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1990 High-Speed Civil Transport Studies

HSCT Concept Development Group
Advanced Commercial Programs

McDonnell Douglas Corporation
Douglas Aircraft Company
Long Beach, California

Contract NAS1-18378
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1990 HIGH-SPEED CIVIL TRANSPORT STUDIES

HSCT CONCEPT DEVELOPMENT GROUP
ADVANCED COMMERCIAL PROGRAMS

DOUGLAS AIRCRAFT COMPANY
LONG BEACH, CA 90846

CONTRACT NAS1-18378

ABSTRACT

This report contains the results of the Douglas Aircraft Company system studies related to high-speed civil transports (HSCTs). The tasks were performed under an 18-month extension of NASA Langley Research Center Contract NAS1-18378.

The system studies were conducted to assess the emission impact of HSCTs at design Mach numbers ranging from 1.6 to 3.2. The tasks specifically addressed an HSCT market and economic assessment, development of supersonic route networks, and an atmospheric emissions scenario.

The general results indicated (1) market projections predict sufficient passenger traffic for the 2000 to 2025 time period to support a fleet of economically viable and environmentally compatible HSCTs; (2) the HSCT route structure to minimize supersonic overland traffic can be increased by innovative routing to avoid land masses; and (3) the atmospheric emission impact on ozone would be significantly lower for Mach 1.6 operations than for Mach 3.2 operations.

FOREWORD

The 1990 High-Speed Civil Transport Study was an 18-month extension of the previous 3 years' work (Phases I to IIIA). The 1990 systems studies evaluation covered the period from 1 October 1989 to 31 March 1991.

Work was accomplished as a task order activity by Douglas Aircraft Company in Long Beach, California. This work was under the direction of the NASA Langley Research Center, Hampton, Virginia, and was funded under Contract NAS1-18378.

The NASA Contracting Officer Technical Representative was Donald L. Maiden. The Douglas program manager was initially Donald A. Graf, HSCT business unit manager, and, in the latter 9 months of the contract, Bruce L. Bunin, business unit manager–Advanced Commercial Programs. Principal investigators were Munir Metwally, market research and economic assessment, and Alan K. Mortlock, technical assessment.

Other Douglas staff that made essential contributions to the HSCT team contract work included:

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SECTION 1
SUMMARY

The 1990 system study report contains technical, environmental, marketing, and economic assessments; discusses issues and concerns; and makes recommendations for further system studies. This report focuses on the atmospheric emission impact, marketing, and economic aspects of the HSCT. It contains results of a Douglas Aircraft Company study to evaluate the commercial viability of the HSCT. The approach was to evaluate, under simulated airline operations, worldwide market demand, fleet requirements, realistic supersonic route structures, and HSCT economic performance. Subsequently, atmospheric emission scenarios were developed, and emission impact was evaluated for three Mach number configurations — 1.6, 2.2, and 3.2.

Market and Economic Assessments — Traffic projections for the years 2000 to 2025 and fleet requirements over a Mach number range of 1.6 to 3.2 have been assessed with regard to Mach number, fare premium, and aircraft range. At Mach 2.2, fleet needs could total 2,300 or more 300-seat aircraft by the year 2025. The prime conditions for economic viability include (1) airplane revenues covering operating costs plus an attractive rate of return to the operator, (2) fares compatible with the subsonic fleet to expand HSCT service, and (3) a market large enough to permit a selling price lower than the investment value of the airplane.

Supersonic Network Evaluation — Only a few candidate global airline network scenarios for HSCT have been assembled. The high-density long-range markets were selected from the Official Airline Guide (OAG) on-line data base. Creative rerouting was conducted to minimize overland segments and to lessen the impact of the environmental restrictions that may be imposed on future supersonic operation.

The data on these network scenarios represent an assembly of global routes from which HSCT global traffic networks can be constructed. The network scenarios provide examples on how supersonic service may bring some changes to the current global route structure. Some of these supersonic network scenarios show good potential of capturing more than half the market share of the long-range traffic.

Atmospheric Emissions Impact Status — An engine emission annual fuel burn model was developed for input to 20 atmospheric models. Atmospheric emission scenarios were produced for three HSCT configurations at Mach 1.6, 2.2, and 3.2 The atmospheric global model results showed that ozone depletion is a function of the aircraft's cruise Mach number primarily because of the strong dependence of ozone impact on injection altitude. The atmospheric impact of ozone depletion of the Mach 1.6 configuration is considerably less than that of the Mach 2.2 and 3.2 configurations for a given combustor technology. The introduction of cruise altitude restrictions after the HSCT enters service could alleviate the ozone impact of the Mach 1.6 and 2.2 configurations. At Mach 3.2, however, the increased fuel burn more than offsets the advantage of lower injection altitude. All configurations will suffer some economic performance penalties if forced below their optimum operating cruise altitude.

SECTION 2
INTRODUCTION

This report presents the results of Douglas HSCT system studies. It is a continuation of environmental and economic studies completed in the 1989 system study. In this report, market projections have been made for the years 2000 to 2025, fleet requirements have been assessed over a Mach number range of 1.6 to 3.2, and a number of supersonic network scenarios have been evaluated.

Additionally, for atmospheric studies, engine emissions have been developed into annual emission fuel burn constituents to provide input data to an atmospheric impact two-dimensional model.

SECTION 3
MARKET AND ECONOMIC ASSESSMENT

NASA Report 4235, submitted by Douglas at the conclusion of the Phase III studies, included an initial screening from Mach 2 to Mach 25, followed by a focus on the Mach 2 to Mach 5 range, as well as a comparison of Mach 3.2 and Mach 5.0. The economic potential for a high-speed commercial transport with respect to technical readiness, market characteristics, aviation infrastructure, and environmental issues was described. A forecast of air travel passengers indicated a need for HSCT service in the 2000-2025 time frame, conditioned on economic viability and environmental compatibility. Design requirements for this study focused on a 300-passenger, three-class aircraft with a range of 6,500 nautical miles, based on accelerated growth predictions for the Pacific region. Aircraft productivity was a key parameter, with aircraft worth in comparison to aircraft price being the airline-oriented figure of merit.

As a follow-up on previous studies, research for Task 11 has focused on three configuration designs: Mach 1.6, 2.2, and 3.2. An economic analysis of supersonic operation based on aircraft specifications has been conducted. The market research reflects refinements in market assumptions and projections, a better understanding of market elasticity and stimulation, the latest preliminary estimates for fleet requirements, the sensitivity of aircraft performance and economics to environmental constraints, and an updated parametric analysis of different design range and passenger configurations. This section covers traffic projection, fleet assessment, and an economic comparison of the three configuration designs at Mach 1.6, 2.2, and 3.2.

Three-view drawings of the baseline configurations used in the 1990 system studies for various environmental and economic studies are shown in Figures 3-1, 3-2, and 3-3. The development of these configurations was based on earlier phases of the current Douglas HSCT system study contract and on the Douglas Advanced Supersonic Transport (AST) activities of the 1970s. The fuselage was designed to accommodate 300 passengers in a nominal seating arrangement of three classes: 10, 30, and 60 percent for first, business, and coach classes, respectively. HSCT performance was analyzed according to commercial domestic and international rules and practices. The HSCT design range was 6,500 nautical miles in an all-supersonic cruise condition.

3.1 TRAFFIC PROJECTION

Traffic projection initially encompassed all international air traffic in 18 International Air Transport Association (IATA) regions. The 10 regions considered to be the best potential for supersonic operation were then studied in more detail. The air traffic forecasts prepared for the 10 regions were based on econometric models that relate traffic to national income, fares, yield, and, where appropriate, other relevant variables. Four of the 10 regions comprise about 85 percent of the total international traffic. Rapid economic growth in the Pacific-Asia region has made this the fastest growing area for passenger traffic. Figure 3-4 shows that North and Mid-Pacific traffic will equal North Atlantic traffic by the year 2000.

Long-term prospects for international passenger traffic gains are relatively good. Overall, traffic is predicted to total about 450 billion annual seat-miles (ASMs) by the year 2000 and

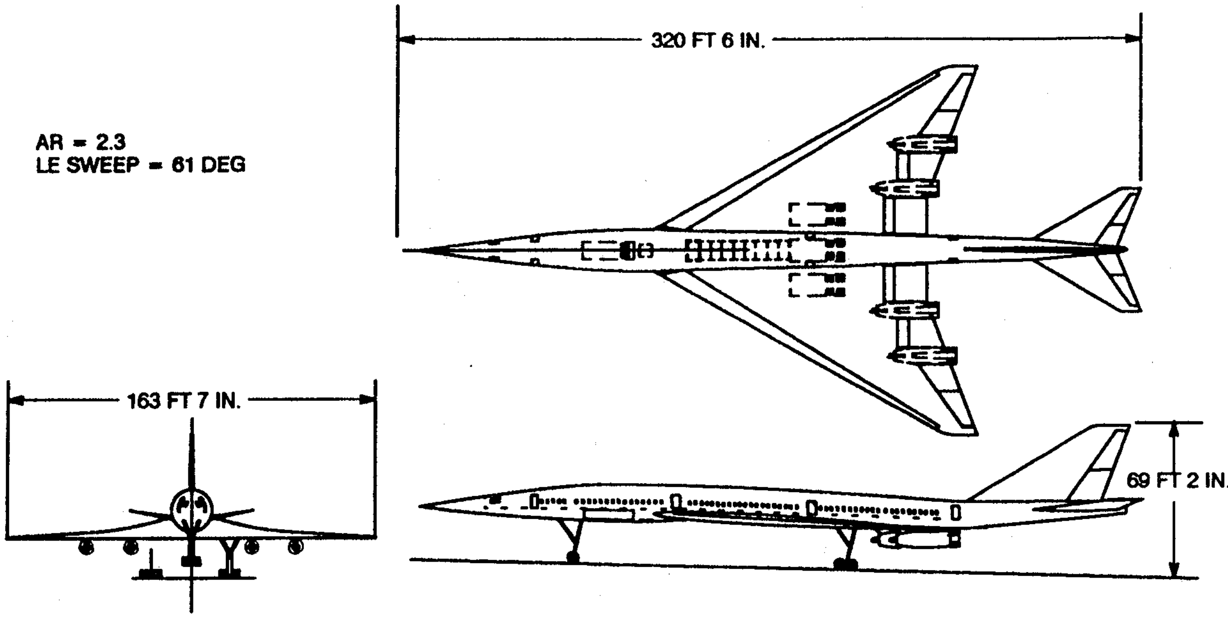

FIGURE 3.-1. DOUGLAS MACH 1.6 TURBULENT BASELINE CONFIGURATION, D1.6-3

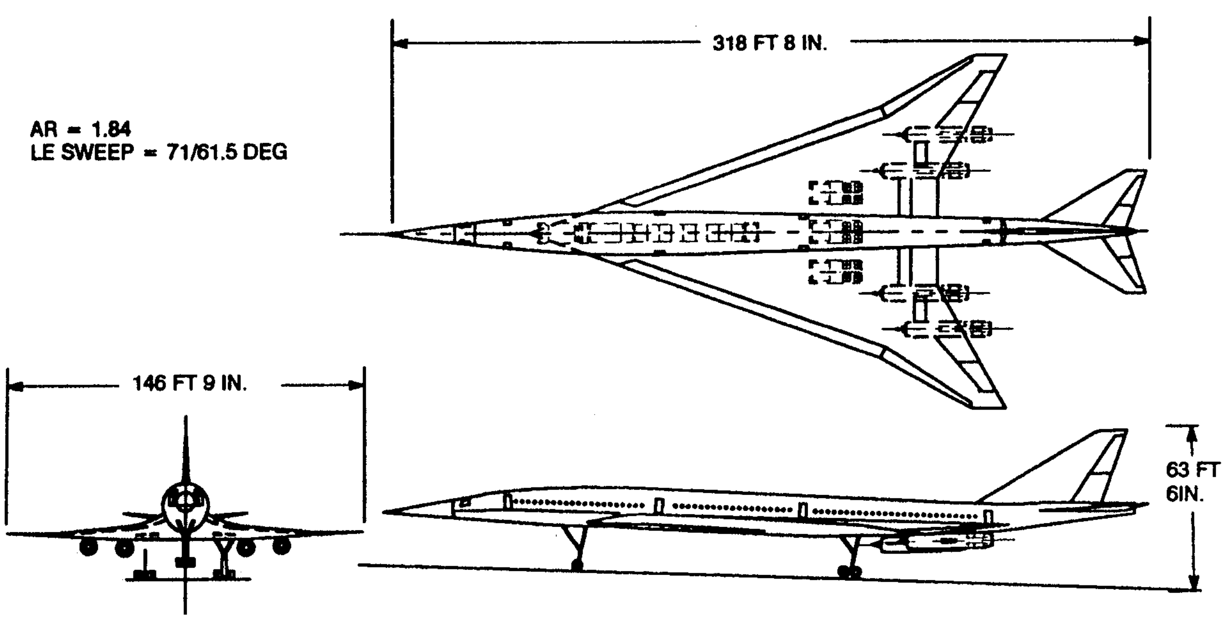

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FIGURE 3-2. DOUGLAS MACH 2.2 TURBULENT BASELINE CONFIGURATION, D2.2-10

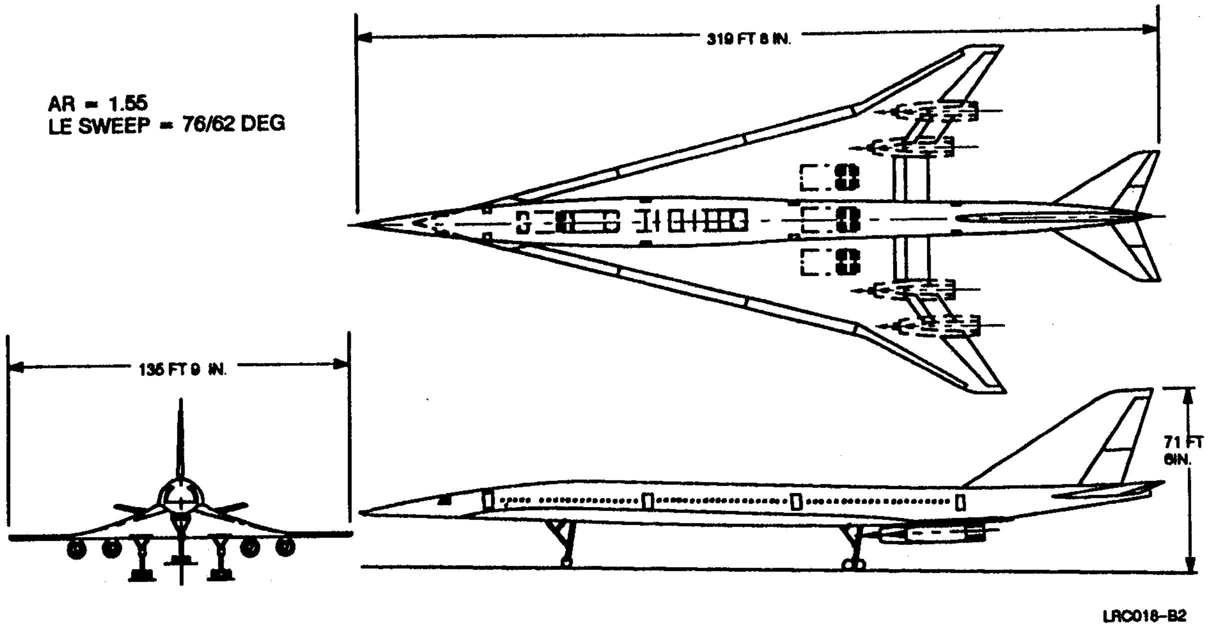

FIGURE 3-3. DOUGLAS MACH 3.2 TURBULENT BASELINE CONFIGURATION, D3.2-7A

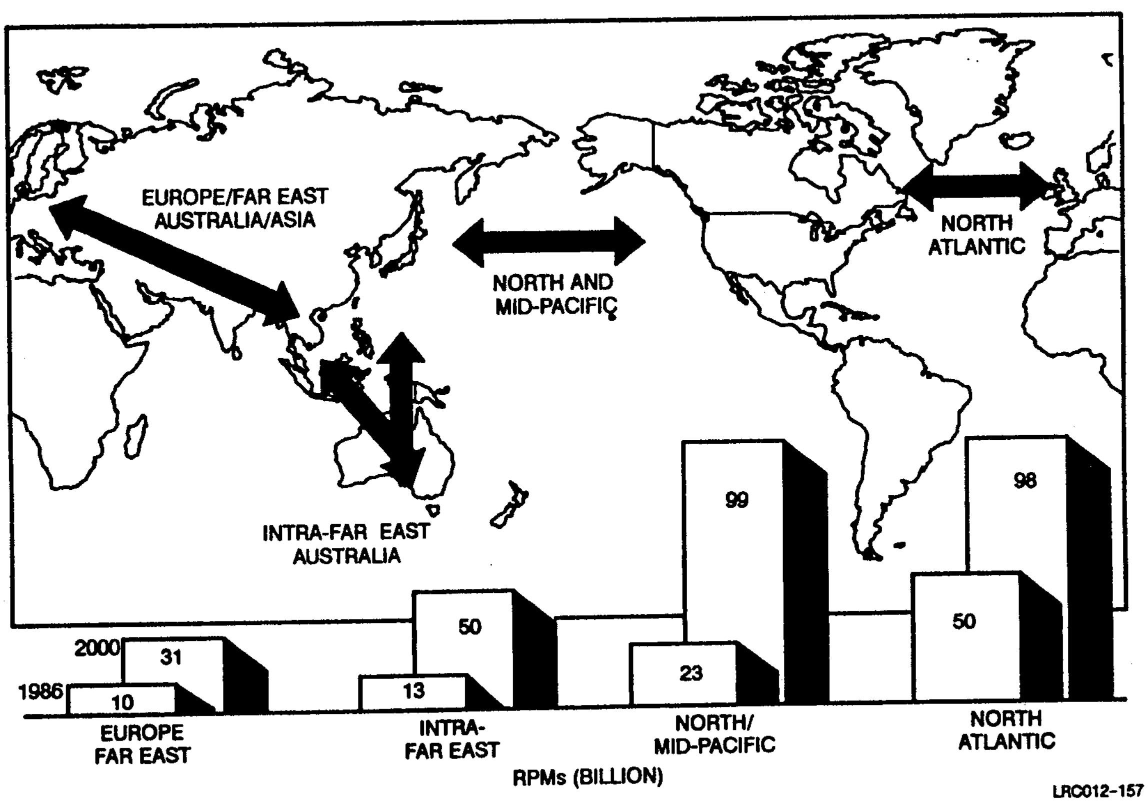

FIGURE 3-4. INTERNATIONAL PASSENGER TRAFFIC - MAJOR REGIONS (85-90 PERCENT OF TOTAL)

2.4 trillion ASMs by the year 2025, or five times the traffic projected for the year 2000. Figure 3-5 shows the distribution of the year 2000's ASMs among the 10 HSCT regions.

3.2 FLEET REQUIREMENT

In order to assess world HSCT fleet requirements, one has to examine the outlook for the commercial aviation industry as a whole. Traffic forecasts, economic parameters, current and future airlines fleet composition, and political trends and regulations must be monitored and analyzed to produce the most reliable projections for world supersonic fleet estimates. Projections of the future subsonic fleet, airline orders for firm and conditionally firm new aircraft, and retirement of the current fleet are among the primary considerations in assessing tomorrow's supersonic fleet.

The passenger traffic estimates, combined with load factor forecasts, produce the total capacity required in terms of available seat-kilometers, as indicated by the top line in Figure 3-6. With a long-term average capacity growth requirement forecast of 5.5 percent, nearly 4.5 trillion available seat-kilometers (ASKs) will be needed by the year 2000 to support the anticipated traffic level. Capacity provided by the current fleet will fall by 50 percent to 1 trillion ASKs in 2000 because of aircraft retirements. Partially offsetting this loss, however, is an additional 800 billion annual ASKs that will be provided by aircraft currently on order. The differential between the total capacity required and that supplied by the current fleet plus aircraft on order represents the capacity gap. This deficiency, which grows to 2.8 trillion ASKs by 2000, will be satisfied by new orders of generic aircraft. The size and range characteristics of the new aircraft required to fill the capacity gap are shown in Figure 3-7.

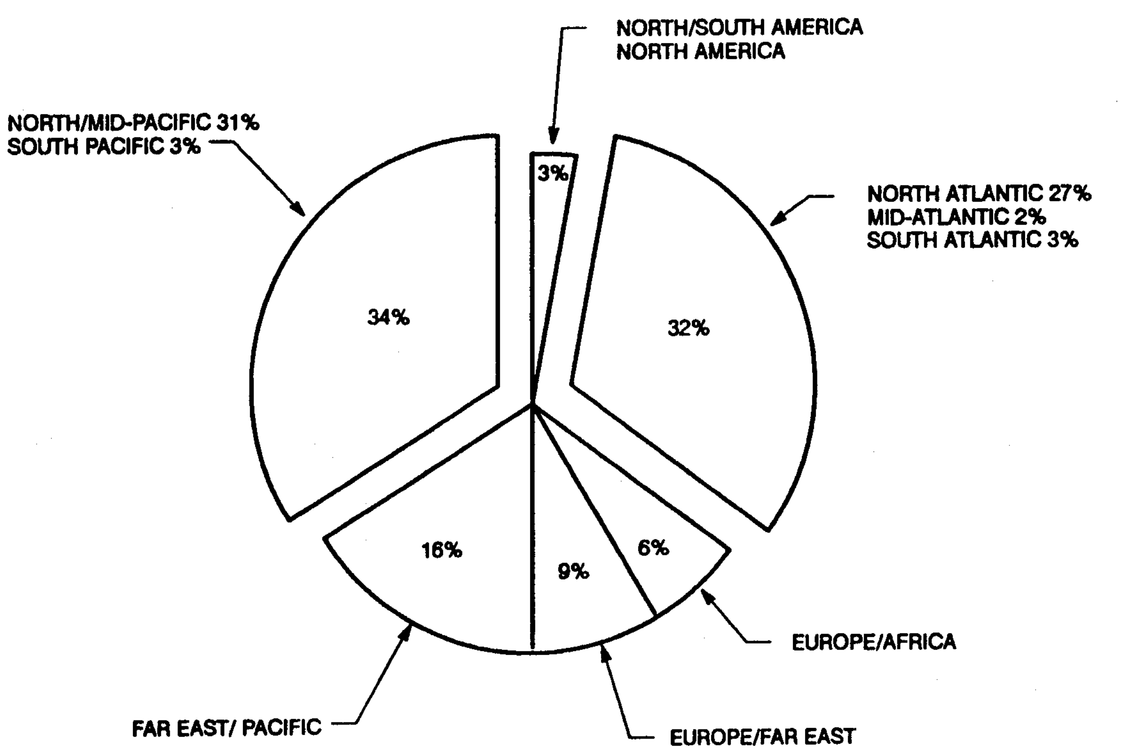

FIGURE 3-5. DISTRIBUTION OF ANNUAL SEAT-MILES FOR MAJOR 10 REGIONS FOR YEAR 2000

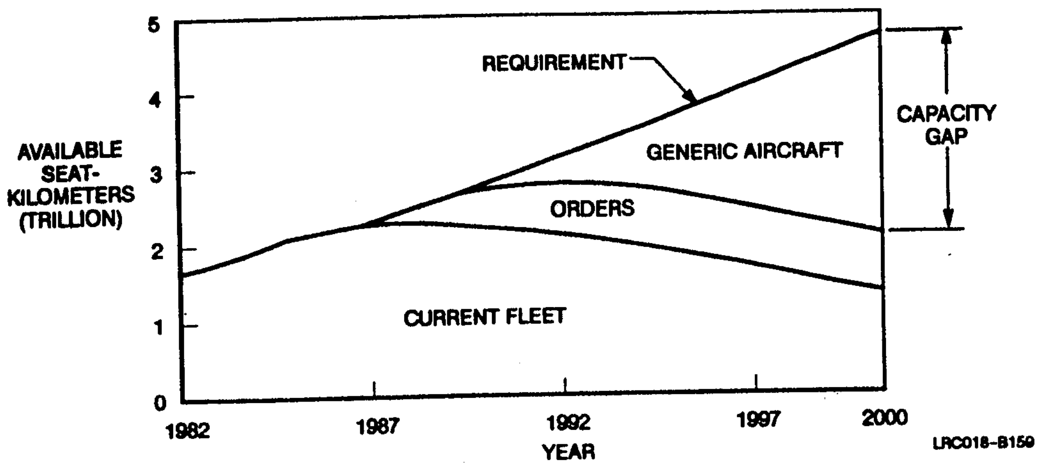

FIGURE 3-6. PASSENGER AIRCRAFT CAPACITY/SUPPLY FORECAST

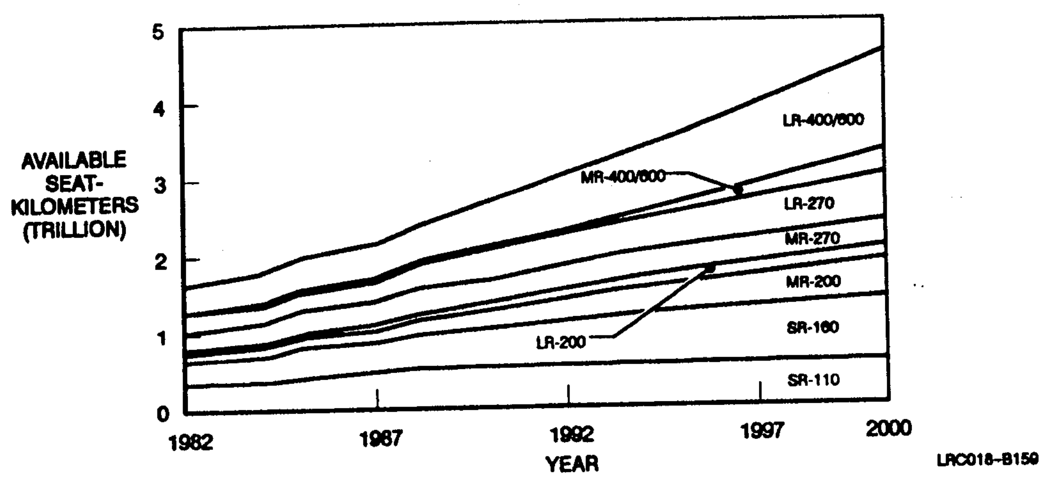

FIGURE 3-7. PASSENGER CAPACITY TRENDS BY GENERIC CLASS

Increased capacity will be demanded for all generic aircraft classes. However, it is significant that certain classes will outperform others on a relative basis. Inherent in the forecast is the fact that both airport and airspace congestion will force carriers to rely increasingly on larger aircraft instead of increased frequencies to satisfy projected traffic demands. Airlines will also rely on aircraft with higher productivity, such as the HSCT, to reduce congestion.

