF THE FEDERAL GOVERNMENT IN FINANCING

Financial matters can only be acknowledged as the vital link in the chain of realizability for any system under consideration. Pertaining directly to this area, it has been established that the federal government will be assuming an expanded role in the financial concerns of the air transportation industry in the next several years. As will be brought out in this section, almost every facet of the air transportation industry is experiencing monetary difficulties which encourage greater federal participation. From the airlines, faced with the outlay of billions of dollars for new aircraft in a time of declining profits, to the airports, needing vast capital expenditures to keep from falling further behind in their race with demand on their facilities, the need for federal involvement is evident.

5.4.1 Airline Financial Picture

The airline financial picture has progressively deteriorated in the last few years. Instead of maintaining a rate of return near that deemed "reasonable" by the Civil Aeronautics Board,[9] as was achieved in the period 1964-66,[10] the airlines have experienced a declining rate of return. Sharing the responsibility for this trend are enormous investments in new equipment, especially in the purchase of new generations of aircraft, coupled with continuing inflation which results in increased expenses, particularly for labor.[11,12,13]

Projections generally agree that the airlines will have to seek outside investment in the period under consideration in this study.[10,11] This gloomy forecast is even more universally adhered to if the industry is expected to contribute financially to airport improvement programs.[9,15] The problem here is not that external money is needed as much as where the money is to come from. The airlines glamour image in investment circles has been tarnished considerably both by their recent drop in earnings and by their miserly attitude toward stock dividends.[14]

If, as a result, outside money sources do begin to dry up, the other alternatives are Civil Aeronautics Board (CAB) approved fare increases or aid from the federal government. The latter option exists due to the government's historical concern with public safety and the nation's economic welfare The form of federal aid preferred by the airlines is investment tax credit.[16] Another possibility is pure subsidy, the historical precedents for which include air mail subsidization and the existing arrangement providing aid to United States sea-borne commerce.

CONCLUSIONS AND RECOMMENDATIONS

1. Airlines will likely need some federal aid in the coming

decade, probably in the form of investment tax credits rather than outright subsidy.

2. Federal involvement in airport and airway financing will entail the establishment of a trust fund similar to the highway trust fund and financed through a system of user charges. Matching grants and loan subsidization is the most likely way money will be dispensed from the trust fund.

3. Direct federal financial sponsorship of civil aviation research and development will continue in the areas of financing demonstration projects, funding programs concerned with public welfare, and, sponsoring those projects too large for private industry to handle.

5.4.2 Airport and Airway Financing

The situation at airports has become increasingly bleak the last several years as the demand on airport facilities by the airlines and public alike has burgeoned overwhelmingly Rather than being a bonanza for airports, the mass utilization of their facilities has acted in conjunction with encroaching public land use and the concomitant introduction of society-oriented restrictions on operations to overtax the system. As a result, airports and related airway systems have been shown to be far from showcases of efficiency. Instead, they have become the major source of expensive delay - both in terms of time and money. With the outlook for ever increasing air traffic to handle the expected snowballing passenger and cargo demand, the only solutions would appear to be in the areas of drastically altered ATC procedures and/or a great influx of investment funds for the purpose of improving and expanding the existing airway and airport system.

Since the early 1930's, the funds for airport and airway development have come from a combination of federal, state, and local sources. Originally, the money for investment in airport facilities had come from local sources. Traditionally, general obligation bonds have been the mainstay of local funding. However, competition for these funds from the whole gamut of public works projects - education, sewers, streets, welfare - is combining with the usually present statutory debt limits to put the squeeze on airport improvement programs. The other large source of local funds has been the revenue bond issue, used extensively for terminal financing. These bonds are attractive to communities because they do not draw on tax money for payment, leaving the tax money for use in other projects. In the absence of past records of reliable earnings, however, revenue bonds for new developments may be unmarketable unless excessively high interest rates are guaranteed. Both of these bonds are susceptible to voter rejection. Clearly, the pressure on these sources of revenue from a myriad of new and growing community needs as well as voter reluctance to passively accept ever increasing community indebtedness is making the local money situation uncomfortably tight and unpromising.[17,18]

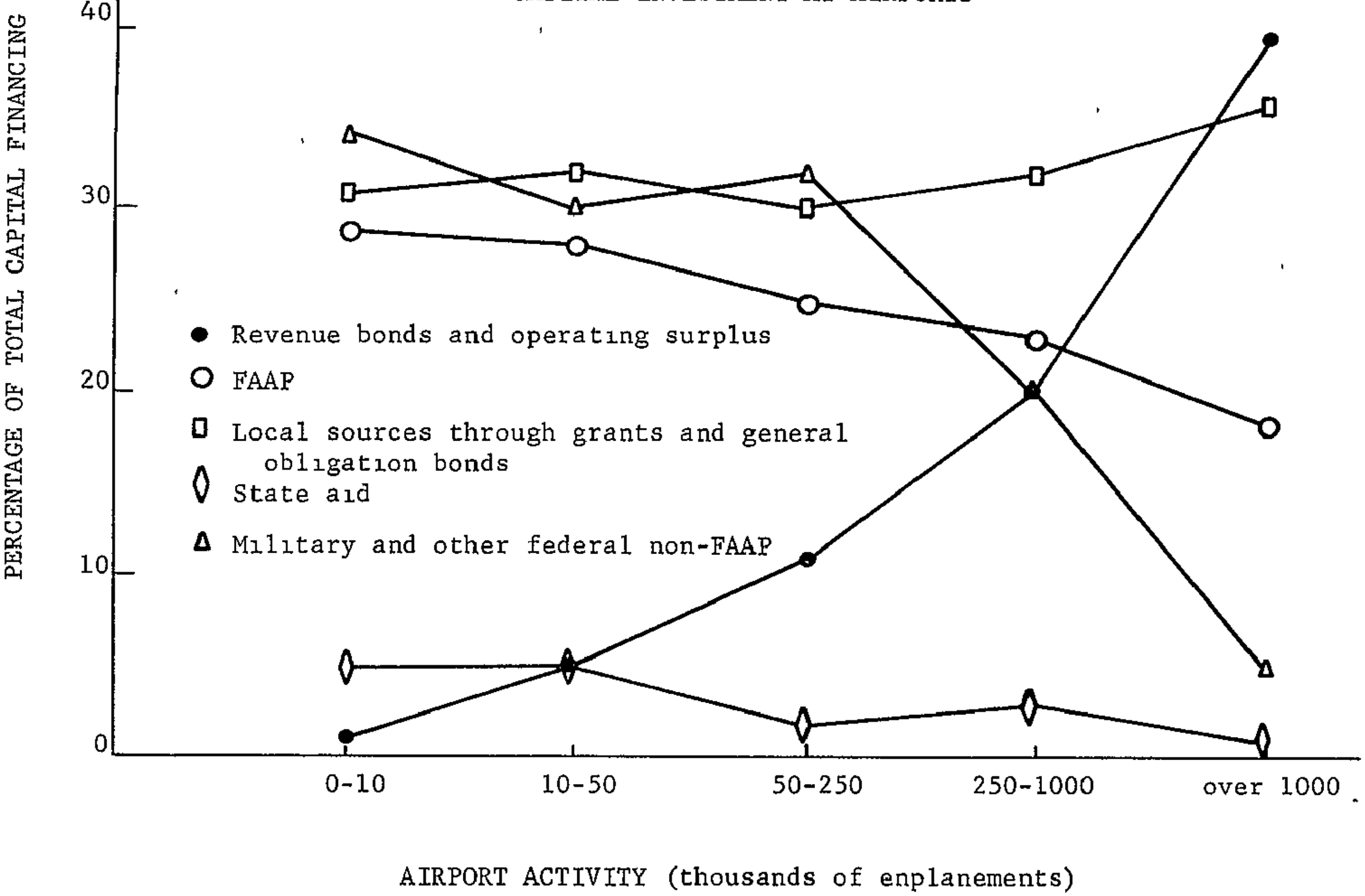
With the advent of the antidepression programs of the 1930's, Federal money became available. Federal involvement continued through the early 1940's as part of the World War II defense effort. In 1946, the Federal Airport Act was passed under which a limited amount of Federal matching funds have been provided through the Federal-Aid Airport Program (FAAP).[17] This continued Federal participation has been justified mainly by Federal concern for both public safety and airport system efficiency. The former is well established by precedent and Congressional mandate.[17] The latter is a direct result of traditional Federal involvement in matters affecting the nation's economic welfare. Both of these benefit from Federal involvement in planning and by Federal encouragement of air system development through financial aid.

Federal financial programs are initiated with the premise that direct aid acts as an inducement for making needed improvements,[19] with conditional aid resulting in overall system uniformity, and the potential threat of withholding aid encouraging proper maintenance and operation of an airport as required by overall system needs.[17] The main benefit of Federal aid has been its role as the "prime stimulant in achieving nationwide airfield development . . . . Federal aid is the device, in the absence of regulatory action, which enables the Federal Government to fulfill its public responsibilities relating to airport safety while simultaneously permitting the imposition of many national objectives upon local government.[17]

State aid in financing airport development has been comparatively meager in the past. As shown in Figure 5.4.2-1, which compares the relative contributions of state, local, and Federal fund sources to airports of several activity levels, experience has shown that the community burden has not been lessened appreciably by state financial assistance. Although the consensus of airport management is for an increased role by the states in airport financing,[20] the state governors unanimously feel that the states cannot assume the burden for airport system development nor should they be expected to do so, at least totally, due to the interstate nature of air transportation. Instead, state governments "will and should give priority to public works programs of direct benefit to the citizens within its

FIGURE 5.4 2-1

SOURCES OF FINANCING FOR PRESENT
CAPITAL INVESTMENT AT AIRPORTS



boundaries"[17] such as schools, sewers, and so on.

With both state and local funds already at a premium, where is the money going to come from for the airport and airway system development required in the next several years? Self-financing of capital development needs by the airports themselves is of limited potentiality as indicated in Figure 5.4.2-2 which shows the complete lack of self-financing capability for the average small airport. Since airports of lesser activity are much more numerous than those of the profit-earning larger sizes, numerically few airports can help themselves. In fact, approximately 75 percent of the air carrier airports in the United States have no appreciable revenue bonding capability.[17]

Greatest attention is focused on increased Federal financial involvement coinciding with a program of nationwide system planning and coordination. The additional Federal financial aid, however, makes it necessary to develop new sources of revenue. The most likely method is by the imposition of an augmented "user charge" system on the air transportation industry. This is generally acknowledged as perhaps the fairest way to apportion the financial burden since those who benefit from the system improvements are those who pay for system development[17,21,22] The term "augmented" user charge system was employed to emphasize that the idea is not a new innovation. Already in use is a tax on fuels used by general aviation aircraft as well as a percentage tax on domestic air passenger tickets. Potential user charges include a percentage tax on charges paid for air freight, a tax imposed on commercial jet aviation fuel, and a passenger service charge or "head tax" as is currently in vogue in Europe.[8] Figure 5.4.2-3 shows the expected annual income over the

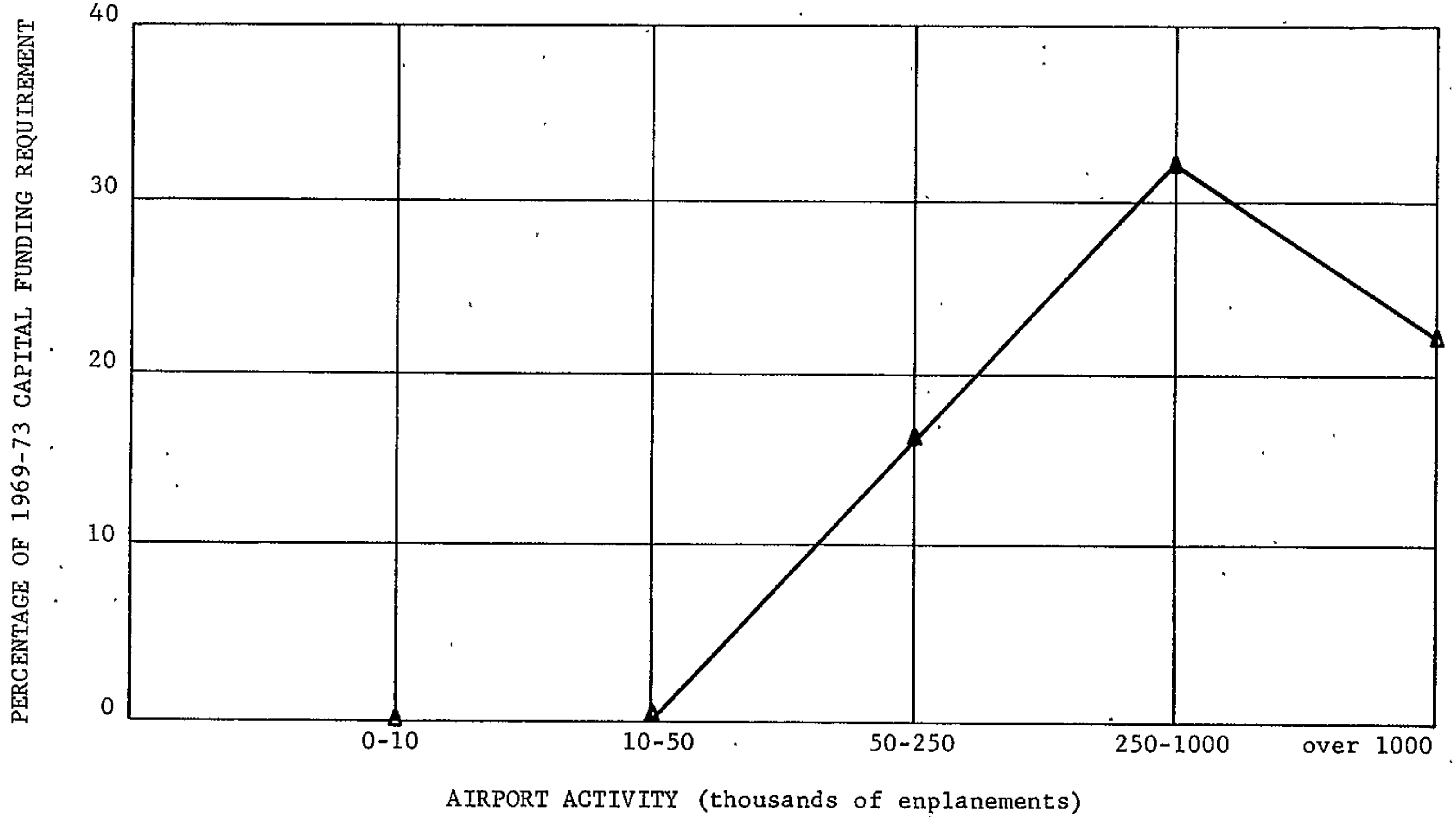


FIGURE 5.4.2-2

SELF-FINANCING CAPABILITY OF AIRPORTS

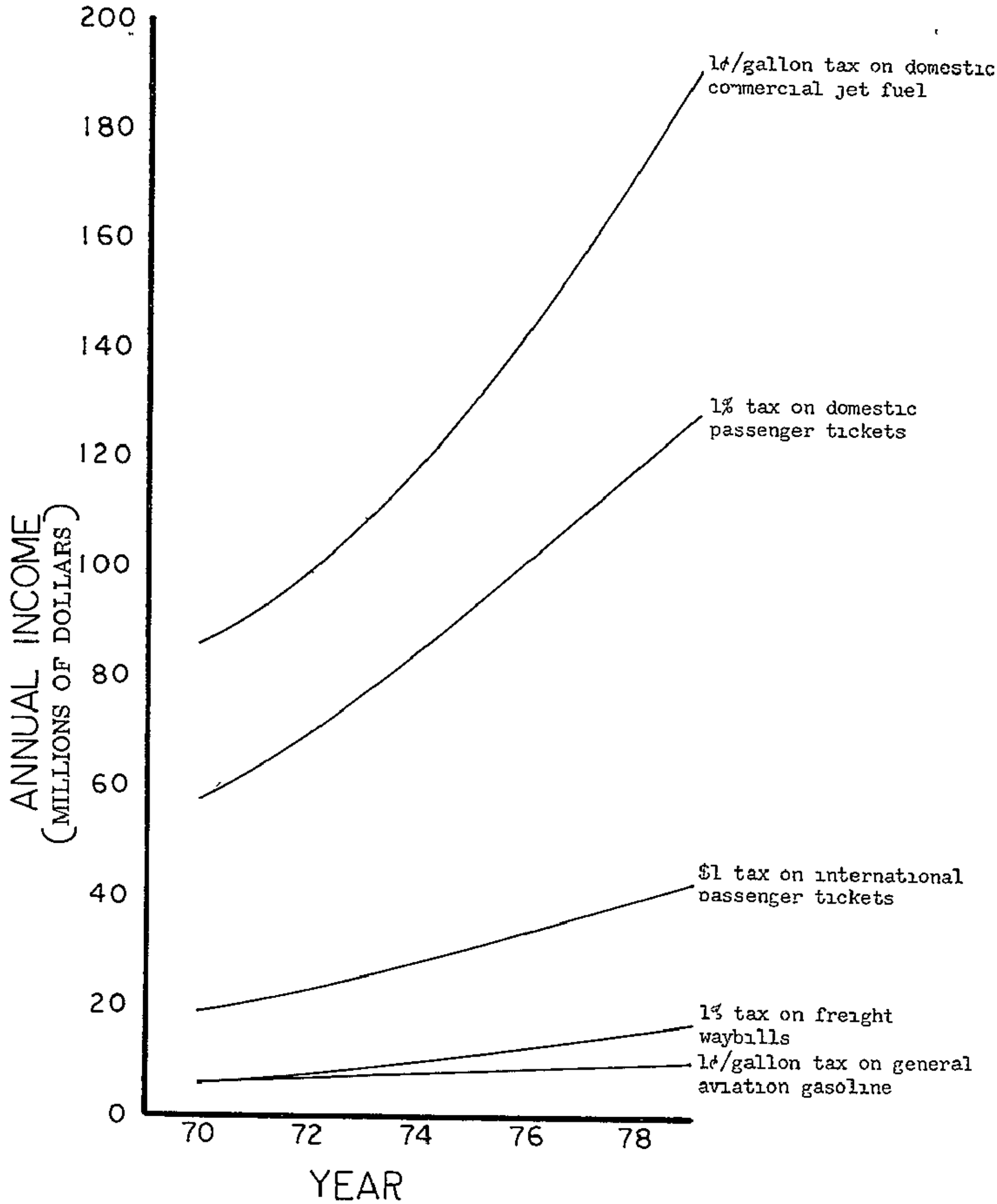
next several years from a unit taxation of these alternative user charges.

About the middle of June, 1969, the Administration of President Nixon made public just such an expanded user charge plan in which a combination of taxes - an eight percent tax on airline tickets for domestic flights, a five percent tax on air-freight waybills, a $3.00 tax on tickets for most international flights, and a nine cent/gallon tax on all fuels used by general aviation - was proposed to generate the income for an airport and airway improvement program covering the next decade.[23] Of particular interest is the absence of any tax on commercial jet aviation fuels in spite of the potential shown in Figure 5 4.2-3. This is most likely because the Federal Government recognizes that the airlines' funding capacity, already imperiled by the present declining return on investment (see Section 5.4.1), could become critically insufficient with the imposition of a fuel tax Both direct and indirect harm to the airlines' financing picture would be incurred, the former from immediate loss of available income, the latter through a declining investment attractiveness to various financing institutions. It is justifiable to assume that the airlines, in attempting to remain economically viable, would be forced to pass the tax on to their customers in the form of increased passenger fares or freight rates. The eventual result, as far as both the consumer and Government are concerned, would be the same as that gained by merely increasing the taxes on domestic and international passenger tickets and on freight waybills.

In choosing between alternative methods of administering the money collected under the user charge system, the Federal trust fund stands head and shoulders above the other possible choices. The

FIGURE 5 4.2-3

ESTIMATED ANNUAL INCOME FROM ALTERNATE SOURCES



similarity of needs during the inception period of the Federal highway program and the airport and airway development program indicates that the advantages of the trust fund leading to its use in the former program still apply to the latter

Among the most notable attributes of a Federally administered trust fund are the following:

1. Use of the funds is restricted to that purpose originally intended.[17] This alleviates the possibility of incurring the enmity of fund contributors if, as is often the case when money is deposited into Federal or state treasures as a general fund, some of the funds are diverted to other needs.
2. The trust fund provides a relatively stable source of money for a program of great longevity.
3. Federal administration of funds with this system guarantees a greater degree of control over system development according to nationwide priorities and in accordance with specific design criteria.
4. The need for a program capable of making up ground in an area long neglected is best served by a trust fund for all the above reasons.[17]

There is a variety of possible ways to dispense the funds each of which has its advantages and disadvantages as enumerated below:

1. Low interest loans at rates below those on the open market could be funded by using the user charge revenues to pay the difference between Government borrowing and Government loaning costs. This method is the least costly alternative from the borrower's viewpoint, however, it merely provides

a new source of debt rather than a means of relieving the existing debt load and cannot avoid the limitations of statutory debt ceilings

2. Loan principal payments or loan subsidy is attractive to the borrower since it not only provides a means of debt payment, but also makes borrowing easier due to Government subsidization of the principal The debt incurred, however, is still subject to debt ceilings and this method of dispensing money would be subject to tight controls.

3. Guaranteed loans of the VA and FHA home financing types would involve the least Federal funds and cost to the taxpayer. Here, in return for a guaranteed interest rate ceiling, the Government guarantees to pay the lender if the borrower defaults. This type of arrangement is particularly useful if the credit rating of the borrower is questionable. Once again, however, statutory debt ceilings are still applicable. Also, this method is not a source of debt payment, but merely encourages additional indebtedness

4. Total grants are a boon for the recipient, but a bane for the grantor. They induce unnecessary development projects due to the lack of the sponsor's financial involvement and, if not controlled closely, could strain the trust fund's capacity. Its usefulness in projects of high priority, however, make it well worth considering.

5. Matching grants, as used in the present FAAP program, have distinct advantages, making them a most attractive alternative. Recipients are encouraged to undertake needed developments, but unnecessary investments are discouraged by the

cost sharing feature. Also, it is easy to include inducements to meet certain design criteria established to provide for system uniformity and efficiency.[17]

The most practical method if dispensing the trust fund money is a combination of subsidized loans and matching grants where the latter alternative is employed in situations where debt ceilings or some other factor precludes the use of loan subsidization.

The current philosophy of the Federal Government as far as airport financial aid is concerned is to avoid involvement with those portions of the airport not directly related to public safety and system efficiency In practice, this has limited aid to the airfield portion of the airport while funding for the terminal area has been taboo due to the latter's potential as a revenue producing agent While this capability is undeniable, Federal involvement in other than just an advisory and technical assistance role is becoming unquestionably necessary. Clear justification for reasons of system efficiency exists where the lack of capacity in a terminal area jeopardizes utilization of Federal investment in the airway and airfield portions of the national air transportation system. Due to the recognized backlog of needed terminal improvements requiring a new capital funding source, at least a temporary suspension of the present philosophy regarding Federal aid is required. A limited and indirect role is probably the more acceptable degree of Government participation. Here it is suggested that the Federal Government merely condone a locally administered uniform passenger service charge imposed at the option of the local government with the concurrence of the air carriers serving the area. The more direct role would result from treating terminal areas in the same manner as the other portions of the airport already eligible for Federal aid.[17]

5.4.3 Government Financial Participation in Research and Development

The involvement of the federal government in aeronautical research and development efforts has a long history. This, however, is a history consisting largely of indirect involvement with civil aviation. Good examples of this indirect nature of federal involvement are the innumerable developments in military aircraft that have found application in civil aviation such as the jet engine and metallurgical advances.