Airline transitions from subsonic aircraft to supersonic will also have an impact on the number of generic aircraft in the medium- and long-range categories. Productivity gains necessary to achieve the 5.5-percent worldwide average ASK escalation will be realized by changes in four components: aircraft units, average seat counts, utilization, and speed. An increase in aircraft units will be the dominant element in increasing ASKs. As larger transports replace smaller ones, the average seat count per aircraft will contribute to productivity gains. A relatively subordinate role will be played by aircraft utilization and increased flight speed unless the HSCT becomes available for commercial airlines. HSCT productivity gain due to speed will then become the dominant component, replacing aircraft units. It is conceivable that productivity gain may ultimately cause a decline in fleet size.

The growth in the world's airline industry will necessitate changes in the number and type of aircraft that serve it. Overall, the 6,500 passenger aircraft operated commercially by the late 1980s will advance to a world fleet approximating 10,000 airliners by the year 2000, a 54-percent unit increase. The dominant position of the short-range fleet will moderate as it falls to 56 percent of the world fleet in 2000 from its present 68-percent unit share. The medium- and long-range fleets will generate a significant relative unit gain over the forecast period.

The 10,000 commercial passenger jetliners forecast for the worldwide fleet in 2000 will be presented by a cross section of aircraft currently in service, transports presently on order, and projected new generic aircraft. Much of today's fleet will still be operating in commercial service by 2000. As shown in Figure 3-8, approximately 28 percent of the fleet in the year 2000 will be composed of units currently in service. The remainder of this fleet will be composed of jets currently on order (17 percent of the year 2000 fleet) and the projected new generic equipment (55 percent).

World demand for new passenger aircraft for the year 2000 is forecast at 5,500 units in addition to those currently on order. Figure 3-9 shows the generic passenger aircraft requirement by class. The medium- and long-range classes (greater than 3,500-nautical-mile range and 250 passengers) are expected to total more than 1,800 aircraft. Approximately one-half of this market is represented by the 10-region HSCT arena. Therefore, the HSCT with no fare premium may replace a maximum of 900 aircraft. At Mach 2.2, the HSCT is twice as productive as a subsonic aircraft of the same size. A fleet of approximately 450 HSCTs can transport the payload of 900 subsonic aircraft. Figure 3-10 shows the generic passenger aircraft requirements, including the HSCT, in the year 2000.

As supersonic speed changes, productivity changes as well, resulting in variations in fleet projections. Fleet requirements are sensitive to fare elasticity. Introduction of fare premiums will reduce fleet sizes. Table 3-1 shows HSCT fleet requirements at different fare premiums for the Mach 1.6, 2.2, and 3.2 configurations. It illustrates how fleet sizes are reduced as fare premiums increase. HSCT needs shown in the table cover the period from the year 2000 to the

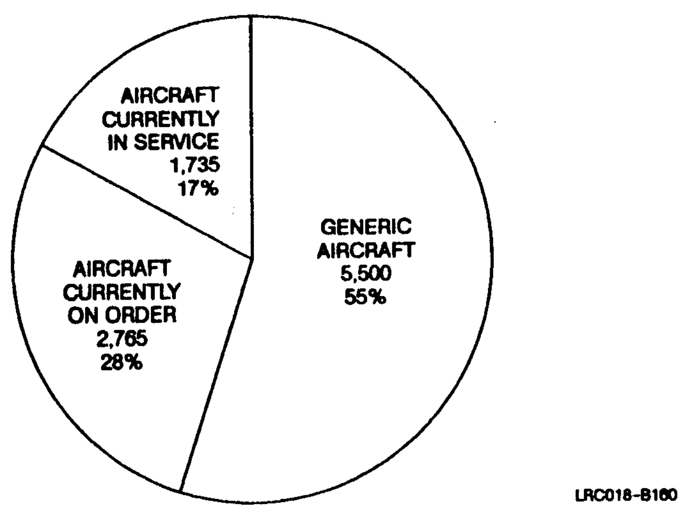

FIGURE 3-8. COMMERCIAL PASSENGER JETLINERS IN YEAR 2000

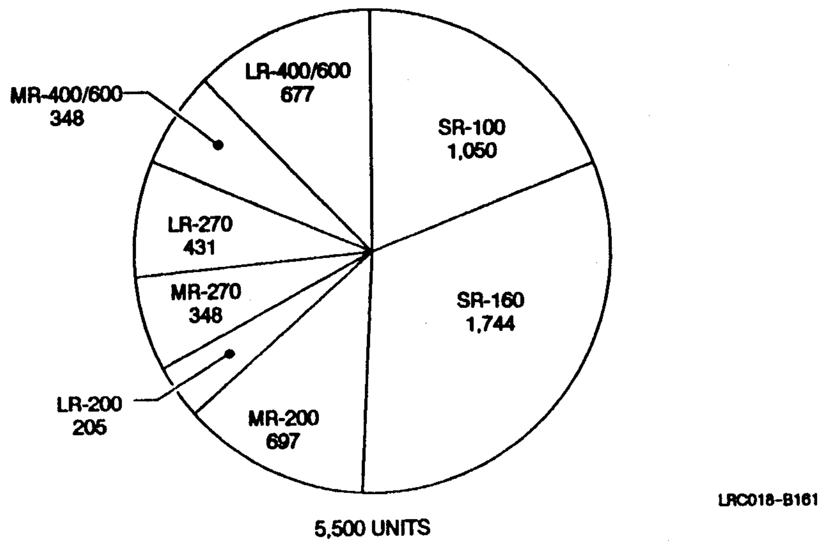

FIGURE 3-9. GENERIC PASSENGER AIRCRAFT REQUIREMENTS IN YEAR 2000

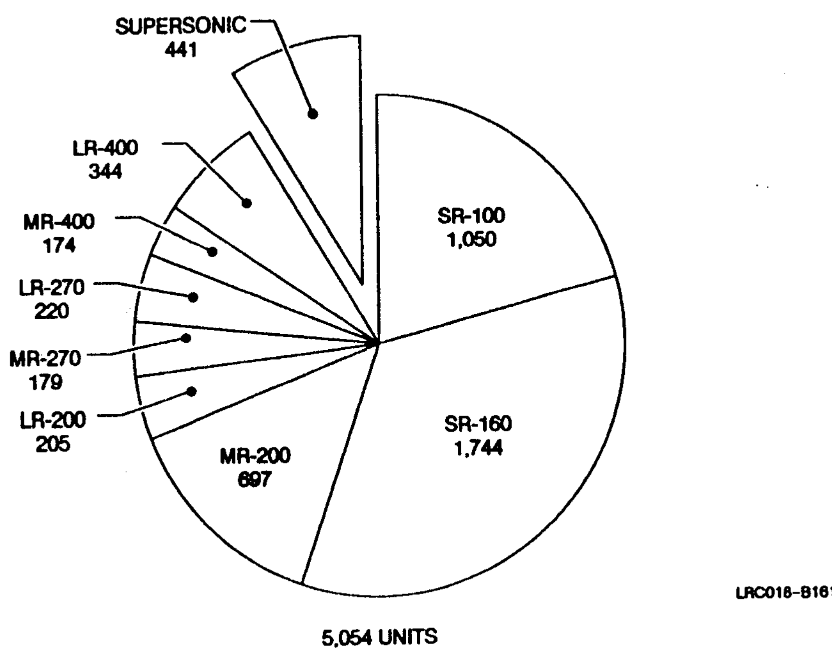

FIGURE 3-10. GENERIC PASSENGER AIRCRAFT REQUIREMENTS INCLUDING SUPERSONIC CLASS IN YEAR 2000

year 2025. Since there would be no HSCT aircraft in the commercial fleet as early as the year 2000, the subsonic fleet will continue to serve world traffic demands until the HSCT is introduced. If production rates are no greater than the rate of traffic growth, production quantities can be absorbed without premature retirement of the subsonic fleet. Figure 3-11 gives fleet projections for the year 2000.

Future fleet assessments need to examine some of the more complex factors that affect fleet projections. A better understanding of elasticity, stimulation, value of time, and fare premium

TABLE 3-1
FLEET PROJECTIONS BASED ON HSCT DEMAND

FARE PREMIUM LEVELS (PERCENT)	NUMBER OF AIRCRAFT					
	MACH 1.6		MACH 2.2		MACH 3.2	
	YEAR 2000	YEAR 2025	YEAR 2000	YEAR 2025	YEAR 2000	YEAR 2025
0	521	2,725	441	2,315	365	1,954
10	368	1,954	358	1,870	314	1,700
20	201	1,097	230	1,194	210	1,147
30	79	450	124	666	137	765
40	34	198	57	314	74	423
50	15	92	29	158	38	220

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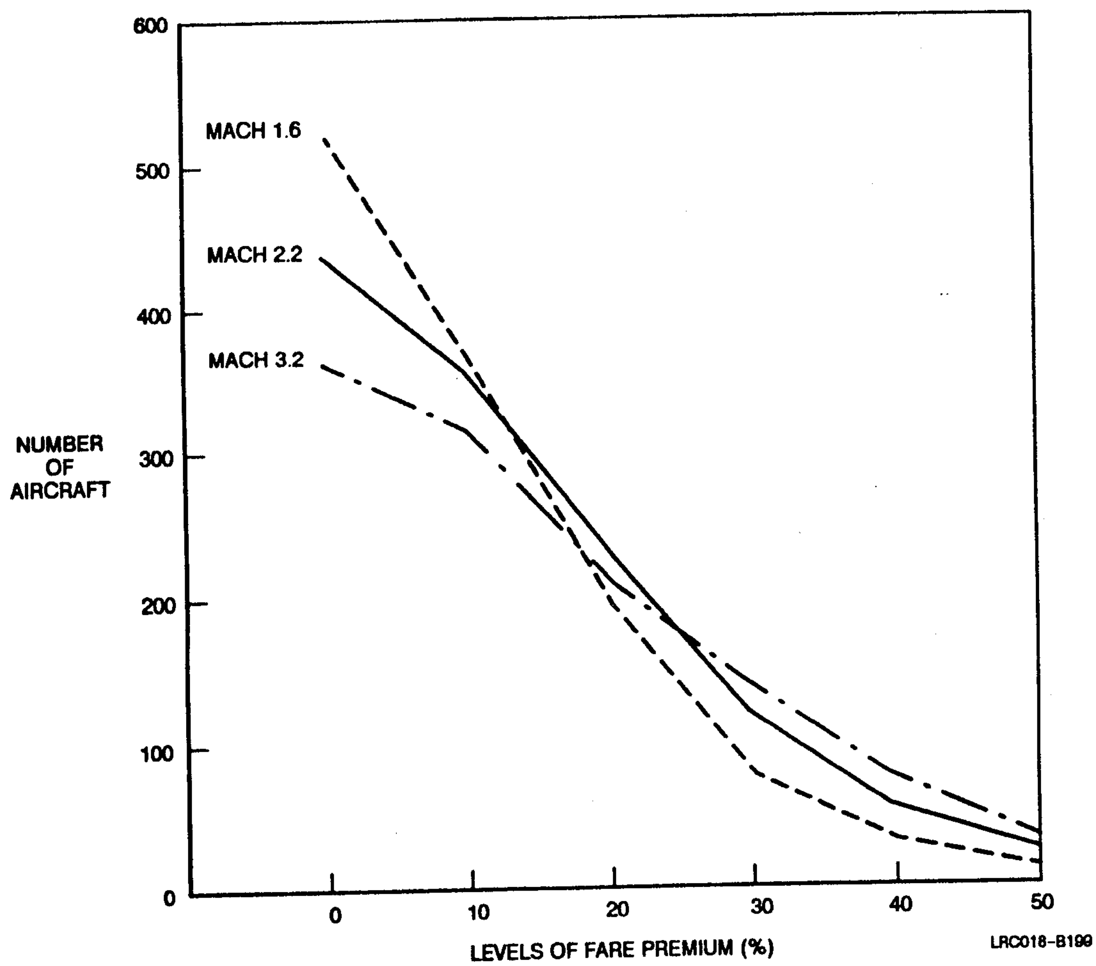

FIGURE 3-11. PROJECTED HSCT DEMAND IN YEAR 2000 AS A FUNCTION OF FARE PREMIUM LEVELS

will be reflected in fleet analyses. If supersonic cruise overland is restricted, fleet requirements will be reduced. The effect of such environmental restrictions as overland operation, cruise altitude, and emission index on supersonic fleet scenarios will be investigated.

3.3 CASH OPERATING COST COMPARISON

For a profitable supersonic operation, the airplane must generate enough revenue to cover its operating costs plus an attractive rate of return to the airlines. This section summarizes the results of the cash operating cost analysis and the commercial value of the three baseline configuration designs at Mach 3.2, 2.2, and 1.6. This evaluation examines the revenue side of the equation, followed by the operating cost, in order to arrive at the operating profit.

3.3.1 Revenue

Passenger revenue is based on published International Civil Aviation Organization (ICAO) fare data, fare premium assumptions, and corresponding HSCT market share statistics. Table 3-2 presents the revenue data for Mach 3.2, 2.2, and 1.6 configurations. As fare premiums increase, the HSCT market share is reduced. Revenue is improved because fares increase and the onboard passenger mix changes to favor the higher yield business- and first-class passengers. Table 3-3 illustrates the differences in revenue generating capabilities of Mach 3.2, 2.2, and 1.6 designs at various fare premiums.

3.3.2 Operating Costs

Cash operating cost studies were conducted to compare the relative operating cost of the Mach 3.2, 2.2, and 1.6 configurations, following the CAB Form 41 format for direct and indirect cash costs. Form 41 covers (1) flying operations, (2) maintenance, (3) passenger service, (4) aircraft and traffic servicing, (5) promotion and sales, and (6) general and administrative. Cost estimates were computed using Douglas operating cost formulas. Input data

TABLE 3-2
REVENUE FOR MACH 1.6, 2.2, 3.2 AIRCRAFT

	MACH 1.6	MACH 2.2	MACH 3.2
REVENUE PER SEAT-MILE ($)	0.072	0.073	0.073
REVENUE PER MILE ($)	21.81	21.93	21.95
REVENUE PER BLOCK HOUR ($)	20,285	25,610	33,473
REVENUE PER TRIP ($)	91,033	91,493	91,213
REVENUE PER AIRCRAFT PER YEAR ($)	63.31 MILLION	75.16 MILLION	91.31 MILLION

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TABLE 3-3
ANNUAL REVENUE PER AIRCRAFT
($ MILLION)

FARE PREMIUM (PERCENT)	MACH 1.6	MACH 2.2	MACH 3.2
0	63.31	75.16	91.31
10	78.20	88.10	105.72
20	93.41	104.62	128.92
30	113.64	121.16	146.54
40	131.98	144.63	169.28
50	137.59	165.75	198.61

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included (1) operational statistics (utilization, departures, fleet size) from the HSCT operational analysis; (2) information such as fuel costs generated during the study; and (3) results of analysis of HSCT configurations, including block times, fuel burn, maintenance cost, and turnaround time. Figure 3-12 shows the percentage breakdown of cash operating cost for a current subsonic transport and the Mach 2.2 aircraft. Fuel, the predominant DOC item, has increased from about one-fourth of the cash operating cost for the subsonic aircraft to over one-third for the Mach 2.2 design. Ownership-related expenses are not included because the cash flow over the life of the HSCT is used to compute its value as an investment. Table 3-4 shows these costs for the Mach 3.2, 2.2, and Mach 1.6 configurations.

3.3.3 Operating Profit

Operating profit may be considered a measure of aircraft profitability. By deducting the operating cost from the revenues, operating profit can be calculated. Figure 3-13 shows the operating performance of the Mach 3.2, 2.2, and 1.6 configurations.

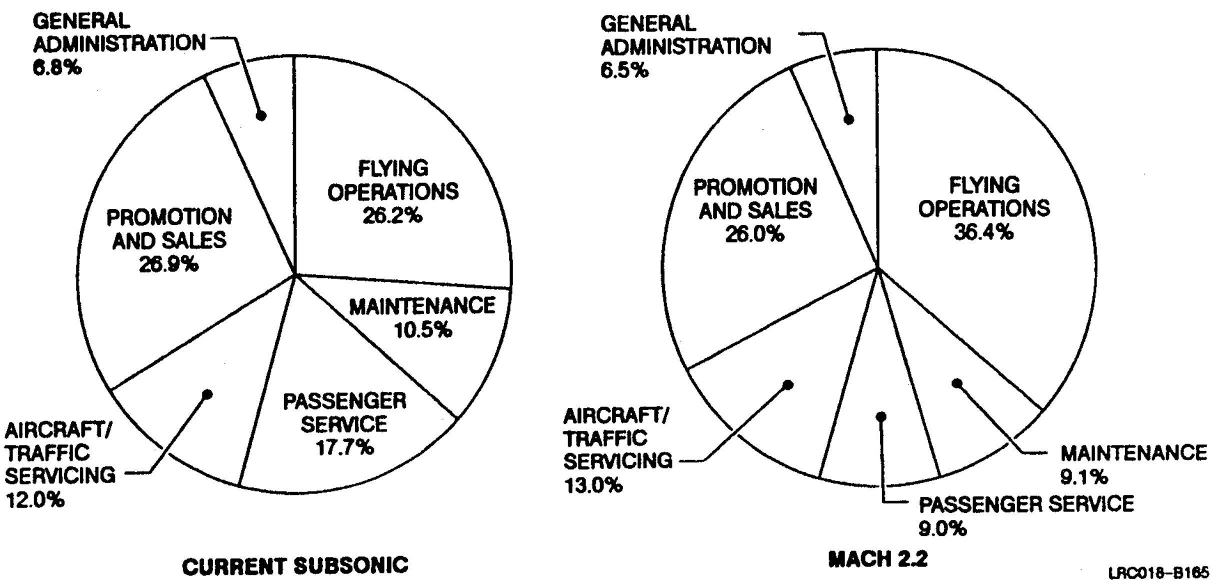

FIGURE 3-12. OPERATING COST BREAKDOWN – NO OWNERSHIP-RELATED COSTS

TABLE 3-4
OPERATING COST DATA FOR MACH 1.6, 2.2, 3.2 AIRCRAFT

		MACH 1.6	MACH 2.2	MACH 3.2
OPERATING COST PER SEAT-MILE	($)	0.05	0.048	0.047
OPERATING COST PER MILE	($)	15.51	14.36	14.18
OPERATING COST PER BLOCK HOUR	($)	14,414.00	16,769.00	21,711.00
OPERATING COST PER TRIP	($)	64,686.00	59,908.00	59,162.00
OPERATING COST PER AIRCRAFT PER YEAR	($)	44.9 MILLION	49.2 MILLION	59.2 MILLION

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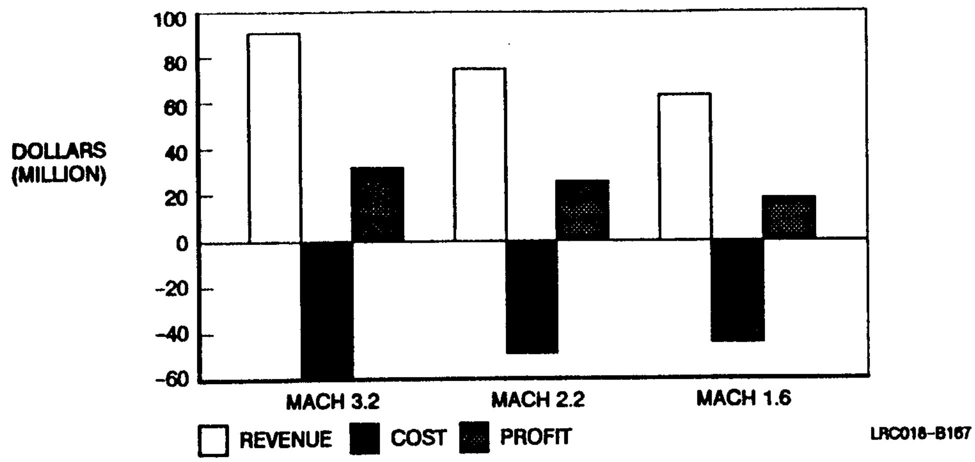

FIGURE 3-13. OPERATING PERFORMANCE (REVENUE - COST = PROFIT)

3.3.4 Aircraft Worth

Aircraft worth is the investment value of an airplane to the airline. The worth of an HSCT is estimated by an iterative process that determines the price to the operator so that a target rate of return on investment is achieved by the airline. Aircraft worth calculation includes corporate tax, depreciation, life of the asset, and the annual operating cash flow. Aircraft characteristics as well as operational parameters are embodied in the cash flow estimates. Results are shown in Tables 3-5 and 3-6 for various fare premiums and at a 10-percent return on investment to the airline.

3.3.5 Conclusion and Further Studies

Necessary conditions for economic viability include (1) airplane revenues covering operating costs plus an attractive rate of return to the operator, (2) fares compatible with subsonic fleet to expand HSCT service, and (3) a market large enough to permit a selling price lower than the investment value of the airplane. Market projections for the 2000 to 2025 time period indicate sufficient passenger traffic for ranges beyond 2,000 nautical miles to support a fleet of economically viable and environmentally compatible high-speed commercial transports. Fleet needs could total 2,300 or more 300-seat aircraft by 2025.

TABLE 3-5
ANNUAL CASH FLOW PER AIRCRAFT
($ MILLION)

FARE PREMIUM (PERCENT)	MACH 1.6	MACH 2.2	MACH 3.2
0	18.32	25.95	32.08
10	31.37	37.07	44.22
20	44.94	51.78	64.42
30	63.45	66.13	79.49
40	81.06	86.99	99.39
50	88.35	105.76	124.87

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TABLE 3-6
AIRCRAFT WORTH AT 10-PERCENT ROI
($ MILLION)

FARE PREMIUM (PERCENT)	MACH 1.6	MACH 2.2	MACH 3.2
0	110	156	193
10	188	223	266
20	270	311	387
30	381	397	478
40	487	523	597
50	531	635	750

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Further analysis of the commercial value of the HSCT, comparing its economic worth to cost-based price, will be required. Additional assessments of HSCT economics will be made considering fuel prices, operational procedures, turnaround time, dispatch reliability, operating cost, and scenarios with and without the supersonic overland restriction. Parametric studies of different design ranges and passenger configurations will continue to be investigated in an effort to optimize the HSCT's economic viability.

SECTION 4
SUPERSONIC NETWORK EVALUATION

Future supersonic aircraft will bring major changes to long-range transportation. The new generation of aircraft will have to overcome many economic and environmental challenges before it can become a reality. The most constraining challenge is the global concern over the effect of engine emissions on the ozone layer, which protects life on earth from ultraviolet radiation. Community noise is another environmental challenge. The HSCT must meet at least the current subsonic noise certification standards to be compatible with the future subsonic fleet.

The sonic boom issue represents a major environmental and economic challenge as well. Supersonic operation overland produces the most desirable economic results. However, unacceptable overland sonic boom characteristics may force HSCT to use subsonic speeds overland.

Environmental concerns are likely to impose some restrictions on supersonic operation, thus introducing major changes to existing route structures and supersonic network composition. Concern over the atmospheric effect may restrict HSCT's cruise altitude and its proximity to the denser ozone layers. It may also interfere with great circle routes because of environmental impact on sensitive areas such as the North Pole. The current subsonic route structure may have to be altered to avoid sensitive areas in the stratosphere or to minimize overland flight tracks. It is important to examine the impact of these restrictions on the economic viability of the overall supersonic operation.

To be profitable, a supersonic transport must offer the traveling public significant time savings on long routes at acceptable fare premium levels. Under these assumptions, a potential market of about 2,000 aircraft will exist by the year 2025. This fleet size will enable engine and airframe manufacturers to build the plane at a cost that provides them with an attractive return on investment and to sell it at a price that allows the airlines to operate with a reasonable profit.

Subsonic overland operation of a supersonic aircraft hinders its economic viability for the following reasons:

- Reduced time savings
- Subsonic operation of a supersonic configuration imposes a penalty on its operating cost (e.g., increased fuel burn)
- Exclusion of some major city-pairs from the global supersonic network
- Increased airline dependence on fare premiums, thus reducing the HSCT's potential market share and profit

The effect of supersonic overland restriction on the aircraft's economic performance and the development of supersonic network scenarios will be investigated and discussed in this section.

4.1 AIRCRAFT ECONOMIC PERFORMANCE

4.1.1 Time Savings

Unrestricted supersonic operation produces optimum economic results. Time savings, the HSCT's most attractive marketing feature, would be maximized. As the percentage of subsonic overland increases, time savings decrease, thus eroding the unique competitive advantage of the HSCT over subsonic aircraft. Figure 4-1 shows how time savings decline at different levels of mixed operation. The highest time savings of supersonic versus subsonic flight is achieved for routes that are entirely overwater, such as between Honolulu and Sydney, where time savings exceed 5-1/2 hours. As the percentage of restricted operation increases, time savings decline, as for example the Dallas Fort Worth-Frankfurt route, where time savings are cut to 3 hours.

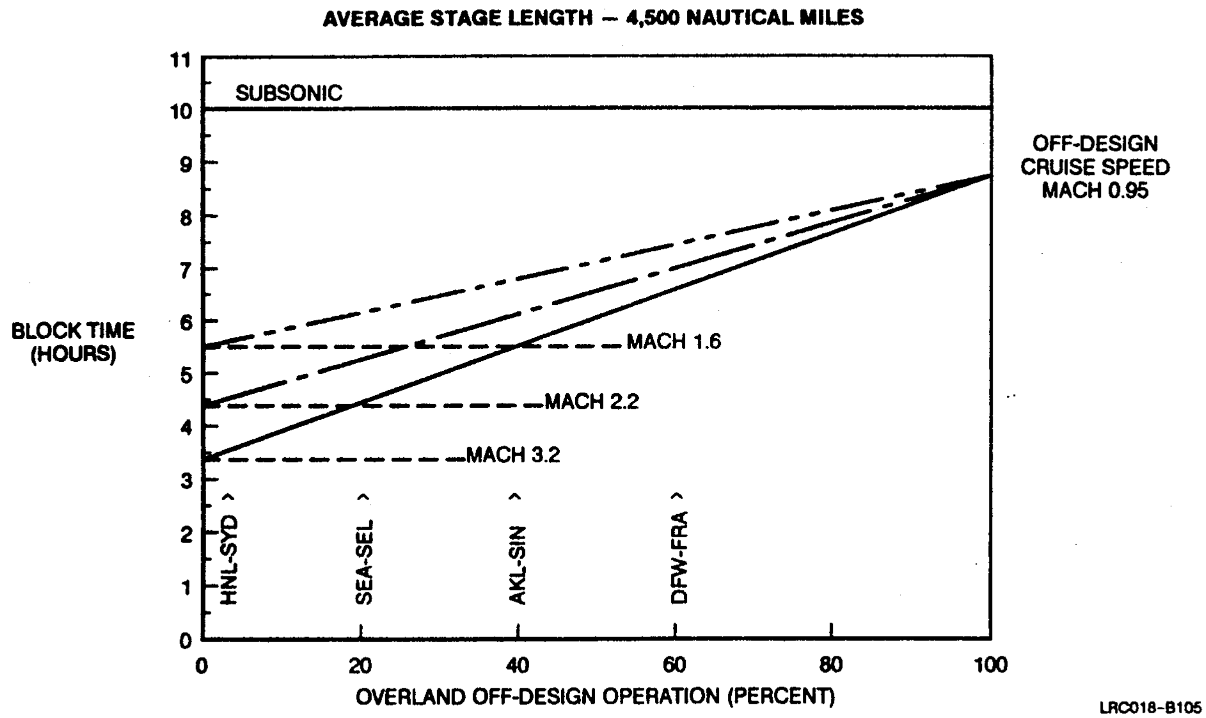


FIGURE 4-1. TIME PERFORMANCE

4.1.2 Operating Cost and Profit

There is a significant reduction in aircraft economic performance when a mixed mode of operation is gradually introduced. The impact of wholly supersonic versus mixed subsonic and supersonic flight on the vehicle's operating economics is illustrated in Figure 4-2. The data presented compare the operating revenue, cost, and profit for a vehicle with all Mach 2.2 operation versus vehicles with a mixed Mach number operation of Mach 2.2 overwater and 0.9 overland, or Mach 2.2 overwater and 1.6 overland. These comparisons are made with 10, 20, and 30 percent of the operation flown at the lower Mach number. At a 30:70 ratio of overland (Mach 1.6) to overwater (Mach 2.2) operation, there is an increase in operating cost of $3 million annually per aircraft and $1.3 billion for the global fleet. This reduces the vehicle's operating profit by the same amount. When the overland portion is flown at Mach 0.9, the increase in operating cost and the corresponding decrease in profit amounts to $5 million per vehicle annually and $2.2 billion for the global fleet.

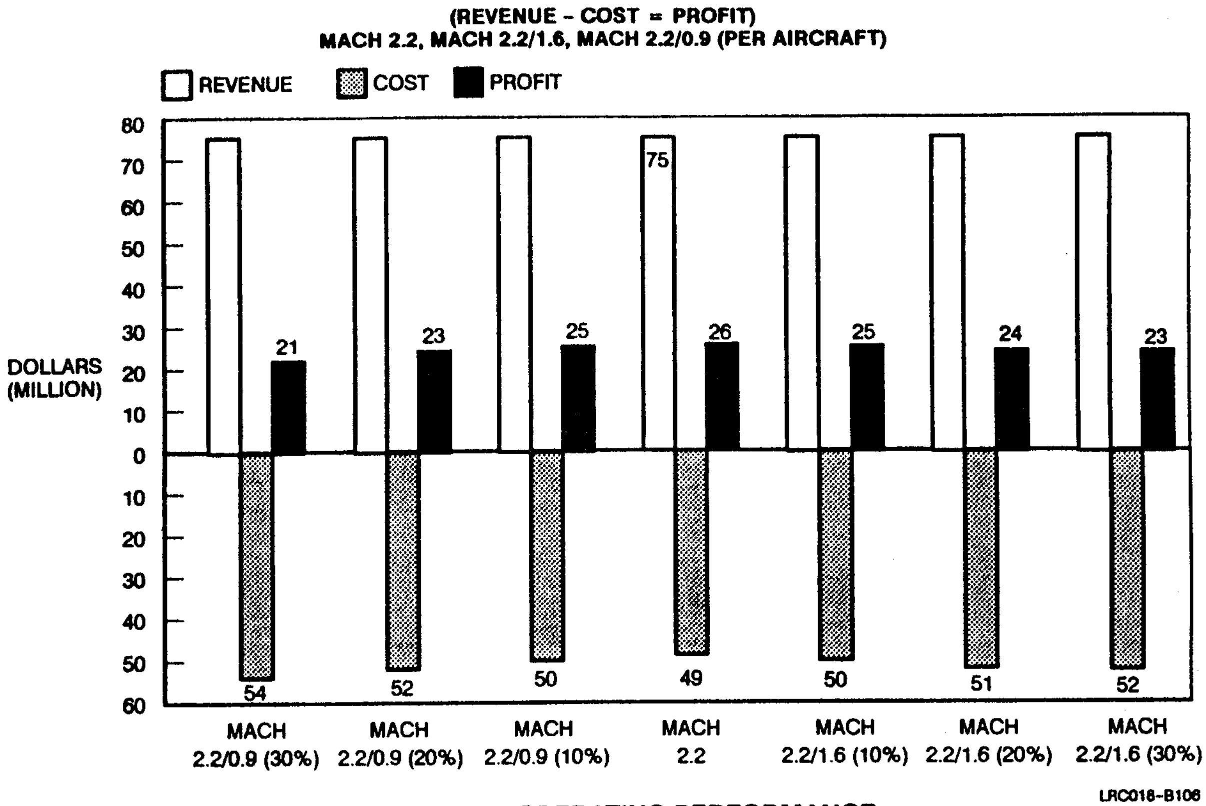


FIGURE 4-2. OPERATING PERFORMANCE

A sonic boom-minimized aircraft at Mach 1.6 will economically outperform a vehicle with mixed operation of Mach 2.2 overwater and Mach 0.9 overland when the overland portion exceeds 30 percent of the flight. Figure 4-3 shows the percentage of cost to revenue and profit to revenue for Mach 2.2/1.6 and Mach 2.2/0.9 configurations at different percentages of subsonic operation. As the percentage of subsonic operation increases, the ratio of cost to revenue rises, while the ratio of profit to revenue declines: These ratios are compared to those of an all Mach 1.6 configuration. The unrestricted Mach 1.6 profitability ratio becomes higher than that of Mach 2.2/0.9 when the overland portion exceeds 28 percent, and higher than that of Mach 2.2/1.6 when the overland portion exceeds 50 percent.

The increase in operating cost is mostly due to the higher fuel burn of the mixed Mach number operation. Figure 4-4 illustrates the decline in HSCT miles per 1,000 pounds of fuel as the percentage of mixed operation increases over an average stage length of 4,500 nautical miles. For example, Mach 3.2 miles per 1,000 pounds of fuel burned declines by 13 percent when 20 percent of the operation is restricted to Mach 0.9 overland, and by 30 percent when the restricted overland portion reaches 60 percent of the flight.

4.1.3 Aircraft Worth

Aircraft worth, which is the investment value of an airplane to the airline operator, is also affected by restricted operation overland. An increase in the percentage of mixed Mach number operation reduces aircraft worth. Figure 4-5 shows that aircraft worth reaches its highest level at full supersonic operation. The data presented compare aircraft worth for vehicles with mixed Mach number operation versus an all Mach 1.6 sonic boom configuration

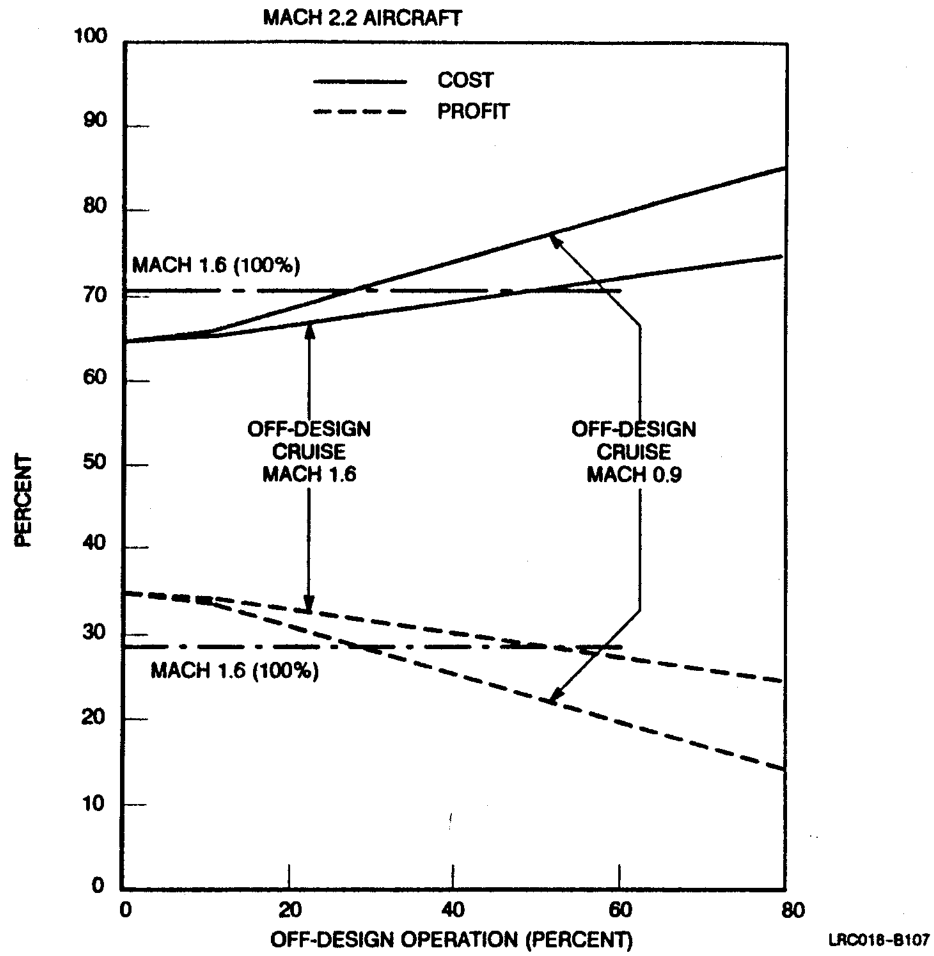


FIGURE 4-3. ECONOMIC PERFORMANCE PERCENTAGE OF OPERATING COST AND PROFIT TO REVENUE

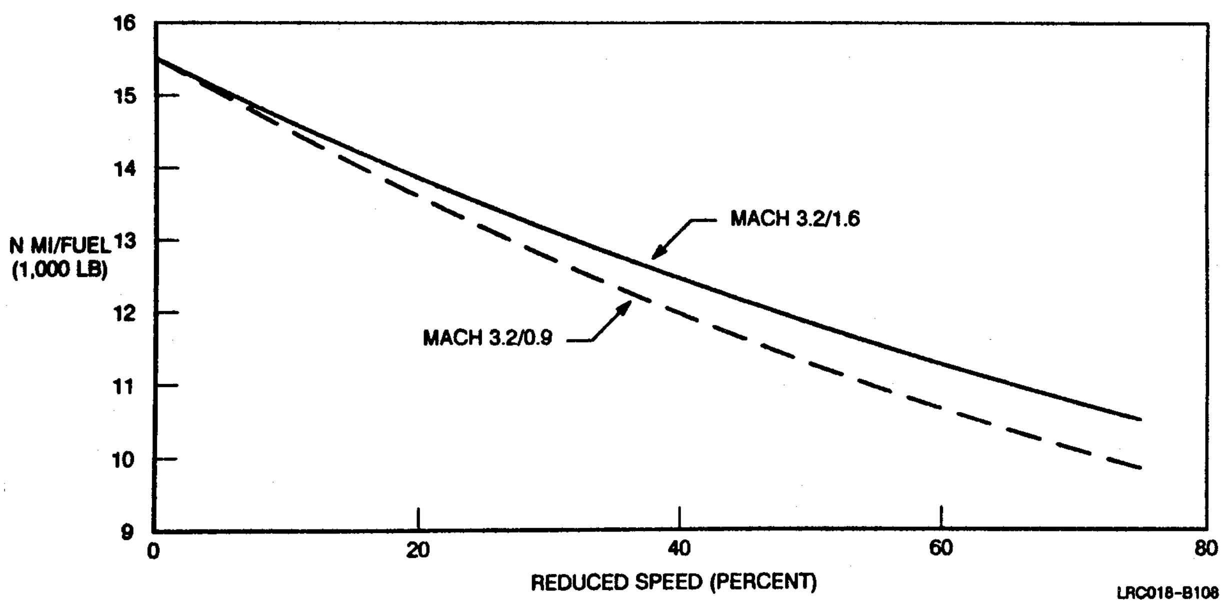


FIGURE 4-4. HSCT MILES PER 1,000 POUNDS OF FUEL AT 4,500 N MI

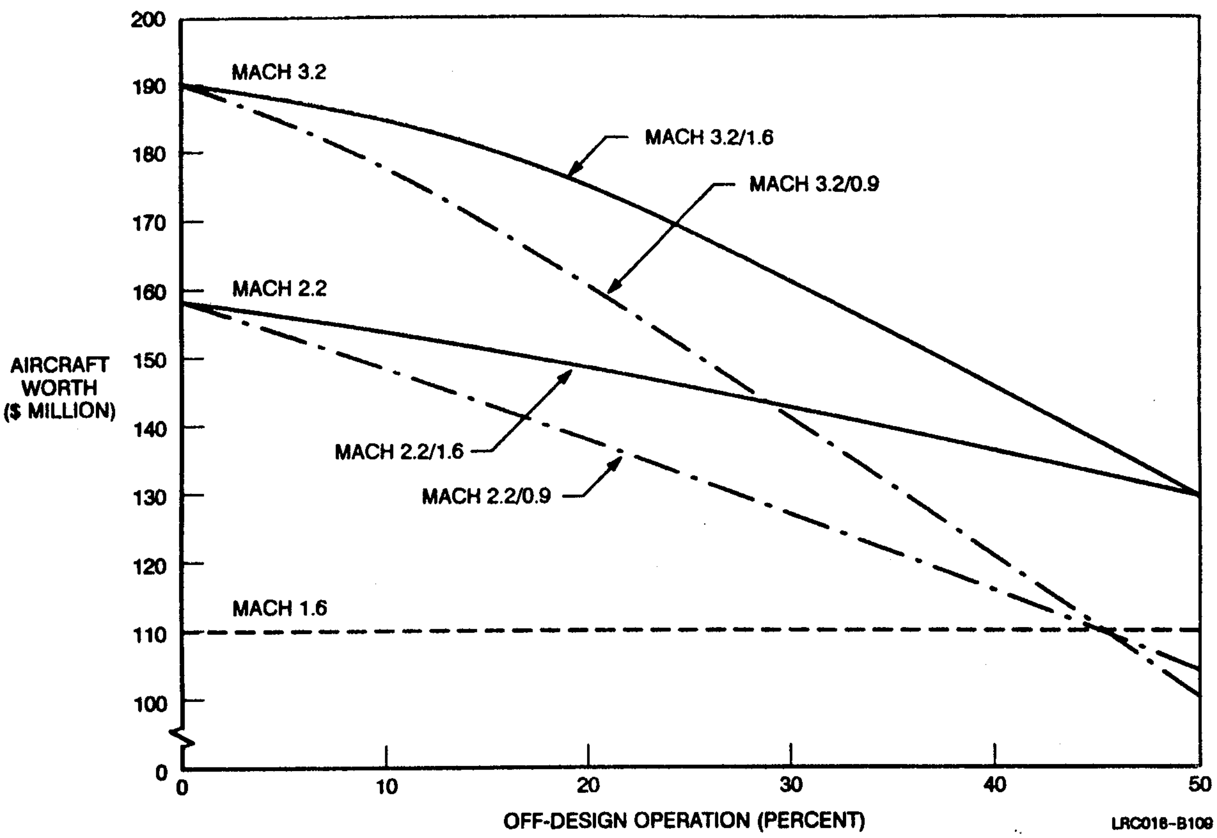


FIGURE 4-5. EFFECT OF OVERLAND OFF-DESIGN OPERATION ON AIRCRAFT WORTH

without performance penalties for refining the planform. Aircraft worth for both the Mach 3.2/0.9 and the Mach 2.2/0.9 continues to decline, intercepting the all Mach 1.6 worth at about 45 percent of restricted operation.

4.1.4 Fare Premium

Airlines can afford to charge the traveler a fare premium for the supersonic flight as long as the surcharge does not exceed the value of the time saved over a subsonic flight. Any restriction of supersonic operation overland will reduce time savings and thus affect the airlines' ability to charge a fare premium. Figure 4-6 explores the relationship between time savings and trip price, and identifies the break-even points of value of time saved and fare premium levels. The curves on the right side represent the value of time saved per class of travel. The left side shows where the value of time saved intercepts the value of fare premium per class. The figure also identifies the maximum level of fare premium the airlines may be able to charge per class of travel. To use this figure, simply locate the number of hours saved on the right side of the horizontal axis and move upward to the value of time saved per class. Move horizontally to the left and read the dollar value on the vertical axis. Continue horizontally across the chart toward the left side to intersect the value curve of the fare premium per class. Move downward to read the fare premium level on the left side of the horizontal axis. For example, the value of 6 hours of time saving for a first-class passenger is $540. This value, when it intersects with the first-class fare premium curve, indicates the maximum level of fare premium the airlines may charge, which is 27 percent. The fewer the number of hours saved, the lower the level of fare premium the airline may be able to charge.

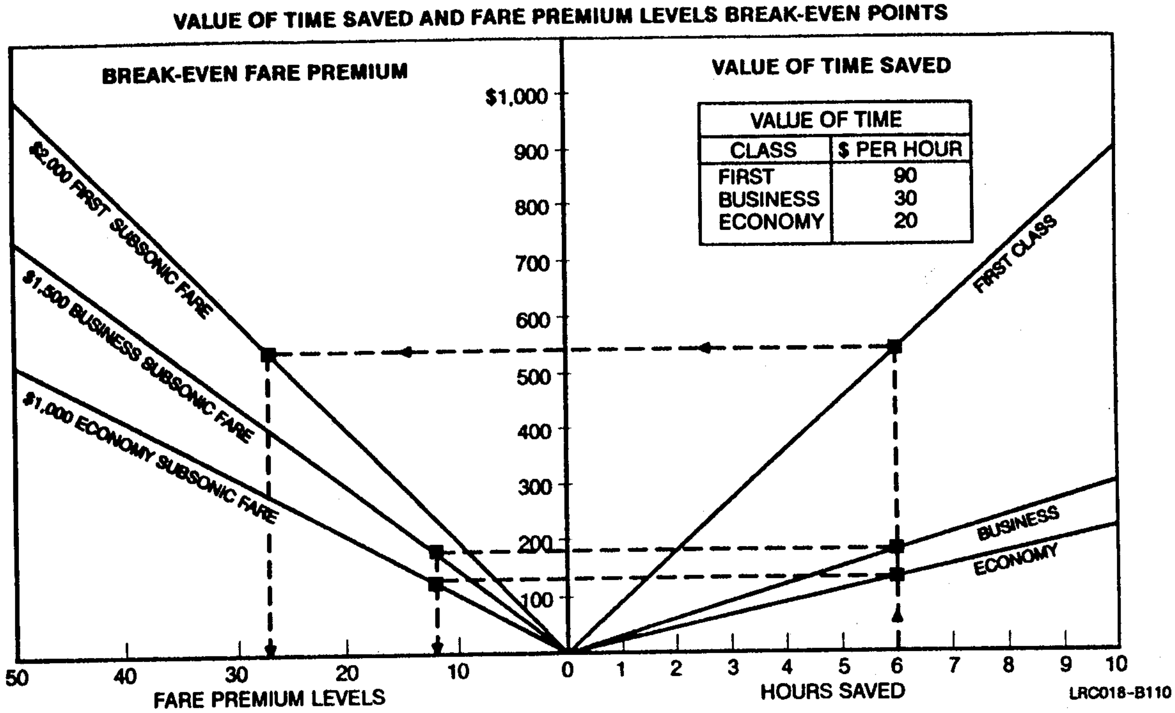


FIGURE 4-6. TIME SAVINGS AND TRIP PRICE RELATIONSHIP

In general, full supersonic operation is highly attractive to all concerned. It provides better economics for the airlines, the passengers, and the manufacturers. It is readily apparent that there are substantial economic and marketing benefits in full supersonic operation, and hence the importance of achieving a low-sonic-boom configuration.

4.2 SUPERSONIC NETWORK SCENARIOS

4.2.1 Methodology

Supersonic restrictions overland and other environmental concerns may change some current subsonic global air route systems. MDC's route structure research group has been investigating several supersonic network scenarios, which were developed to assess the impact of environmental restrictions on the HSCT's market potential and economics. Attention is focused on reaching an optimum supersonic route structure to facilitate evaluation of different technical, operational, environmental, economic, and marketing scenarios that may ultimately influence the design of the HSCT. Figure 4-7 is a flowchart of supersonic network development. The process of structuring network scenarios starts with examining all international IATA regions and identifying the regions with the highest potential for supersonic operation.

The most current operational information on the world's airlines is reflected in their flight schedules as published in the Official Airline Guide (OAG). From the OAG on-line data base, all nonstop routes with a range greater than 2,000 statute miles were listed. Weekly departures, scheduled seats, aircraft miles, and seat miles were aggregated for each city-pair. The seat share for the city-pair was computed as a percent of the IATA region's total seats.