Today, however, direct federal sponsorship of civil aviation research and development is becoming necessary We are living in a world of intense international competition in the air transportation business putting pressure on a government traditionally concerned with the nation's economic welfare. The air transportation industry of the United States has become an important cog in our national economy. This is particularly true where it interfaces with the international market due to the unhealthy nature of the United States' balance of payments in recent years. Thus, it is vital that the airlines representing the U. S. retain the position they enjoy in international competition. It follows that they must necessarily take the lead in adopting economically promising technological innovations This practice, however, may be injurious to the nation's economy if a deficit in the balance of payments results from a considerable airline investment in foreign technologically advanced equipment. This was an important consideration in the recent government financial involvement in the SST program.[25] Knowing that the French and British governments were jointly financing the Concord's development, as was the

Russian government with its TU-144, and also aware of the inability of any individual company or combination of companies to handle completely the research and development costs alone, the federal government found it necessary to accept a portion of the financial burden. However, the precedent setting arrangement for repayment of government funds along with a reasonable return on this investment as the SST is marketed makes the federal involvement less than a direct subsidy.

In general, direct federal financial aid of civil aviation research and development should serve the primary function of bearing the "financial burden of advancing aeronautical technology to the point where the private sector can see the opportunity for profit or where user government agencies can proceed to systems development."[26] This is best accomplished by:

1. "Funding applied research that exceeds the resources of private industry but that serves as a stimulant to the industry and provides a source of fundamental information."

2. "Funding development programs when private economic resources or motivation are inadequate for achieving national objectives."

3. "Funding programs associated with the public welfare."[2]

The first area mentioned includes such things as sponsorship of specific demonstration projects[8] The federal involvement in the SST program falls into the second area. Typical of the last area are FAA tests conducted to develop techniques and materials for air passenger safety in the event of aircraft crashes.

Federal financial involvement in the future will continue in each of the areas above. It is likely, however, that direct sponsorship of any individual project to the degree experienced in the SST program will not become commonplace. Instead, this will remain dependent on the existence of a set of similarly motivating circumstances.

5.5 GOVERNMENT POWERS, POLICIES, AND PRACTICES

The orderly planning and coordinated implementation of an overall transportation system and attendant facilities is complicated by the diverse relationships between the federal government and the governing bodies of the states, regions, and municipalities. Basically, only those functions enumerated in the Constitution and subsequent implementing legislation are reserved for action at the federal level, all other functions become the responsibility of the state or local political jurisdiction (the "home rule" philosophy is still a very potent force in our national political life).[8] After considering the multiplicity of factors affecting the air transportation system, it was decided that three are of such critical importance that they should receive special attention. They are: a) airport and support facilities, b) noise, and c) air-traffic control.

The structure of government in the United States has been stable. Changes have been few, evolutionary, and slow to develop. There is no reason to expect any deviation from this pattern in the future.[8] It is assumed, therefore, that the benefits and structures which flow from our present system of federal, state, county, city, and regional governmental units will continue to apply to the air transportation industry. Proposals which do not recognize the statutory, constitutional, and sovereign rights of each governmental jurisdiction are impractical. At the same time, changes in emphasis can and must take place within the basic government structure so that it can accommodate itself, to some extent, to the changing demands placed upon it by a rapidly expanding industry. In this section, the relationship between the air transportation industry and government at its various levels will be considered.

5.5.1 The Federal Level

The federal government should play an important role in the orderly development of the national air transportation system by exercising leadership in the identification of important problem areas and by financing key demonstration projects. Carefully structured programs should be directed toward the development of various means of transportation, some incorporating advanced technology, so that the public will be able to select those systems which best meet their requirements

AIR TRAFFIC CONTROL

The development, installation, and operation of the air traffic control system has been and should remain a federal responsibility. The ability to efficiently handle the traffic, both en route and in terminal areas, is decreasing rapidly, owing in large measure to the fact that the funding for all phases of the airway system has fallen behind the technology. An aggressive and energetic research and development program is needed, followed by adequate procurement of both the personnel to man the facilities and the required hardware.

AIRPORTS

The federal government participates in planning and in certain regulatory functions with respect to the nation's airports through the Federal Aviation Administration, limited federal funds have been disbursed to public airports under the Federal Aid to Airports Program (FAAP), a grant-in-aid program.[17] The federal government has also attempted to improve the nation's airport pattern by adopting a policy of fostering the development of regional airport when such a facility can conveniently serve two or more communities having insufficient traffic to support full service individual airports. As congestion increases at the principal airport serving major metropolitan areas, the federal government, through the CAB and FAA, should induce the diversion of both air carrier and general aviation traffic to peripheral airports. The success of this policy depends upon the suitability of the peripheral airport and available transportation to final destination.

Although such federal policies may result in a more efficient distribution of traffic among airports, the problem of accommodating traffic growth will require a major additional effort. Attention must be focused on movement between point of origin and airport and between airport and destination The Department of Transportation should play a leading part in the overall effort, in cooperation with state, regional, and local agencies. DOT should also provide the leadership in conducting systems studies to identify, analyze, and rank air transportation goals as well as the research and development needed to attain these goals.

NOISE

The federal government has become increasingly involved in the aviation noise problem. The technical aspects of noise and its control will be discussed in Section 5.6. Noise not only leads to the imposition of restrictions on operations at present airports but also makes far more difficult the selection of sites for future airports. Although the problem of noise in the vicinity of airports manifests itself locally, proposed or actual remedial measures frequently affect matters within the jurisdiction of the federal government. Thus, takeoff or landing procedures and patterns to reduce noise in communities adjacent to airports involve the FAA [29] Proposed limitations on noise-generation characteristics of aircraft and engines would become part of the FAA certification procedures Research efforts to reduce noise at the source concern the Department of Transportation, FAA, NASA, and other federal organizations. Programs for land use can be within the scope of HUD and DOT programs.

The federal government should maintain an energetic leadership in the government/industry study of flight procedures and steep-glide slope approaches in the interest of noise attenuation. Smoke emanation from aircraft engines should also be the subject of study at the federal level

Noise in relation to the use of land in the vicinity of airports is an additional aspect of the problem which requires federal attention Although basic determinations with respect to zoning are local matters, there are federal programs which can contribute to the alleviation of noise.[29] HUD in particular should be able to make worthwhile contributions in this area by arranging for proper location of redevelopment projects

Similarly, the Department of Transportation and other government agencies concerned can locate compatible projects (i.e., highway access roads, transit facilities, railroad spurs, etc.) in airport neighborhoods so that they underlie frequently used flight paths, in a true transportation corridor. In addition, eligibility for land acquisition and eminent domain for noise protection under the Federal Aid to Airports Program can be established with rights to administer uniform laws for the nation

In all of these efforts it is important to recognize that without local support no worthwhile gains will be made. Even a program which would make federal funds available for the acquisition of property and the conversion of such property to noise-compatible use would be of no consequence unless the local government can be persuaded of the value and acceptability of such a program and will participate wholeheartedly.

RESEARCH AND DEVELOPMENT

In reviewing the progress made by air transportation during the past decade randomness by which new technologies found their way into the total air transportation system and the dependence of these new technologies on military Research and Development was noted. An essential requirement of the future will be to undertake systems studies of the total air transportation system with the objective of identifying and ranking research and development goals. Such studies would begin by relating air transportation to the nation's transportation system and national goals as has been attempted in this program. They would end by identifying, analyzing and ranking R & D goals in terms of safety, time, and economic advantages of penalties to the system as a whole.

Although it has been traditional for most aeronautical R & D to be carried out by industry, universities and nonprofit institutions, strong government leadership will be required in the future in certain areas. Federal involvement in air transportation R & D will be required in the following ways:[29]

(1) Setting R & D goals and priorities through studies of the total transportation system.

(2) Funding applied research that exceeds the resources of private industry but that serves as a stimulant to the industry and provides a source of fundamental information.

(3) Funding development programs when private economic resources or motivation are inadequate for achieving national objectives.

(4) Funding programs associated with the national welfare.

(5) Carrying out programs that require interaction among governmental agencies.

Participation and leadership must come from both the legislative and executive branches of the government through wise policies and effective policy implementation. With the creation of the DOT, the federal agencies and their charters are now structured in such a way that the government can exert its proper leadership role. However, all aviation legislation should be reviewed for consistency to eliminate unnecessary restrictions and duplication, and ensure that sound economic development is fostered. Leadership should be provided by the DOT in carrying out systems studies to identify, analyze and rank R & D goals. These goals should be formulated with reference to the nation's total transportation system, including the increasing public demand for air transportation as well as the various economic factors that bear on this aspect Although an in-house government capability should be developed and maintained by the DOT in transportation systems analysis, industry and other private institutions should also be encouraged to participate in carrying out these studies.

The long record of excellent performance by NASA and its predecessor, NACA, in research and development clearly suggests that it should play an even greater role in this area. NASA's role should be expanded to involve not only flight vehicles and propulsion systems but all aspects of R & D of importance to the national air transportation system. It will be important for NASA to adopt a policy of directing its attention to those R & D goals, including the development and construction of carefully selected experimental hardware, that optimize the productivity of the total air transportation system.[29]

Such expanded activities would involve, for example, the development of new technology relating to air-traffic control as well as airports and their support facilities. This is not intended to insinuate that the responsibilities and authorities of DOT and the FAA be diminished but only to allow for more effective operation and use of capability. Unlike NASA, which is oriented toward R & D, DOT and FAA are oriented primarily toward regulatory and operational activities. The FAA has been unusually effective as an instrument for the construction, maintenance and operation of federal aids to navigation. However, the technologies that formed the basis for the development of these aids were derived largely from military-supported R & D. Although DOT and the FAA would continue their traditional role of establishment and operation of air-navigation facilities, airways control, and traffic management, the new technologies that will be required to support this difficult assignment are unlikely to come from R & D sponsored by these agencies.

GENERAL AVIATION

Before the airlines became the predominant mode of intercity common carriage in the United States, the operational conflicts between general aviation and air carrier traffic were few. Now, however, with larger and faster transport aircraft moving with greater frequency along the airways and into and out of airports, there is growing concern that there are basic incompatibilities between aircraft performance factors of this traffic and those of general aviation. If this concern is warranted, federal intervention will be necessary.[28]

Regulation of airway use is wholly within the control of the federal government. Somewhat more complicated is the question of where the federal interest lies with respect to regulation or control of general aviation use of nonfederal airports. It is frequently pointed out that when a local sponsor accepts funds from the Federal Aid to Airport Program funds it agrees to "keep the airport open to all types, kinds and classes of aeronautical use without discrimination between such types, kinds and classes." Sometimes overlooked is the proviso "that the Sponsor may establish such fair, equal and not unjustly discriminatory conditions to be met by all users of the airport, as may be necessary for the safe and efficient operation of the airport, and provided further, that the Sponsor may prohibit or limit any given type, kind, or class of aeronautical use of the airport if such action is necessary for the safe operation of the airport, or necessary to serve the civil aviation needs of the public."

It would seem that this language may well involve the federal government in decisions on regulation, limitation, or restriction of use at congested metropolitan airports. Classification itself is an area where federal effort would be worthwhile. Immediate attention should be given to the development of a precise and practical method by which the various segments of the general aviation community can be classified.

DEMONSTRATION PROJECTS

As a part of the overall effort by the federal government to effect a better transportation system for the United States much work is being done in the use of advanced technology. The expenditure of federal funds in this connection is encouraged with respect to both air and ground vehicles. Intercity short-haul transportation may be a fertile field for the use of STOL or VTOL aircraft. Airport-to-city-center, and suburb-to-city-center travel might also benefit from the use of this equipment. It is recommended that the Department of Transportation conduct an intensified study in these areas.

5.5.2 The State and Regional Levels

For operations wholly within state boundaries, state governments perform limited regulatory functions similar to those of the federal government Thus, for example, some state regulatory bodies certify intrastate airlines and act on tariff proposals.

AIRPORT PLANNING

In many states an aviation department or bureau inspects, licenses, and issues standards and regulations for airports. Application for funds from the Federal Aid to Airport Programs (FAAP) by local communities are frequently required by state law to conform with state planning and to have the approval of the state department concerned. States in many instances provide grants-in-aid to airports, to supplement FAAP moneys.[8]

There is a growing trend toward the establishment of state departments of transportation with the responsibility for overall transportation planning. Such departments may well fill a long-standing gap in planning, too often the plans for highways, transit facilities, and airports have originated with various uncoordinated groups. State transportation departments, together with regional planning groups established under state governments, can perform many essential functions In all of these activities, the state governments must of necessity operate in a manner which does not conflict with federal activities.

REGIONAL AIRPORTS

State governments have in some instances assumed direct responsibility for airport operation. More often they have established, either alone or by joint action with neighboring states, regional bodies to operate airports in defined areas which exceed the geographical limits of local jurisdictions.[28] The establishment of such regional organizations is a healthy trend, more often than not, airports serve extensive geographical areas rather than individual communities By broadening the boundaries of the operating body, the financial burden can be spread over the population served by the facility. Conflicts between local jurisdictions with respect to airport policies are lessened when all jurisdictions involved are represented on the governing board.

Establishing broader areas for airport planning and operation also facilitates the solution of problems arising from conflicts between general aviation and air carrier traffic. The development of "reliever" airports can be meshed with the development of a major terminal, so that general aviation flights will have acceptable facilities in the same area.

NOISE

Noise is a serious problem at the state and regional levels of government, as well as at the federal and local level. More than one governor has had to heed the complaints of the people living in the vicinity of an airport and use the power of his office to secure agreement on noise-abatement measures. In the selection of a new airport facility, complaints from those who might be exposed to aircraft noise are probably the most significant obstacles faced by the developer. State legislators, too, have been brought into the conflict through the vigorous protests of their constituents. Although activity in this field has so far been limited to the individual efforts of certain legislators, it is always possible that statutory action may be taken, particularly with respect to airports controlled by state governments.

Where regional bodies operate airports, noise is a very direct problem; in some cases it has been dealt with directly through rules or regulations.

One of the problems faced regional authorities in coping with the airport noise problem is their inability to control land use beyond the confines of the airport.[3] In most cases the regional airport body has no control over adjacent land use, and even where the neighboring land is undeveloped the zoning power resides in local jurisdiction. For the most part, in the vicinity of developed major airports, zoning and existing land use is predetermined.

This situation is not likely to change in the near future. It must be emphasized once again that proposed solutions which ignore the pattern of governmental organization in the United States are impractical.

5.5.3 The Local Level

Most of the publicly owned airports in the United States are the responsibility of local municipalities, and the impact of policies and decisions at the federal and state levels is felt at the local level.[8] It is imperative that local airport management keep itself informed concerning proposals and possible actions of government aviation bodies at higher levels, (route cases before the CAB, actions of the FAA with respect to airways and airports, and, of course, policies and actions of state bodies concerned with aviation matters).

Conversely, the higher levels of government should give timely advice to the local authority, so that there is opportunity for feedback.

AIRPORTS

In some cases, planning at the federal or regional level will indicate that a local airport is not appropriate for air carrier activity, and this presents difficult problems for local decision. In most cases municipally operated airports will continue to serve the traffic in the area. The forecast increase in activity, however, will necessitate capital expenditures far beyond the demand which have previously been made.

There is grave doubt that all local communities will be able to individually raise the needed funds through grants or loans. Some federal action will be needed if funds are to be produced in time to meet the demands of forecast traffic.

NOISE

The problem of jurisdiction with respect to noise control has already been discussed. Problems sometimes arise even when the airport is municipally operated, if it is physically located outside the municipal boundaries, or adjacent to a neighboring municipality. Zoning can be a useful device if both the airport and the adjacent areas are within the boundaries of the community, and provided the adjacent lands are undeveloped.[29] Unfortunately, such a situation is rare.

In some instances undeveloped lands near the airport can be acquired for buffer-zone purposes. Tax relief has also been suggested as compensation for airport noise As airports become larger, however, these remedies become more difficult to apply and consequently are of limited value.

ADDITIONAL AIRPORTS

It is a rare community that has geographical boundaries large enough so that when an existing airport has become congested another facility can be located within the community limits.

When a new airport must be built by a municipality, it is most likely that it will have to be located within another jurisdiction. The consent of residents of the proposed area must be obtained in most instances, and the need must therefore be expressed to the public in a convincing manner. Establishment of a regional board, district, or authority may be helpful in overcoming public resistance by giving the residents of the new location a voice in the construction and operation of the facility.[28]

5.5.4 Conclusions

1. There is an established structure of government in the United States which fixes relationships between federal, state, county, city, and regional governmental units. A change in emphasis, markedly improving cooperation between political entities, is increasingly evident and reflects the urgent requirements of the air transport industry and associated forms of transportation.

2. Federal level

   (a) The capacity of the federal airways system is insufficient to handle the rapidly expanding requirements of increasing air traffic.

   (b) The federal government should play a major role in developing the national transportation system by exercising leadership in the identification of important problem areas and by financing key demonstration projects.

   (c) The noise resulting from aircraft operations is an increasingly serious problem. Noise-abatement requirements may well prevent realization of the full potential of airport facilities.

   (d) General aviation operations are increasing even more rapidly than are air carrier activities.

   (e) Carefully planned and programmed demonstration projects provide an excellent means for the public to evaluate and select the most suitable forms of transportation. Such projects are particularly important in the development of mixed-mode solutions to the airport access problem.

   (f) NASA's role, in research and development, should expand to involve not only flight vehicles and propulsion systems but all aspects of R & D of importance to the national air transportation system.

3. State level Increasingly, regional organizations are being set up to deal with various aspects of the transportation problem. Section 204 of the Demonstration Cities Act encourages the establishment of this type of authority. Such

entities can prove effective in dealing with problems of airport site selection, airport planning and financing, mixed-mode transportation for access to and from airports, aircraft noise, and compatible land use

4. Local level. A great many of the foregoing problems also occur at the local level (county or municipality). Local jurisdictions can make an important contribution to the solution of these problems. Of serious concern is the imminent loss of a significant number of privately owned public-use airports in developed or developing areas, because they are not eligible for grants-in-aid. This happens at a time when additional "reliever" airports for use by smaller aircraft in large metropolitan areas are a necessity.

5.5.5 Recommendations

1. Additional appropriations are urgently needed for the necessary research, development, procurement, and manning of U. S. airway navigation and communications equipment. The imposition of equitable charges on all users is needed to offset the extensive appropriations required

2. Aggressive government/industry research programs to alleviate aircraft noise should be continued under the direction of the Department of Transportation, and NASA, with emphasis on the following.

   (a) Adoption of an accepted standard of measurement for aircraft noise.

   (b) Development of an engine that will be both quieter and more economical.

   (c) Establishment of flight systems or procedures that will result in necessary noise attenuation with no derogation of safety.

3. The federal government should sponsor programs for the compatible use of land under the flight path in the vicinity of airports. Government and regional agencies must play an important part in such programs.

4. Adequate and equitable provision in the national air space system must be made for general aviation users. General aviation must in turn accept prescribed standards of aircraft equipment and pilot proficiency.

5. The federal involvement of carefully planned demonstration projects in various phases of the overall transportation problem is necessary to enable the public to select those systems which best meet their requirements.

5.6 ENVIRONMENTAL POLLUTION

Environmental Pollution is an undesirable change in the physical, chemical, or biological characteristics of air, land and water that may harmfully affect human life or that of other desirable species, our industrial processes, living conditions, and cultural assets; or that may waste or deteriorate raw material resources. Pollutants are the residues of the things we make, use, and throw away. Pollution increases not only because as people multiply the space available to each person becomes smaller, but also because the demands per person are continually increasing, so that each contributes more year by year. As the earth becomes more crowded, one person's trash basket is another's living space.

Many of the debilitating effects of a dirty environment on human beings cannot be assessed, physiologically or psychologically. The hidden costs of people's lost time and the accompanying expenditure of resources-traveling to work and returning to pleasant or perhaps only bearable homes, or to find open spaces for recreation, are also increasing. The problem is of the utmost urgency because many of the effects of pollution on our environment may be irreversible or, at least, may take generations to correct.

In considering the costs of environmental pollution, two aspects are considered: the cost imposed on society by the mere existence of pollution and the costs involved in eliminating the polluting agents. These two costs can be related in such a way as to provide a rational approach to determining at what level the cost of pollution is minimum to society. Two lists representing the two categories of cost, that of control and that of "malfits" to society, would provide the raw material. "Malfits" as used in this discussion means negative benefits or "robbery" of public rights and resources

If the items in each list could be assigned realistic dollar values - and for the moment assume that this is possible - they could be conveniently represented as curves similar to those presented in Figure 5.6-1a. As the level of pollution rises above zero, the cost of pollution (curve C_p) may remain at zero because our measurements are not sensitive to the costs of very low pollution levels. At some point the curve C_p can be expected to begin rising and to continue rising at an increasing rate, eventually becoming vertical at extremely high concentrations where all life would cease. The cost of control (curve C_c), on the other hand, is zero at the level of pollution prevailing in the absence of controls. To reduce pollution below this point costs must be increased. The C_c curve eventually becomes vertical as it rises to the left, indicating that at low levels of pollution all our resources cannot further reduce the level

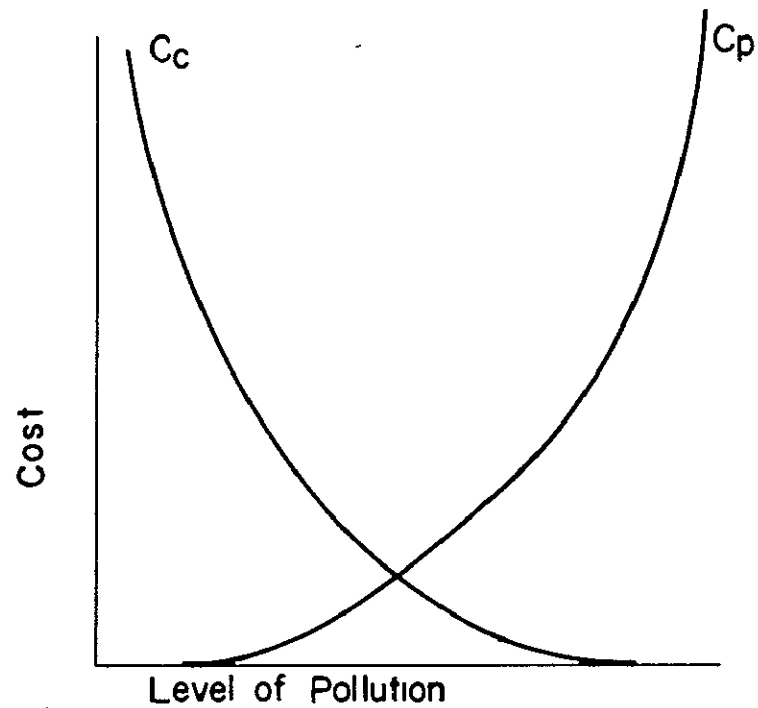


FIGURE 5.6-1a

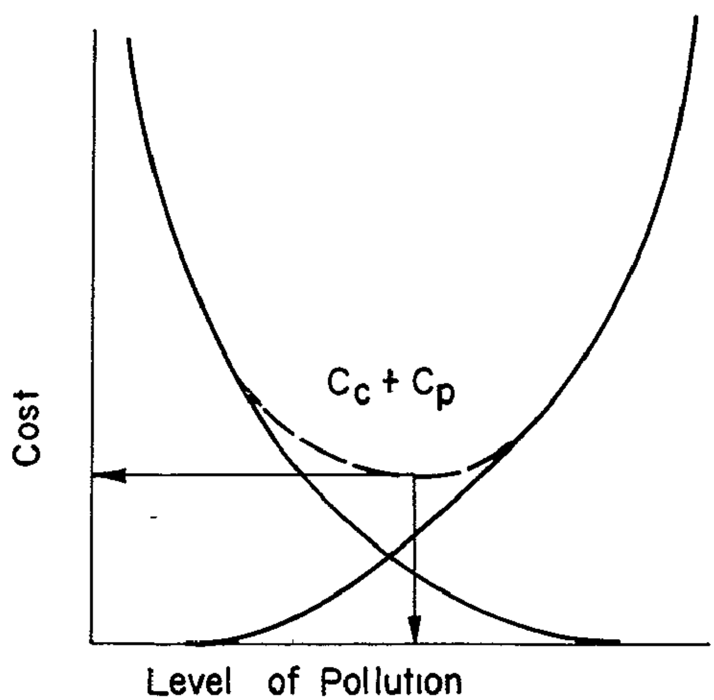


FIGURE 5.6-1b

of pollution

The curve shown in Figure 5.6-1b is the sum of the C_p and C_c curves and presents theoretically the level of environmental pollution that presents the point where both the costs of pollution and the costs of control, taken together, are minimum From a social point of view, this presents the minimum cost to society but it will not be necessarily a level that is socially acceptable in the 1980's Society should and will demand that this "robbery" is stopped and adopt a philosophy of preventing all environmental pollution

5.6 1 Air Pollution

Increased concern about the general problem of air pollution has focused attention on all possible sources, as well as mobile sources. Mobile sources include air pollutant emissions from aircraft, automobiles, and diesel trucks and buses. Air contaminant emissions from mobile sources are similar to those from other combustion sources, but tend to emit larger quantities of carbon monoxide and organic matter. They also emit significant quantities of oxides of nitrogen and particulate matter.