Information is reported for each IATA region by city-pairs sorted in descending order of scheduled seats. The long-range data extracted from the OAG world airline schedule include 900 city-pairs exceeding 2,000 statute miles. As shown in Figure 4-8, these city-pairs are

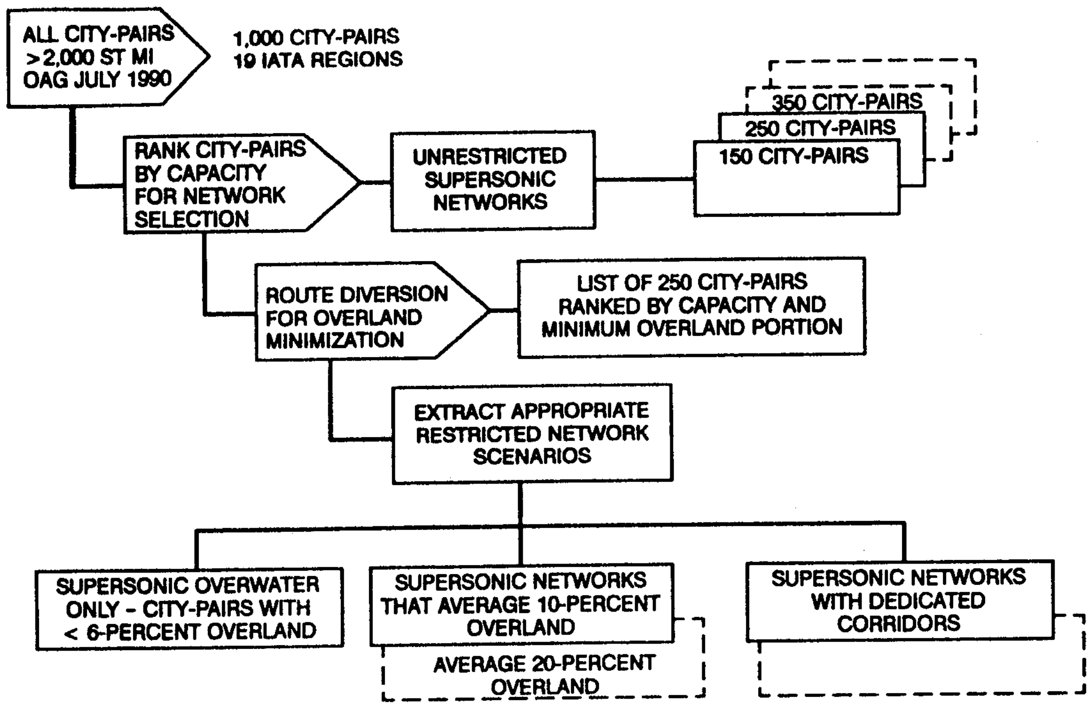


FIGURE 4-7. SUPERSONIC NETWORK SCENARIOS FOR UNRESTRICTED AND RESTRICTED OPERATION

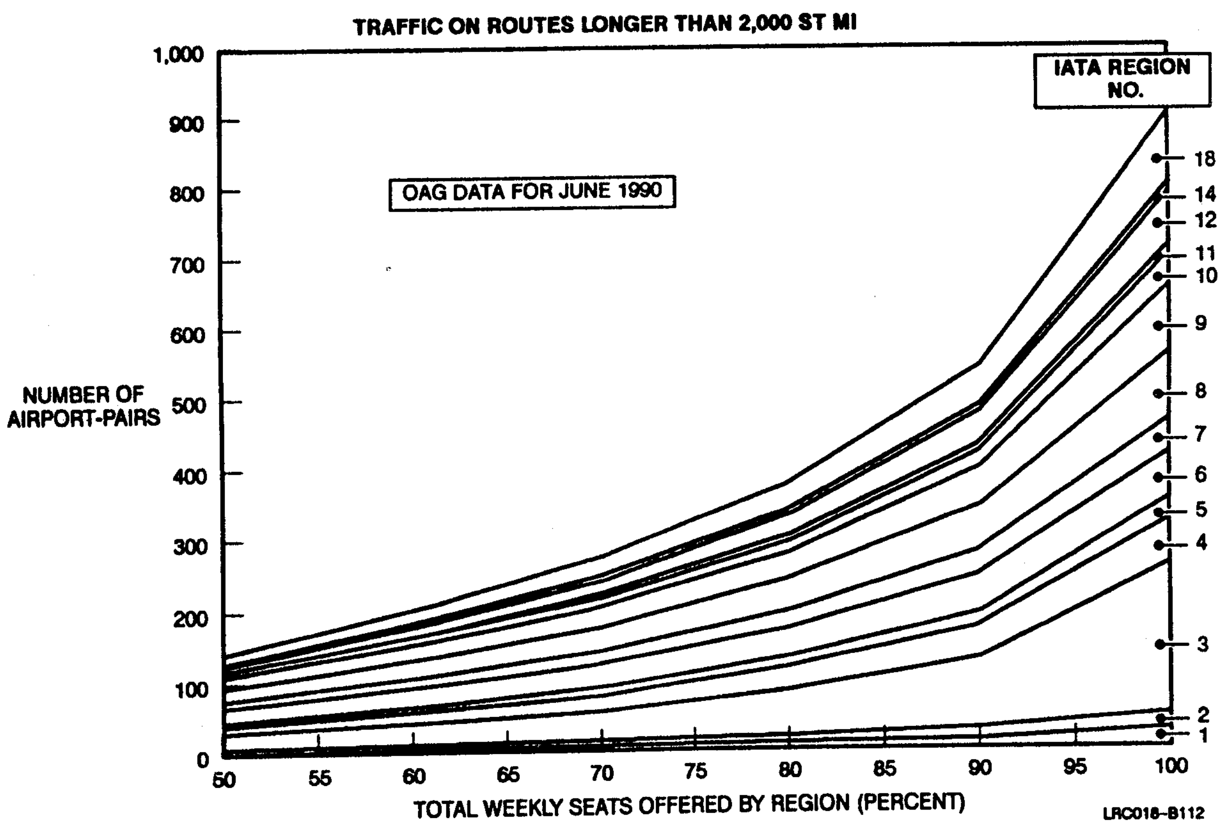


FIGURE 4-8. TRAFFIC ANALYSIS BY IATA REGIONS

distributed among 14 IATA regions. Not all of these city-pairs are necessarily candidates for HSCT service. The most logical candidates are the high-density traffic routes, defined by scheduled seat capacity.

Using the long-range data set, sorted in descending order of scheduled seats, many subsets of top city-pairs can be selected as unrestricted supersonic network scenarios. These supersonic network scenarios can only be used if a low-boom configuration is successfully developed. To visualize the global network formed by the top 250 city-pairs, their great circle routes were plotted on a world map in Figure 4-9.

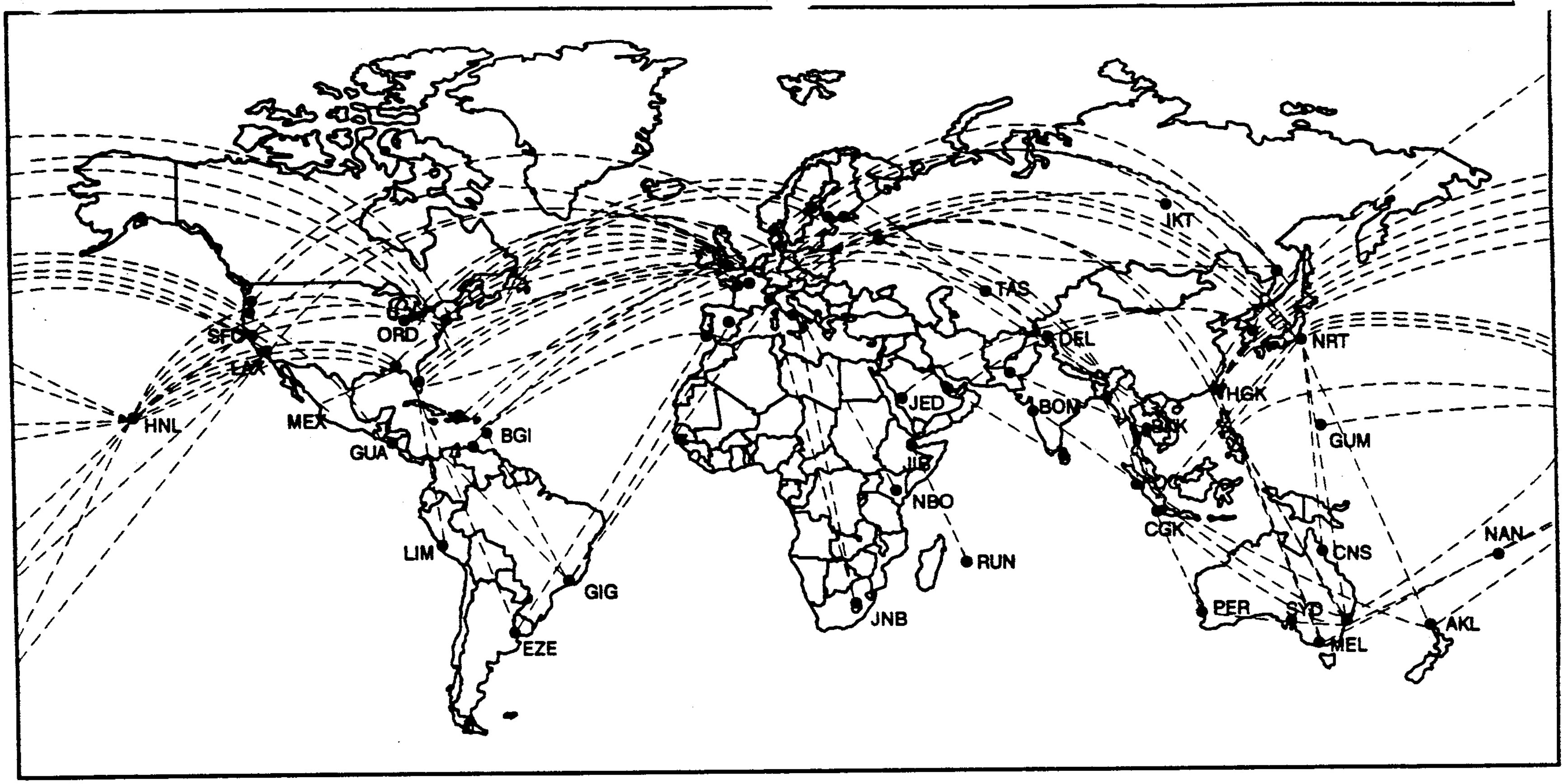
4.2.2 Route Diversion Analysis

Until a satisfactory solution to the sonic boom problem is obtained, supersonic flight overland will be restricted. Modifications to great circle routes are required to find an alternative flight path that eliminates or minimizes overland flight to unpopulated land masses. Using the long-range data set, a subset of the top 250 city-pairs was selected to conduct route diversion analyses. The basic traffic data for the 250 city-pairs are presented in Appendix A. The traffic data are also sorted by departures, aircraft miles, annual seat miles, and aircraft hours. This ranking highlights the fact that membership in the top set is controlled by the choice of ranking criteria.

The 250 candidate city-pairs route were each analyzed for possible diversion to eliminate or reduce overland tracks. The process involved generating a strip chart for each candidate route. A strip chart is an oblique map projection showing an area 15 to 20 degrees on either side of the great circle track between origin and destination. By selecting the great circle route to be the equator of the projection, the highest possible scale accuracy is obtained for the chart. From such charts, diverted routes can be designed, and overland segments, if any, can be measured directly. Figure 4-10 shows the strip chart for the London-New York route. Data presented in Figure 4-10 show that the overland track has been reduced more than 20 percent through diversion, while the increase in great circle distance is limited to only 3 percent. The generated strip charts of a few key routes are presented in Appendix B.

The results of the route diversion analysis are summarized in Appendix C. The table compares the overland portions of the diverted route and its original great circle route. Some of the routes are all overwater with no diversion required. Others become all overwater through diversion. Still others exhibit various degrees of overland reduction through diversion. However, some are all overland, where no feasible diversion is possible. The all-overland routes are strong candidates for removal from possible HSCT service.

In evaluating flight performance, the ground track profile becomes important. If the overland segments of the route occur at the beginning and end of the flight, performance is least affected. However, if the overland segments happen to fall anywhere along the track after cruise speed has been reached, performance penalties can be severe. The aircraft must fly lower and slower over the land segment and then climb back up to higher cruise altitude. The amount of fuel burned by this maneuver depends on how heavy the aircraft is at the start of the maneuver. The ground track profiles on a normalized linear scale are summarized in Appendix C . Each track profile is flagged according to the type it exhibits. Type 1 profile is all overwater or has overland portions at either end of the track. Type 2 is a profile with over-



AVERAGE STAGE LENGTH 3,666 ST MI

PERCENT OF LONG-RANGE TRAFFIC – 70 PERCENT

1. NORTH AMERICA – SOUTH AMERICA (5)
   GIG-MIA NO. 20
2. NORTH AMERICA – CENTRAL AMERICA (6)
   JFK-MEX NO. 61
3. NORTH TRANSATLANTIC (69)
   JFK-LHR NO. 2
4. MID TRANSATLANTIC (10)
   MAD-MIA NO. 132
5. SOUTH TRANSATLANTIC (3)
   GIG-MAD NO. 120
7. EUROPE – SOUTH AFRICA (3)
   JNB-LHR NO. 101
8. EUROPE – MIDDLE EAST (12)
   DXB-LON NO. 78
9. EUROPE – FAR EAST (26)
   NRT-SVO NO. 24
10. AMERICAS – MID PACIFIC (23)
   HNL-NRT NO. 10
11. AMERICAS – SOUTH PACIFIC (5)
   AKL-HNL NO. 50
12. WITHIN NORTH AMERICA (55)
   HNL-LAX NO. 1
16. WITHIN AFRICA (1)
   JIB-RUN NO. 245
18. WITHIN FAR EAST (25)
   NRT-SIN NO. 12
19. MISCELLANEOUS (8)
   BKK-DXB NO. 84

FIGURE 4-9. TOP 250 POTENTIAL SUPERSONIC ROUTES (NO RESTRICTIONS)

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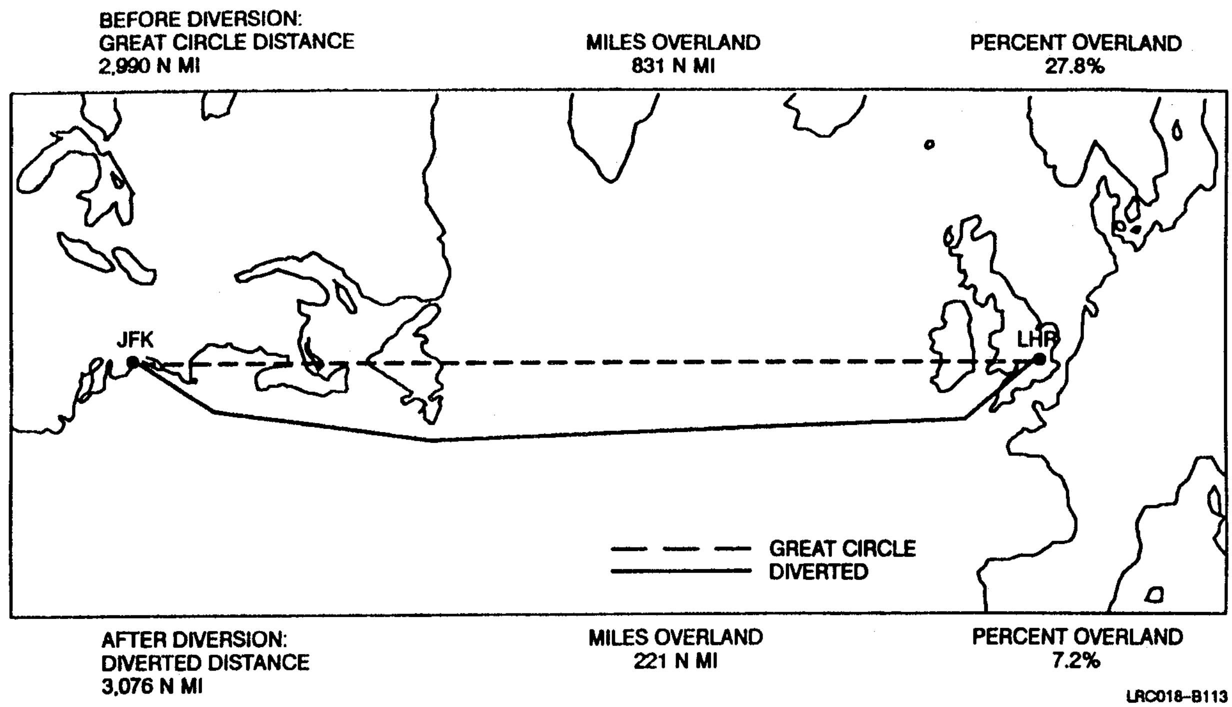


FIGURE 4-10. CITY-PAIR EVALUATION – JFK (NEW YORK)-LHR (LONDON)

land segments anywhere in the middle of the track. Type 3 consists of tracks exhibiting more than 50 percent of overland segments, which are candidates for elimination. Type 4 identifies tracks that are 100-percent overland. An example of route diversion and optimization is depicted in Figure 4-11 for the New York-Tokyo route. By rerouting the flight via Seattle, distance increased by 693 miles, and the percentage overland declined from 88 to 35 percent, as illustrated in Figure 4-11A. By diverting the route through the Arctic Ocean, Bering Strait, and North Pacific, the percentage of overland flight was further reduced to 20 percent at a cost of 227 extra nautical miles, as shown in Figure 4-11B. The ground track profile is displayed on a normalized scale in Table 4-1.

The 250-network scenario represents 64 percent of the annual seat-miles for long-range routes over 2,000 statute miles. The average impact of route diversion compared to the great circle route is a 4-percent increase in network distance and a 41-percent reduction in overland distance. To visualize the global network formed by the top 250 city-pairs, their great circle routes were plotted on a world map in Figure 4-12. A 150 city-pair network is also considered as a candidate supersonic scenario. The 150-network scenario is similar to the 250 city-pair scenario without the bottom 100 city-pairs. The 150-network scenario represented 52 percent of the annual seat-miles for all long-range routes over 2,000 statute miles. Although the 150 city-pair network is structurally only 60 percent of the 250 city-pair network, 80 percent of the traffic is still present. The average impact of route diversion compared to the great circle routes is a 5-percent increase in network distance and a 41-percent reduction in overland distance. The great circle routes for the 150 city-pair network are shown in Figure 4-13. The most apparent feature, when the map is compared to the 250-network map, is that the global pattern does not change, but gets denser.

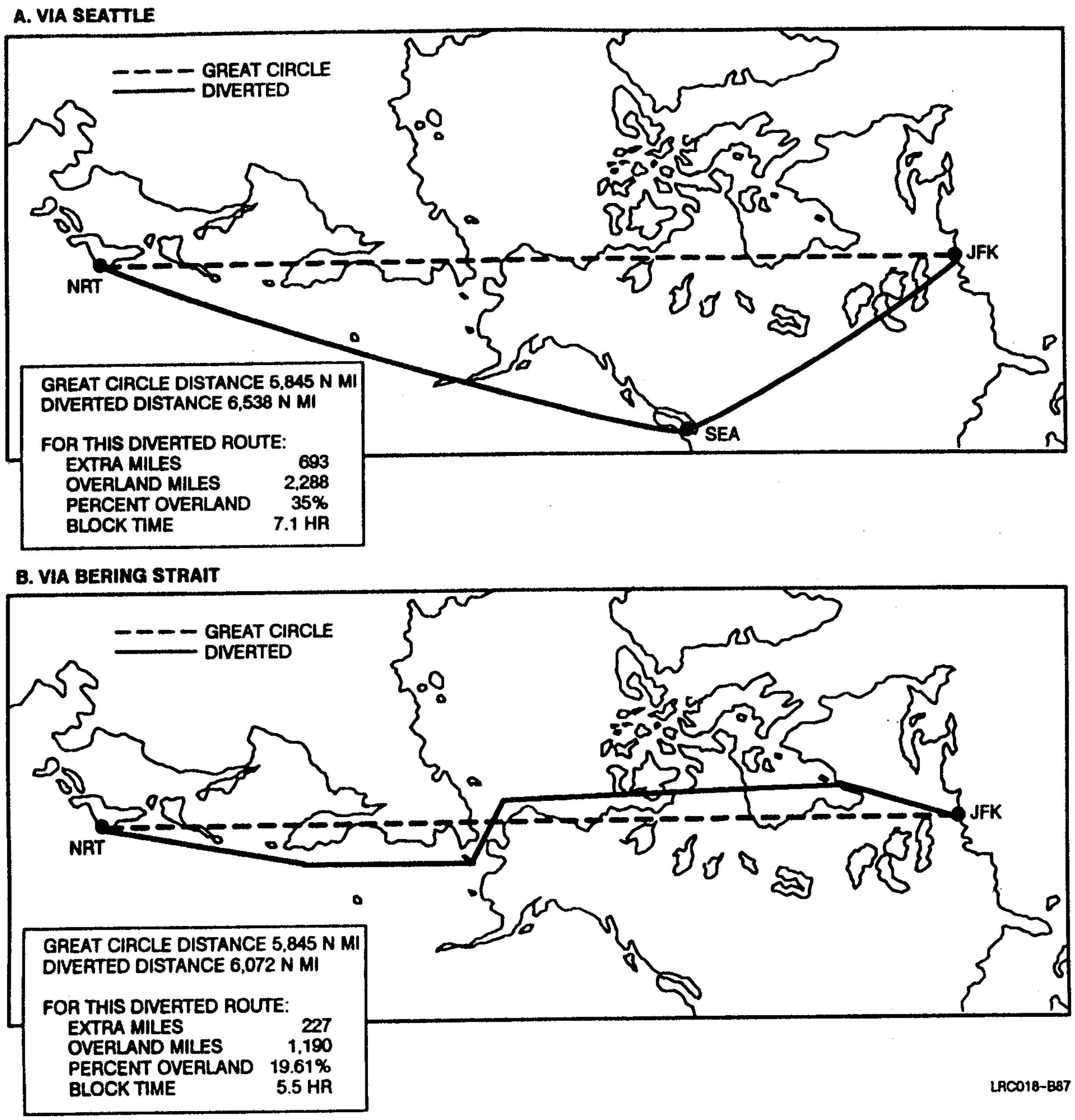


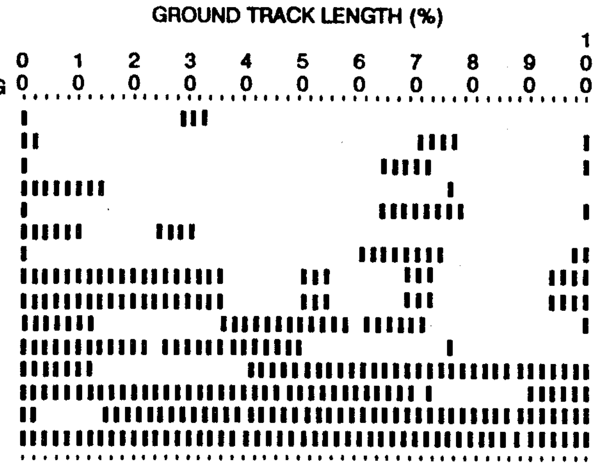
FIGURE 4-11. DIVERTED ROUTING – NEW YORK-TOKYO

4.2.3 Overwater Network Scenario

The basic HSCT 250-network scenario was based on the high-density traffic as reported by the OAG. The ground track display shows a mix of desirable and undesirable flight profiles, and some routes that exhibit a high percentage of overland portions. The 250 city-pairs list sorted in descending order of scheduled seats in Appendix A was resorted in ascending order of percentage of the overland segment, as shown in Appendix C. All routes exhibiting more than half the distance overland were eliminated. A list of 207 city-pairs, with an overland portion that does not exceed half the distance in each case, was used to extract a variety of supersonic network scenarios. For example, to extract an all-overwater network, only routes with a 6-percent overland segment, 3 percent for climb and 3 percent for descent, would be

TABLE 4-1.
EXAMPLE OF GROUND TRACK PROFILE DISPLAY FOR NEW YORK-TOKYO

AIRPORT PAIR	GC RANGE (N MI)	DIVERTED RANGE	DIST	OVERLAND (%)	FLAG
LIM-MIA	2,277	2,647	183	6.9	2
CPH-SEA	4,214	5,074	624	12.3	2
LHR-NRT	5,147	5,880	759	12.9	2
EZE-MIA	3,831	4,137	691	16.7	2
FRA-NRT	5,053	5,211	917	17.6	2
JFK-NRT	5,845	6,072	1,190	19.6	2
CDG-NRT	5,237	5,607	1,110	19.8	2
LAX-LHR	4,727	5,138	1,978	38.5	2
LAX-LGW	4,747	5,138	1,978	38.5	2
BKK-DXB	2,635	2,635	1,415	53.7	2
MEL-SIN	3,260	3,260	1,757	53.9	3
BKK-KHI	1,998	1,998	1,451	72.6	3
LHR-SIN	5,872	5,872	4,886	83.2	3
NRT-SVO	4,048	4,048	3,663	90.5	3
BKK-FCO	4,775	4,775	4,775	100.0	4



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selected. Under these assumptions, only 100 city-pairs would qualify for the overwater network scenario. Figure 4-14 shows the great circle routes of the 100 city-pair overwater network. The 100 overwater network represents 28 percent of total long-range annual seat-miles. The average impact of route diversion compared to the great circle route is a 6-percent increase in network distance and a 92-percent reduction in overland distance.

To structure a network with an overland portion averaging 10 percent of the total network, the top 200 city-pairs are selected from the same list. The 200 network carries 50 percent of long-range annual seat-miles. It covers 13 IATA regions and has an average stage length of 3,998 statute miles. An increase of 5.7 percent in distance results in a 69-percent reduction in overland segments. Figure 4-15 illustrates the great circle route structure of the 200 city-pairs on the world map.

4.3 CONCLUSION

Only a few candidate global airline network scenarios for HSCT have been assembled. They are patterned after the high-density long-range markets from the OAG on-line data base. Creative rerouting was conducted to minimize overland segments and to lessen the impact of the environmental restrictions that may be imposed on future supersonic operation.

The data on these network scenarios represent an assembly of global routes from which HSCT global traffic networks can be constructed. The network scenarios provide examples on how supersonic service may bring some changes to the current global route structure. Some of these supersonic network scenarios show good potential of capturing more than half the market share of the long-range traffic.

4.4 RECOMMENDATIONS FOR FURTHER STUDY

Further analysis is still required to accurately assess the effect of these supersonic network scenarios on aircraft economic performance, productivity, and fleet projections. Supersonic network research and development will continue to search for more ways to respond to the environmental concerns, operational policies, marketing strategies, and specific network requirements of customer airlines.

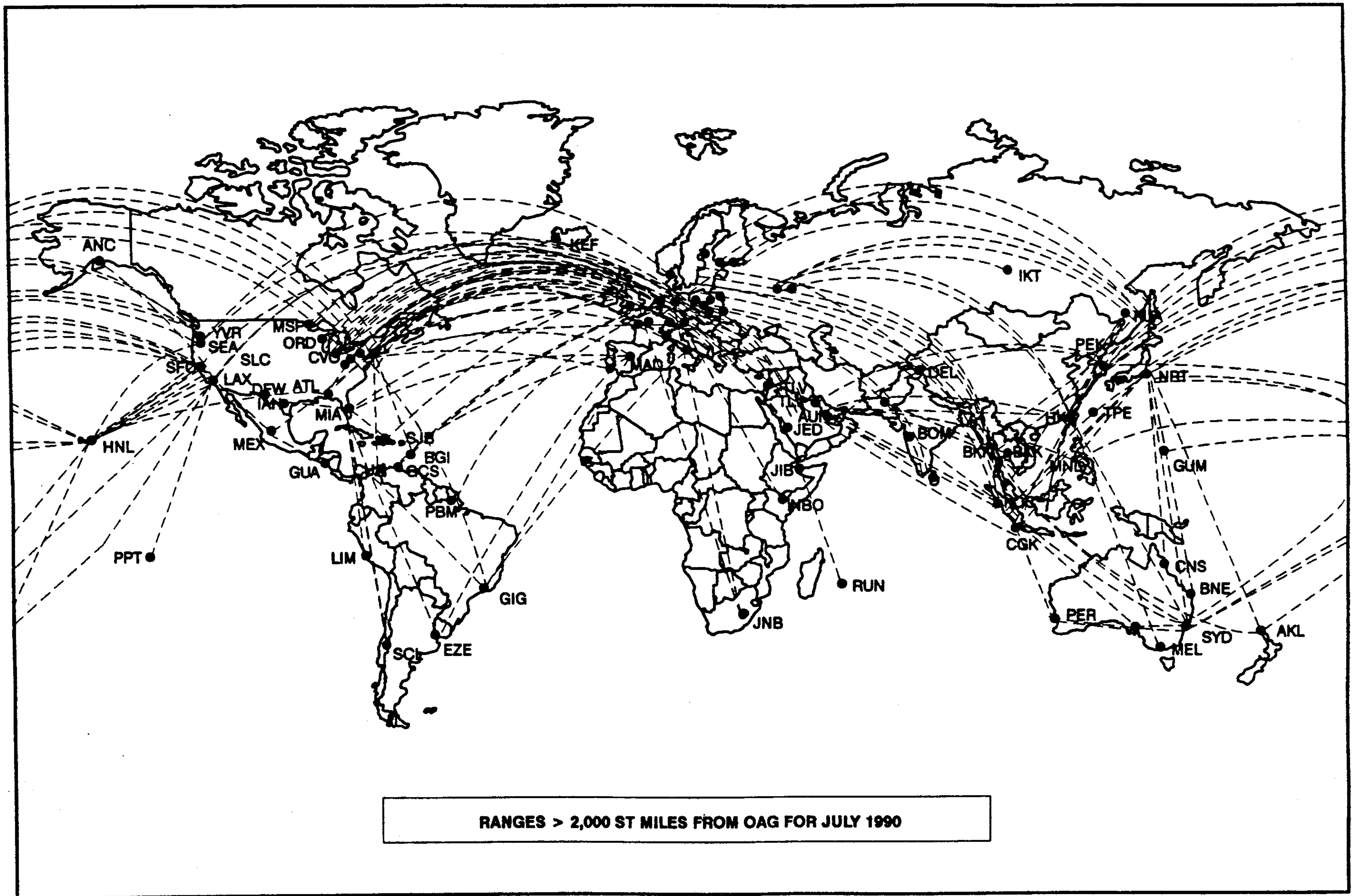

FIGURE 4-12. HSCT TOP SEAT RANK 250 AIRPORT-PAIRS

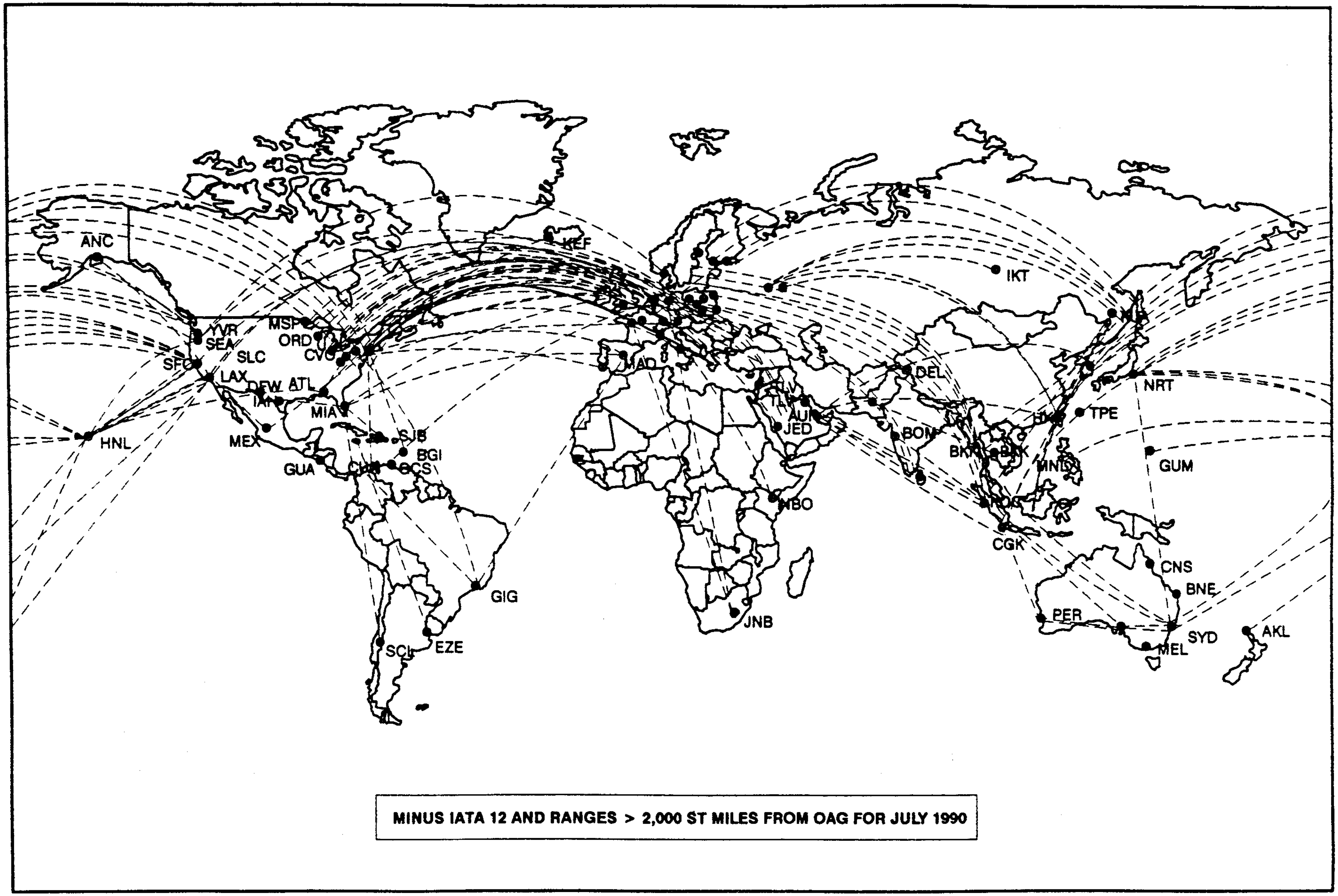

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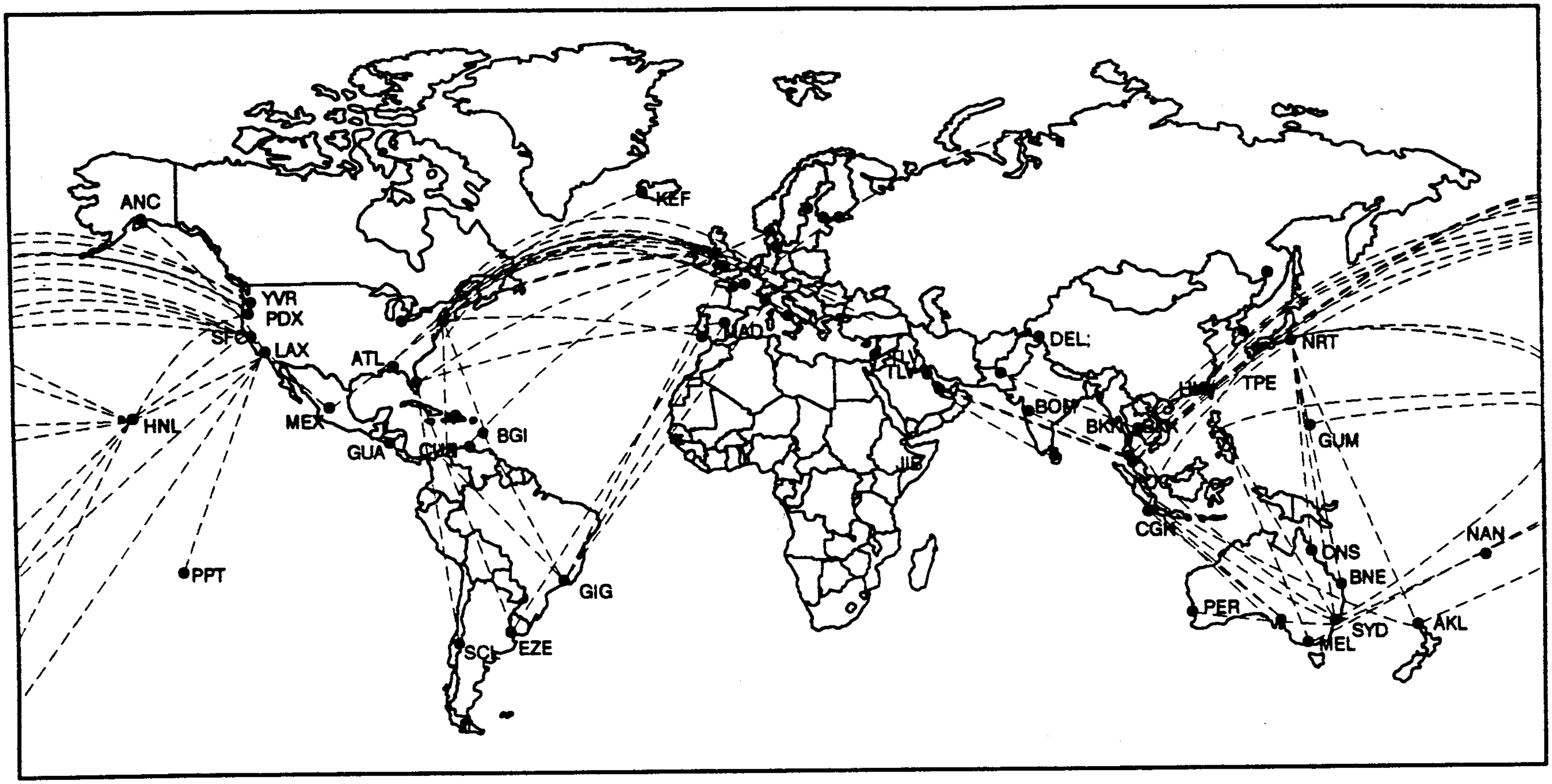
FIGURE 4-13. HSCT TOP SEAT RANK 150 AIRPORT-PAIRS



AVERAGE STAGE LENGTH 3,900 ST MI

PERCENT OF LONG-RANGE TRAFFIC – 28 PERCENT

1. NORTH AMERICA – SOUTH AMERICA (4)
   GIG-JFK NO. 16
2. NORTH AMERICA – CENTRAL AMERICA (3)
   BGI-JFK NO. 19
3. NORTH TRANSATLANTIC (26)
   JFK-CDG NO. 80
4. MID TRANSATLANTIC (5)
   MAD-MIA NO. 99
5. SOUTH TRANSATLANTIC (5)
   GIG-MAD NO. 87
10. AMERICAS – MID PACIFIC (19)
    HNL-NRT NO. 2
11. AMERICAS – SOUTH PACIFIC (6)
    AKL-HNL NO. 10
12. WITHIN NORTH AMERICA (8)
    HNL-LAX NO. 1
18. WITHIN FAR EAST (20)
    NRT-SIN NO. 6
19. MISCELLANEOUS (4)
    DXB-KUL NO. 68

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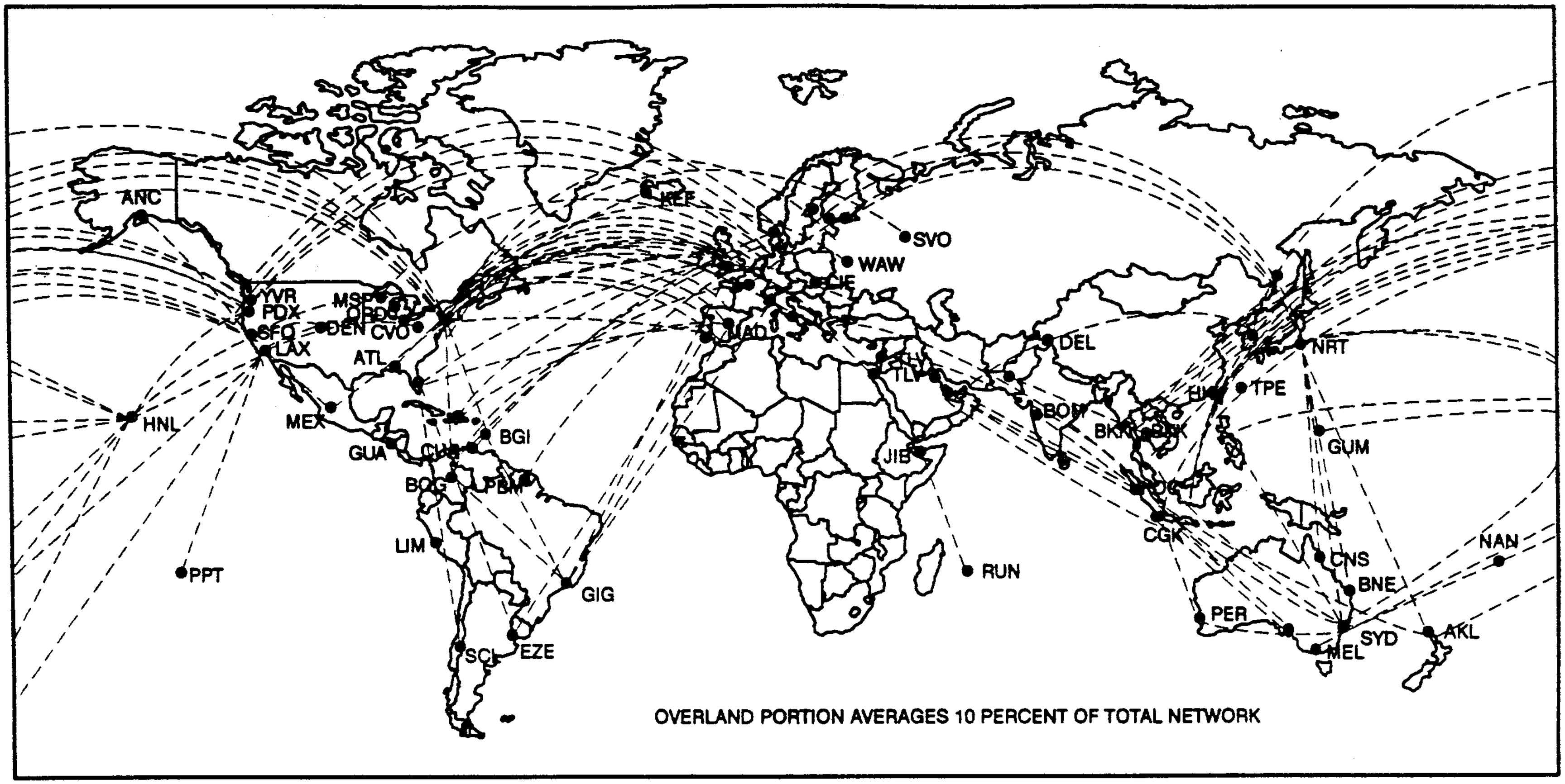
FIGURE 4-14. 100 CITY-PAIRS FOR OVERWATER ONLY – SUPERSONIC NETWORK



AVERAGE STAGE LENGTH 3,996 ST MI

PERCENT OF LONG-RANGE TRAFFIC – 50 PERCENT

1. NORTH AMERICA – SOUTH AMERICA (7)
   GIG-MIA NO. 69
2. NORTH AMERICA – CENTRAL AMERICA (6)
   JFK-MEX NO. 89
3. NORTH TRANSATLANTIC (83)
   JFK-LHR NO. 112
4. MID TRANSATLANTIC (14)
   MAD-MIA NO. 99
5. SOUTH TRANSATLANTIC (5)
   GIG-MAD NO. 87

8. EUROPE - MIDDLE EAST (5)
   LHR-TLV NO. 180
9. EUROPE - FAR EAST (5)
   LHR-NRT NO. 142
10. AMERICAS – MID PACIFIC (28)
    HNL-NRT NO. 2
11. AMERICAS – SOUTH PACIFIC (6)
    AKL-HNL NO. 26
12. WITHIN NORTH AMERICA (14)
    HNL-LAX

16. WITHIN AFRICA (1)
    JIB-RUN NO. 177
18. WITHIN FAR EAST (22)
    NRT-SIN NO. 6
19. MISCELLANEOUS (4)
    DXB-KUL NO. 68

LRC012-94

FIGURE 4-15. SUPERSONIC NETWORK SCENARIO FOR 200 CITY-PAIRS

SECTION 5
ATMOSPHERIC EMISSIONS IMPACT STATUS

Atmospheric emissions impact studies focused on generating inputs for two-dimensional global atmospheric chemistry models. Airframe concepts at Mach 1.6, Mach 2.2, and Mach 3.2 were used in conjunction with several low-NO_x candidate engine concepts from both Pratt & Whitney and General Electric. The procedure used to generate the atmospheric model inputs was upgraded and automated under independent research funds. A brief description of the procedure is included in this report and a complete description of the new methodology is provided in NASA CR 181882.

The impact of atmospheric emissions for airframe/engine concepts on global ozone concentrations was estimated through correlation with Lawrence Livermore National Laboratories (LLNL) two-dimensional (2-D) atmospheric model runs. A large matrix of emission scenarios was provided to LLNL by Douglas under an independent research effort, and estimates of global ozone impact were generated with the LLNL two-dimensional global atmospheric model. The emissions scenarios developed for the 1990 emission studies were cross-referenced with the independent research results to arrive at an estimated global ozone column change. These estimates are included in this report.

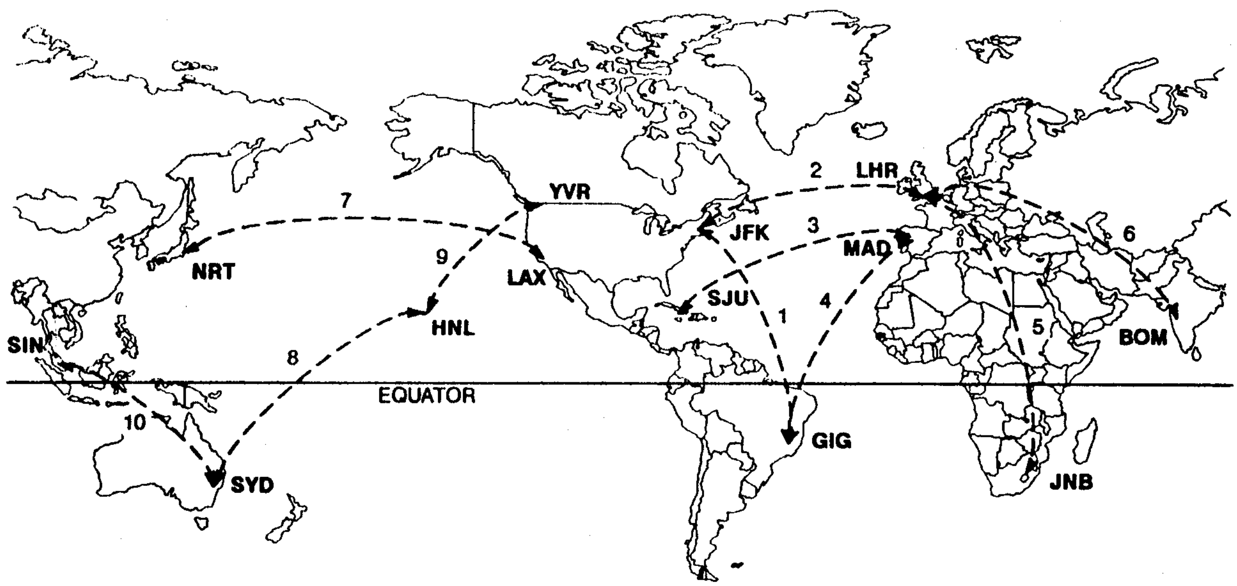
The potential impact of regulations restricting cruise altitude was investigated in terms of economic penalties and ozone benefits. Baseline aircraft at Mach 1.6, 2.2, and 3.2 were flown with several different cruise altitude ceiling limits. Fuel burn and emission constituent data were generated for these restricted flight paths and compared to baseline cases. The ozone impact of these restrictions was then estimated by cross-referencing the results with the LLNL 2-D model runs described above. Economic impact in terms of operating cost and aircraft worth were quantified. These studies provide insight into the feasibility and practicality of protecting atmospheric ozone through cruise altitude restrictions.

5.1 BRIEF METHODOLOGY REVIEW

The operational network of an HSCT is broken down into 10 IATA regions worldwide. For each of these regions, a city-pair is chosen that best describes the average latitude distribution. The 10 regions, along with their corresponding city-pairs, are shown in Figure 5-1. A mission is flown for each city-pair with the airframe/engine combination in question to determine the fuel burn in each region as a function of altitude and latitude. The 10 regions are then compiled into one data set representing the total annual worldwide fuel burn in each latitude and altitude band as specified by the 2-D atmospheric models.

Final input to the global atmospheric models is broken down into seven distinct engine emission constituents. These are NO, NO_2, SO_2, CO, H_2O, CO_2, and THC (trace hydrocarbons). In addition, summary data for all oxides of nitrogen are provided ($NO + NO_2$) as NO_x. The total constituent emissions are determined by multiplying the total fuel burn by the emission index for each constituent.

The worldwide fuel burns are a function of many parameters, including economic forecasts for the time period in question. An overall data flowchart is presented in Figure 5-2. This chart shows the dependency of the emissions data on a wide array of estimates and



REGION	CITY-PAIRS
1 NORTH-SOUTH AMERICA	NEW YORK - RIO DE JANEIRO (JFK-GIG)
2 NORTH ATLANTIC	NEW YORK - LONDON (JFK-LHR)
3 MID-ATLANTIC	SAN JUAN - MADRID (SJU-MAD)
4 SOUTH ATLANTIC	RIO DE JANEIRO - MADRID (GIG-MAD)
5 EUROPE AFRICA	JOHANNESBURG - LONDON (JNB-LHR)
6 EUROPE FAR EAST	BOMBAY - LONDON (BOM-LHR)
7 NORTH AND MID-PACIFIC	LOS ANGELES - TOKYO (LAX-NRT)
8 SOUTH PACIFIC	HONOLULU - SYDNEY (HNL-SYD)
9 INTRA-NORTH AMERICA	HONOLULU - VANCOUVER (HNL-YVR)
10 INTRA-FAR EAST AND PACIFIC	SINGAPORE - SYDNEY (SIN-SYD)

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FIGURE 5-1. HSCT REPRESENTATIVE CITY-PAIRS

assumptions concerning not only aircraft and engine performance, but also passenger demand forecasts.

5.2 ATMOSPHERIC EMISSION SCENARIOS

Emissions forecasts were developed for five engines — a P&W Mach 1.6 turbine-bypass engine (TBE), P&W Mach 2.2 TBE, P&W Mach 3.2 TBE, P&W Mach 3.2 variable-stream-control engine (VSCE), and GE Mach 3.2 variable-cycle engine (VCE). All five combustors contained a low-NO_x combustor design in the 5-$EINO_x$ range. Douglas baseline missions were flown for each of the airframe/engine combinations. The airframes used at each Mach number correspond to the baseline configurations described earlier. Mission profiles were all supersonic with no allowance for subsonic overland operations. Table 5-1 shows the total annual fuel burn by region for each engine as determined through a complete performance analysis.