Overall, aircraft cannot be considered a significant source of air pollution but may present local nuisances or aggravate area pollution in the vicinity of airport operations. However, with the increase in size and number of aircraft that are projected for the 1980 time period, it is important that engine exhaust emissions and the valid relationship of these to the overall pollution problem be understood.

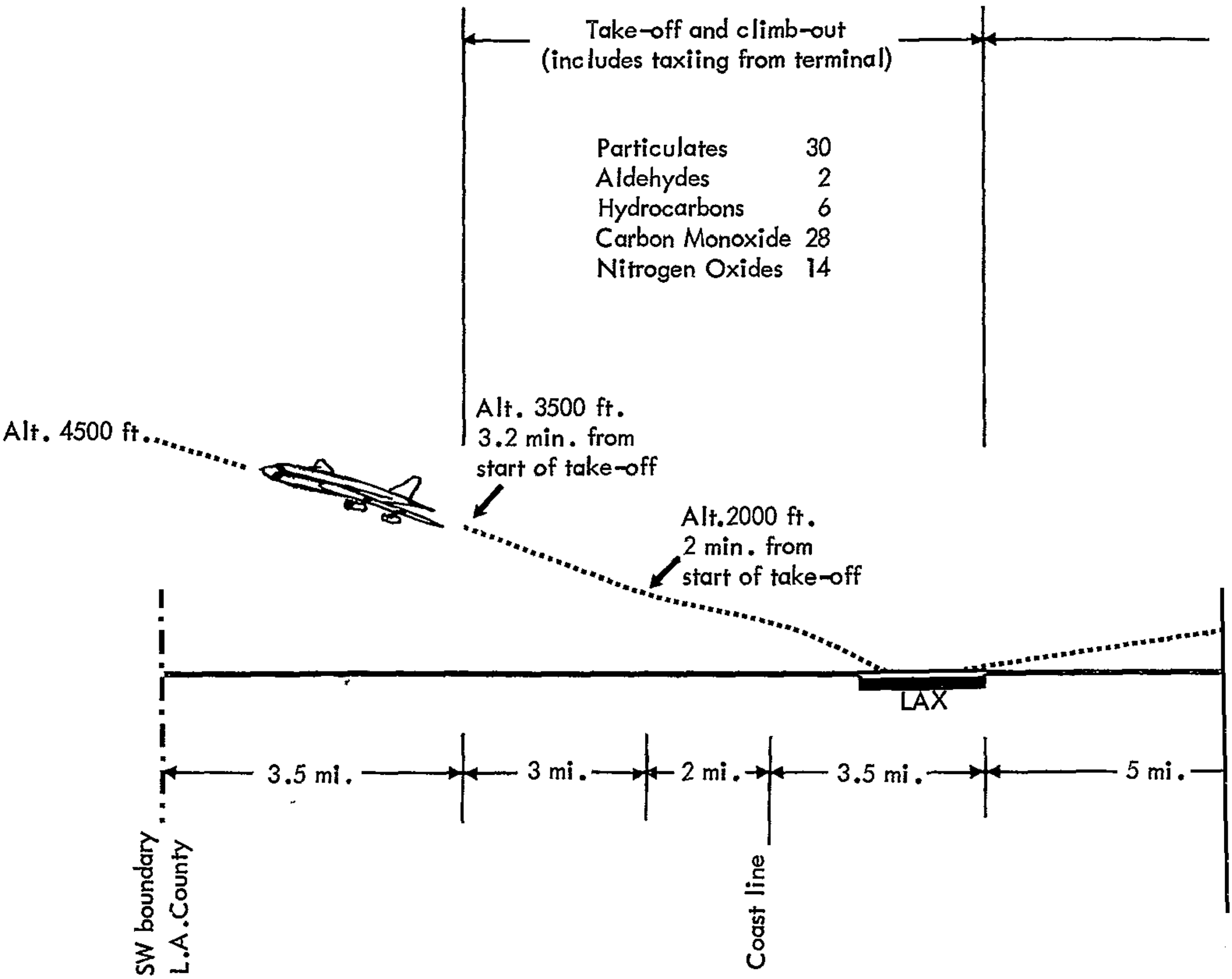
The first commercial jet aircraft began regular passenger service in October of 1958 and its exhaust smoke attracted a great deal of attention. By the late 1960's the smoke problem had become serious at major airports in the U. S. and Europe. The city of Los Angeles, already plagued by smog problems, requested the assistance of the airlines in determining the nature of the emissions from jet aircraft. The results of their studies are summarized in Figure 5.6.1-1. In 1962 and again in 1967 emissions from aircraft jet engines were measured by engineers at Barttesville. In the fall of 1964, the U. S. Public Health Service got into the act and undertook a study of Kennedy International Airport.

Intense jet engine smoke was first associated with water injection used for power boost on takeoff, but dry engines, subsequently developed, have retained the smoke problem. With experimental investigation continuing and technology advancements that are expected in the future to provide thrust for the jumbo jets it is not considered unrealistic to expect a smokeless engine. Particulates and dense smoke on the basis of pounds per flight has been reduced to some extent by the more powerful turbofan as shown in Table 5.6.1-1 which relates emissions for the three major types of commercial aircraft today· jet, turboprop, and piston-powered engines. The emissions are presented on the basis of pounds per flight where a flight is a combination of a landing and a takeoff that takes place below the altitude of 3500 feet. Emissions at cruise altitude are not of major concern.

For comparison purposes, the following table shows the emission factors for aircraft and automobiles. The levels for aircraft are based on Los Angeles work reported in 1960 on the Pratt & Whitney aircraft JT3E-6 turbojet engine.

PROFILE OF FLIGHT PATTERNS AND A
COMMERCIAL JET AIRCRAFT OPERATIONS

Emissions to Atmosphe

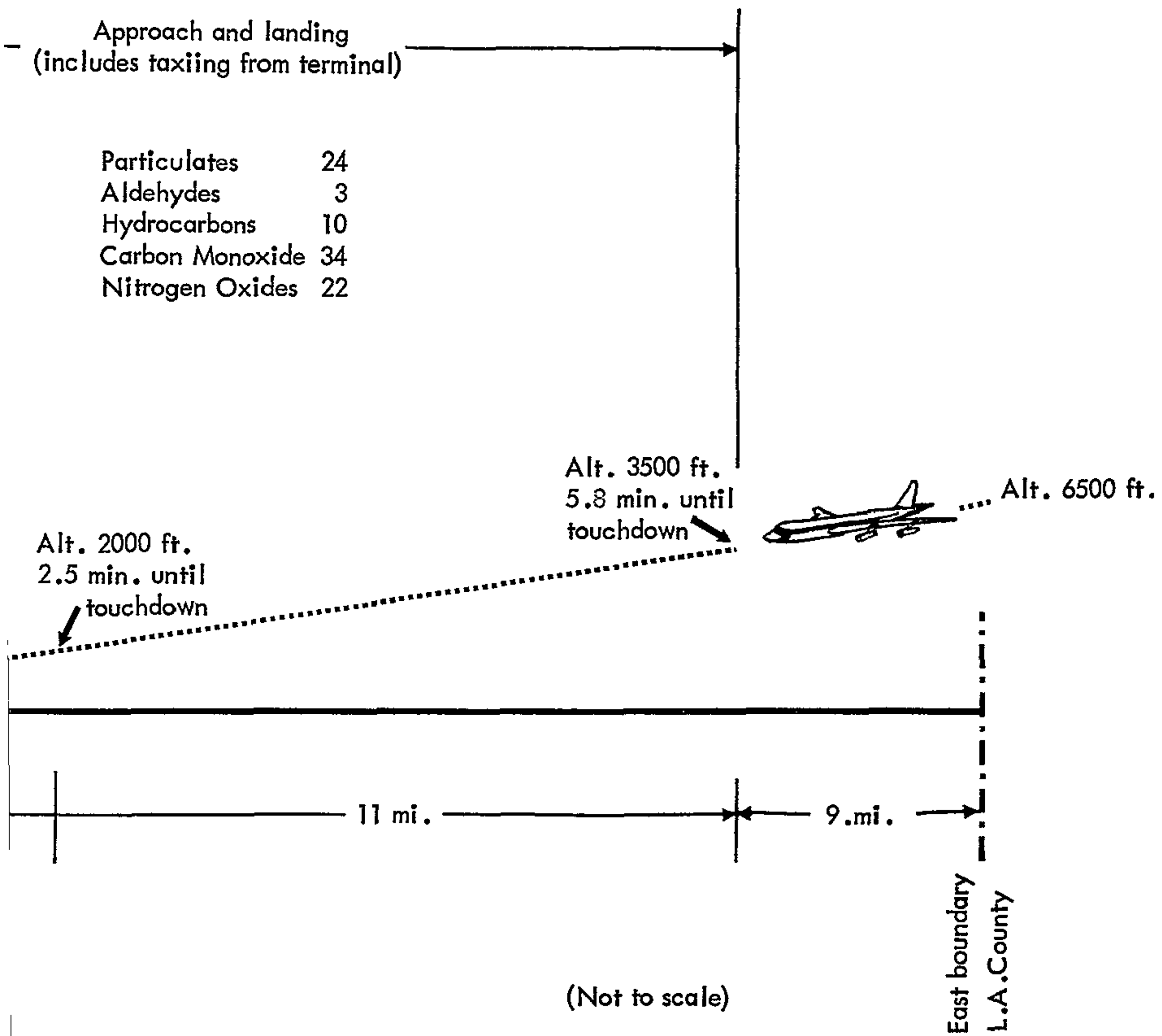


Figure

FOLDOUT FRAME 1

ONTAMINANT EMISSIONS FROM
OS ANGELES INTERNATIONAL AIRPORT

ounds per Jet Aircraft



.1-1

FOLDOUT FRAME 2

Estimated Emission Factors

Pollutants	Jet A/C w/o Water Injec. lb/1000 gals.	Automobiles lb/1000 gals.
Aldehydes	6	4
Carbon Monoxide	56	2910
Hydrocarbon	15	524
Oxides of Nitrogen	37	113
Particulate	34	11

The two significant comparisons are the relationship of the gaseous contaminants (aldehydes, carbon monoxide, hydrocarbon, and oxides of nitrogen) and the particulates emitted from this engine to that emitted by automobile.

With the exception of particulate emissions, the jet aircraft emissions are insignificant in comparison to automobile emissions. It would appear that if the visible contaminants can be eliminated then the air pollution contribution would be very small. From knowledge gained of the design variables affecting the combustion process and smoke generation the following items have been determined to offer the largest gains in smoke elimination: a) primary zone changes (to provide a leaner fuel-air ratio at the head of the combustor), b) vaporizer burners, c) fuel injection techniques, and d) fuel additives.

A smoke density reading of 20 percent (based on the Von Brand scale) is considered to be the maximum acceptable level for engines by 1980. This is just below the threshold of visibility and would result in smokeless aircraft operation. Reductions in smoke density of 50-70 percent would be required by the 1980's. Also, particulate emissions per flight are expected to be reduced by over 50 percent as a result.

Several tests have been conducted on JT & D engines to determine effects of operation with one fuel additive approved for use during test stand operation only. Under simulated commuter aircraft flight operations smoke densities showed 15 percent and 19 percent reflectance readings at takeoff and climb power settings respectively. However, due to adverse engine effects from the fuel additive, the use of this additive as a means of reducing smoke density is not recommended. In addition, use of this additive results in the emission of toxic metallic oxide compounds. The long-term effect of these toxic compounds on humans, animals and vegetation is unknown. Therefore, emphasis must be placed on combustion chamber and fuel injection design characteristics to minimize exhaust smoke

5.6.2 Land Use

Land use in and around airports should be compatible with airport operations from a standpoint of noise, obstructions and hazards. The integration of airport and community planning will encourage the establishment of compatible land uses around the airport and in addition may offer a satisfactory airport location for community recreation and transportation facilities, municipal utilities and industry.

Land areas surrounding the airport often fall under the jurisdiction of several municipalities, districts, or counties often making regulation of land uses difficult. From the standpoint of regulation of land uses in respect to aircraft noise and hazards there is an obvious need for an entity authorized by the state that is over and above the local jurisdiction. The choice of such an approach is the responsibility of the jurisdiction involved in the problem, and should be made only after a thorough investigation of local requirements. Whatever the type of regulation and coordination selected, it should have the basic power of self-sufficiency to insure permanency, impartiality, and efficiency. Procedures related to the regulation of land uses around airports which may be used in conjunction with government programs include property acquisition through outright purchase or by power of eminent domain, the enactment of zoning legislation; the purchase of easement, the use of housing and building codes, the reduction of property taxes, and land conversion.

An airport system study should be developed as part of the comprehensive metropolitan planning program. It should be the responsibility of each metropolitan planning agency, in cooperation with local airport sponsors, to prepare airport system plans as soon as possible, so that they will be reflected in future revisions of the National Airport Plan (NAP). A proposed airport project, to receive federal aid, must be included in the NAP.

Congress, in 1954, authorized the Urban Planning Assistance Program, which is supervised by the Department of Housing and Urban Development. This encouraged comprehensive land use planning at all levels of government and provided a logical basis for the coordination of various federal-aid programs.

Each and every airport, and its environs, is different from every other airport and must be considered individually in solving its problems of incompatible land uses in the airport area. The regulation of land uses around an airport can be achieved with the least cost to the community through zoning, the use of housing and building codes and the reduction of taxes. The federal government and several of the states have developed programs to aid local governments in shaping their local environment by providing guidance, research, planning, technical assistance, and financial aid. This service should continue in the future.

It is important that all technical resources be used to the fullest extent to insure compatible land use in and around airports in the future.

5.6.3 Noise and the Sonic Boom

Basically, one may view the aircraft noise and sonic boom problems as a pollution or community environmental problem. The major problems considered result from noise produced by flight operation of aircraft. For most conventional aircraft, noise during takeoffs and landing is of primary concern, although noise from cruise flight is of concern for some types of V/STOL aircraft operating at relatively low altitudes.

Noise produced by ground-runup operations presents a problem in a limited number of localities In general, however, means of limiting noise for extended group-runup operations are available; thus, no urgent technical problems appear to exist in this area.

A survey of current and potential problems associated with aircraft noise resulted in the general conclusion that, although emphasis and funds for noise and sonic boom research and development are increasing, the projected rate of progress is likely to fall short of providing needed solutions Two areas of concern for jet-noise suppression are the high-speed jet as used by the SST and the low-speed jets generated by current turbofan engines. The SST has been banned, in this study, from overland flight because of the sonic boom.

The approach to jet-noise suppression must be re-examined both theoretically and experimentally and redirected towards a better understanding of noise generation. The major objectives in jet-noise research are an understanding of jet-noise-generating mechanisms and quantitative descriptions of how radiated noise and aerodynamic mixing characteristics of jets are related and how they are both dependent on the geometric configuration and flow velocity of the nozzle (or suppressor).

No method exists that completely identifies the physical principles of noise production in a rotor-stator set Until the aerodynamic characteristics of the blades can be related to the noise generation, design of a quiet compressor will be a matter of trial and error, and predictions of engine noise output will be educated guesses It is important that the noise-generating mechanisms be identified so that the compressor and turbine can be designed to meet minimum noise criteria.

Engineering data have been gathered in the past eight years on the design of acoustic liners for compressor-noise suppression. But the physics of the problem (such as the propagation of high-intensity noise through the moving turbulent medium, and the energy dissipation in a porous material of high-intensity noise superposed on airflow) has received little attention. The study of noise attenuation by porous linings requires extension to include high-intensity sound waves and the investigation of aerodynamic devices for improving the absorptive properties of the linings in high-speed airflow.

The most identifiable and most annoying feature of some types of helicopter and V/STOL aircraft is the impulsive noise, commonly referred to as blade slap, which can be generated under conditions of blade-vortex interaction, critical Mach number, and severe blade stall. A second problem sometimes involved with the conventional helicopter is the nonimpulsive rotational (and vortex) noise generated by the main and antitorque-producing tail rotor blades. As the disk loading and top speed of either of these rotor systems is increased, both types of noise (nonimpulsive rotational and vortex) increase and become more annoying and objectionable.

Much information has been gathered on the propagation of noise through the atmosphere and along the surface of the earth, but only the coarser parameters of the atmosphere affecting propagation have been considered. Such parameters as surface temperature, humidity, and wind velocity are certainly of prime importance, but consideration of these parameters along greatly limits accuracy of predicting the propagation characteristics of the atmosphere (particularly near the ground) and the earth surface.[42]

The results of several series of NASA-FAA tests clearly show that reasonable noise abatement takeoff procedures reduce noise over important segments of the takeoff path.[43] The resulting amount of noise reduction will vary widely with the type of jet aircraft and with operating conditions.

The increased-glide-angle approach during landing appears to reduce aircraft noise levels moderately. However, the procedure tends to create several other technical problems that may require considerable study.[44]

Over the past 10 years most of the work in "psycho-acoustics" related to aircraft noise has been concerned with the application of the perceived-noise-level concept.[45,46] Little initial consideration was given to such factors as structure of the sound wave in terms of its time history, duration effects, presence of impulsive spectra, and tonal components of the noise Current work is being pursued to combine the effects of level, duration, and spectural irregularity, i.e., tone components into a measure that is presently called "effective perceived noise level."

Operation of V/STOL aircraft in the central business district will have to be essentially noise free or at most, no noisier than present day ground traffic, to be acceptable to the public in the 1980's and therefore practical. It has been suggested that a suitable provisional level for initial design of VTOL aircraft should not exceed 95-100 PNdB measured 500 ft. in any direction at a point of observation from the aircraft.[46] It seems at this point that a prediction of a maximum allowable noise level of 90 db would not be unrealistic to expect by the 1980 time period. This noise standard would be measured and administered according to FAA regulation on noise.[48]

5.6.4 Conclusions

1. The public will reach a point where they insist that "robbery" of environmental resources from society as a result of environmental pollution be ended and that a philosophy of total control of pollution be adopted.
2. Increased attention will be focused on aircraft pollutant emissions in the future requiring increased R & D efforts to cope with these problems
3. Improved technology will be required for design of an engine which will result in smokeless aircraft operation in the 1980's.
4. There is a need for the development of model housing and building codes that specify noise construction standards for

building in airport environs. Such codes could be made part of zoning regulations around airports

5. Comprehensive plans should be developed using a systems approach to insure compatible land use in airport environs.
6. The maximum allowable community noise level in the 1980 time period is predicted to be 90 db.
7. Technology for suppression of the sonic boom will not be advanced enough by the 1980 time period to allow overland SST flights.

5.6.5 Recommendations

1. The atmospheric environmental field should be surveyed and R & D programs should be initiated that are aimed at the most limiting environmental problems in the foreseeable future.
2. Develop criteria for land use categories, in terms of noise exposure, suitable for zoning and planning of residential, commercial, industrial, public assembly and other functions.
3. Identify the noise-producing mechanism of jet noise in terms of appropriate flow and geometric factors for mean jet velocities less than 1500 fps and mean jet velocities greater than 2000 fps.
4. Pursue a noise suppressor development program based upon knowledge gained from research.
5. Develop methods for accurately predicting the noise produced by vehicle in motion on the ground or in flight.
6 Extend present knowledge of the physical parameters of sound that influence individual reactions to aircraft noise, develop psycho-acoustic measures suitable for use in all

aircraft/engine certification requirements, and develop more accurate psychological and sociological techniques for predicting community response to aircraft noise

7. Continue both government and industry design studies aimed at minimizing sonic boom, with emphasis on unconventional as well as conventional aircraft configurations.

8. Undertake and pursue a physical response research program to further study the effects of sonic boom

5.7 COST PENALTY ON THE SYSTEM

To force the system to handle a passenger with a minimum amount of delay, a penalty factor was added to the total system operating cost analysis. Essentially, the procedure amounted to paying the customer at a fixed rate for the time spent waiting for his flight and while actually en route. Almost identical methods have been used in previous studies, but the "wage" to be used has always been a rather nebulous, often completely unjustifiable quantity.[51,52,8]

The value developed for this study is derived by calculating the average family income of a typical air traveler. This value is corrected for the fact that this same typical air traveler is not necessarily the family wage earner.

Approximately 60 percent of the total air passenger traffic for U. S. domestic flights was for business reasons in 1965 (increasing slightly to about 63 percent by 1980).[53] Assuming all these air travelers to be the wage earners in their families, it is still necessary to consider what portion of the remaining 40 percent of the air passenger traffic consists of wage earners. It is reasonable to assume that these non-business flights, undertaken for personal

TABLE 5.7-1

CALCULATION OF FAMILY INCOME OF TYPICAL AIR TRAVELER

Family Income, dollars[53]	Portion of All Air Travelers[53]	Representative Income in Range, dollars**	Contribution to Typical Air Traveler's Family Income, dollars
Under 2000	.01	1000	10.00
2000-2999	.01	2500	25.00
3000-3999	04	3500	140.00
4000-4999	.05	4500	225.00
5000-5999	.05	5500	275.00
6000-7499	.13	6750	877.50
7500-9999	.15	8750	1312.50
10000-14999	.30	12500	3750.00
Over 15000	.26	20000	5200.00
Annual family income of typical air traveler			$ 11815.00

**Taken as the midpoint of wage range except for $20000 figure which was estimated.

$$\text{Average hourly wage of typical air traveler} = \frac{\$11815}{\text{year}} \times \frac{\text{year}}{2080 \text{ working hours}}$$

$$= \$5.68 \text{ per working hour}$$

Correction of "Wage" Due to Non-Wage Earner Portion of Air Traveler Population reasons such as vacations, family visits, and so on, are participated in by the entire family. Assuming only one wage earner per family, the average size of which can be shown to approximate 3.7 people,[55] calculation of a corrected hourly "wage" proceeds as follows.

$$\$5.68 \times (.60 + .40/3.7) = \$4.02 \text{ per hour}$$

The next major decision is how best to apply this "wage" in the total system operating cost analysis For this it is necessary to determine the passenger preflight waiting time. Then an equation is used to combine the hourly "wage" and this waiting time to find the cost penalty imposed on the system.

The waiting time was obtained by assuming that the passenger demand remains constant over the entire range of operational hours in a day. This assumption relieves the difficulties in handling calculations dealing with characteristically nonuniform air passengers demand on the system. Justification of this assumption lies in the viewpoint that at present demand is a function of the schedule being offered in contrast to the argument (adhered to particularly by the airlines themselves) that scheduling is done to fit the existing demand. Assuming the former, it follows that demand will adjust accordingly if a uniformly spaced flight schedule is used. With a constant demand, it is easy to see that the average waiting time between the uniformly scheduled flights equals the number of operational hours per day divided by twice the daily flight frequency.

One might think it logical to simply multiply this average waiting time by the already calculated "wage" to get the total cost. First, however, it is necessary to modify the "wage" to get a value more in line with its ultimate purpose. It was calculated on the basis of a 40 hour week while the potential time over which it could be applied against the system is the entire number of hours of airline operation per week. Therefore, a multiplicative constant of 40 divided by the total number of operational hours per week is applied to this "wage". This constant could be thought of as representing the probability that the delay time encompasses some part of the air traveler's working hours.

The final equation determining the cost penalty for waiting time delay is:

$$\text{Waiting cost per passenger} = \frac{\text{hours of operation per day}}{2 \times \text{number of flights per day}} \times$$

$$\frac{\text{40 work hours per week}}{7 \times \text{hours of operation per day}} \times \text{"wage"} = \frac{\$11.49}{\text{number of flights per day}}$$

This is the penalty factor added to the system cost analysis to account for preflight waiting time.

To further influence the system to the benefit of the customer, a penalty cost was imposed for en route flight time. The effect is to force the system into determining the best trade-off between decreasing block time and increasing vehicle cost. This is calculated as simply the block time between cities times the corrected "wage" determined earlier:

$$\text{Enroute cost per passenger} = \text{hours en route} \times \frac{\text{40 working hours per week}}{7 \times \text{hours of operation/day}}$$

$$\times \text{"wage"} = \$22.97 \times \frac{\text{hours en route}}{\text{hours of operation per day}}$$

To decide the number of hours the system is to remain in operation per day, it is necessary to weigh the desired result against present-day reality. Uniformly spacing flights around the clock would be the best solution, but this assumes demand could, in turn, be assumed to readjust to a constant (or near constant) value for the full 24-hour period. At present, there is a marked decrease in airline activity in the early morning hours, raising a question whether operations can realistically be scheduled uniformly throughout the entire day.[55] The system benefits from 24-hour service, however, make it the more attractive alternative. Besides simplifying the analysis considerably, utilization of the system's components to the fullest extent is the least expensive operational approach. An example is the striving by the airlines to keep an airliner in the air and earning money as much as possible. The savings which could be realized by not having to design for peak demands is a benefit of unquestioned importance. Hopefully, spacing flights uniformly throughout the day would have the effect of evening out demand in real life as well as in our hypothetical system. Accepting the 24-hour operational day, the cost penalty for flight time becomes.

En route cost per passenger = \$.96 x hours en route

The passenger's disembarking time was also considered. For instance, the incorporation of STOLports near the central business district of a city would be preferable to the air traveler to landing at a CTOLport on the outskirts of the metropolitan area. The proposed air transportation system, however, was not designed such that it was responsive to increasing and decreasing disembarking time. For this reason, no further consideration was given to including a disembarking time cost penalty.

The total cost per passenger imposed on the system to induce increased efficiency of operation from the passenger's viewpoint is:

$$\text{Cost per passenger} = \frac{\$11.49}{\text{number of flights per day}} + \$.96 \times \text{hours en route}$$

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APPENDICES

A.2.1 MULTIMODE GRAVITY MODEL

In this Appendix passenger demand predictions for air transportation are determined as part of a multimode gravity model which accounts for demands based on all forms of transportation (auto, bus, train, ...). Although this model was not used in obtaining the optimum air transportation system determined in this investigation, the demand results are included to aid future investigations.

Early conversations with the Department of Transportation yielded consideration of the demand model, CN-25.[1] The formulation as they use it is:

$$T_k(i, j) = \frac{W_k(i, j)}{\sum_k W_k(i, j)} T(i, j)$$

where:

$T_k(i, j)$ = one-way average daily demand from i to j using mode k.

$$T(i, j) = b_0\, b_1 \left\{ \left[(F_i) x 10^{-5}\right]\left[(F_j) x 10^{-5}\right] \right\}^{b_2} \left\{ \sum_k W_k(i, j) \right\}^{b_3}$$

and:

$$W_1(i, j) = a_1 t^{-a_2}\, c^{-a_3}\, (f')^{a_4}$$

F_i = Number of families earning more than $10,000 in i.

t = total travel time from i to j including access, egress, and line haul time.

c = total travel cost from i to j in current dollars.

f' = 1-exp(-kf).

f = average daily frequency of service for mode k on trips from i to j

b_0 = a scale factor depending on the year for which the cost is normalized.

This model has several advantages. They are:

(1.) The model is cost and time sensitive.

(2.) The model allows for induced demand and model trade off caused by service improvements; e.g., time and/or cost reduction.

(3.) The model is not mode specific. Four modes--air, rail, bus, and auto are considered, but they could be changed and new modes could be added and the model would still be functional.

(4.) Some data for the Northeast and California corridors are available [2,3]

The disadvantages are·

(1.) Data for modes other than air are almost nonexistent for areas other than the Northeast and California corridors.

(2.) Calibration of the model is quite involved as there are four modes to consider.

A.2.1.1 Calibration

There are several ways to estimate the constants of a prediction model such as CN-25. Expressing the relationship in terms of Logarithms forces the function to be linear so that a multiple regression analysis can be used.

The models used in this study, however, were correlated using a completely different method. Basically, the procedure employed is a search technique on a squared error term to minimize the total squared error (TSE). The total squared error is

$$\text{Total Squared Error} = \sum_{\substack{\text{all} \\ \text{points}}} \left[\text{Actual - Predicted} \right]^2$$

In the case of the D.O.T.'s CN-25 model:*

*Frequency was dropped from consideration as will be discussed in a following section.

6

$$\text{T.S.E.} = \sum_{\substack{\text{all} \\ \text{points}}} \left\{ \text{ACTUAL} - \left(\frac{a_1 t^{-a_2} c^{-a_3}}{\sum_k a_1 t^{-a_2} c^{-a_2}} \right)^{b_1} \left[\frac{F(i)}{10^5} \cdot \frac{F(j)}{10^5} \right]^{b_2} \left[\sum_k a_1 t^{-a_2} c^{-a_3} \right]^{b_3} \right\}^2$$

A search procedure called Pattern Search was then applied to this sum so that by adjusting a_1, a_2, a_3, b_1, b_2, and b_3 the term could be minimized. The values for these constants at which the total squared error is a minimum are the correct values for the expression.

The search procedure employed is an accelerated ridge climbing (descending) technique Essentially the procedure finds the direction of improvement for each variable and moves in that direction Each successful move is then followed by another larger step in the same direction. (A more detailed discussion of the procedure can be found in Foundations of Optimization by Wilde and Beightler)

It is noted that there are other search procedures that have produced faster results such as the Gaass-Levingburg method.[4]

The first decision made in the actual calibration was to drop frequency from consideration as it was felt that for longer distances, the effect of frequency on the demand becomes less.

A.2.1.2 Data for Models

Data availability was an almost insurmountable problem for the calibration of the model. There was little data available on modes of travel other than air, outside of isolated corridor studies conducted in the past. A decision was made then to disregard any Origin-Destination pairs for calibration that did not have data available for all four modes. Next it was decided to use the base year 1960 for the calibration since 1960 was a census year and there seemed to be some data available for that year on the various modes.

Further research was made and the region of study was narrowed down to the Northeast and California corridors as they had the best data. This meant that most of the O-D pairs used for calibration would not be the ones used in actual predictions; but this was unavoidable so the study was continued.

Finally, the study was condensed to include 30 O-D pairs composed of 12 cities from the Northeast corridor and nine cities from the California corridor (See Table A.2.1.2-1 for city-pairs considered). The data for these routes was readily available on all four modes.[2,3]

It was then necessary to obtain reliable information on populations of the various cities in number of families earning more than $10,000, access and egress times and costs for the various modes of travel in each city, and finally, travel time and cost for each of the routes considered The procedures used were the same for both calibration and actual prediction data.

A.2.1.3 Travel Time and Cost

The basic source of data for travel time was Future U. S. Transportation Needs by A. H. Norling.[5] Table VI-30 on Page VI-38 of that reference is reproduced below.

TABLE A.2.1.2-1

CITY-PAIRS USED FOR CALIBRATION OF DEMAND MODEL

Boston	- New York and Newark
Boston	- Philadelphia
Boston	- Wilmington
Boston	- Baltimore and Washington, D. C.
Providence	- Philadelphia
New Haven	- Baltimore and Washington, D. C.
New York and Newark	- New Haven
New York and Newark	- Philadelphia
New York and Newark	- Wilmington
New York and Newark	- Baltimore and Washington, D. C.
Trenton	- Wilmington
Baltimore and Washington, D. C.	- Bridgeport
Bakersfield	- Los Angeles
Fresno	- Los Angeles
Los Angeles	- Sacramento
Los Angeles	- San Diego
Los Angeles	- San Francisco
Los Angeles	- San Jose
Los Angeles	- Santa Barbara
Los Angeles	- Stockton

AVERAGE CITY-CENTER TO CITY-CENTER TRAVEL TIME BY MODE AND BY STRAIGHT-LINE DISTANCE FOR SAMPLE CITY-PAIRS

Straight-Line Distance Between City-Centers (in miles)	Total Travel Time by Mode (in hours)			
	Rail	Bus	Air	Auto
50	1.7	1.8	2.2	1.7
100	3.0	3.1	2.3	3.3
250	7.4	7.6	2.6	8.2
500	13.3	14.9	3.2	24.9
1,000	25.1	29.6	4.3	49.6
1,500	36.9	44.3	5.4	74.3
2,500	60.6	73.6	7.6	123.6

A functional relationship is defined by this chart so that intermediate figures of mileage can also be located. For the calibration and actual prediction runs, the travel time was obtained from this chart.

The same source was used for travel cost Table VI-33 on Page VI-36 is reproduced below.

TOTAL CITY-CENTER TO CITY-CENTER TRAVEL COSTS OVER STRAIGHT-LINE DISTANCES FOR SAMPLE CITY-PAIRS

Straight-Line Distance Between City-Pairs (in miles)	(In Dollars per Person)					
		Rail			Air	
	Bus	Coach	1st Class	Auto	Coach	1st Class
50	$ 2.50	$ 2.75	$ 4	$ 2	$ 11	$ 11
100	4.50	4.75	7	3	14	15
250	10.	12.25	18	12	22	26
500	18.	24.50	36	27	37	44
1,000	34.	71.		59	65	81
1,500	49.	107.		91	94	118
2,500	80.	178.		154	151	195

The above charts were used for calculations of travel time and costs for most of the city-pairs. Some data was available, however, on the pairs in the California Corridor from Reference 9. Whenever such data was available directly, it was used.

A.2.1.3 Access-Egress Time and Cost

The first decision made here was to assume access time and cost equal to egress time and cost. This is a controversial assumption but relatively unimportant when the possible percentage error is considered.

The next decision was to assume access and egress times and costs to be equal for all cities for rail and bus. They are given below:

	TIME	COST
RAIL	12	.56
BUS	14	.35

The access and egress times and costs for air were estimated for each of the cities from the Airlines Guide[6] using weighted averages for the various airports. These figures are given below:

TABLE A.2.1.3-1

ACCESS TIME AND COST

CITY (SMSA)	ACCESS TIME (Minutes)	ACCESS COST ($)
New York - Newark	65	5.10
Chicago	60	6.10
Los Angeles	40	3.83
Atlanta	60	3.50
Washington, D. C. - Baltimore	37	8 43
San Francisco - Oakland	40	4.10
Dallas - Fort Worth	43	7.20
Boston	25	1.90
Miami - Fort Lauderdale	38	5.00
Detroit - Ann Arbor	60	7 10
Pittsburgh	60	6.70
Philadelphia	50	3.50
Denver	50	3.10
Cleveland	60	4.30
St. Louis	50	4.30
Minneapolis - St. Paul	50	3.30
Kansas City	10	1.10
Houston	45	4.30
New Orleans	60	5.90
Seattle - Tacoma	43	2.70
Cincinnati	25	5.50
Providence	45	3.10
Hartford	25	6.70
New Haven	11	1.70
Bridgeport	12	1.90
Trenton	15	2.70
Wilmington	30	3.50
Bakersfield	15	1.50
Fresno	20	3 10
Sacramento	60	6.30
San Diego	10	1.50
San Jose	15	1.50
Santa Barbara	20	4.30
Stockton	40	2.70

A.2.1.4 Populations

Another necessary input for calibration purposes was the number of families in each city earning more than $10,000 in 1960. This data was obtained from the City and County Data Book.[7] To project these population figures into the future, it was necessary to determine the percentage growth rate of each city and the percent growth rate of the number of families earning more than $10,000.[8] (This rate is two percent for the entire country). The projected population for each city was then obtained by multiplying the compounded growth rate of the general population in each city by the compounded growth rate of the number of families earning above $10,000 in the country by the number of families earning more than $10,000 in 1960. The projected numbers foe each city in 1980 are shown in Table A.2.1.4-1.

A.2.1.5 Terminal Time

Terminal time, or the average time spent waiting in the terminals for the four modes involved also needed to be determined. Estimates of the times were obtained and are shown below. Two assumptions were made concerning the terminal times considered First, waiting times at each end of the trip were considered to be equal, and secondly, there is no terminal cost, i.e., there is no cost associated with waiting.

TERMINAL WAITING TIME

Intercity Mode	Time (Minutes)
Air	60
Rail	40
Bus	35
Auto	0

TABLE A.2.1.4-1

NUMBER OF FAMILIES EARNING MORE THAN
$10,000 IN 1980

New York - Newark	6,215,224
Chicago	3,140,457
Los Angeles	4,077,455
Atlanta	778,286
Washington, D. C. - Baltimore	2,345,242
San Francisco - Oakland	1,549,318
Dallas - Fort Worth	1,195,579
Boston	1,075,412
Miami - Ft. Louderdale	1,013,981
Detroit - Ann Arbor	1,849,573
Pittsburgh	924,668
Philadelphia	2,150,048
Denver	617,434
Cleveland	826,400
St. Louis	1,026,387
Minneapolis - St. Paul	758,179
Kansas City	559,071
Houston	961,351
New Orleans	515,232
Seattle - Tacoma	690,581
Cincinnati	515,151

A.2.1.6 Results and Conclusions

In the calculation of the demand forecasts, three sets of values for the constants were used. These values were then used to calculate the city-pair travel demand for 1966 and compared with actual data for that year. A comparison involving air travel demand only was made since the data was readily available and consideration was only being given to an air transportation system in the program. The three sets of values employed were:

(1) D.O.T.'s-actual figures used in the D.O T 's Northeast Corridor study were applied to the national model.

(2) Revised D.O.T.-all values except b_1 were held constant and a search procedure was applied on b_1. It was assumed that time-cost relationships were correct but that the scaling factor would change somewhat.

(3) Calibrated-all six values were allowed to vary and the resulting minimum point was used as the basis for estimation.

In the calibration run, the following results were obtained based on available 1960 data.

MODEL	SQUARED ERROR
D.O.T.	7.62×10^{10}
Revised D.O.T.	7.76×10^{9}
Calibrated	1.05×10^{9}

From these results the decision was made to drop the D.O.T. set of values and continue to work with the other two sets

The program was then set up with the following two sets of values for the constants contained in the models·

CONSTANT	REVISED D.O.T.	CALIBRATED
a_1	1.1144	5.0000
a_2	1 9102	2.0500
a_3	0.9551	1.5000
b_1	4015.0000	8200.0000
b_2	0.8254	0 2000
b_3	0.7655	0 4000

Population figures for 1966 were then fed into the program in order to determine 1966 demand figures (Travel time and travel cost estimates were not altered. Better results could probably have been obtained if the figures for time and cost were more accurate for the date considered.)

Two measures of accuracy were applied to the output of the program as compared with actual demand as reported by the CAB[9] on 160 of the 420 routes estimated. (This is only taking air transportation into consideration. For all four modes of travel 1680 demand figures were generated.) The two measures of accuracy employed were:

(1) Average Absolute Error

$$\frac{\text{ABS (ACTUAL-PREDICTED)}}{\text{ACTUAL}} \div 160$$

(2) Average Error

$$\frac{\text{(PREDICTED - ACTUAL)}}{\text{PREDICTED}} \div 160$$

The first measure, Average Absolute Error, is a gauge of the sensitivity or actual reliability of the model. It shows whether or not the model will predict figures within a given degree of certainty. (One disadvantage, however, is that for low values of predictions, this measure begins to fail since for all values of the predicted that are less than the actual, the error will be less than one (1).) The second measure shows whether or not the first measure has a low value due to the condition mentioned above. This second measure should stay approximately zero but may become either positive or negative. A high positive value indicates that the model is over-estimating on the average while a high negative value is indicative of underestimation on the average.

The table below gives the error measures for 1966 air demand data.

MODEL	AAE	AE
Revised D.O.T.	0.787	0 120
Calibrated	0.959	-0.100

A look at the models shows that the average error values are approximately equal for both models although one is positive and the other is negative. The Average Absolute Error, however, is significantly lower for the revised D.O.T model The only way that this can be justified is by recognition of the fact that the calibration data did not encompass the same area as the calculations and that there may not have been sufficient data to develop a sound model. Regardless of the cause, however, the revised D.O.T. model shows significantly better results for 1966 air travel demand figures but does not differ a great deal from the calibrated model in total squared error. The decision was made, therefore, to continue to use the revised D.O.T. model. The following pages show the results of the forecasts (Note once again travel time and cost were held constant over the years. Note, also, that the figures are given times 10^{-1}.)

Although the calibrated model did not improve the air demand prediction results to any extent, the possibility of developing a reliable national transportation model encompassing all modes is good and the potential results are promising. The major problem is in data but a concerted effort in examining all data available should show some results

Finally, it is extremely interesting to note that for modes of travel other than air, the revised D.O.T. model overestimates. There are only a few points available for comparison, however, so no decisions can be reached. The few points available do indicate, however, that the calibrated model comes closer than the revised D.O.T. model for modes other than air. Table A.2.1.6-1 contains daily predictions for 1980 using the calibrated model Best results may be obtained by considering the revised D.O.T output for air and the calibrated model output for all other modes.

TABLE A 2.1.6-1

PASSENGER DEMAND FOR AIR TRANSPORTATION (CALIBRATED MODEL)

YEAR 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	100	58	83	46	46	70	38	80	86	42	13	55	70	80	72	73	67	62	40	77
CHI.	55	0	67	72	86	29	76	76	67	49	55	82	66	48	51	57	76	76	60	51	41
L.A.	22	37	0	50	55	94	74	41	47	53	42	50	78	45	58	57	64	69	48	74	44
ATL.	46	39	28	0	73	39	65	60	65	62	55	72	46	56	58	54	66	65	43	31	55
W.DC	25	47	30	40	0	43	68	80	76	66	22	16	51	38	74	67	69	66	62	21	61
S.F.	25	16	52	21	24	0	72	33	35	42	33	39	61	77	45	45	49	49	36	68	35
DAL.	38	42	41	36	37	39	0	48	61	60	53	61	62	25	61	60	71	43	44	3	57
BOS.	21	42	23	33	44	19	27	0	57	70	61	63	39	66	57	53	52	47	43	28	59
MIA.	44	37	26	35	42	19	34	31	0	59	54	71	40	33	58	45	51	65	54	28	55
DET.	47	27	29	34	36	23	33	39	33	0	23	67	52	5	57	63	67	59	51	37	33
PIT.	23	30	23	30	12	18	29	34	30	13	0	41	42	4	50	51	55	45	43	29	6
PHI.	7	45	27	40	9	22	34	35	39	37	23	0	47	55	70	60	64	59	54	34	68
DEN.	30	36	43	25	28	33	34	21	22	28	23	26	0	45	56	58	64	60	44	49	46
CLE.	38	26	25	31	21	44	14	36	29	3	2	30	25	0	53	55	60	52	45	31	29
S.L.	44	28	32	32	41	25	34	31	32	31	27	38	31	29	0	62	47	63	52	34	46
MIN.	40	31	31	30	37	25	33	29	24	35	28	33	32	30	34	0	65	55	44	42	54
K.C.	40	42	35	36	38	27	39	29	28	37	30	35	35	33	26	36	0	68	54	39	64
HOU.	37	42	38	35	36	27	24	26	30	33	25	32	33	28	35	30	38	0	42	37	56
N.O.	34	33	26	24	34	20	24	24	30	28	24	30	24	25	29	24	30	23	0	29	48
SEA.	22	28	41	17	11	38	1	16	15	20	16	19	27	17	19	23	22	20	16	0	30
CIN.	43	23	24	30	34	19	32	32	32	18	3	37	25	16	25	30	35	31	26	16	0

TABLE A.2.1.6-1 (Continued)

PASSENGER DEMAND FOR AIR TRANSPORTATION
(REVISED D.O.T. MODEL)

YEAR 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	88	5	32	5873	0	9	5432	15	166	482	40642	3	158	20	11	7	7	6	1	38
CHI.	48	0	7	38	87	2	23	12	7	685	102	44	9	311	861	276	98	15	9	1	418
L.A.	3	4	0	2	3	460	9	1	2	3	1	2	15	1	3	3	3	6	2	9	1
ATL.	18	21	1	0	55	1	12	4	20	24	17	20	2	15	31	3	6	13	29	0	41
W.DC	3230	48	2	30	0	1	7	102	11	267	2002	13446	2	293	21	9	5	6	7	1	69
S.F.	0	1	253	0	1	0	5	0	1	1	0	1	5	4	1	1	1	2	3	10	0
DAL.	5	13	5	7	4	3	0	1	5	8	3	4	12	3	22	6	34	474	36	1	5
BOS.	2988	7	1	2	56	0	1	0	2	18	19	424	1	14	3	2	1	1	1	0	4
MIA.	8	4	1	11	6	0	3	1	0	5	3	8	1	3	4	1	1	7	8	0	3
DET.	91	377	2	13	147	1	5	10	3	0	891	117	3	8621	63	25	13	5	4	1	363
PIT.	265	56	1	9	1101	0	2	11	2	490	0	422	1	4201	13	5	3	2	2	0	2089
PHI.	22353	24	1	11	7395	1	2	233	4	64	232	0	1	140	11	5	3	4	3	0	19
DEN.	2	5	8	1	1	2	7	0	0	2	0	1	0	1	5	6	0	4	1	2	1
CLE.	87	171	1	8	161	2	2	7	2	4742	2311	77	1	0	20	8	4	2	2	0	219
S.L.	11	474	2	17	12	1	12	1	2	35	7	6	3	11	0	19	256	11	9	0	89
MIN.	6	152	2	2	5	1	3	1	1	14	3	3	3	5	10	0	31	3	1	1	7
K.C.	4	54	2	3	3	1	19	1	1	7	2	2	0	2	141	17	0	7	3	0	6
HOU.	4	8	3	7	3	1	260	1	4	3	1	2	2	1	6	1	4	0	151	1	3
N.O.	3	5	1	16	4	1	20	0	4	2	1	2	1	1	5	1	2	83	0	0	3
SEA.	1	1	5	0	0	6	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
CIN.	21	230	1	22	38	0	3	2	2	199	1149	11	1	121	49	4	3	2	2	0	0

TABLE A.2.1.6-1 (Continued)

PASSENGER DEMAND FOR BUS TRANSPORTATION (CALIBRATED MODEL)

YEAR 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	CAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	35	3	25	158	2	9	123	13	55	93	241	5	65	18	13	9	8	10	2	36
CHI.	19	0	6	36	46	2	22	16	9	148	60	29	15	88	50	62	51	14	16	3	89
L.A.	2	3	0	4	3	59	10	2	3	4	3	3	17	3	5	5	6	8	4	13	3
ATL.	14	20	2	0	43	1	21	10	32	35	33	24	6	28	34	10	16	22	63	2	45
W.DC	67	26	2	24	0	2	10	60	16	74	95	163	5	81	26	15	11	9	12	1	53
S.F.	1	1	54	0	1	0	9	2	2	3	2	2	11	9	4	4	4	4	3	20	2
DAL.	5	12	5	12	6	5	0	4	9	13	10	7	23	4	32	15	34	110	69	11	14
BOS.	68	8	1	6	33	1	2	0	6	26	29	103	3	26	8	6	5	4	5	1	14
MIA.	7	5	1	18	9	1	5	3	0	9	10	11	2	8	9	4	5	11	21	1	9
DET.	20	81	2	19	41	2	7	15	5	0	78	52	9	132	52	35	24	9	11	3	83
PIT.	51	33	2	18	52	1	5	15	5	43	0	97	5	111	29	19	13	6	9	2	117
PHI.	132	16	2	13	90	1	4	57	6	29	53	0	5	54	17	11	9	7	9	2	31
DEN.	3	6	10	3	3	6	13	2	2	5	3	3	0	6	17	18	21	12	7	8	6
CLE.	36	49	2	16	44	5	2	14	5	73	61	30	3	0	32	22	16	8	9	2	68
S.L.	10	27	3	18	14	2	18	4	5	28	16	9	10	18	0	35	70	21	25	6	57
MIN.	7	34	3	6	8	2	8	4	2	19	10	6	10	12	18	0	37	8	7	4	22
K.C.	5	28	3	9	6	2	19	3	3	12	7	5	11	9	43	20	0	17	14	3	20
HOU.	4	6	4	12	5	2	61	2	6	5	3	4	7	4	11	4	10	0	61	2	11
N.O.	5	9	2	35	7	1	38	3	11	6	5	5	4	5	14	4	8	33	0	2	14
SEA.	1	2	7	1	1	11	6	1	1	2	1	1	5	1	3	2	2	1	1	0	2
CIN.	20	49	2	25	29	1	8	8	5	46	64	17	4	37	32	12	11	6	8	1	0