Complete input data sets for 2-D global atmospheric chemistry models were created for each engine concept. These data sets are very large and are not included in this report. The complete data sets for the P&W TBE engines can be found in NASA CR 181882. These data sets were generated by breaking the total mission into four segments — takeoff, climb, cruise, and descent. Emission indices were determined at each of the four segments on the basis of

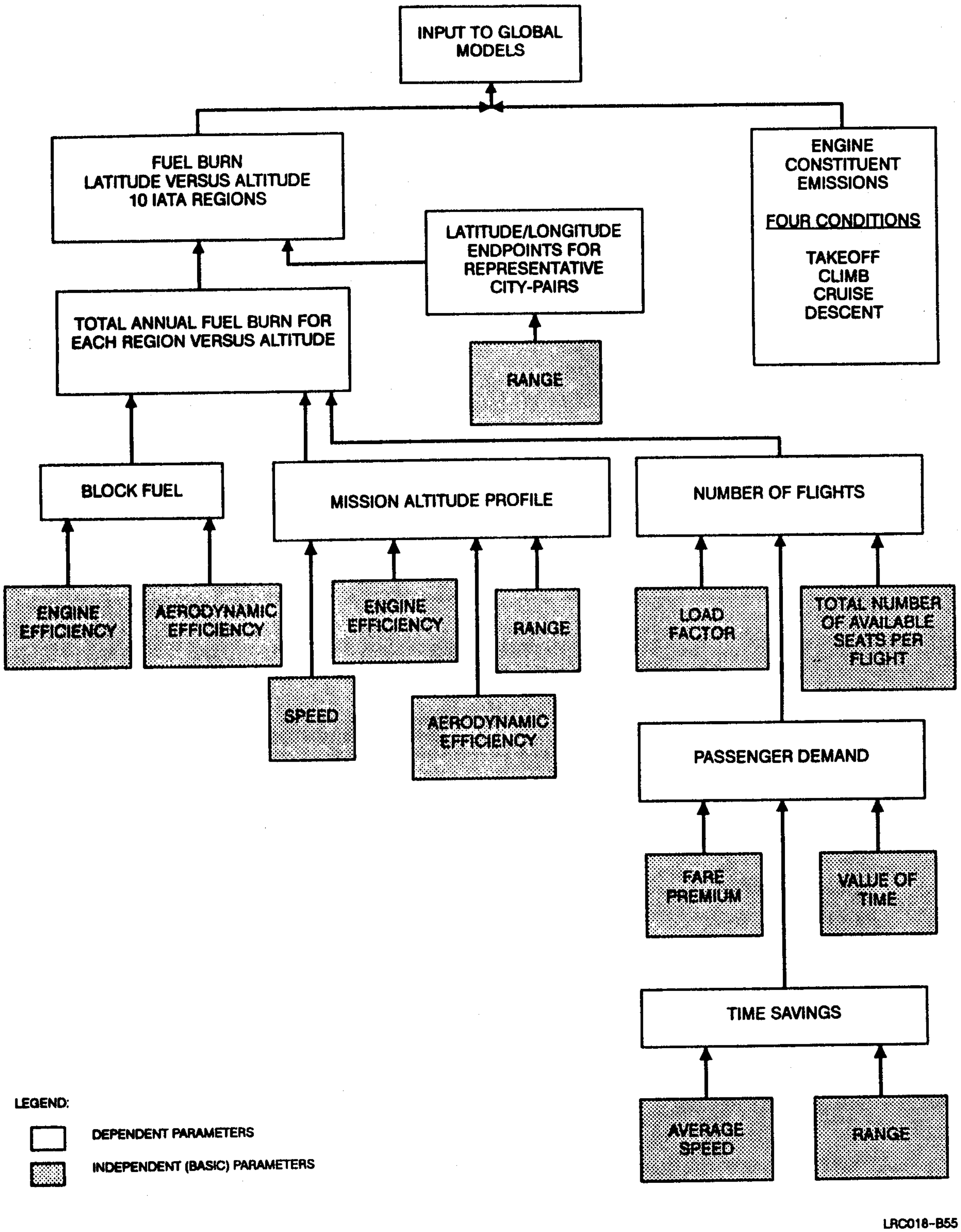

FIGURE 5-2. DATA FLOW FOR GENERATING INPUTS TO GLOBAL ATMOSPHERIC MODELS

data supplied by the engine manufacturers. This is believed to improve the fidelity of the emissions estimates compared to methods that consider only the cruise segment. NO_x emission indices for each engine concept at the various operating conditions are presented in Table 5-2.

TABLE 5-1
TOTAL ANNUAL FUEL BURN BY REGION

REGION	FUEL BURN (10^6 LB) P&W MACH 1.6 TBE	P&W MACH 2.2 TBE	P&W MACH 3.2 TBE	P&W MACH 3.2 VSCE	GE MACH 3.2 VCE
NORTH-SOUTH AMERICA	1,729	1,735	1,864	2,371	2,133
NORTH ATLANTIC	20,029	20,168	21,774	27,656	24,889
MID-ATLANTIC	1,445	1,453	1,565	1,985	1,788
SOUTH ATLANTIC	2,262	2,255	2,393	3,039	2,730
EUROPE-AFRICA	4,339	4,391	4,791	6,110	5,493
EUROPE-FAR EAST	6,805	6,814	7,283	9,224	8,296
NORTH AND MID-PACIFIC	23,992	23,934	25,411	32,261	28,968
SOUTH PACIFIC	2,612	2,618	2,806	3,563	3,202
INTRA-NORTH AMERICA	159	163	182	231	209
INTRA-FAR EAST AND PACIFIC	10,390	10,527	11,487	14,594	13,133

TABLE 5-2
NO_X EMISSION INDICES FOR VARIOUS ENGINE CONCEPTS

ENGINE	EI = LB/1,000 LB FUEL BURNED TAKEOFF EI	CLIMB EI	CRUISE EI	DESCENT EI
P&W MACH 1.6 TBE	5.5	6.7	5.3	3.7
P&W MACH 2.2 TBE	3.5	6.1	4.5	2.7
P&W MACH 3.2 TBE	3.5	7.9	5.1	1.5
P&W MACH 3.2 VSCE	2.3	4.5	4.4	4.5
GE MACH 3.2 VCE	3.6	7.8	6.3	10.1

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5.3 OZONE IMPACT TRADE STUDIES

The baseline emissions scenarios developed for this task were used in conducting trade studies to investigate the effects of parameters such as fleet size, fare premium, Mach number, year of service, and engine type on the global ozone concentration as predicted by the LLNL 2-D model (through correlation with IRAD data).

The cruise Mach number of an aircraft determines its optimum cruise altitude and has a strong impact on the fuel burn. Higher Mach numbers lead to higher cruise altitudes and typically result in increased fuel consumption. Researchers have shown that the impact of aircraft emissions on ozone is very sensitive to injection altitude, particularly in the stratosphere at about 70,000-80,000 feet. As this altitude is approached by increasing Mach number, the impact of the NO_x emissions increases. This effect is shown in Figure 5-3 by the baseline

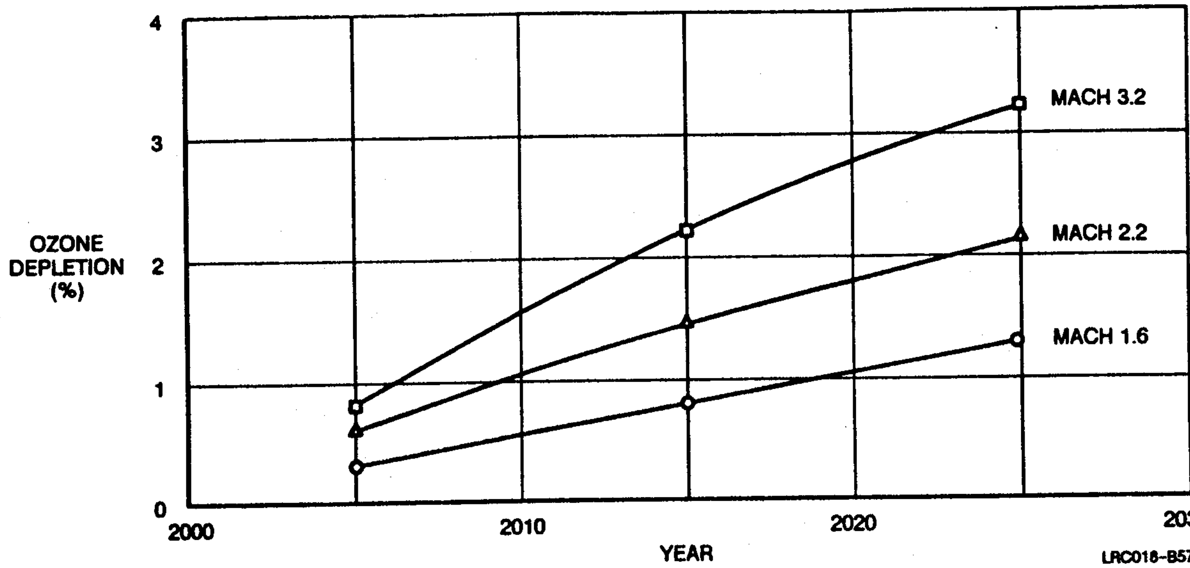

FIGURE 5-3. OZONE DEPLETION BY YEAR - P&W TBE ENGINE

emissions scenarios. From this plot, it is readily seen that column ozone depletion is a strong function of Mach number. The figure also shows that ozone concentration is further decreased as the fleet size is increased over a period of production years. In the 20 years from 2005 to 2025, the ozone impact of HSCT emissions based on passenger demand may be expected to increase by a factor of four.

The difference in ozone depletion between the three engine types is shown in Figure 5-4. This figure illustrates the problem of relying solely on $EINO_x$ as the figure of merit for ozone depletion. The P&W VSCE has the lowest $EINO_x$ value of all the Mach 3.2 engines, as indicated in Table 5-2, but the mission fuel burn was higher than that for the P&W TBE. This resulted in a larger impact on global ozone concentration for the VSCE. This emphasizes the

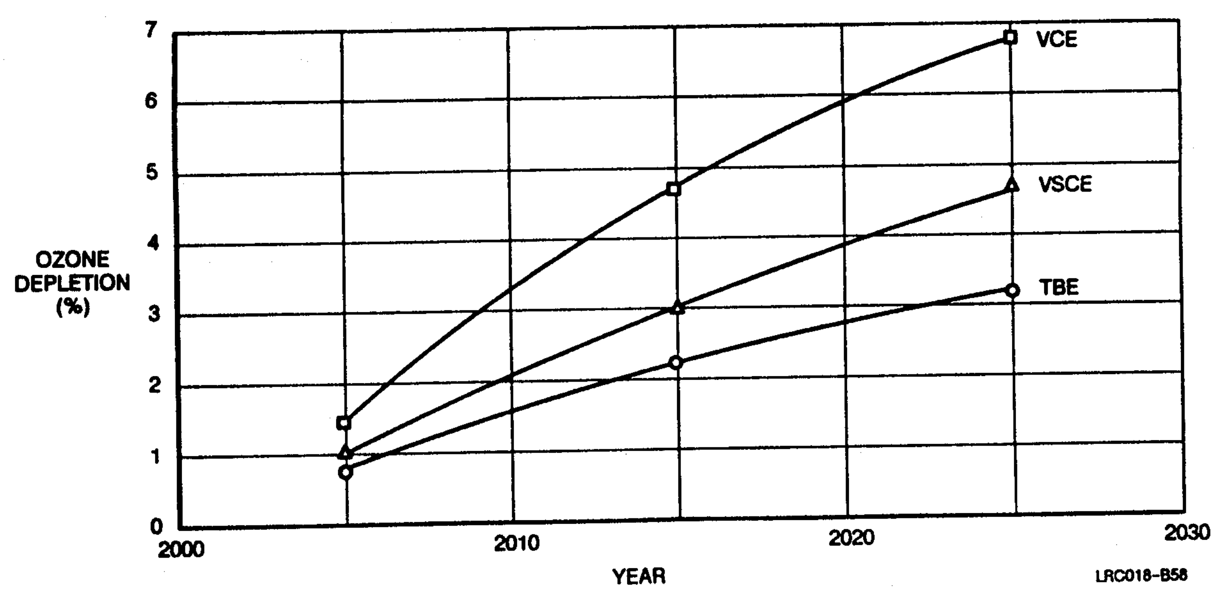

FIGURE 5-4. OZONE DEPLETION VERSUS ENGINE TYPE - MACH 3.2

need for the engine manufacturers to maintain high cruise efficiency while improving $EINO_x$ combustor standards.

A direct comparison of fleet size, number of flights, and ozone depletion is shown in Figure 5-5. The ozone depletion for a given fleet size is found by cross-referencing the fleet size with the number of flights for the appropriate Mach number. The number of flights can then be translated vertically to the top plot to determine the column ozone depletion. For a given annual passenger demand, and hence number of flights, the ozone impact is greater for a Mach 3.2 fleet than for a Mach 1.6 fleet, even though the Mach 3.2 fleet is smaller.

Logically, it would be assumed that a larger fleet size would lead to a greater ozone impact. This is not always the case, however, because the important parameter is actually the number of flights. One aircraft making 1000 annual flights will have a greater ozone impact than 500 aircraft making one annual flight. This effect is important when comparisons are made for different Mach numbers. Faster airplanes can make more flights per day, thereby allowing for smaller fleet sizes to achieve equal productivity. Therefore, the Mach 3.2 fleet is smaller

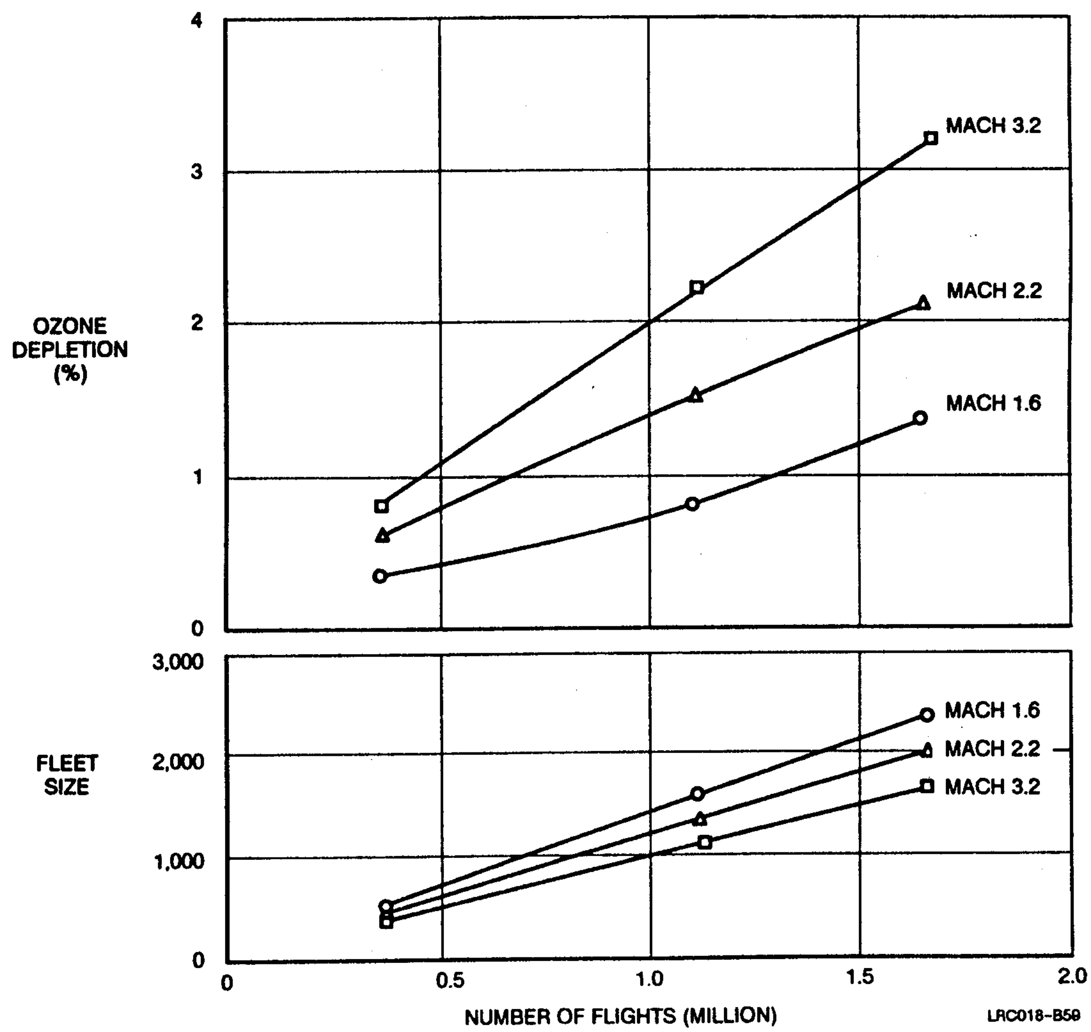

FIGURE 5-5. OZONE DEPLETION AND FLEET SIZE VERSUS NUMBER OF FLIGHTS FOR P&W TBE

than the Mach 2.2 or Mach 1.6 fleet for an equivalent number of annual flights and equal productivity.

One important economic parameter to consider is fare premium, i.e., the percentage increase of an HSCT fare over an equivalent subsonic fare. Current baseline design objectives include zero fare premium. This is considered to be optimistic with regard to the operating cost of an HSCT, but conservative with regard to ozone impact. Optimistic lower fare premiums create higher passenger demands, and hence, more flights. This relationship was shown earlier in Figure 5-2. A plot showing the impact of fare premium for Mach 3.2 and Mach 1.6 scenarios is shown in Figure 5-6. This figure compares a baseline 0-percent fare premium

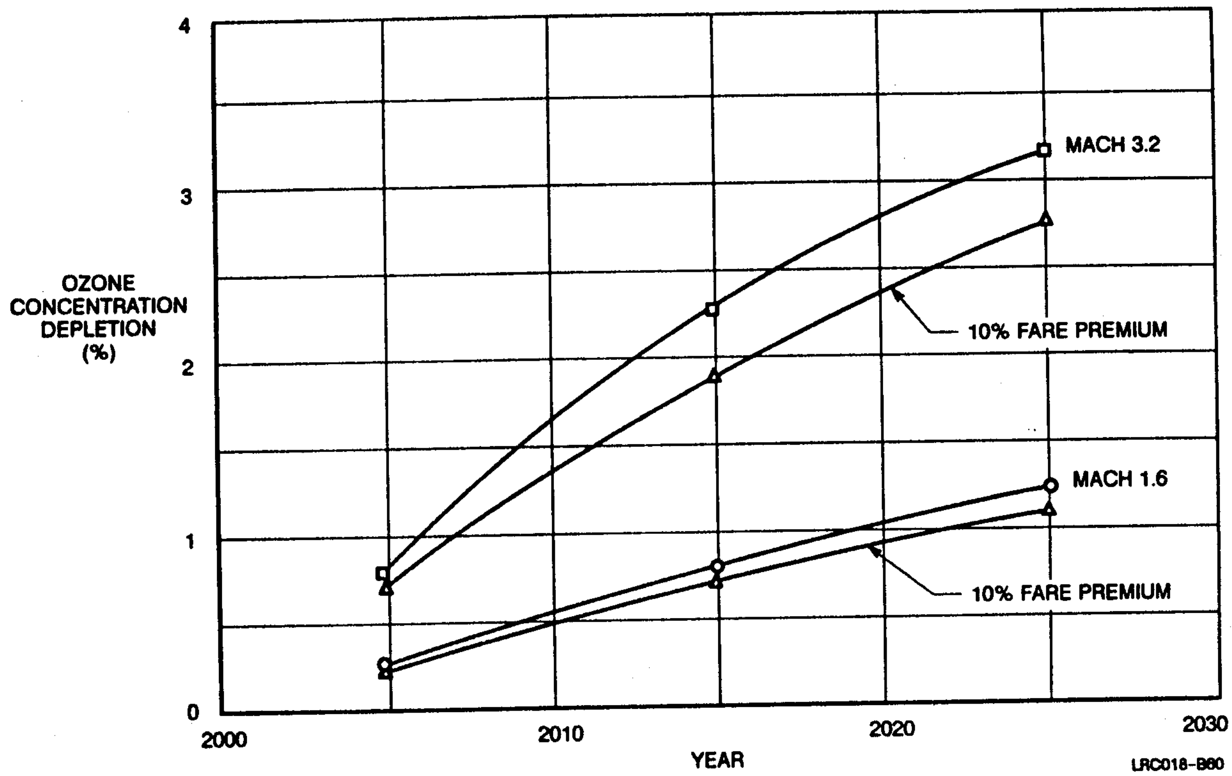

FIGURE 5-6. FARE PREMIUM IMPACT ON OZONE CONCENTRATION

with a 10-percent fare premium. As can be seen, an increase in fare premium reduces ozone impact by reducing the number of annual flights.

The 1990 emissions trade studies show that there is a wide range in the potential ozone impact from HSCT aircraft depending on the economic and flight performance of the fleet. These studies highlight approaches for minimizing ozone impact as well as approaches that should be avoided. The sensitivity of the results to tentative economic assumptions also reveals the uncertainty involved in the evaluation of emissions impact for a fleet of HSCTs.

5.4 CRUISE ALTITUDE RESTRICTIONS

One potential means of regulating and controlling the impact of supersonic aircraft emissions on atmospheric ozone is for international regulators to mandate a cruise altitude ceiling for supersonic flight, ensuring that NO_x is not emitted in the more sensitive altitude bands. The economic and performance impacts of such a regulation are strongly influenced by Mach number, optimum cruise altitude of the aircraft, and the cruise restriction altitude. For instance, a 60,000-foot ceiling restriction is not likely to have any impact on a Mach 1.6 configuration, but would significantly erode the performance of a Mach 3.2 configuration and, to a lesser extent, that of the Mach 2.2 configuration.

A series of cruise altitude restrictions were applied to the three baseline configurations to investigate the overall economic and ozone concentration impacts. Altitude restrictions ranging from 40,000 to 80,000 feet were applied to the Mach 1.6, 2.2, and 3.2 aircraft. The impact of these restrictions on ozone concentration is shown in Figure 5-7. Altitude restrictions at

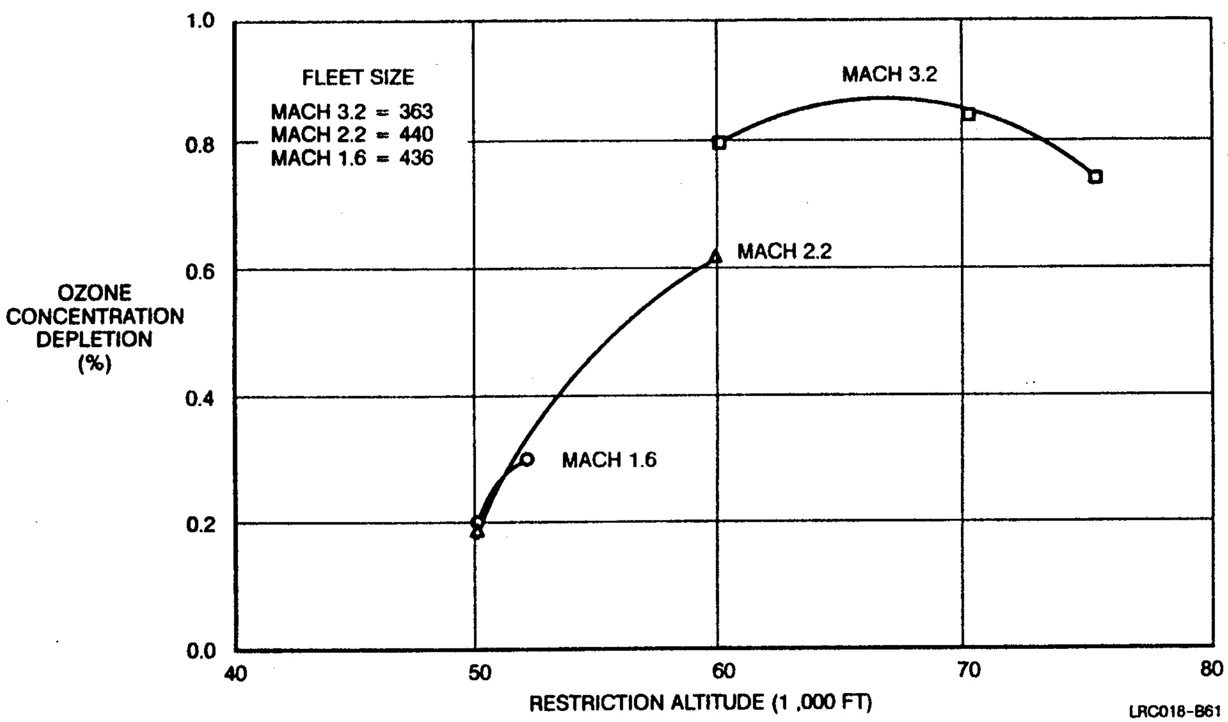

FIGURE 5-7. CRUISE ALTITUDE RESTRICTION OZONE IMPACT

Mach 3.2 tended to actually increase the ozone impact because of the sharp increase in fuel burn resulting from off-design operation. Altitude restrictions at 50,000 feet and below had a favorable ozone impact on the Mach 2.2 and Mach 1.6 aircraft, driving the estimated ozone depletion down to less than 0.5 percent. In general, the effectiveness of the restrictions is increased as the ceiling altitude is lowered.