TABLE A.2 1.6-1 (Continued)

PASSENGER DEMAND FOR RAIL TRANSPORTATION (CALIBRATED MODEL)

YEAR 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	CAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	18	2	13	119	1	4	107	5	44	73	255	2	47	8	6	4	3	4	1	18
CHI.	10	0	2	22	30	60	11	8	4	116	51	14	7	65	85	62	40	6	7	1	50
L.A.	1	1	0	2	1	67	4	1	1	2	1	1	8	1	2	2	2	3	2	6	1
ATL.	7	12	1	0	21	1	11	5	17	19	23	16	3	20	38	5	9	12	27	1	37
W.DC	65	17	1	17	0	1	4	40	7	64	99	209	2	67	15	6	5	4	5	38	39
S.F.	1	33	37	1	1	0	5	1	1	1	1	1	5	9	2	2	2	2	1	12	1
DAL.	2	6	2	6	2	3	0	2	4	6	1	3	14	91	16	7	28	73	30	5	7
BOS.	59	4	1	2	22	0	1	0	3	18	26	67	1	17	3	3	2	2	2	1	7
MIA.	3	2	1	9	4	0	2	1	0	4	4	5	1	4	4	2	2	5	10	1	4
DET.	24	64	1	10	25	1	3	10	2	0	80	55	4	153	38	26	14	4	5	1	60
PIT.	40	28	1	12	55	1	1	14	2	44	0	63	2	129	21	9	6	2	4	1	108
PHI.	140	8	1	9	115	1	2	37	3	30	34	0	2	60	9	5	4	3	4	1	24
DEN.	1	4	4	1	1	2	8	1	1	2	1	1	0	3	8	10	11	5	3	3	3
CLE.	26	26	1	11	37	5	50	9	2	84	71	33	1	0	36	14	8	3	4	1	60
S.L.	4	47	1	21	8	1	9	2	2	21	11	5	4	20	0	25	57	11	16	1	49
MIN.	3	34	1	3	4	1	4	2	1	14	5	3	5	7	14	0	31	3	3	2	13
K.C.	2	22	1	5	3	1	15	1	1	7	4	2	6	5	31	17	0	11	8	1	15
HOU.	2	3	2	7	2	1	40	1	3	2	1	2	3	2	6	2	6	0	51	1	5
N.O.	2	4	1	15	3	1	16	1	5	3	2	2	2	2	9	2	4	28	0	1	8
SEA.	1	1	3	0	21	7	3	0	0	1	0	0	2	1	1	1	1	1	0	0	1
CIN.	10	28	1	21	21	1	4	4	2	33	59	13	2	33	27	7	8	3	4	0	0

TABLE A 2.1.6-1 (Continued)

PASSENGER DEMAND FOR AUTO TRANSPORTATION (CALIBRATED MODEL)

YEAR 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	8	0	6	356	0	1	534	2	20	85	1673	1	29	4	2	2	1	2	0	10
CHI.	4	0	1	9	11	0	5	3	2	93	28	7	3	75	169	72	31	4	3	1	116
L.A.	0	0	0	1	0	55	2	0	0	1	0	0	4	0	1	1	1	1	1	3	0
ATL.	3	5	0	0	14	0	5	2	8	9	10	6	1	9	14	2	4	5	17	0	28
W.DC	196	6	0	8	0	0	2	25	3	47	390	1008	1	78	6	3	2	2	3	0	26
S.F.	0	0	30	0	0	0	2	0	0	0	0	0	2	3	1	1	1	1	2	5	0
DAL.	1	3	1	3	1	1	0	1	2	3	2	1	6	1	8	3	17	112	16	2	3
BOS.	294	2	0	1	14	0	0	0	1	7	12	101	0	8	1	1	1	1	1	0	3
MIA.	1	1	0	4	1	0	1	1	0	2	2	2	0	2	2	1	1	3	5	0	2
DET.	11	51	0	5	26	0	2	4	1	0	264	24	2	1426	21	10	6	2	2	0	139
PIT.	47	15	0	5	214	0	1	6	1	145	0	121	1	1198	9	4	3	1	2	0	848
PHI.	920	4	0	4	554	0	1	56	1	13	67	0	1	48	4	2	2	1	2	0	9
DEN.	0	2	2	1	0	1	3	0	0	1	0	0	0	1	3	4	0	2	1	1	1
CLE.	16	41	0	5	43	1	0	4	1	784	659	26	1	0	11	6	4	1	2	0	143
S.L.	2	93	0	8	3	0	5	1	1	12	5	2	2	6	0	10	124	5	7	0	57
MIN.	1	40	0	1	2	0	2	1	0	6	2	1	2	3	6	0	23	1	1	1	6
K.C.	1	17	1	2	1	0	10	0	0	4	2	1	0	2	68	12	0	4	3	0	6
HOU.	1	2	1	3	1	0	62	0	1	1	1	1	1	1	4	1	2	0	74	0	2
N.O.	1	2	0	9	2	1	9	0	3	1	1	1	1	1	4	1	2	40	0	0	3
SEA.	0	0	1	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
CIN.	5	64	0	15	14	0	2	2	1	76	466	5	1	78	32	3	3	1	2	0	0

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A.2.2 ALLOCATION ALGORITHMS

A.2.2.1 General Discussion

In any transportation system, it is essential to determine the usage of each route in terms of the number and type of vehicles to be utilized in order to satisfy the demand for travel between nodes in the network. Many procedures have been developed in the past to solve problems of this nature. In fact, it can be attacked from several different points depending upon which method or methods best fit the problem at hand Dynamic, linear, and nonlinear programming, network flow theory, and simulation all have been used to derive solutions to network related systems.[1,2,3] This investigation in its attempt to develop an optimum system, has made use of several linear programming procedures and simulation algorithms during the course of the program. Although satisfactory results were obtained only through the use of system simulation, it was felt that less sophisticated procedures considered early in the investigation should be described for future reference.

A.2.2.2 Transportation and Transhipment Problems, The Classical Transportation Problem

The Classical Transportation Problem arises when one must determine an optimal schedule of shipments that:

(a) originates at various sources where fixed stockpiles of a commodity are available;

(b) are sent directly to their final destinations where various fixed amounts are required,

(c) exhaust the stockpiles and fulfill the demand; hence, total demand equals total supply;

and finally, the cost must

(d) satisfy a linear objective function, that is, the cost of each shipment is proportional to the amount shipped, and the total cost is the sum of the individual costs.

The corresponding mathematical model for the transportation problem is the following. Find x_{ij} ($i=1, 2, \ldots, m$, $j=1, 2, \ldots, n$) in order to minimize

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

subject to the restrictions,

$$\sum_{j=1}^{n} X_{ij}=a_i, \text{ for } i=1, 2, \ldots, m.$$

$$\sum_{i=1}^{m} X_{ij}=b_j, \text{ for } j=1, 2, \ldots, n.$$

$$X_{ij} \geqq 0, \text{ for all } i \text{ and } j.$$ [2]

Although the transportation network investigated is not in the proper form for adaptation to the classical problem one can force it to meet the requirements of the model. More specifically, let:

X_{ij} = number of aircraft of type i to flight over route j per given period of time.

C_{ij} = cost of flying aircraft type i over route j per flight (this may be in terms of monetary cost, trip time, etc.)

b_j = demand for transportation over route j per given period of time on any aircraft type.

Q_i = total number of seats available on aircraft type i per given time period.

In the air transportation model, then, one is given a mix of aircraft types, each with a different capacity, cruise speed, and possible range, and a different cost associated with each route and each aircraft type One may attempt to minimize the cost of the fleet by assigning aircraft to a route on a least-cost basis until all demand is filled and all supply is exhausted. The advantages of the use of the classical transportation problem are several in number:

1 - more efficient solution procedures can be used than in the complete simplex method due to the simple structure of the model.

2 - an integer number of aircraft of each type is available with known seating capacities and load factors.

3 - the demand for travel on each route is also an integer number, i.e., we cannot allocate 33.5 people to a given airplane.

Disadvantages, however, outweigh the obvious advantages and have since led to the discontinuance of work on this model. These disadvantages include·

1 - the problem, as stated, is static and not subject to changes.

2 - all cost, demand, and aircraft data must be known exactly for correct solution.

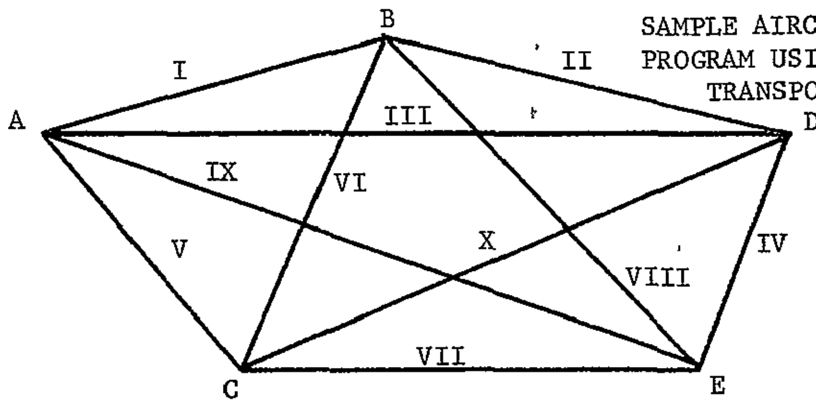
3 - modeling with three different aircraft types and 420 routes is too large and bulky for easy calculations.

4 - the number of aircraft must be finite and known for a given time period

5 - the number of aircraft assigned to individual routes is not necessarily an integer number.

Hence, due to these disadvantages, the classical transportation problem was not used. However, future research in this area is a possibility and with some corrections it may be feasible A sample program making use of the transportation algorithm follows.

FIGURE A.2.2-2



SAMPLE AIRCRAFT ALLOCATION PROGRAM USING THE CLASSICAL TRANSPORTATION PROGLEM ALGORITHM

TABLE A 2.2-1

AIRCRAFT CHARACTERISTICS

AIRCRAFT TYPE	CRUISE SPEED	SEATING CAPACITY	NUMBER OF PLANES	AVAILABLE SEATS, TOTAL
A	200 mph	200	30	6000
B	300	150	25	3750
C	400	175	20	3500

TABLE A 2.2-2

ROUTE CHARACTERISTICS

FLIGHT ROUTE	DISTANCE	AIRCRAFT BLOCK TIME			TRAVEL DEMAND
		A	B	C	
I	700	3 50	2.50	1 80	1500
II	350	1.75	1 20	0 90	1650
III	200		0.70	0 50	1200
IV	1200	6 00	4.00	3.00	750
V	500	2.50	1.70	1 30	800
VI	850		2 80	2 30	1000
VII	2100	10 50	7 00	5 30	2500
VIII	1000	5 00	3 30	2 50	500
IX	300	1 50	1.00	0 80	750
X	650		2 30	1.80	100

In this sample problem the C_{ij} term is measured in hours but may be converted to dollars if it is assumed that DOC is proportional to block time. Hence, one may then solve for minimum cost.

Given three types of vehicles with their number, cruise speed, and seating capacity known. The transportation algorithm will determine which aircraft to fly over which routes at least cost while satisfying the demand for air travel over each route The output will be in terms of the number of each aircraft type flown over each route, the average load factor over each route, and the total minimum direct operating cost.

The steps involved in iterating towards the final optimal solution will not be included here. For a review of the procedures used, references 1 and 2 are excellent.

Table A.2.2-3 gives the initial tableau for the problem. The first allocation is made by the familiar Northwest Corner rule. The final tableau is given in Table A.2.2-4.

TABLE A.2-2-3

INITIAL TABLEAU

ROUTE A/C	I	II	III	IV	V	VI	VII	VIII	IX	X	0	SEAT. CAP.
A	3.5 1500	1.8 1650	1 1200	6 750	2.5 800	4.3 100	10 5	5	1.5	3 3	0	6000
B	2.5	1.2	0.7	4	1.7	2 8 900	7 2500	3.3 350	1	2.3	0	3750
C	1.8	0.9	.5	3	1.3	2.3	5 3	2.5 150	.8 750	1.8 1000	0 1600	3500
DEMAND	1500	1650	1200	750	800	1000	2500	500	750	1000	1600	13,250

The column headed D is a dummy route with a zero cost associated with it. It has been included in the tableau in order to satisfy the equality constraint imposed upon the algorithm as discussed previously. Obviously, this allocation is not yet optimum and several iterations are necessary to reach a minimum cost solution The final tableau is shown below in Table A.2-2-4. The number of aircraft used on each route and the average load factor per route are shown in Table A.2.2-5.

TABLE A.2.2-4

FINAL TABLEAU

ROUTE A/C	I	II	III	IV	V	VI	VII	VIII	IX	X	O	SEAT. CAP.
A		1650	1200		800				750		1600	6000
B	1500					1000		250		1000		3750
C				750			2500	250				3500
DEMAND	1500	1650	1200	750	800	1000	2500	500	750	1000	1600	13,250

As one can see, all demands are satisfied in such a way as to minimize the total cost. Also, it is quite evident that minimizing the cost over each route does not necessarily result in lowest total cost. The allocation of 1600 seats to aircraft type A to be flown over the dummy route indicates that aircraft type A is not to be utilized at its maximum capacity Had the demand over the 10 routes exactly equaled available seats, all aircraft would have been fully utilized.

TABLE A.2.2-5

FINAL ROUTE ALLOCATION

Route	Aircraft Type	Planes Used	Route Load Factor (%)
I	B	20	100
II	A	9	95.67
III	A	6	100
IV	C	5	85.72
V	A	4	100
VI	B	7	95.24
VII	C	15	95.24
VIII	B	2	83.33
	C	2	71.43
IX	A	4	93 75
X	B	7	95.24

TABLE A.2.2-6

FINAL AIRCRAFT ALLOCATION

Aircraft Type	No. of Routes Used On	No. of Planes Used
A	4	23
B	4	26*
C	3	22*

*Due to unfilled capacity on most routes the total number of planes of Type B and C are more than had existed to begin with. This can be reconciled if one considers that a plane can fly more than once in a given time period.

A.2.2.3 THE TRANSHIPMENT PROBLEM

In looking at the problem of routing of aircraft over the system network, some consideration was given in the early part of the program to including one-stop flights in an attempt to more realistically model the commercial air transportation system in the United States. One method of solution for this problem is through the use of the transhipment problem algorithm. In this linear programming technique, each source or destination is also permitted to act as an intermediate point for shipments from other sources to other destinations. In the aircraft allocation problem the shipments would be the demands for travel between any two cities.

The transhipment problem can be very satisfactorily utilized either if the cost of travel, measured in terms of route operating cost, is less for any given route if a stopover is made or if there is an upper limit over any given route on the number of people that may fly, due to aircraft utilization limits, daylight flight hour provisions, etc. Since these two conditions do exist in many instances the transhipment model may be used. One limiting factor however is that a demand-balance equation must exist for every city. That is:

Gross Demand = Demand In + Demand Generated
Gross Demand = Demand Out + Demand Satisfied

In equation form, we have:

$$(1) \qquad {}_{i \neq j} x_{ij} = a_j^* = {}_{k \neq j} x_{yk} = b_j^* = x_{jj}^* \quad (j = 1, 2, \ldots, n)$$

Where

x_{ij} = Total demand from city i to j for $i \neq j$

x_{jj}^* = Gross demand for travel at city j

$a_j^* =$ Demand generated at j

$b_j^* =$ Demand satisfied at j

In general, the net demand generated a_j and the net demand satisfied b_j, are related to a_j^* and b_j^* by

(2) $a_j = a_j^* - \text{Min}\ (a_j^*, b_j^*)$ $\quad b_j = b_j^* - \text{Min}\ (a_j^*, b_j^*)$

The transhipment problem, then consists in finding X_{ij} and Min Z satisfying (1) and the objective equation

(3) $C_{ij}\ X_{ij} = Z$ where $i \neq j$[1]

As in the transportation problem, C_{ij} again refers to the cost of shipment from city i to city j in terms of distance, time, or money.[1,2] Work on the transhipment problem algorithm, however, was unable to continue due to the complexity of the network when possible one-stop flight paths were taken into consideration. This, along with a difficulty in determining cost data for the routes with stops included, led to simulation procedures being used for allocation of aircraft.

The Simplex Algorithm

A third, more complex and realistic method for determining the allocation of aircraft over various routes is through the use of the simplex algorithm Previous work in the use of this algorithm for aircraft allocation has primarily been done by Miller.[4,5,6] The algorithm developed in this investigation is an extension of Miller's work which considered overall cost including terminal and user costs whereas Miller takes only aircraft operating cost into consideration. The "simplex method" is the name that has been attached to a method for solving any linear programming problem, of which the allocation problem is one. It is an algebraic procedure which progressively approaches the optimal solution through a well-defined iterature process until the optimum is finally reached. The mathematical statement of a general form of the linear programming problem is the following. Find $X_1, X_2, \ldots, X_n$ which maximizes (minimizes) the linear function,

$$Z = C_1X_1 + C_2X_2 + \ldots + C_nX_n$$

subject to the restrictions,

$$\begin{array}{l} A_{11}X_1 + A_{12}X_2 + \ldots + A_{1n}X_n \leqq b_1 \\ A_{21}X_1 + A_{22}X_2 + \ldots + A_{2n}X_n \leqq b_2 \\ \vdots \\ A_{m1}X_1 + A_{m2}X_2 + \ldots + A_{mn}X_n \leqq b_m \end{array}$$

and

$$X_1 \geqq 0,\ X_2 \geqq 0, \ldots X_n \geqq 0^2$$

for our problem, the mathematical statement is the following: find $\ldots X_{hij}$ ($h = 1, 2, \ldots k$, $i = 1, 2, \ldots n$, $j = 1, 2, \ldots n$) in order to minimize . . .

$$\sum_h \sum_j \sum_i C_{hi} X_{hi} + \sum_h \sum_i \sum_j X_{hij} L_f M_n (C_i + C_j) + \sum_h \sum_i \sum_j w T_{hij} L_f M_n X_{wk}$$

subject to the restrictions

$$\sum_j X_{hij} - C_i \sum X_{hji} \geqq 0 \qquad \text{for all } i \text{ and } h.$$

$$\sum_n M_n X_{nij} \geqq D_{ij} \qquad \text{for all } i \text{ and } j.$$

$$X_{hij} \geqq 0 \qquad \text{for all } h, i, \text{ and } j.$$

where . . .

C_{hij} = direct operating cost plus indirect operating cost plus initial investment of aircraft type h from city i to city j.

X_{hij} = number of non-stop one-way flights from city i to city j via aircraft type h. This is the unknown value that is to be determined.

C_i = average cost per passenger enplaning at terminal city i.

C_j = average cost per passenger deplaning at terminal city J.

L_f = average aircraft load factor. This is assumed to be constant over all routes and aircraft types.

T_{hij} = total travel time by aircraft type h from city i to city j. This includes access time to and egress time from the terminals.

W = average hourly wage of aircraft passenger. This is used to determine the cost of travel to the user who is considered part of the system.

M_h = maximum seating capacity of aircraft type h.

D_{ij} = demand for travel by air from city i to city j.

All of these are considered on either a daily or weekly basis, depending upon the information available. This type of analysis is very well suited to the aircraft allocation problem However, in attempting to calculate this problem, the scope of the problem became too large for computation either by hand or by digital electronic computers available. For example, based on a network of 21 hubs and 420 routes with three types of aircraft flying, the objective function would have a minimum of 1260 terms with 1260 unknowns to be determined. In addition, there would be approximately 500 constraint equations. Although this problem was found to be too large for computation, it was felt that it could indeed be an extremely useful and valuable tool for transportation research purposes and that more work should be devoted to a refinement of the procedures.

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5. Miller, R E , *Domestic Airline Efficiency*, The M. I T Press, Cambridge, Mass., 1963.

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A.2.3 PROJECTED CARGO DEMAND

Figure A.2.3-1 is a graph of the projected yearly cargo demand in tons versus year. The points for the years 1965, 1970, 1975, and 1980 are based on FAA projected demand for the 21 major hubs multiplied by a factor based on the number of people employed in manufacturing in these hubs. Table A.2.3-1 gives the number of people employed in manufacturing in each of the 21 major hubs and the total for the United States. Tables A.2.3-2, A.2.3-3, A.2 3-4, and A.2-3-5 give the projected one-way cargo demand for each of the 450 possible pairs for 1975, 1980, 1985, and 1990, respectively, in tons per day.