As would be expected, HSCT economic performance deteriorates when the vehicle is operated away from its optimum design altitude as a result of higher fuel consumption, reduction in the aircraft design range, and a loss of some long-range routes. Resizing the aircraft is a means to regain lost range, but will result in a weight and performance penalty proportional to the amount of range that must be recovered. Figure 5-8 shows the relationship between weight and range penalties for cruise altitude restrictions at Mach 3.2. The left side of the

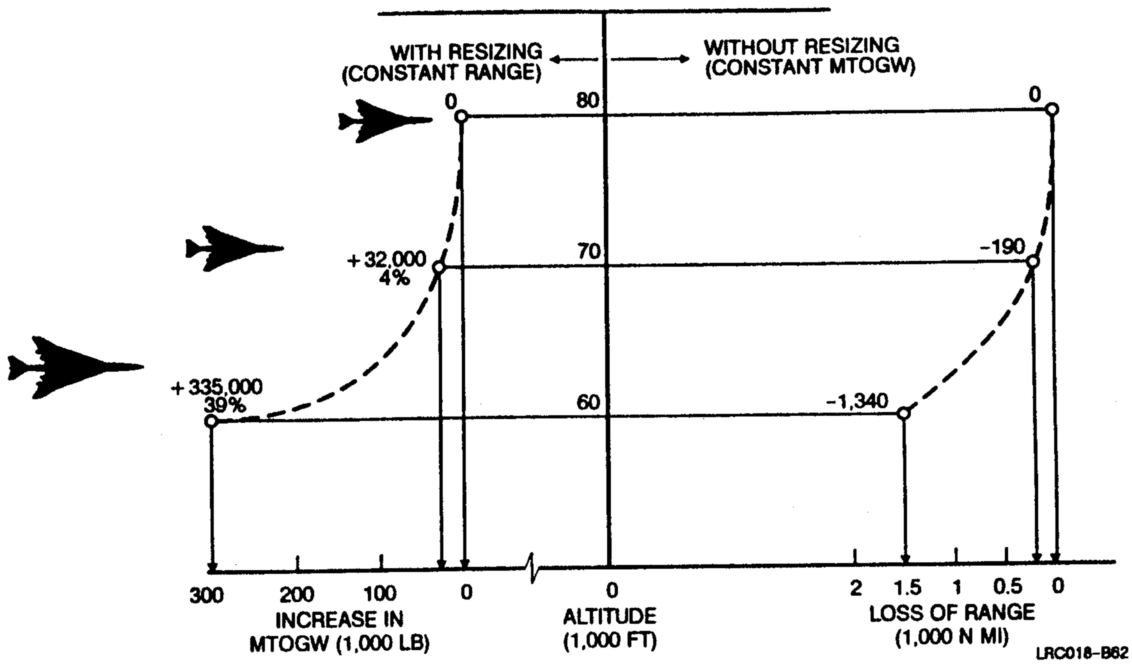

FIGURE 5-8. EFFECTS OF CRUISE ALTITUDE RESTRICTION ON MTOGW AND RANGE - MACH 3.2

chart describes the weight impact of resizing the vehicle, while the right side describes the range penalty incurred without resizing.

While resizing the aircraft is a viable means of regaining lost range, it is probably not practical for an HSCT in light of the significant weight and performance penalties associated with it. In most cases, the Mach number of an aircraft would be lowered before it would be resized to fly at off-design altitudes. The one scenario that would require resizing at off-design altitudes would be the imposition of cruise altitude restrictions well into the development phase when the engine and airframe are beyond a point of no return. For this reason, the following economic analysis of cruise altitude restrictions is focused on baseline vehicles with no resizing. The effect of cruise altitude restrictions on the operating economics will be examined for the following scenarios as indicated in the matrix below.

CRUISE ALTITUDE	MACH 3.2	MACH 2.2	MACH 1.6
80,000 FT	X		
70,000 FT	X	X	
60,000 FT	X	X	X
50,000 FT		X	X
40,000 FT			X

Cruise altitude restrictions will affect the economics of an HSCT in several ways. One prominent effect will be a reduction in market capture caused by the loss of long-haul routes (city-pairs) as a result of the range penalty. This effect is shown for the Mach 3.2 vehicle in terms of annual seat-miles (ASMs) in Figure 5-9. A 60,000-foot restriction, for instance, is estimated to reduce ASMs by 14 percent.

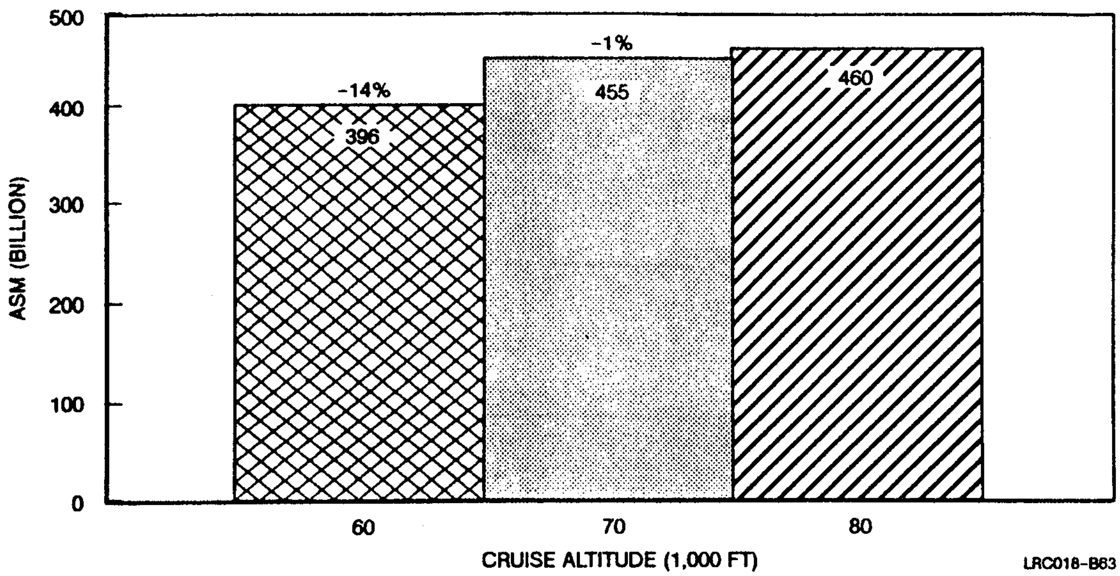

FIGURE 5-9. EFFECT OF CRUISE ALTITUDE RESTRICTION ON MARKET CAPTURE (ANNUAL SEAT-MILES)

Cruise altitude restrictions will increase HSCT operating cost and will subsequently reduce operating profit. This effect is increased as the altitude restrictions become more severe, as illustrated in Figure 5-10 for a Mach 3. 2 vehicle. The breakdown of operating cost for three cruise altitude restriction scenarios is shown in Figure 5-11. These pie graphs show how the fuel cost is driven up while profits go down for increasingly severe restrictions. The strong dependency of operating cost on fuel for these altitude restrictions is shown in Figure 5-12.

Aircraft worth, a parameter that estimates the investment value of an aircraft to an airline operator, also declines when aircraft are restricted to off-design cruise altitudes. The decline in aircraft worth and operating profit for a Mach 3.2 vehicle at restricted cruise altitudes is

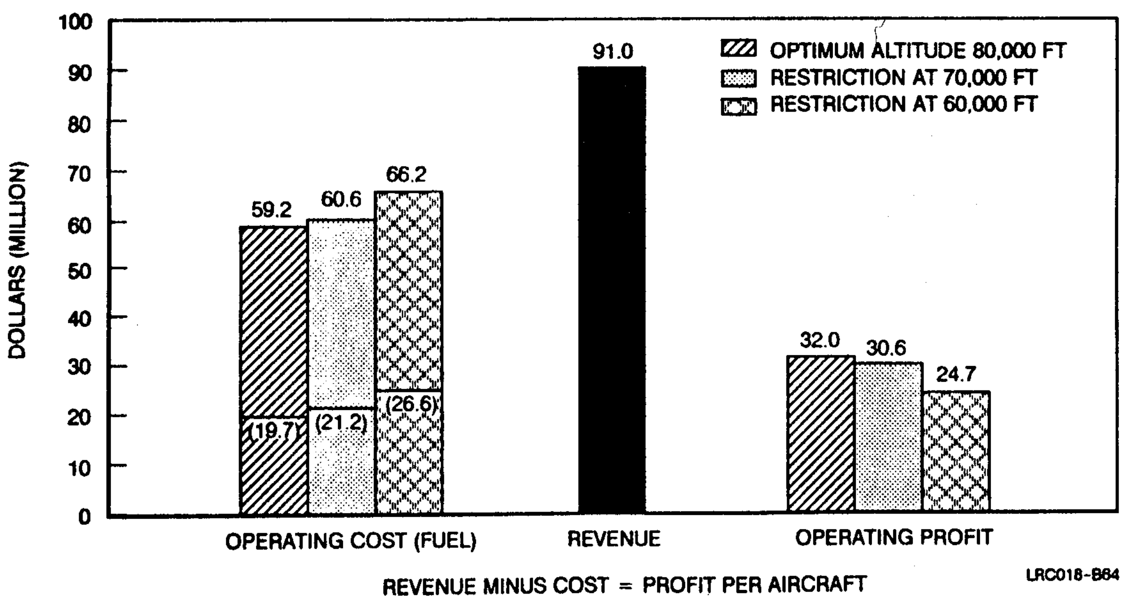

FIGURE 5-10. EFFECT OF CRUISE ALTITUDE ON OPERATING PERFORMANCE - MACH 3.2

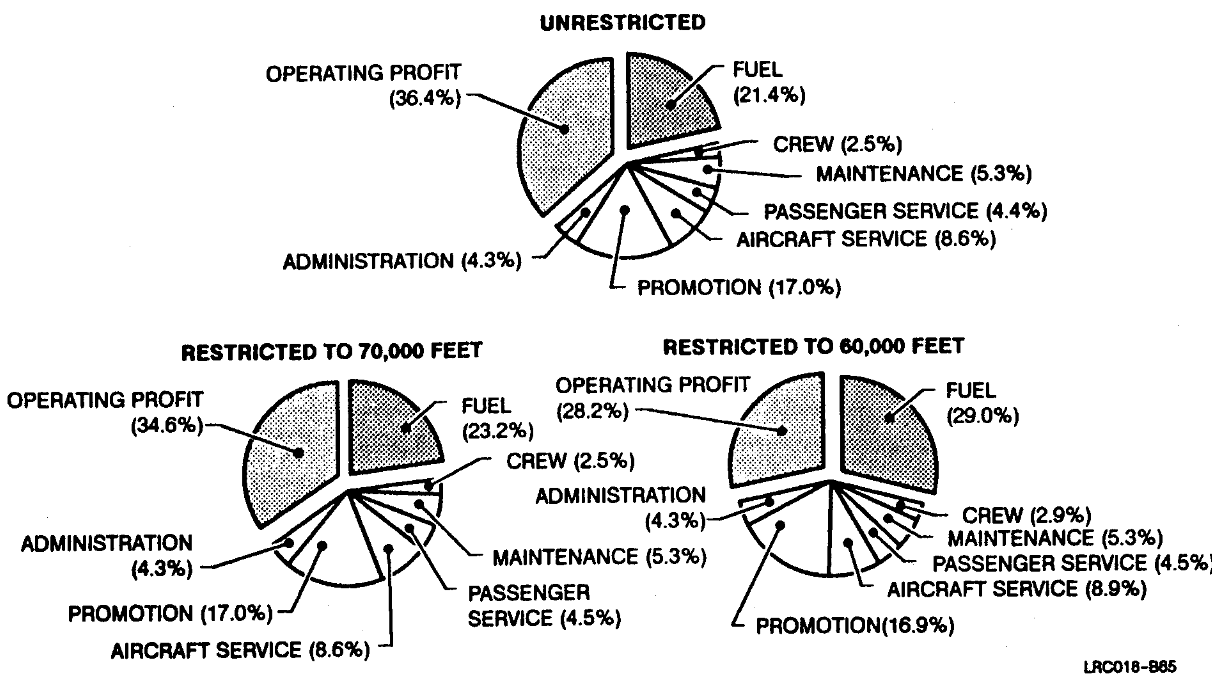

FIGURE 5-11. EFFECT OF CRUISE ALTITUDE RESTRICTIONS ON OPERATING COST AND PROFIT - MACH 3.2

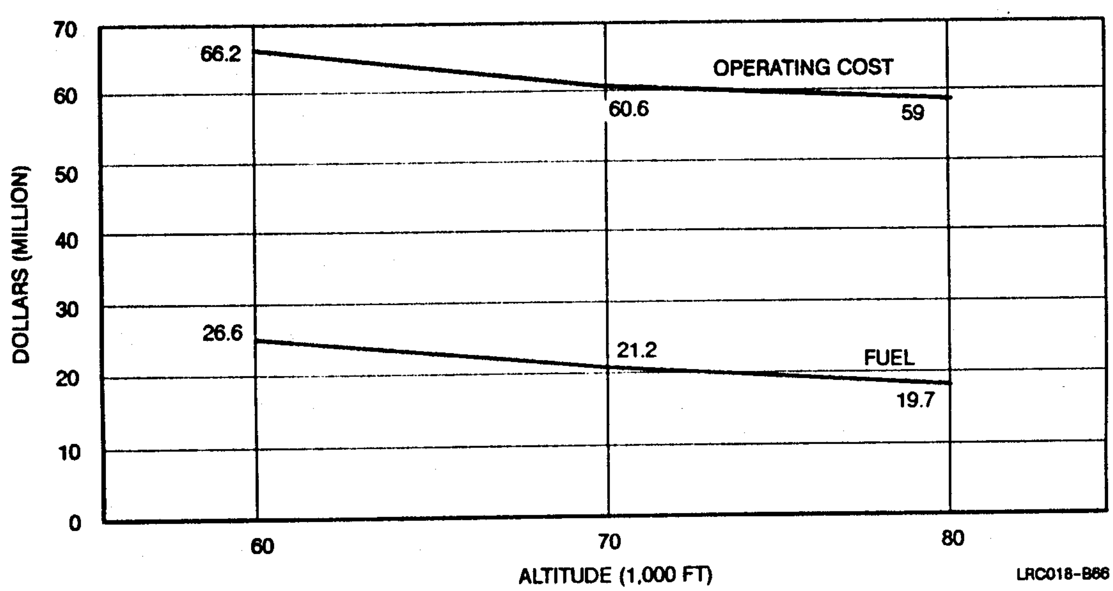

FIGURE 5-12. EFFECT OF CRUISE ALTITUDE RESTRICTION ON OPERATING COST AND FUEL COST - MACH 3.2 WITHOUT RESIZING

illustrated in Figure 5-13. At 70,000 feet the aircraft worth declined by 4 percent, and at 60,000 feet the aircraft worth showed a stronger decline of 23 percent. The close relationship between profit and aircraft worth is reflected by the equivalent rate of decline for these parameters at off-design cruise altitudes.

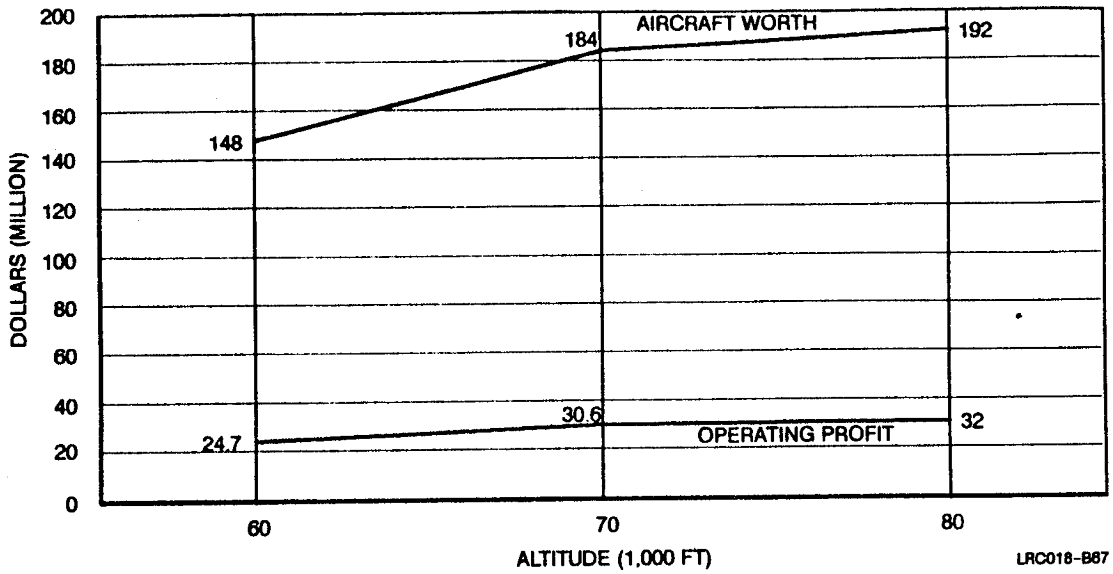

FIGURE 5-13. EFFECT OF CRUISE ALTITUDE ON AIRCRAFT WORTH AND OPERATING PROFIT - MACH 3.2 WITHOUT RESIZING

A summary of the economic impact of cruise altitude restrictions is provided in Table 5-3. Shown are the operating cost, profit, and aircraft worth, with corresponding percentage changes. Portions of these data are displayed graphically in Figure 5-14. This figure shows that the expected increase in aircraft worth with increasing Mach number at a design range of 6,500 nautical miles can be counteracted by altitude restrictions. For instance, the Mach 2.2 operating profit and aircraft worth exceeds that of the Mach 3.2 aircraft for a 60,000-foot restriction.

5.5 CONCLUSIONS

- Results showed that ozone depletion is a function of the cruise Mach number of the aircraft, primarily because of the strong dependence of ozone impact on injection altitude.
- For the P&W turbine bypass engine with a cruise $EINO_x$ of approximately 5, the only configuration that results in ozone depletions in the 1-percent range is the Mach 1.6

TABLE 5-3
AIRCRAFT ECONOMIC PERFORMANCE AT DIFFERENT CRUISE ALTITUDES

CRUISE ALTITUDE (1,000 FT)	OPERATING COST ($ MILLION) PERCENT OF CHANGE						PROFIT ($ MILLION) PERCENT OF CHANGE						AIRCRAFT WORTH ($ MILLION) PERCENT OF CHANGE					
	M3.2	%	M2.2	%	M1.6	%	M3.2	%	M2.2	%	M1.6	%	M3.2	%	M2.2	%	M1.6	%
80	59						32						192					
70	60.6	+2.7	49				30.6	-4.4	26				184	-4	156			
60	66.2	+12	50	+2	45		24.7	-23	25	-4	18		148	-23	151	-3	110	
50			54	+10	46	+2			20	-23	17	-6			125	-20	103	-6.4
40					51	+13					12	-33					73	-33

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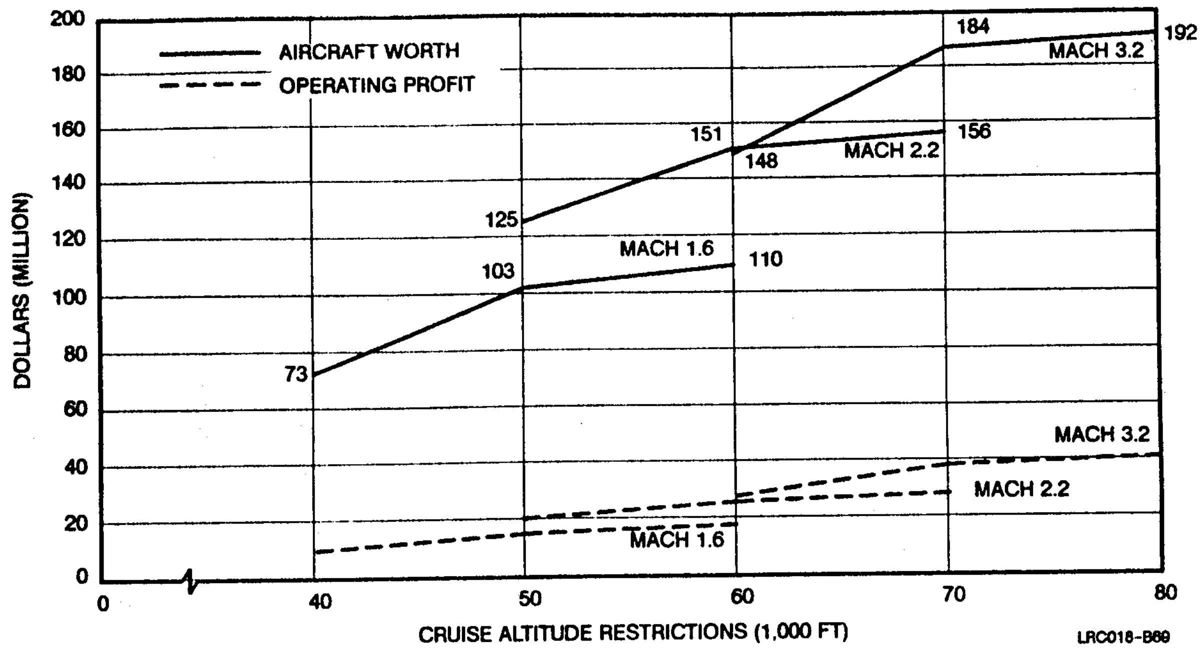

FIGURE 5-14. EFFECT OF CRUISE ALTITUDE RESTRICTIONS ON AIRCRAFT WORTH AFTER COMMENCEMENT OF PRODUCTION (WITHOUT RESIZING)

aircraft. Both the Mach 2.2 and Mach 3.2 configurations result in considerably higher ozone depletions, especially in the out-years when production is in full swing. The accuracy of this result, however, is contingent on the accuracy of the Lawrence Livermore 2-D atmospheric model.

- Of the three engine concepts studied at Mach 3.2, the turbine-bypass engine creates the smallest ozone impact. This is largely a function of its low fuel burns resulting from high-performance characteristics. Although the variable-stream-control engine has lower $EINO_x$ values, it burns considerably more fuel than the turbine-bypass engine and consequently has a greater impact on the ozone column.
- The above-mentioned results indicate the importance of considering all aspects of engine emissions and not just the $EINO_x$.
- The introduction of cruise altitude restrictions was shown to alleviate ozone impact for all Mach numbers except 3.2. At Mach 3.2, the increased fuel burn more than offset the advantage of lowering the injection altitude and resulted in an increase in ozone depletion.
- Restricting supersonic aircraft to an off-design lower cruise altitude will impose penalties on economic performance in the form of higher operating costs and, hence, reduced profits. These penalties are unlikely to be acceptable from a flight performance and economic standpoint. Therefore, any altitude restrictions must be established prior to the final Mach number selection and aircraft development stage.

5.6 FUTURE PLANS AND RECOMMENDATIONS

- The two most pressing needs in the engine emissions and ozone study area are improving the global atmospheric models and developing low-NO_x combustors. The prediction of annual fuel burns from HSCT fleets can be considered to be a fairly mature process. The wide variation in ozone concentration results from the various atmospheric models clearly needs to be addressed before the intricacies of fleet sizes, flight paths, etc. can be meaningfully addressed by the airframers.

- There is an urgent need for well-defined emissions criteria. Trade studies, such as those conducted in this study, are valuable inasmuch as they can identify trends and rule out scenarios that are clearly unacceptable. However, before the final design and Mach number selection for an HSCT can be made, emissions criteria must be defined so that costly redesigns and delays can be avoided.
- Three-dimensional atmospheric models may become an industry standard if their accuracy proves to be superior to two-dimensional models and the computer costs are not excessive. To support three-dimensional models, it will be necessary to revamp current methodologies for generating global scenarios.
- It would be mutually beneficial if a standardized methodology and format were defined and followed by industry and university researchers.
- Current HSCT emissions scenarios do not adequately account for the effect of the subsonic fleet. This can be misleading with regard to data interpretation and may be causing significant error in the overall ozone results. The optimum solution to this problem would be for the airframers to agree on a representative subsonic fleet for the time period in question, and then include these emissions in the total HSCT predictions.
- Along with the commercial subsonic fleet, prediction accuracy would be improved by including military flights. Difficulties arise when eastern European countries are brought into consideration because flight data are difficult to obtain. Some effort, however, should be made to incorporate as much of the current aviation activity as possible so that sound decisions regarding engine emissions can be made for both supersonic and subsonic aircraft.
- The impact of traffic seasonality should be included in the development of engine emissions scenarios. The global transport and atmospheric chemistry have a seasonal dependence, as does the air traffic. These factors need to be addressed to determine their impact on overall ozone concentration results.
- Certain routes have the potential to be rerouted to avoid flights through regions that are thought to be particularly sensitive to ozone depletion. For example, transatlantic flights might be rerouted away from the typical polar routes if this proved to be beneficial from an ozone standpoint. Alternative emissions scenarios simulating these types of rerouting can be developed and sent to global modelers for assessment.

SECTION 6
CONCLUSIONS

Following are conclusions drawn from the system studies in the environmental, marketing, economic, and emission impact areas:

- Long-term prospects for international passenger traffic gains are good. Supersonic traffic demands are promising.
- World demands for new passenger aircraft, including supersonic transports, are showing healthy growth. HSCT projections for the year 2025 could total 2,300 aircraft. However, accurate HSCT fleet forecasts will require a better understanding of many complex factors such as elasticity, stimulation, fare premium, and supersonic cruise overland restrictions.
- Supersonic operation may introduce major changes to the current global route structure to avoid overland flights. With creative rerouting, some supersonic network scenarios show good potential of capturing half the long-range markets.
- The atmospheric impact model results of vertical ozone depletion show a significant dependence on cruise injection altitude.
- Ozone depletion is significantly less with the Mach 1.6 configuration than with the Mach 2.2 and Mach 3.2 configurations for a given combustion technology.
- The introduction of cruise altitude restrictions after production implementation alleviates ozone impact for all Mach numbers except 3.2. At Mach 3.2, the increased fuel burn more than offset the advantage of lowering the injection altitude and resulted in an increase in ozone depletion.
- Restricting supersonic aircraft to an off-design lower cruise altitude will impose penalties on economic performance in the form of higher operating costs and, hence, reduced airline operating profits. The penalties are unlikely to be acceptable from a flight performance economic standpoint. Therefore, any altitude restrictions must be established prior to final Mach number selection in the aircraft development stage.