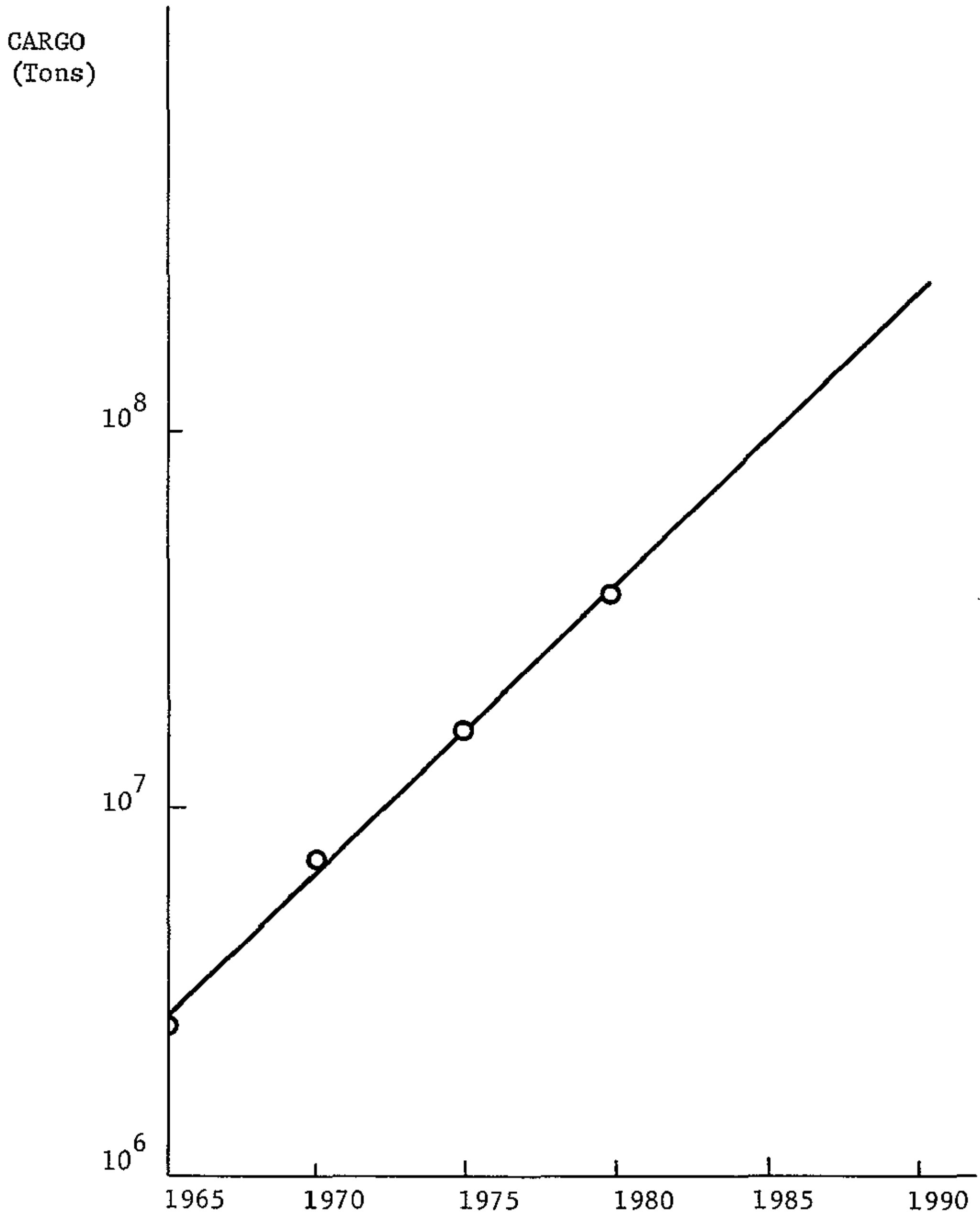


FIGURE A 2 3-1

CARGO DEMAND FORECAST

TABLE A.2.3-1

NUMBER OF PEOPLE EMPLOYED IN MANUFACTURING

City	Manufacturing Employees-1963[2]
New York - Newark	1,397,438
Chicago	860,637
Los Angeles	745,968
Atlanta	95,695
Washington, D. C - Baltimore	240,602
San Francisco	196,163
Dallas	109,517
Boston	293,248
Miami	43,245
Detroit	493,913
Pittsburgh	272,183
Philadelphia	535,807
Denver	69,539
Cleveland	280,285
St Louis	259,686
Minneapolis - St Paul	163,820
Kansas City	111,104
Houston	108,585
New Orleans	49,051
Seattle	121,556
Cincinnati	153,930
Total employed in manufacturing in U S 1963[3]	13,095,000

TABLE A.2.3-2

CARGO DEMAND 1975

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	155	135	17	43	35	20	53	8	89	49	97	13	51	47	30	20	20	9	22	28
CHI.	155	0	83	11	27	22	12	33	5	55	30	60	8	31	29	18	12	12	5	14	17
L.A.	135	83	0	9	23	19	11	28	4	48	26	52	7	27	25	16	11	10	5	12	15
ATL.	17	11	9	0	3	2	1	4	1	6	3	7	1	3	3	2	1	1	1	2	2
W.DC	43	27	23	3	0	6	3	9	1	15	8	17	2	9	8	5	3	3	2	4	5
S.F.	35	22	19	2	6	0	3	7	1	13	7	14	2	7	7	4	3	3	1	3	4
DAL.	20	12	11	1	3	3	0	4	1	7	4	8	1	4	4	2	2	2	1	2	2
BOS.	53	33	28	4	9	7	4	0	2	19	10	20	3	11	10	6	4	4	2	5	6
MIA.	8	5	4	1	1	1	1	2	0	3	2	3	0	2	1	1	1	1	0	1	1
DET.	89	55	48	6	15	13	7	19	3	0	17	34	4	18	17	10	7	7	3	8	10
PIT.	49	30	26	3	8	7	4	10	2	17	0	19	2	10	9	6	4	4	2	4	5
PHI.	97	60	52	7	17	14	8	20	3	34	19	0	5	19	18	11	8	8	3	8	11
DEN.	13	8	7	1	2	2	1	3	0	4	2	5	0	3	2	1	1	1	0	1	1
CLE.	51	31	27	3	9	7	4	11	2	18	10	19	3	0	9	6	4	4	2	4	6
S.L.	47	29	25	3	8	7	4	10	1	17	9	18	2	9	0	5	4	4	2	4	5
MIN.	30	18	16	2	5	4	2	6	1	10	6	11	1	6	5	0	2	2	1	3	3
K.C.	20	12	11	1	3	3	2	4	1	7	4	8	1	4	4	2	0	2	1	2	2
HOU.	20	12	10	1	3	3	2	4	1	7	4	8	1	4	4	2	2	0	1	2	2
N.O.	9	5	5	1	2	1	1	2	0	3	2	3	0	2	2	1	1	1	0	1	1
SEA.	22	14	12	2	4	3	2	5	1	8	4	8	1	4	6	3	2	2	1	0	2
CIN.	28	17	15	2	5	6	2	6	1	10	5	11	1	6	5	3	2	2	1	2	0

TABLE A.2.3-3

CARGO DEMAND 1980

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	376	326	42	105	86	48	128	19	216	119	234	30	122	113	72	49	47	21	53	67
CHI.	376	0	201	26	65	53	29	79	12	133	73	144	19	75	70	44	30	29	13	33	41
L.A.	326	201	0	22	56	46	26	68	10	115	64	125	16	65	61	38	26	25	11	28	36
ATL.	42	26	22	0	7	6	3	9	1	15	8	16	2	8	8	5	3	3	1	4	5
W.DC	105	65	56	7	0	15	8	22	3	37	20	40	5	21	20	12	8	8	4	9	12
S.F.	86	53	46	6	15	0	7	18	3	30	17	33	4	17	16	10	7	7	3	7	9
DAL.	48	29	26	3	8	7	0	10	1	17	9	18	2	10	9	6	4	4	2	4	5
BOS.	128	79	68	9	22	18	10	0	4	45	25	49	6	26	24	15	10	10	4	11	14
MIA.	19	12	10	1	3	3	1	4	0	7	4	7	1	4	4	2	2	1	1	2	2
DET.	216	133	115	15	37	30	17	45	7	0	42	83	11	43	40	25	17	17	8	19	24
PIT.	119	73	64	8	20	17	9	25	4	42	0	46	6	24	22	14	9	9	4	10	13
PHI.	234	144	125	16	40	33	18	49	7	83	46	0	12	47	44	27	19	18	8	20	26
DEN.	30	19	16	2	5	4	2	6	1	11	6	12	0	6	6	4	2	2	1	3	3
CLE.	122	75	65	8	21	17	10	26	4	43	24	47	6	0	23	14	10	10	4	11	13
S.L.	113	70	61	8	20	16	9	24	4	40	22	44	6	23	0	13	9	9	4	10	13
MIN.	72	44	38	5	12	10	6	15	2	25	14	27	4	14	13	0	6	6	3	6	8
K.C.	49	30	26	3	8	7	4	10	2	17	9	19	2	10	9	6	0	4	2	4	5
HOU.	47	29	25	3	8	7	4	10	1	17	9	18	2	10	9	6	4	0	2	4	5
N.O.	21	13	11	1	4	3	2	4	1	8	4	8	1	4	4	3	2	2	0	2	2
SEA.	53	33	28	4	9	7	4	11	2	19	10	20	3	11	10	6	4	4	2	0	6
CIN.	67	41	36	5	12	9	5	14	2	24	13	26	3	13	13	8	5	5	2	6	0

TABLE A.2.3-4

CARGO DEMAND 1985

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	870	754	97	243	198	111	296	44	499	275	541	70	283	262	166	112	110	50	123	156
CHI.	870	0	464	60	150	122	68	182	27	307	169	333	43	174	162	102	69	68	31	76	96
L.A.	754	464	0	52	130	106	59	158	23	266	147	289	38	151	140	88	60	59	26	66	83
ATL.	97	60	52	0	17	14	8	20	3	34	19	37	5	19	18	11	8	8	3	8	11
W.DC	243	150	130	17	0	34	19	51	8	86	47	93	12	49	45	28	19	19	9	21	27
S.F.	198	122	106	14	34	0	16	42	6	70	39	76	10	40	37	23	16	15	7	17	22
DAL.	111	68	59	8	19	16	0	23	3	39	22	42	6	22	21	13	9	9	4	10	12
BOS.	295	182	158	20	51	42	23	0	9	105	58	114	15	59	55	35	24	23	10	26	33
MIA.	44	27	23	3	8	6	3	9	0	15	9	17	2	9	8	5	3	3	2	4	5
DET.	499	307	266	34	86	70	39	105	15	0	97	191	25	100	93	59	40	39	18	43	55
PIT.	275	169	147	19	47	39	22	58	9	97	0	105	14	55	51	32	22	21	10	24	30
PHI.	541	333	289	37	93	76	42	114	17	191	105	0	27	109	101	63	43	42	19	47	60
DEN.	70	43	38	5	12	10	6	15	2	25	14	27	0	14	13	8	6	5	2	5	8
CLE.	283	174	151	19	49	40	22	59	9	100	55	109	14	0	53	33	23	22	10	25	31
S.L.	262	162	140	18	45	37	21	55	8	93	51	101	13	53	0	31	21	20	9	23	29
MIN.	166	102	88	11	28	23	13	35	5	59	32	63	8	33	31	0	13	13	6	14	18
K.C.	112	69	60	8	19	16	9	24	3	40	22	43	6	23	21	13	0	9	4	10	12
HOU.	110	68	59	8	19	15	9	23	3	39	21	42	5	22	20	13	9	0	4	10	12
N.O.	50	31	26	3	9	7	4	10	2	18	10	19	2	10	9	6	4	4	0	4	5
SEA.	123	76	66	8	21	17	10	26	4	43	24	47	6	25	23	14	10	10	4	0	14
CIN.	156	96	83	11	27	22	12	33	5	55	30	60	8	31	29	18	12	12	5	14	0

TABLE A.2.3-5

CARGO DEMAND 1990

	N.Y.	CHI.	L.A.	ATL.	WASH.	S.F.	DAL.	BOS.	MIAMI	DET.	PITT.	PHIL.	DEN.	CLEV.	S.L.	MINN.	K.C.	HOUS.	N.O.	SEA.	CINN.
N.Y.	0	2145	1859	238	600	489	273	731	108	1231	678	1335	173	698	647	408	277	271	122	303	384
CHI.	2145	0	1145	147	369	301	168	450	66	758	418	822	107	430	399	251	171	167	75	187	236
L.A.	1859	1145	0	127	320	261	146	390	58	657	362	713	93	373	345	218	148	144	65	162	205
ATL.	238	147	127	0	41	33	19	50	7	84	46	91	12	48	44	28	19	19	8	21	26
W.DC	600	369	320	41	0	84	47	126	19	212	117	230	30	120	111	70	48	47	21	52	66
S.F.	489	301	261	33	84	0	38	103	15	173	95	187	24	98	91	57	39	38	17	43	54
DAL.	273	168	146	19	47	38	0	57	8	96	53	105	14	55	51	32	22	21	10	24	30
BOS.	731	450	390	50	126	103	57	0	23	258	142	280	36	147	136	86	58	57	26	64	80
MIA.	108	66	58	7	19	15	8	23	0	38	21	41	5	22	20	13	9	8	4	9	12
DET.	1231	758	657	84	212	173	96	258	38	0	240	472	61	247	229	144	98	95	43	107	136
PIT.	678	418	362	46	117	95	53	142	21	240	0	260	34	136	126	80	54	53	24	59	75
PHI.	1335	822	713	91	230	187	105	280	41	472	260	0	66	268	248	157	106	104	47	116	147
DEN.	173	107	93	12	30	24	14	36	5	61	34	66	0	35	32	20	14	13	6	15	19
CLE.	698	430	373	48	120	98	55	147	22	247	136	268	35	0	130	82	56	54	25	61	77
S.L.	647	399	345	44	111	91	51	136	20	229	126	248	32	130	0	76	51	50	23	56	71
MIN.	408	251	218	28	70	57	32	86	13	144	80	157	20	82	76	0	32	32	14	36	45
K.C.	277	171	148	19	48	39	22	58	9	98	54	106	14	56	51	32	0	22	10	24	30
HOU.	271	167	144	19	47	38	21	57	8	96	53	104	13	54	50	32	22	0	9	24	30
N.O.	122	75	65	8	21	17	10	26	4	43	24	47	6	25	23	14	10	9	0	11	13
SEA.	303	187	162	21	52	43	24	64	9	107	59	116	15	61	56	36	24	24	11	0	33
CIN.	384	236	205	26	66	54	30	80	12	136	75	147	19	77	71	45	30	30	13	33	0

A.2.9 VEHICLE AND TERMINAL ALLOCATIONS - 1980

In this Appendix, the vehicle allocations for New York, Chicago and Los Angeles in 1980 are given (Table A.2.9-1). The terminal requirements for all twenty-one major hubs are also given (Table A.2.9-2).

As a result of this investigation, these data are available for all twnety-one major hubs in 1975, 1980, 1985 and 1990.

TABLE A 2.9-1

VEHICLE ALLOCATIONS
(ALL DATA EXCEPT TOTAL $ IS 1-WAY)

CITY PAIR	DISTNCE (MI)	DAILY DEMAND	VEHL TYPE	HRS REQRD	TRIPS REQRD	BLOCK HRS	BLOCK MPH	SEAT MILES	TIME COST $	ROUTE DOC $	ROUTE IOC $	TOTAL COST $	MAX FARE
FROM N Y C													
1- 2	713	9391	2	65.3	39	1.7	426	11123	17873	88811	148578	510524	25.14
1- 3	2451	7561	3	69.5	16	4.3	564	31373	36978	203219	286967	1054329	86.44
1- 4	748	1952	2	13.8	8	1.7	433	2394	6046	18720	31142	111814	26.38
1- 5	205	11888	2	22.5	50	4	456	4100	7862	68328	119905	392190	7.23
1- 6	2571	3519	3	31.7	7	4.5	568	14398	21085	92479	130156	487441	90.67
1- 7	1374	3079	3	16.1	6	2.7	511	6595	13853	48743	63876	252944	48.46
1- 8	188	7104	2	12.4	30	.4	456	2256	5533	40083	70764	232759	6.63
1- 9	1092	7631	2	72.2	32	2.3	484	13978	19263	94612	150684	529118	38.51
1-10	482	6629	2	37.0	28	1.3	365	5398	11135	52167	86603	299812	17.00
1-11	317	2835	2	12.8	12	1.1	296	1522	5628	18808	32804	114481	11.18
1-12	83	4436	2	3.3	18	.2	456	598	3609	20662	38087	124715	2.93
1-13	1631	1636	3	9.3	3	3.1	529	3914	11117	27647	35558	148644	57.52
1-14	405	4039	2	20.5	17	1.2	336	2754	7401	29326	49730	172917	14.28
1-15	875	1894	2	15.4	8	1.9	455	2800	6219	20541	33552	120625	30.86
1-16	1018	1911	2	17.1	8	2.1	475	3258	6677	22592	36267	131070	35.90
1-17	1097	1323	2	13.6	6	2.3	485	2633	5410	17793	28324	103055	38.69
1-18	1420	1635	3	8.3	3	2.8	514	3408	10601	24956	32586	136285	50.08
1-19	1171	1629	3	7.1	3	2 4	492	2810	9966	21795	29081	121684	41.30
1-20	2408	1440	3	12.8	3	4.3	563	5779	11436	37555	53099	204180	84.92
1-21	570	3397	2	20.4	14	1.5	391	3192	7540	28292	48586	168837	20.10

TABLE A 2.9-1 (Continued)

VEHICLE ALLOCATIONS
(ALL DATA EXCEPT TOTAL $ IS 1-WAY)

CITY PAIR	DSTNCE (MI)	DAILY DEMAND	VEHL TYPE	HRS REQRD	TRIPS REQRD	BLOCK HRS	BLOCK MPH	SEAT MILES	TIME COST $	ROUTE DOC $	ROUTE IOC $	TOTAL COST $	MAX FARE
FROM CHICAGO													
2- 3	1745	4859	3	32.6	10	3.3	535	13960	20796	97002	131422	498441	61.54
2- 4	587	1133	3	3.0	2	1.5	395	939	8131	9590	13374	62190	20.70
2- 5	597	3434	2	21.0	14	1.5	399	3343	7759	28970	49482	172422	21.05
2- 6	1858	2255	3	17.2	5	3.4	541	7432	12621	50903	68565	264177	65.52
2- 7	803	2323	2	18.1	10	1 8	443	3212	6715	24385	40232	142664	28.32
2- 8	851	1723	2	13.2	7	1.9	451	2383	5951	17672	28960	105166	30.01
2- 9	1188	4173	2	40.8	17	2.4	495	8078	12445	53188	91256	313779	41.90
2-10	238	4727	2	10.4	20	.5	456	1904	5085	28514	49488	166176	8.39
2-11	410	1277	2	6.1	5	1.2	338	820	4423	8670	14681	55548	14.46
2-12	666	2348	2	16.0	10	1.6	415	2664	6314	21930	36982	130452	23.49
2-13	920	1299	2	10.0	5	2.0	462	1840	5472	13241	21504	80435	32.44
2-14	308	2409	2	10.6	10	1.1	292	1832	5212	15512	27141	95730	10.86
2-15	262	2052	1	9.6	17	.6	466	891	2496	13919	22053	79636	9.24
2-16	355	2056	1	18.9	17	1.1	319	1207	3587	15515	24890	87984	12.52
2-17	414	1357	1	13.2	11	1.2	344	911	2986	10694	16855	61070	14.60
2-18	940	1113	3	4.1	2	2 0	464	1504	8565	12576	16492	75266	33.15
2-19	833	1151	3	3.7	2	1.9	447	1333	8676	11671	15547	71788	29.38
2-20	1737	932	3	6.5	2	3.2	535	2779	8265	19332	26204	107602	61.26
2-21	252	2855	2	6.6	12	.6	456	1210	4250	17410	30082	103482	8.89

TABLE A 2.9-1 (Continued)

VEHICLE ALLOCATIONS
(ALL DATA EXCEPT TOTAL $ IS 1-WAY)

CITY PAIR	DISTNCE (MI)	DAILY DEMAND	VEHL TYPE	HRS REQRD	TRIPS REQRD	BLOCK HRS	BLOCK MPH	SEAT MILES	TIME COST $	ROUTE DOC $	ROUTE IOC $	TOTAL COST $	MAX FARE
FROM LOS ANG													
3- 4	1936	957	3	7.1	2	3.6	545	3098	8768	21024	28214	116012	68.28
3- 5	2300	2678	3	24.7	6	4.1	559	11040	15708	72356	95675	367479	81.11
3- 6	347	13104	2	61.3	55	1.1	311	7634	16772	89161	153947	519760	12.24
3- 7	1240	3130	2	32.3	13	2.5	500	6448	10225	41885	71574	247368	43.73
3- 8	2596	1510	3	13.7	3	4.6	568	6230	12411	39953	56193	217113	91.55
3- 9	2339	4383	3	37.6	9	4.2	560	16841	23162	110026	155890	578154	82.49
3-10	1983	2397	3	18.1	5	3.6	547	7932	13858	53559	71722	278279	69.93
3-11	2136	756	3	7.7	2	3 9	553	3418	7150	22724	30235	120217	75.33
3-12	2394	1803	3	17.0	4	4.3	562	7661	12554	49836	70491	265761	84.43
3-13	831	2482	2	18.6	10	1.9	448	3324	7276	24887	40896	146120	29.31
3-14	2049	1277	3	11.2	3	3.7	550	4918	9465	32977	44034	172952	72.26
3-15	1589	1200	3	9.1	3	3.0	526	3814	8080	27111	34967	140315	56.04
3-16	1524	1393	3	8.8	3	2.9	522	3658	9246	26282	34051	139158	53.75
3-17	1356	1098	3	5.3	2	2.7	509	2170	9120	16095	21123	92677	47.82
3-18	1374	1595	3	8.1	3	2.7	511	3298	10233	24371	31938	133086	48.46
3-19	1673	1224	3	9.4	3	3.1	531	4015	8393	28183	36150	145451	59.00
3-20	959	2574	3	10.3	5	2.1	467	3836	10999	31842	41650	168982	33.82
3-21	1897	1421	3	10.5	3	3 5	543	4553	10214	31039	41730	165965	66.90

TABLE A.2.9-2

TERMINAL REQUIREMENTS FOR 1980

Terminal		Range 500	Range 1500	Range 3000	Total	Terminal Operating Cost
1	PASS OUT/IN	0	64430	20499	84929	254787.00
N Y C	VEHL OUT/IN	0	270	41	311	
2	PASS OUT/IN	5465	35959	11443	52867	158601 00
CHICAGO	VEHL OUT/IN	45	149	23	217	
3	PASS OUT/IN	0	18716	38686	57402	172206.00
LOS ANG	VEHL OUT/IN	0	78	82	160	
4	PASS OUT/IN	897	7994	2691	11582	34746.00
ATLANTA	VEHL OUT/IN	7	31	6	44	
5	PASS OUT/IN	2715	31910	5724	40349	121047.00
WASH DC	VEHL OUT/IN	22	131	12	165	
6	PASS OUT/IN	0	15495	18033	33528	100584.00
SAN FRN	VEHL OUT/IN	0	64	36	100	
7	PASS OUT/IN	1353	15089	5882	22324	66972.00
DAL/FW	VEHL OUT/IN	11	61	11	83	
8	PASS OUT/IN	453	16790	4902	22145	66435.00
BOSTON	VEHL OUT/IN	4	69	10	83	
9	PASS OUT/IN	0	26965	11897	38862	116586 00
MIAMI	VEHL OUT/IN	0	111	22	133	

TABLE A.2.9-2 (CONTINUED)

TERMINAL REQUIREMENTS FOR 1980

Terminal		Range 500	Range 1500	Range 3000	Total	Terminal Operating Cost
10	PASS OUT/IN	2471	22579	6841	31891	95673.00
DETROIT	VEHL OUT/IN	21	93	13	127	
11	PASS OUT/IN	4027	5755	1880	11662	34986 00
PITTSBG	VEHL OUT/IN	34	25	5	64	
12	PASS OUT/IN	714	19227	3351	29292	69876.00
PHILADA	VEHL OUT/IN	6	80	8	94	
13	PASS OUT/IN	0	8559	4243	12802	38406.00
DENVER	VEHL OUT/IN	0	34	8	42	
14	PASS OUT/IN	2366	13546	2115	18027	54081.00
CLEVELD	VEHL OUT/IN	19	54	5	78	
15	PASS OUT/IN	3258	7968	1955	13181	39543.00
ST LOUS	VEHL OUT/IN	26	31	5	62	
16	PASS OUT/IN	2444	7564	2735	12743	38229.00
MIN/STP	VEHL OUT/IN	20	33	5	58	
17	PASS OUT/IN	2372	5618	1773	9763	29289.00
KANSAS	VEHL OUT/IN	19	22	4	45	
18	PASS OUT/IN	0	5071	7352	12423	37269.00
HOUSTON	VEHL OUT/IN	0	19	14	33	

TABLE A 2.9-2 (CONTINUED)

TERMINAL REQUIREMENTS FOR 1980

Terminal		Range 500	Range 1500	Range 3000	Total	Terminal Operating Cost
19	PASS OUT/IN	1129	4289	5388	10806	32418.00
N ORLEN	VEHL OUT/IN	9	17	11	37	
20	PASS OUT/IN	0	663	10890	11553	34659.00
SEATTLE	VEHL OUT/IN	0	3	27	30	
21	PASS OUT/IN	2554	12415	4118	19087	57261.00
CINCINN	VEHL OUT/IN	21	49	8	78	

TOTAL TERMINAL OPERATING COST = $ 1653654.00

A.3.1 1980 ENGINE TECHNOLOGY

Since specific fuel consumption and the specific thrust can be affected by any of three parameters--μ, T_{max}, or r, the use of three dimensional graphs is appropriate. The problem is to project these relationships so that they may be utilized for engines reflecting technology applicable to the 1980's. The compressor pressure ratio scale and T_{max} scale have in some cases been elongated to encompass greater 1980 parametric values. Bypass ratio surfaces are free to vary from approximately zero to 12:1. The S.F.C. and S.T. charts show bypass ratios of zero and 4:1. Specific fuel consumption (SFC) charts are representations for sea level--static, and 36,000 ft.--M = 0.8 respectively. The specific fuel chart is discussed in the report body.

Relationships illustrating thrust and S.F.C. for the two engines of the Boeing 747 aircraft are given in Figure A.3.1-4. Both have the same "grid pattern" from altitude 0 to 15,000 ft and from 35,000 to 45,000 ft. while the thrust and S.F.C. values for any of the corresponding Mach number--altitude points are different. In essence then, if any corresponding points on either of the two grid patterns (one: 0 to 15,000 ft., two: 35,000 to 45,000 ft.) match up, then the whole grid would coincide. It would thus be possible to translate these grids to any position by locating one point in each grid. These points are sea level, static, and M = 0.8 at 36,000 ft.

Figure A.3.1-5 plots four points taken from the two 747 charts. Two of the points represent static sea level conditions, the other two, M = 0.8 at 36,000 ft. These four points which demonstrate change in thrust with decreasing S.F.C. enable two projections shown on Figure A.3.1-5. From Figure A.3.1-2 a S F.C. value of 0.24 is obtained for static sea level approximating the following 1980 conditions:

$\mu = 12:1$

$r = 24:1$

$T = 1800$

Figure A 3.1-3 generates a point value of S.F.C. equal to 0.33 for M = 0.8 at 36,000 ft

$\mu = 12.1$

$r = 31:1$

$T_{max} = 1600$

The two specific fuel consumptions are then projected vertically along a chart in Figure A.3.1-5. Two points are thus defined· sea level, static, M = 0 8 at 36,000 ft. The two former grids are now superimposed onto the chart, thus giving an approximation of the 1980 performance characteristics of an engine powering a M = 0.8 aircraft.

Figure A.3.1-6 shows relationships of bypass ratio to turbine temperature and to relative weight Many of these simple parametric approximations working together can rapidly size an engine.

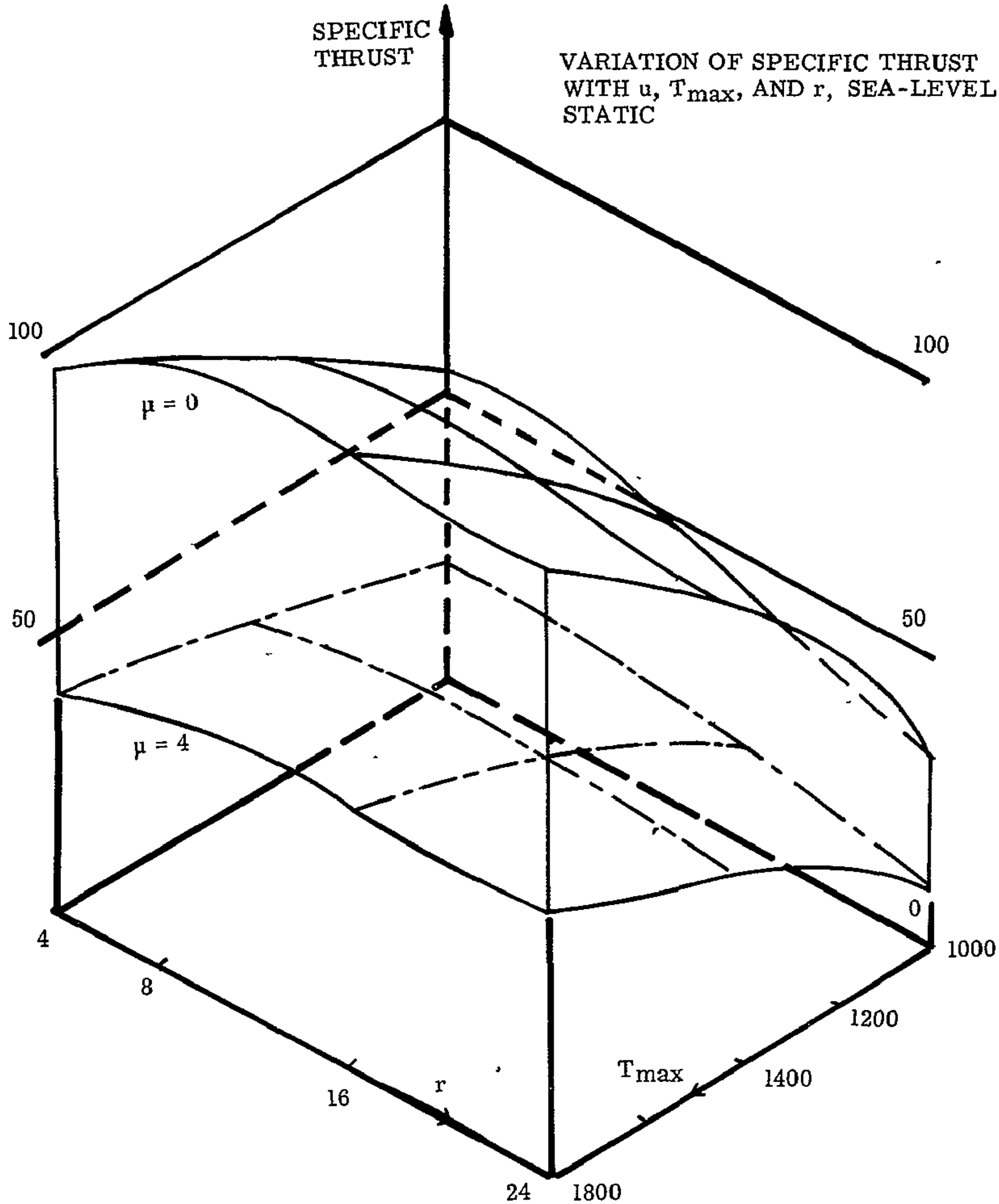

SPECIFIC
THRUST
VARIATION OF SPECIFIC THRUST
WITH u, T_{max}, AND r, SEA-LEVEL
STATIC
100
100
$\mu = 0$
50
50
$\mu = 4$
0
4
8
16
r
24
1800
T_{max}
1400
1200
1000

FIGURE A.3.1-1

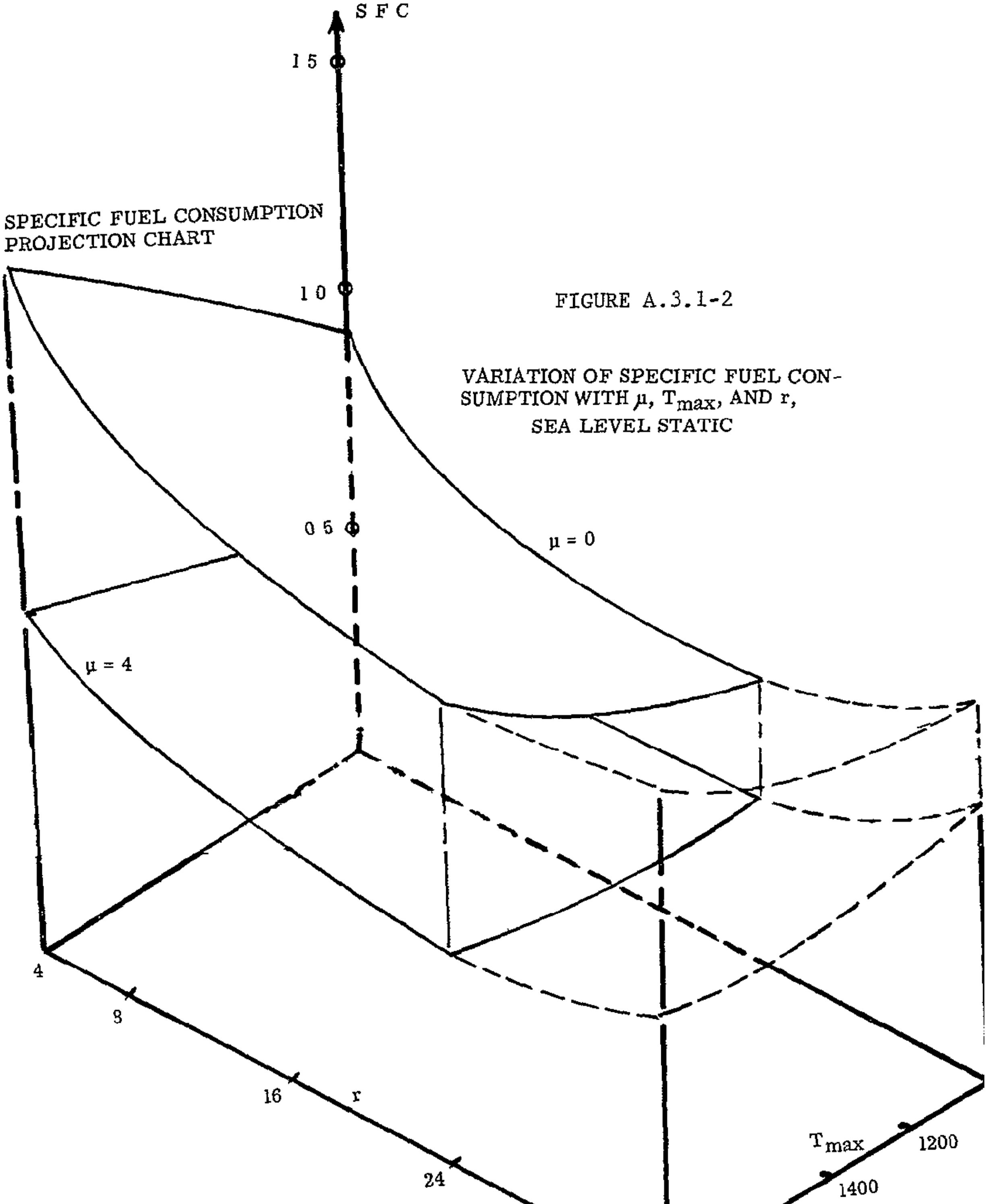


FIGURE A.3.1-2

VARIATION OF SPECIFIC FUEL CONSUMPTION WITH μ, T_{max}, AND r, SEA LEVEL STATIC

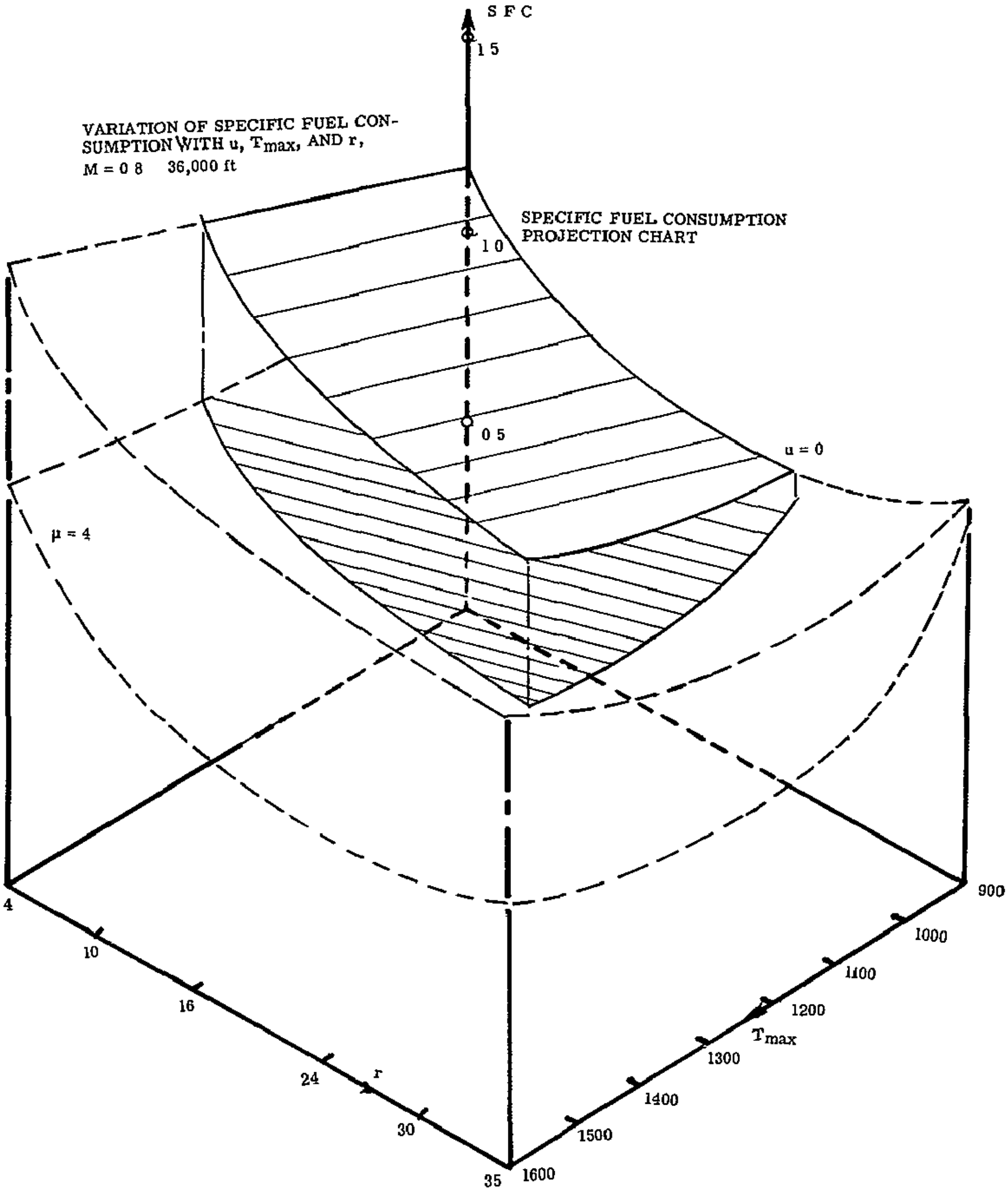
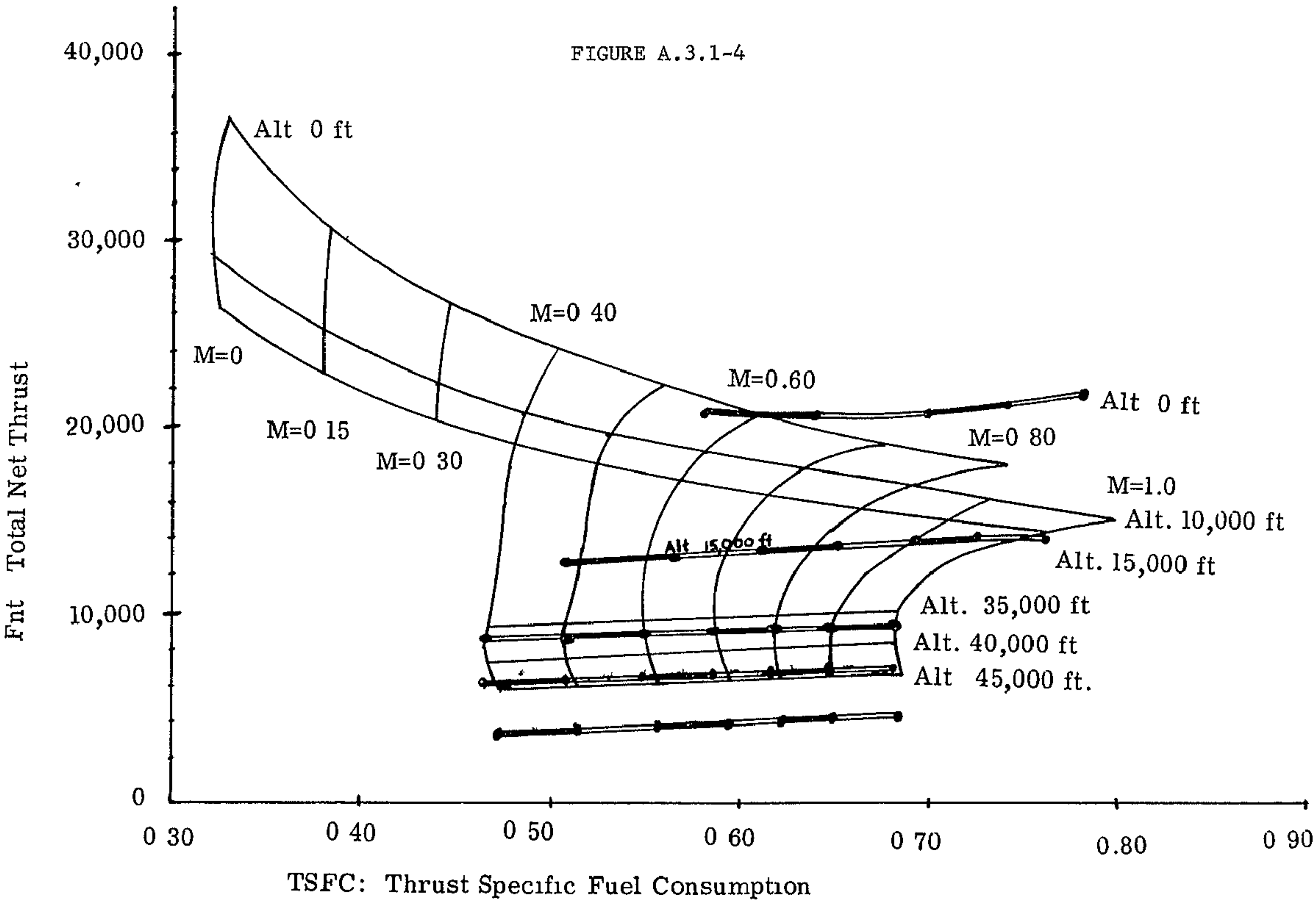

S F C
1 5
VARIATION OF SPECIFIC FUEL CONSUMPTION WITH u, Tmax, AND r,
M = 0 8 36,000 ft
SPECIFIC FUEL CONSUMPTION
PROJECTION CHART
1 0
0 5
u = 0
μ = 4
4
10
16
24
r
30
35
1600
1500
1400
1300
Tmax
1200
1100
1000
900

FIGURE A.3.1-3

MAXIMUM CONTINUOUS RATING CHART
FOR JT9D-3 ENGINE OF BOEING 747

FIGURE A.3.1-4



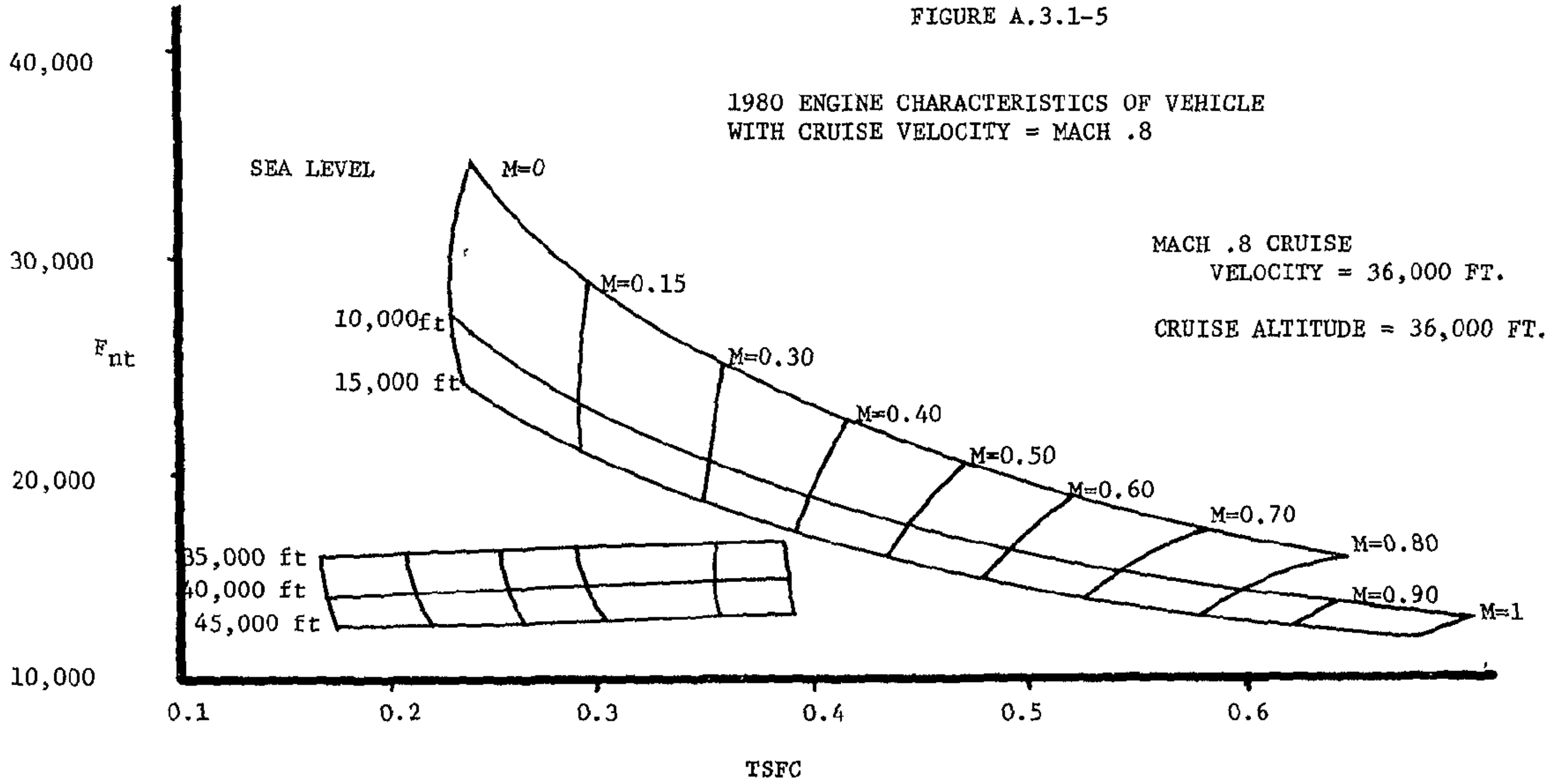
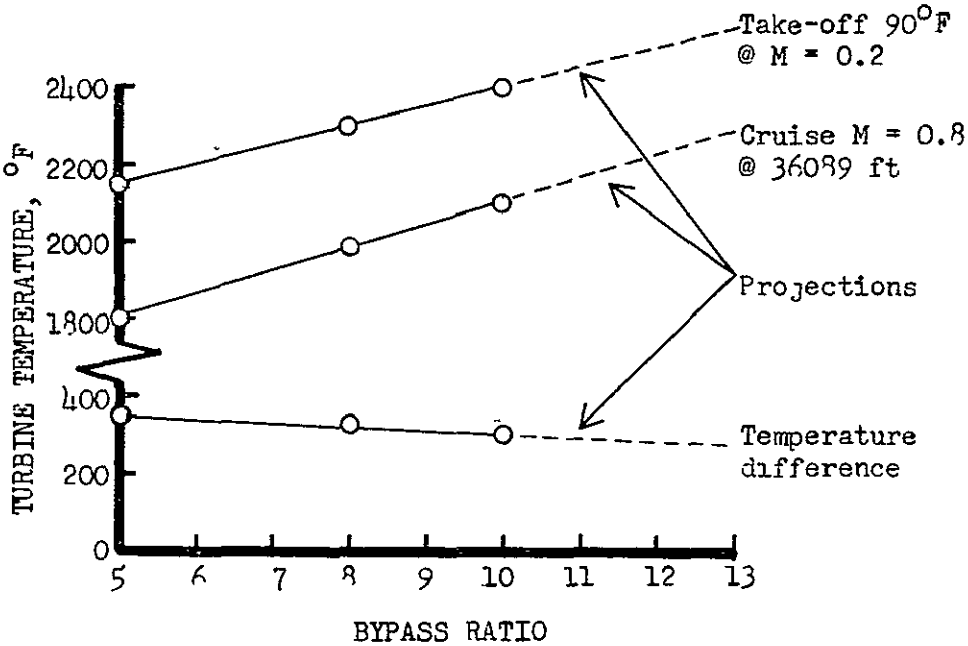


FIGURE A.3.1-5
1980 ENGINE CHARACTERISTICS OF VEHICLE
WITH CRUISE VELOCITY = MACH .8
SEA LEVEL
M=0
M=0.15
M=0.30
M=0.40
M=0.50
M=0.60
M=0.70
M=0.80
M=0.90
M=1
10,000ft
15,000 ft
35,000 ft
40,000 ft
45,000 ft
MACH .8 CRUISE
VELOCITY = 36,000 FT.
CRUISE ALTITUDE = 36,000 FT.
40,000
30,000
20,000
10,000
F_{nt}
0.1
0.2
0.3
0.4
0.5
0.6
TSFC

BY-PASS RATIO vs TEMPERATURE



RELATIVE ENGINE WEIGHT vs BY PASS-RATIO

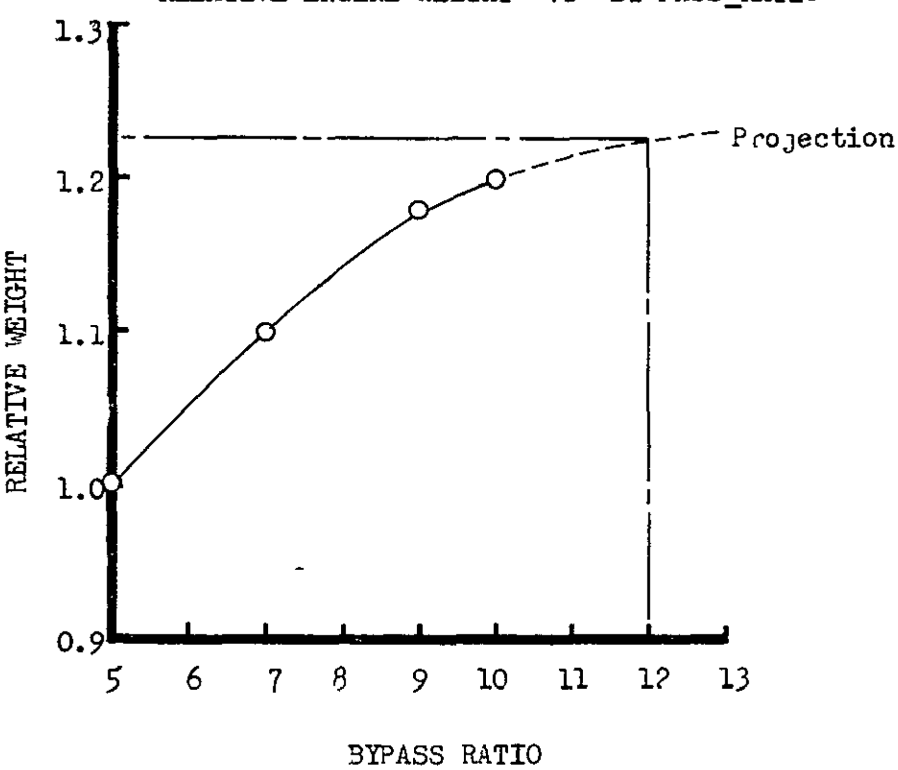


FIGURE A.3.1-6

A.4.1 TERMINAL CAPITAL COSTS

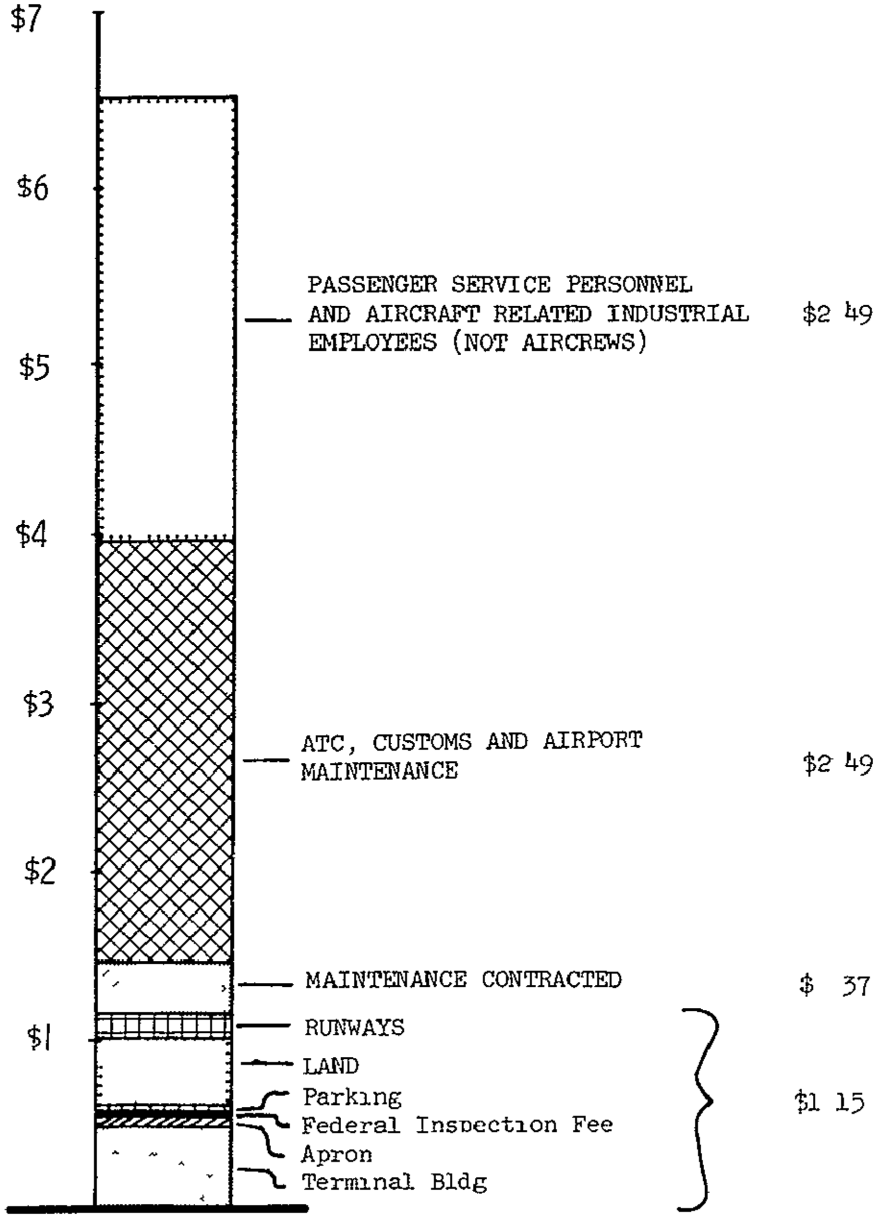
HOLIDAY (July, 1969) gave figures for an average domestic flight of 756 miles with an average passenger load of 55.44 passengers. The direct operating cost consisted of: cockpit crew $273, fuel and oil $307, maintenance, overhaul, modifications $444; and depreciation, rentals, hull insurance $246. The indirect operating cost comprised: airport expenses $294, inflight service $215; other aircraft operating costs $85, landing fees $32, selling expense $70, advertising $68, reservations $63, non-operating expenses $48, and general and administrative expense $180. The indirect operating costs total $1055 or amount to $19.05 per passenger for the average flight.

The third estimate was prepared on the basis of the number of employees and the number of passengers at some airports on average days in 1966-67. The data for Denver-Stapleton airport indicates that there is an employee at the airport for each passenger that boards or disembarks from a plane and has a much higher employee-to-passenger ratio than any other airport reporting. The Kansas City Municipal airport has the lowest employee-to-passenger ratio. The New York Hub with the three airports has 29 percent of the passengers with an employee-to-passenger ratio of 38 percent.

It is estimated in this study, using the New York airports as a representative hub, that 8 percent of the employee-to-passenger ratio is equivalent to the flight crews, pilots, and cabin attendants. Further, it is estimated that 10 percent out of the ratio can be considered the concession employees, who are paid from sources not connected with ticket sales. Of the remaining 20 percent out of the

38 percent, it is estimated that ten percent are required to maintain and service the facilities regardless of the number of passengers and that ten percent are required to furnish services which are directly related to the number of passengers handled Assuming that the average salary of the employees is $7200 per year (compared with $7223 for 1966 aircraft and traffic servicing personnel)[1] for 240 working days, the hourly rate is $3.00 or $24.00 per day. With pensions, etc., $25.00 per day was estimated as the cost of each employee. Thus, the cost of passenger service personnel and aircraft related industrial employees is estimated at $2.50 and the cost of air traffic control, customs and airport maintenance personnel is estimated at $2.50 per passenger enplaned or deplaned at the New York airport hub when the airports are operating at full average capacity.

The capital cost of the airport and its terminal facilities are estimated on the basis of requirement forecasts through 1980 by the Federal Aviation Agency.



COST PER PASSENGER ENPLANED OR DEPLANED
NEW YORK AIRPORT HUB

FIGURE A.4.1-1

TABLE A.4.1-1

ESTIMATED PASSENGER AND EMPLOYEE POPULATIONS AT CERTAIN AIRPORTS
ON AVERAGE DAY 1966-1967

Airport	Passengers	Employees	Employees-to-Passenger Ratio
Atlanta	29,600	12,000	24.7%
Chicago--O'Hare	50,000	16,000	32.0%
Denver--Stapleton	5,500	5,500	100.0%
Kansas City Municipal	6,700	1,100	16.4%
Los Angeles	42,000	33,000	78.5%
Miami	22,000	5,000	22.7%
Seattle--Tacoma	10,000	4,000	40.0%
Washington, D.C.--National	26,000	13,100	50.4%
New York--Kennedy	46,800	23,000	49.1%
New York--La Guardia	17,200	3,300	19.2%
New York--Newark	14,000	3,300	23.6%
TOTAL	269,800	119,300	45.9%
Three New York airports	78,000	29,600	38.0%

REFERENCES

1. Statistical Abstract of the United States 1968, U. S. Bureau of the Census, Washington, D. C., 1968, p. 575, Table 1, pp. 872-889.

2. Official Airline Guide, Quick Reference--North American Edition, Rueben H. Donnelley Corporation, Oak Brook, Illinois, May 15, 1969.

3. Eastman, Samuel Ewer, "Comparative Cost and Capacity Estimates of Vertiport and Airports 1975-1985," AIAA Paper No. 69-208, AIAA/AHS VTOL Research, Design, and Operations Meeting, Feb. 17-19, 1969, American Institute of Aeronautics and Astronautics, N. Y., p. 3.

4. Aviation Demand and Airport Facility Requirement Forecasts For Large Air Transportation Hubs Through 1980, U. S. Department of Transportation, Federal Aviation Administration, August, 1967.

A.5.1 AIRPORT AND AIRWAY FINANCING

The amount of revenue which could be expected to be generated over the next several years by imposing a "user charge" type tax on domestic commercial jet fuel was not readily available as was the revenue from the alternative user charges mentioned. In contrast to the several years (1970-74) of forecasted data given for the general aviation fuel tax, the domestic passenger ticket, tax, the freight waybill tax, and the international passenger service charge (see Table A.5.1-1), only the revenue expected in the fiscal year 1970 was found for the tax on air carrier turbine fuel (see Table A.5.1-2).

The obvious solution is to calculate the needed revenue values from FAA predictions of fuel consumption for the next decade (see Table A.5.1-3). Unfortunately, it can be seen that the 1970 fore-case consumption of jet fuel did not correspond to that value calculated from the estimate of revenue from a 1¢/gallon tax for this same year. This was definitely not an isolated discrepancy since it was also discovered that the situation was the same for general aviation fuel--the predicted fuel consumption data did not check with the values obtained from the revenue estimates for the next several years no matter how the data was juggled.

Fortunately, a close correlation between data sources was evident in the near duplication of corresponding user charge revenues as estimated for 1970 (see Tables A.5.1-1 and A.5.1-2). Based on this "confirmation" of Table A.5.1-2 data, the value for the 1970 revenue from a turbine fuel tax was also accepted as correct. Another useful data correlation was noted when the following calculation was made.

> Extrapolated aviation gasoline consumption = (1970 aviation gas consumption from Table A.5.1-1 revenue estimate/ Table A.5.1-3 figure for general aviation gas consumption in 1970) x Table A.5.1-3 general aviation gas consumption for year desired.

The results, tabulated in Table A.5.1-4 and shown in Figure A.5.1-1, confirm the close match between this NASA-WVU projection and plotted data derived from Table A.5.1-1.

Encouraged by these two data correlating findings, a similar computation was used to project the lone 1970 jet fuel revenue figure (changed to fuel consumed) into the next decade. This calculation was based on the following ratio·

> Extrapolated commercial jet fuel consumed = (1970 air carrier turbine fuel consumption from Table A 5.1-2 revenue estimate/Table A.5.1-3 figure for air carrier jet fuel consumption in 1970) x Table A.5.1-3 air carrier jet fuel consumption for year desired.

TABLE A.5.1-1

REVENUE FORECAST FROM ALTERNATIVE USER CHARGES[1]
(millions of dollars)

User Charge	1970	1971	1972	1973	1974
1¢/gallon general aviation fuel tax	6.1	6.5	6 9	7.4	7.8
1% domestic passenger ticket tax	57.5	63.4	70.0	77.1	84.9
1% freight waybill tax	5.8	6.6	7.6	8.8	10.0
$1 international passenger service charge	19.0	20.9	23.0	25.5	28.0

TABLE A.5.1-2

1970 FORECAST REVENUES FROM ALTERNATIVE USER CHARGES
(millions of dollars)

User Charge	1970 Revenue
1% air passenger ticket tax	58
1% tax on airfreight waybills	6
1¢/gallon tax on air carrier turbine fuel	86
1¢/gallon tax on non-commercial aviation gasoline	6

TABLE A.5.1-3

FORECAST FUEL CONSUMPTION FOR DOMESTIC CIVIL AVIATION[3]
(millions of gallons)

	JET FUEL			AVIATION GASOLINE		
Fiscal Year	Air Carrier	General Aviation	Total	Air Carrier	General Aviation	Total
1963	2250	25	2275	635	245	880
1964	2561	36	2597	615	255	870
1965	3058	61	3119	557	277	834
1966	3907	109	4016	464	333	797
1967	4568	129	4697	335	371	706
1968*	5560	150	5710	190	415	605
1969*	6840	175	7015	100	440	540
1970*	7470	195	7665	70	470	540
1971*	8010	210	8220	60	500	560
1972*	8620	225	8845	60	530	590
1973*	9500	240	9740	50	560	610
1974*	10350	265	10615	40	590	630
1979*	16450	440	16890	30	780	810

*Forecast data, note also that 1963-1967 data partially estimated

TABLE A.5.1-4

GENERAL AVIATION GAS CONSUMPTION

YEAR	Table 3 general aviation gas consumption forecast (millions of gallons)	Calculated value based on ratio mentioned in text (millions of gallons)
1970	470	610
1971	500	650
1972	530	690
1973	560	730
1974	590	770
1979	780	1010

TABLE A.5.1-5

AIR CARRIER JET FUEL CONSUMPTION

YEAR	Table 3 air carrier jet fuel consumption forecast (millions of dollars)	Calculated value based on ratio mentioned in text (millions of dollars)	Estimated revenue from 1¢/gallon tax (millions of dollars)
1970	7470	8600	86
1971	8010	9200	92
1972	8620	9900	99
1973	9500	10900	109
1974	10350	11900	119
1979	16450	18900	189

FIGURE A.5.1- 1

GENERAL AVIATION
GASOLINE CONSUMPTION

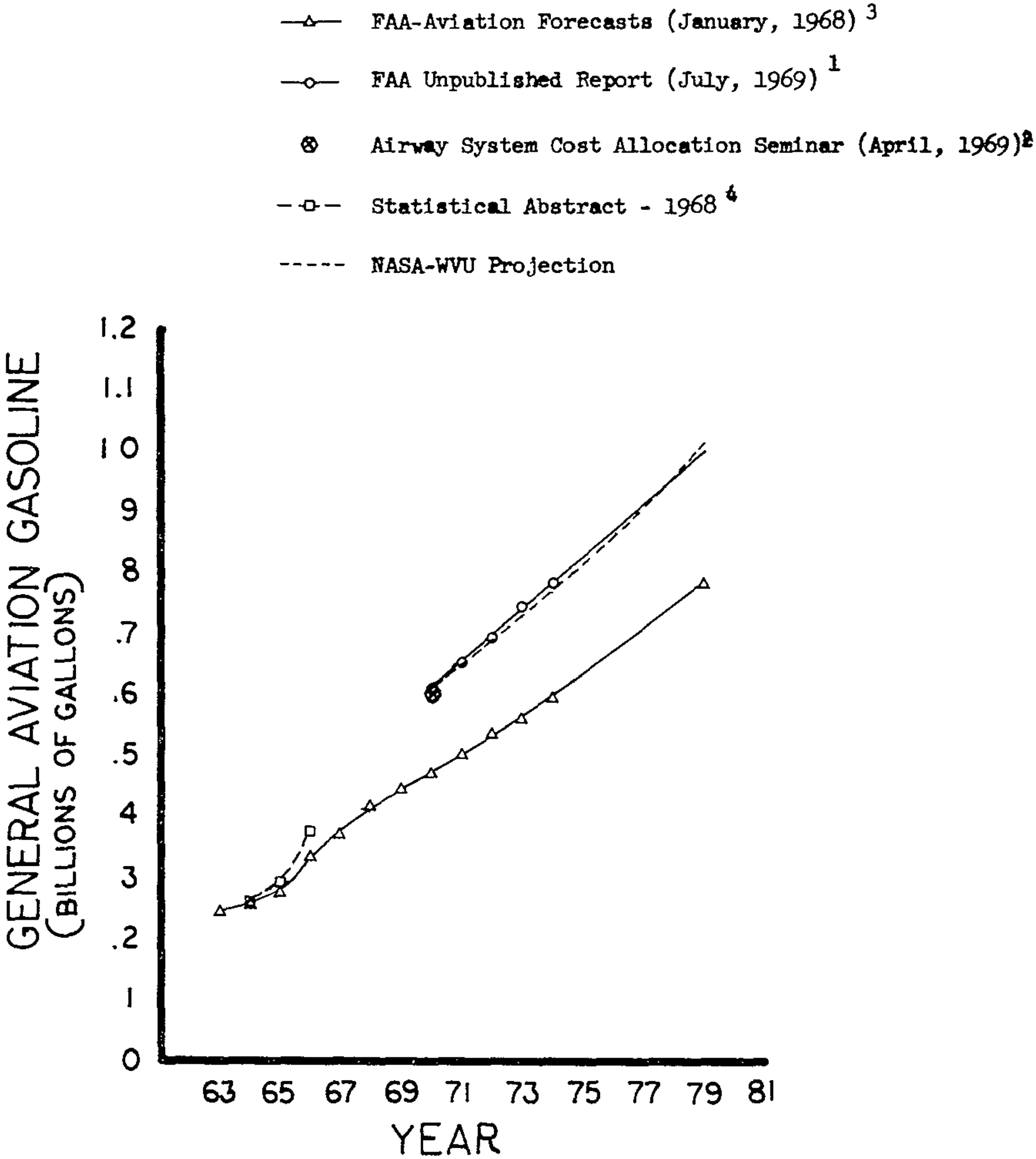
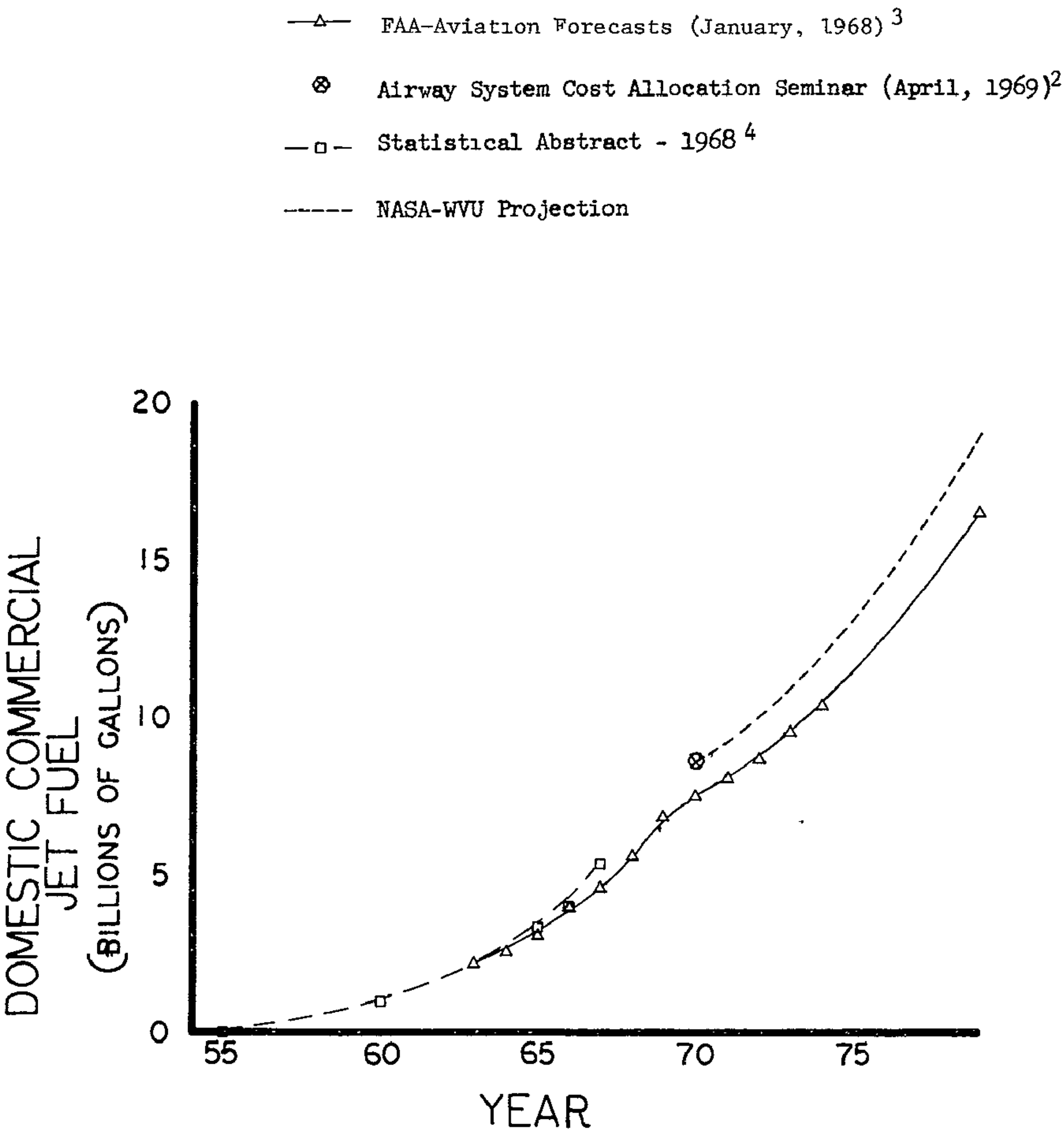


FIGURE A.5.1-2

DOMESTIC COMMERCIAL
JET FUEL CONSUMPTION



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2. Harper, Clarke, chairman, "Airway System Cost Allocation Seminar," Attachment E, First Annual Planning Review Conference, Washington, D. C., April 23-25, 1969, p. 2.

3. Aviation Forecasts Fiscal Years 1968-1979, Department of Transportation, Federal Aviation Administration, Office of Policy Development, Economics Division, January, 1968, p. 31.

4. U. S. Bureau of the Census, Statistical Abstract of the United States: 1968, 89th edition, (Washington, D. C., 1968), p. 571.

A.6.1 GUEST LECTURERS

Lecturer	Topic
Mrs. Joan Barriage Federal Aviation Administration Department of Transportation	"V/STOL Aircraft"
Mr. Robert Bacon Federal Aviation Administration Department of Transportation	"Air Terminal Design"
Mr. James Blackwell NASA LRC	"Convention Take-Off And Landing Aircraft"
Mr Joseph Chambers NASA LRC	"V/STOL Aircraft"
Mr George Chatham NASA Headquarters	"Future Air Transportation Needs and Possibilities"
Mr William Connor NASA LRC	"Acceptable Ride Comfort Levels"
Mr. Cornelius Driver NASA LRC	"Supersonic Transports"
Mr. David Fetterman NASA LRC	"Hypersonic Aircraft"
Mr. Thomas Foughner NASA LRC	"Aeroelasticity And Flutter"
Mr. Richard R Heldenfels Mr. Herbert Hardrath Mr. John Davis, Jr. Mr. Robert Jackson NASA LRC	"Aircraft Structures, Materials, And Dynamic Loads"
Mr. Arvin Keith NASA LRC	"Aircraft Propulsion"
Mr Harry Lawrence NASA LRC	"Air Collision Avoidance"
Mr. John Lowry NASA LRC	"Aircraft Demand Projections"
Mr. Dominic Maglieri NASA LRC	"Aircraft Noise And Sonic Boom"
Mr. Edward Polhamus NASA LRC	"Aircraft Aerodynamics"

Mr Robert Rummel Trans World Airlines	"The Airlines' Needs In The 1980's"
Mr. Robert Schade NASA LRC	"Air Traffic Control"
Professor William Seifert Massachusetts Institute of Technology	"Air Transportation - 1980"
Dr. Paul Shuldiner Office of High Speed Ground Transportation Department of Transportation	"A Systems Design For Transportation In The Northeast Corridor"
Mr. Roy Steiner NASA LRC	"Aircraft Ground Handling Problems"
Graduate Student Design Delegation from Georgia Institute of Technology (Mr. Michael Deizenroth) (Mr. Manual Pareya) (Mr. William Pugh) (Mr. Larry Residori)	"Systems Design of A 1980 Air Transportation System"

A 6.2 TOURS

Date	Facility
July 2, 1969	NASA - Langley Research Center
August 6, 1969	NASA - Wallops Station
August 11, 1969	Langley Air Force Base
August 14, 1969	Air Route Traffic Control Center, Leesburg, Virginia

UNITED STATES AIR TRANSPORTATION 1980