SECTION 7
RECOMMENDATIONS

Following are the recommendations for the environmental, marketing, economic, and emission impact areas:

- Continue market and economic analysis of HSCT commercial value and economics, considering fuel prices, operational procedures, dispatch reliability, and environmental concerns.
- Continue parametric studies of different design ranges and passenger configurations to optimize the HSCT's economic viability.
- Continue supersonic network research on ways to respond to environmental concerns, operational policies, marketing strategies, and airline requirements.
- Continue to assess the effect of these supersonic network scenarios on aircraft economic performance, productivity, and fleet projections.
- In atmospheric emission impact, continue Mach number trade studies after (1) two-dimensional atmospheric models have been updated to include fine grid densities and the effects of heterogeneous chemistry and (2) the city-pair network has been updated.
- Use three-dimensional atmospheric models for baseline atmospheric impact scenarios and compare the results to the two-dimensional model data.
- Future effects of HSCT operation on ozone depletion should include the effects of the subsonic fleet in the atmosphere for an appropriate year (e.g., 2015).
- Consider the effects of including additional subsonic operation (e.g., military, USSR, China, cargo, and turboprop).
- Evaluate the effects of traffic seasonality on atmospheric effects.
- Develop alternative emission scenarios to avoid routes having high sensitivity to ozone depletion (e.g., rerouting of polar routes).

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APPENDIX A

BASIC TRAFFIC DATA BASE
250 CITY-PAIRS
IN DESCENDING ORDER OF
SCHEDULED SEATS

LRC018-80

AIRPORT CODES	CITY CODES	DIST (SM)	IATA CODE	DEPTS	AIRCRAFT MILES	SEATS	AIRCRAFT HOURS	ASMS000	DEPTS RANK	ACM RANK	SEAT RANK	HOUR RANK	ASM RANK
HNL-LAX	HNL-LAX	2551	12	154	392854	46351	790	118242	1	1	1	1	3
JFK-LHR	NYC-LON	3441	3	97	333777	33591	620	115584	2	2	2	4	4
HNL-NRT	HNL-TYO	3813	10	79	301227	32377	634	123453	4	4	3	3	1
HNL-SFO	HNL-SFO	2394	12	83	198702	24597	409	58886	3	6	4	5	8
LAX-NRT	LAX-TYO	5440	10	58	315520	22570	658	122782	5	3	5	2	2
FRA-JFK	FRA-NYC	3844	3	46	176824	15763	390	60595	8	7	6	6	7
NRT-SFO	TYO-SFO	5112	10	41	209592	15524	381	79360	9	5	7	7	5
NRT-SIN	TYO-SIN	3324	18	41	136284	15450	280	51355	10	13	8	12	11
BKK-NRT	BKK-TYO	2881	18	46	132526	15142	275	43624	7	14	9	13	16
CDG-JFK	PAR-NYC	3623	3	48	173904	15048	354	54521	6	8	10	9	9
FCO-JFK	ROM-NYC	4264	3	29	123656	12104	264	51612	14	16	11	15	10
JFK-MXP	NYC-MIL	3983	3	28	111524	11949	217	47592	15	19	12	20	13
GIG-MIA	RIO-MIA	4172	1	33	137676	9872	275	41187	13	12	13	14	18
JFK-NRT	NYC-TYO	6727	10	24	161448	9220	333	62024	20	10	14	10	6
BRU-JFK	BRU-NYC	3655	3	38	138890	8971	313	32790	11	11	15	11	29
NRT-SVO	TYO-MOW	4659	9	37	172383	8967	375	41776	12	9	16	8	17
HNL-OSA	HNL-OSA	4093	10	20	81860	8954	170	36648	43	45	17	42	23
LAX-LHR	LAX-LON	5440	3	21	114240	8736	216	47523	37	17	18	21	15
JFK-MAD	NYC-MAD	3578	3	22	78716	8713	156	31175	23	51	19	51	34
EWR-ORY	NYC-PAR	3638	3	21	76398	8596	151	31272	31	53	20	53	33
AMS-JFK	AMS-NYC	3632	3	26	94432	8499	205	30868	16	30	21	23	35
LHR-YYZ	LON-YYZ	3544	3	23	81512	8428	176	29868	21	46	22	35	41
JFK-TLV	NYC-TLV	5663	3	18	101934	8403	185	47585	55	23	23	31	14
SIN-SYD	SIN-SYD	3908	18	21	82068	8390	150	32787	39	44	24	55	30
NRT-SEA	TYO-SEA	4757	10	20	95140	8004	174	38075	45	29	25	39	22
SIN-TPE	SIN-TPE	2012	18	22	44264	7806	91	15705	24	117	26	124	97
HNL-SEL	HNL-SEL	4538	10	24	108912	7763	235	35228	19	20	27	18	26
LHR-SIN	LON-SIN	6757	9	19	128383	7595	250	51319	50	15	28	16	12
LHR-ORD	LON-CHI	3939	3	21	82719	7574	181	29833	38	42	29	33	42
NRT-SYD	TYO-SYD	4863	18	19	92397	7345	175	35718	52	32	30	37	25
ANC-NRT	ANC-TYO	3426	10	26	89076	7340	187	25145	17	35	31	29	53
BOM-LHR	BOM-LON	4479	9	20	89580	7213	194	32310	41	33	32	28	31
EWR-LGW	NYC-LON	3472	3	18	62496	7152	123	24832	54	66	33	72	54
BOS-LHR	BOS-LON	3254	3	21	68334	6979	134	22710	26	59	34	61	63
JFK-ZRH	NYC-ZRH	3919	3	21	82299	6954	162	27252	36	43	35	48	50
AKL-HNL	AKL-HNL	4403	11	20	88060	6875	163	30271	40	39	36	47	39
FRA-ORD	FRA-CHI	4328	3	26	112528	6760	244	29257	18	18	37	17	44
HNL-SYD	HNL-SYD	5074	11	20	101480	6642	201	33701	44	24	38	25	27
LAX-LGW	LAX-LON	5463	3	17	92871	6614	178	36133	63	31	39	34	24
LAX-SEL	LAX-SEL	5956	10	17	101252	6428	222	38285	64	25	40	19	21
HNL-ORD	HNL-CHI	4235	12	21	88935	6181	169	26177	33	36	41	43	51
JFK-SNN	NYC-SNN	3072	3	17	52224	6139	105	18860	62	88	42	95	71
BKK-SYD	BKK-SYD	4684	18	15	70260	6069	131	28428	67	58	43	62	45
IAD-LHR	WAS-LON	3665	3	17	62305	6019	114	22060	61	68	44	88	65
DFW-FRA	DFW-FRA	5125	3	21	107625	5978	204	30637	27	21	45	24	36
JFK-MEX	NYC-MEX	2090	2	21	43890	5943	100	12420	35	120	46	105	123
FRA-IAD	FRA-WAS	4067	3	21	85407	5936	187	24142	32	40	47	30	56
FRA-HKG	FRA-HKG	5694	9	14	79716	5908	174	33642	80	49	48	38	28
NRT-YVR	TYO-YVR	4663	10	19	88597	5851	165	27284	53	37	49	46	49
LHR-SFO	LON-SFO	5351	3	14	74914	5719	151	30602	90	56	50	54	37
HKG-SFO	HKG-SFO	6898	10	14	96572	5670	172	39111	82	28	51	40	20
ATL-LGW	ATL-LON	4216	3	21	88536	5495	170	23167	25	38	52	41	61
PER-SIN	PER-SIN	2428	18	15	36420	5458	76	13251	69	150	53	150	114
LAX-SYD	LAX-SYD	7490	11	14	104860	5446	208	40789	87	22	54	22	19

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AIRPORT CODES	CITY CODES	DIST (SM)	IATA CODE	DEPTS	AIRCRAFT MILES	SEATS	AIRCRAFT HOURS	ASMS000	DEPTS RANK	ACM RANK	SEAT RANK	HOUR RANK	ASM RANK
BKK-FRA	BKK-FRA	5570	9	13	72410	5409	156	30132	98	57	55	50	40
HNL-SEA	HNL-SEA	2675	12	21	56175	5404	114	14456	34	79	56	87	108
BKK-LHR	BKK-LON	5928	9	13	77064	5377	161	31877	100	52	57	49	32
ATH-JFK	ATH-NYC	4919	3	12	59028	5179	123	25475	108	72	58	70	52
DFW-LGW	DFW-LON	4754	3	21	99834	5145	197	24460	28	26	59	26	55
LHR-NRT	LON-TYO	5954	9	14	83356	5124	165	30509	88	41	60	45	38
DXB-LGW	DXB-LON	3397	8	16	54352	5123	123	17404	65	84	61	71	79
CPH-SEA	CPH-SEA	4849	3	20	96980	4900	196	23761	42	27	62	27	58
DEL-FRA	DEL-FRA	3801	9	13	49413	4891	114	18590	101	98	63	85	73
FRA-NRT	FRA-TYO	5814	9	13	75582	4821	145	28030	103	54	64	56	46
BKK-DXB	BKK-DXB	3032	19	19	57608	4811	118	14587	46	75	65	79	105
GIG-JFK	RIO-NYC	4800	1	13	62400	4792	123	23002	104	67	66	73	62
JFK-LGW	NYC-LON	3459	3	14	48426	4785	97	16551	85	103	67	110	83
CDG-YMX	PAR-YMQ	3444	3	17	58548	4775	127	16445	60	73	68	64	86
MEL-SIN	MEL-SIN	3752	18	13	48776	4684	103	17574	107	101	69	99	77
HKG-YVR	HKG-YVR	6368	10	14	89152	4669	165	29732	83	34	70	44	43
BOS-FRA	BOS-FRA	3657	3	14	51198	4655	100	17023	76	91	71	102	80
DME-KHV	MOW-KHV	3812	9	21	80052	4634	182	17665	30	48	72	32	75
LIM-MIA	LIM-MIA	2620	1	19	49780	4608	103	12072	51	94	73	98	129
ATL-FRA	ATL-FRA	4600	3	14	64400	4550	121	20930	73	64	74	75	67
NRT-ORD	TYO-CHI	6257	10	12	75084	4435	138	27750	119	55	75	60	47
LHR-YMX	LON-YMQ	3251	3	14	45514	4305	99	13996	91	112	76	108	110
LHR-TLV	LON-TLV	2229	8	12	26748	4252	57	9479	117	237	77	222	173
BKK-FCO	BKK-ROM	5495	9	10	54950	4248	118	23344	129	81	78	80	60
KWI-LHR	KWI-LON	2897	8	12	34764	4215	83	12210	116	156	79	136	124
JNB-LHR	JNB-LON	5634	7	11	61974	4197	138	23646	123	70	80	58	59
CPH-JFK	CPH-NYC	3843	3	15	57645	4162	126	15995	68	74	81	66	93
LAX-OGG	LAX-OGG	2481	12	14	34734	4123	74	10229	86	157	82	154	159
LHR-PHL	LON-PHL	3533	3	14	49462	4123	112	14567	89	97	83	90	106
AMS-YYZ	AMS-YYZ	3720	3	14	52080	4118	112	15319	70	90	84	89	101
BAH-LHR	BAH-LON	3160	8	14	44240	4103	101	12965	74	118	85	101	116
LCA-LHR	LCA-LON	2035	8	18	36630	4078	89	8298	56	148	86	129	207
LAX-TPE	LAX-TPE	6770	10	10	67700	4077	138	27601	135	61	87	59	48
ANC-SEL	ANC-SEL	3769	10	13	48997	4060	114	15302	97	100	88	84	102
DFW-SJU	DFW-SJU	2163	2	14	30282	4060	66	8782	77	185	89	178	192
BKK-KHI	BKK-KHI	2299	18	13	29887	4008	65	9215	99	189	90	182	178
BKK-SEL	BKK-SEL	2294	18	14	32116	4000	72	9176	75	175	91	157	179
FRA-YYZ	FRA-YYZ	3939	3	14	55146	3990	119	15716	81	80	92	78	96
CDG-IAD	PAR-WAS	3848	3	17	65416	3986	144	15339	58	62	93	57	100
BRU-ORD	BRU-CHI	4145	3	19	78755	3980	175	16497	47	50	94	36	84
DXB-FRA	DXB-FRA	3006	8	14	42084	3955	99	11887	79	124	95	107	130
EZE-MIA	BUE-MIA	4409	1	13	57317	3951	117	17421	102	77	96	82	78
GIG-MAD	RIO-MAD	5058	5	16	80928	3948	154	19967	66	47	97	52	70
BGI-JFK	BGI-NYC	2091	2	17	35547	3923	85	8203	57	154	98	133	210
PER-SYD	PER-SYD	2035	18	23	46805	3923	90	7983	22	108	99	128	221
DEL-LHR	DEL-LON	4180	9	10	41800	3911	91	16349	131	125	100	123	89
GUA-LAX	GUA-LAX	2193	2	19	41667	3910	95	8574	49	126	101	117	198
CCS-JFK	CCS-NYC	2115	1	19	40185	3836	90	8113	48	131	102	125	216
FRA-SIN	FRA-SIN	6383	9	9	57447	3771	111	24072	148	76	103	91	57
CDG-TLV	PAR-TLV	2041	8	17	34697	3738	75	7629	59	158	104	152	233
HKG-LGW	HKG-LON	5991	9	9	53919	3724	124	22310	149	85	105	67	64
MAD-MIA	MAD-MIA	4413	4	10	44130	3686	89	16267	137	119	106	131	90
LHR-SEA	LON-SEA	4783	3	9	43047	3680	87	17601	156	123	107	132	76
OSA-SIN	OSA-SIN	3069	18	11	33759	3639	68	11168	126	164	108	172	150

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AMS-ATL	AMS-ATL	4388	3	13	57044	3611	123	15845	96	78	109	68	95
IAH-LGW	HOU-LON	4840	3	14	67760	3500	127	16940	84	60	110	65	81
DME-IKT	MOW-IKT	2604	9	21	54684	3444	120	8967	29	83	111	76	187
CDG-NRT	PAR-TYO	6027	9	10	60270	3435	118	20703	130	71	112	81	68
OGG-SFO	OGG-SFO	2335	12	14	32690	3409	66	7960	92	173	113	180	222
DXB-KUL	DXB-KUL	3434	19	12	41208	3366	84	11558	114	127	114	134	134
BOM-SIN	BOM-SIN	2435	18	12	29220	3359	60	8179	110	199	115	203	213
BOM-FRA	BOM-FRA	4079	9	9	36711	3288	80	13412	141	147	116	141	112
HNL-LAS	HNL-LAS	2757	12	9	24813	3243	50	8941	150	257	117	262	189
LHR-NBO	LON-NBO	4248	7	9	38232	3235	79	13742	155	143	118	146	111
ORD-ZRH	CHI-ZRH	4428	3	14	61992	3172	123	14047	94	69	119	74	109
IAD-NRT	WAS-TYO	6736	10	6	40416	3168	84	21340	299	129	120	135	66
JED-LHR	JED-LON	2960	8	9	26640	3142	58	9298	153	241	121	218	175
HNL-MNL	HNL-MNL	5290	10	9	47610	3138	90	16599	151	104	122	127	82
JFK-LIS	NYC-LIS	3357	3	12	40284	3109	81	10437	115	130	123	138	157
AKL-LAX	AKL-LAX	6512	11	8	52096	3093	96	20141	157	89	124	111	69
ORD-SJU	CHI-SJU	2072	2	14	29008	3080	65	6382	93	204	125	187	279
CVG-ORY	CVG-PAR	4144	3	12	49728	3048	100	12631	112	96	126	103	119
HNL-IAH	HNL-HOU	3896	12	7	27272	3038	49	11836	243	229	127	264	132
AUH-SIN	AUH-SIN	3672	19	8	29376	3018	56	11082	162	198	128	223	151
HNL-STL	HNL-STL	4120	12	7	28840	3017	55	12430	247	208	129	234	122
BKK-CPH	BKK-CPH	5344	9	10	53440	3010	115	16085	128	86	130	83	92
LGW-MIA	LON-MIA	4429	4	11	48719	3001	109	13292	124	102	131	94	113
CDG-FDF	PAR-FDF	4266	4	8	34128	2957	72	12614	164	162	132	158	121
ATH-SIN	ATH-SIN	5626	9	7	39382	2928	77	16473	184	134	133	149	85
ARN-JFK	STO-NYC	3908	3	14	54712	2920	123	11412	72	82	134	69	141
CDG-LAX	PAR-LAX	5652	3	9	50868	2903	102	16408	145	92	135	100	87
FRA-JNB	FRA-JNB	5396	7	8	43168	2901	96	15653	168	122	136	114	98
HKG-SEA	HKG-SEA	6474	10	10	64740	2901	120	18781	133	63	137	77	72
DTW-NRT	DTT-TYO	6380	10	7	44660	2900	93	18502	226	115	138	120	74
BAH-HKG	BAH-HKG	3978	19	7	27846	2884	56	11473	189	222	139	224	138
BAH-LGW	BAH-LON	3144	8	7	22008	2884	48	9067	190	283	140	266	183
GUM-HNL	GUM-HNL	3797	10	13	49361	2884	94	10950	105	99	141	118	153
LHR-MIA	LON-MIA	4414	4	7	30898	2884	65	12730	257	180	142	186	118
AMS-LAX	AMS-LAX	5562	3	8	44496	2864	92	15930	160	116	143	121	94
JFK-MUC	NYC-MUC	4028	3	13	52364	2837	104	11427	106	87	144	96	139
BOS-SNN	BOS-SNN	2885	3	7	20195	2807	40	8099	197	300	145	304	218
BOS-LGW	BOS-LON	3272	3	7	22904	2800	46	9162	196	275	146	281	180
LGW-MSP	LON-MSP	4022	3	7	28154	2800	63	11262	255	219	147	194	146
OSA-SFO	OSA-SFO	5374	10	7	37618	2800	68	15047	265	144	148	171	104
SEA-SEL	SEA-SEL	5180	10	7	36260	2800	80	14504	267	151	149	143	107
DEL-SIN	DEL-SIN	2582	18	8	20656	2793	42	7211	166	295	150	299	248
CDG-MIA	PAR-MIA	4577	4	8	36616	2758	78	12624	165	149	151	147	120
CGK-NRT	JKT-TYO	3623	18	7	25361	2730	51	9891	207	253	152	256	165
HNL-NAN	HNL-NAN	3171	11	9	28539	2730	58	8657	152	213	153	217	196
AMS-ORD	AMS-CHI	4106	3	8	32848	2724	69	11185	161	169	154	165	149
LHR-YVR	LON-YVR	4707	3	10	47070	2713	94	12770	136	105	155	119	117
LGW-NRT	LON-TYO	5967	9	6	35802	2706	72	16148	304	153	156	159	91
JFK-WAW	NYC-WAW	4253	3	11	46783	2700	96	11482	122	109	157	116	136
FRA-SFO	FRA-SFO	5681	3	7	39767	2667	80	15151	236	133	158	142	103
DUS-ORD	DUS-CHI	4214	3	12	50568	2665	110	11230	113	93	159	92	148
HEL-JFK	HEL-NYC	4103	3	11	45133	2665	100	10935	120	113	160	104	154
JFK-ORY	NYC-PAR	3623	3	10	36230	2625	74	9510	134	152	161	153	170
BCN-JFK	BCN-NYC	3820	3	12	45840	2618	103	10001	109	111	162	97	163

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CMB-DXB	CMB-DXB	2043	19	12	24516	2610	52	5332	111	260	163	252	321
CDG-PTP	PAR-PTP	4204	4	7	29428	2583	56	10858	203	197	164	226	155
AMS-YMX	AMS-YMQ	3429	3	7	24003	2576	51	8834	181	266	165	255	191
BAH-FRA	BAH-FRA	2755	8	9	24795	2559	54	7051	140	258	166	238	255
KUL-MEL	KUL-MEL	3946	18	6	23676	2559	45	10097	302	268	167	288	161
SFO-TPE	SFO-TPE	6439	10	10	64390	2544	131	16381	138	65	168	63	88
DEN-HNL	DEN-HNL	3347	12	10	33470	2530	70	8468	132	167	169	163	199
AKL-SIN	AKL-SIN	5222	18	9	46998	2525	96	13184	139	107	170	112	115
MEL-NAN	MEL-NAN	2401	18	8	19208	2516	39	6040	173	311	171	322	290
EZE-MAD	BUE-MAD	6257	5	6	37542	2487	69	15564	290	145	172	168	99
HKG-SYD	HKG-SYD	4581	18	6	27486	2480	54	11361	297	227	173	243	144
KHV-VKO	KHV-MOW	3823	9	7	26761	2450	79	9366	251	236	174	145	174
LED-TAS	LED-TAS	2102	9	7	14714	2450	34	5150	254	391	175	367	331
UUS-VKO	UUS-MOW	4146	9	7	29022	2450	100	10158	269	202	176	106	160
HKG-MEL	HKG-MEL	4601	18	6	27606	2442	54	11238	296	226	177	242	147
AUH-CGK	AUH-JKT	4101	19	7	28707	2414	55	9897	188	212	178	230	164
BRU-YMX	BRU-YMQ	3461	3	9	31149	2409	67	8338	143	178	179	173	205
BOS-CDG	BOS-PAR	3436	3	9	30924	2404	59	8260	142	179	180	208	208
CCS-MAD	CCS-MAD	4349	4	9	39141	2398	75	10429	144	139	181	151	158
AMS-DXB	AMS-DXB	3208	8	7	22456	2384	48	7648	177	279	182	265	231
AMS-AUA	AMS-AUA	4893	4	8	39144	2362	80	11556	158	138	183	140	135
PEK-SHJ	BJS-SHJ	3609	19	8	28872	2345	71	8464	174	207	184	162	200
FRA-PEK	FRA-BJS	4836	9	6	29016	2343	59	11331	292	203	185	209	145
KHI-PEK	KHI-BJS	3003	18	9	27027	2325	59	6983	154	230	186	212	257
BOS-ZRH	BOS-ZRH	3732	3	7	26124	2319	49	8654	198	244	187	263	197
LGW-YYZ	LON-YYZ	3564	3	11	39204	2299	89	8194	125	137	188	130	211
AMS-IAH	AMS-HOU	4998	3	7	34986	2296	72	11475	178	155	189	156	137
DME-HTA	MOW-HTA	2937	9	14	41118	2296	114	6744	78	128	190	86	266
UUD-VKO	UUD-MOW	2758	9	14	38612	2296	110	6332	95	141	191	93	280
HNL-PHX	HNL-PHX	2910	12	6	17460	2286	34	6652	298	341	192	366	269
FRA-MIA	FRA-MIA	4820	4	9	43380	2277	90	10976	147	121	193	126	152
DXB-MNL	DXB-MNL	4290	19	6	25740	2256	52	9678	288	245	194	253	167
EWR-LHR	NYC-LON	3454	3	7	24178	2240	47	7737	231	263	195	275	229
JFK-MAN	NYC-MAN	3330	3	7	23310	2240	47	7459	248	271	196	278	240
HAV-YQX	HAV-YQX	2345	2	7	16415	2212	34	5187	242	362	197	364	330
BKK-OSA	BKK-OSA	2601	18	7	18207	2209	36	5747	191	327	198	336	302
CNS-NRT	CNS-TYO	3653	18	6	21918	2206	42	8060	283	284	199	298	219
AKL-NRT	AKL-TYO	5490	18	6	32940	2202	66	12090	270	168	200	177	128
GVA-JFK	GVA-NYC	3852	3	7	26964	2196	58	8459	240	233	201	216	201
JIB-RUN	JIB-RUN	2392	16	5	11960	2179	25	5213	341	449	202	447	328
KUL-NRT	KUL-TYO	3337	18	8	26696	2156	53	7195	172	238	203	249	249
MAD-MEX	MAD-MEX	5631	4	5	28155	2150	55	12107	347	218	204	236	127
HNL-SAN	HNL-SAN	2609	12	7	18263	2114	36	5515	245	325	205	345	309
DXB-ZRH	DXB-ZRH	2959	8	6	17754	2113	39	6251	289	334	206	316	283
FRA-YMX	FRA-YMQ	3647	3	7	25529	2071	56	7553	238	250	207	227	235
FCO-GIG	ROM-RIO	5694	5	5	28470	2063	58	11748	327	214	208	215	133
MIA-SCL	MIA-SCL	4146	1	12	49752	2037	98	8443	118	95	209	109	202
BOG-JFK	BOG-NYC	2481	1	7	17367	2030	39	5036	193	346	210	314	339
HNL-SJC	HNL-SJC	2413	12	7	16891	2030	35	4898	246	354	211	359	349
DXB-HKG	DXB-HKG	3694	19	5	18470	2025	36	7480	326	322	212	341	238
HKG-LHR	HKG-LON	5989	9	5	29945	2025	70	12129	335	187	213	164	126
CAI-LHR	CAI-LON	2192	8	8	17536	2024	40	4437	163	339	214	305	371
HNL-NGO	HNL-NGO	4006	10	4	16024	2024	33	8108	403	369	215	368	217
AMS-DHA	AMS-DHA	2946	8	6	17676	2015	36	5937	273	335	216	333	294

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DUS-LAX	DUS-LAX	5671	3	6	34026	2007	68	11381	287	163	217	170	143
BOM-HKG	BOM-HKG	2670	18	6	16020	1998	34	5335	278	370	218	361	320
AMS-BOS	AMS-BOS	3445	3	7	24115	1988	54	6849	176	265	219	237	261
BOS-GLA	BOS-GLA	3020	3	7	21140	1988	43	6004	195	287	220	294	292
CDG-DTW	PAR-DTT	3948	3	7	27636	1988	61	7849	202	225	221	199	224
DTW-FRA	DTT-FRA	4147	3	7	29029	1988	57	8244	224	201	222	220	209
JFK-VIE	NYC-VIE	4224	3	11	46464	1988	96	8398	121	110	223	115	204
ANC-SFO	ANC-SFO	2014	12	14	28196	1974	63	3975	71	217	224	190	394
MNL-RUH	MNL-RUH	4831	19	5	24155	1965	47	9493	351	264	225	279	171
CAI-LGW	CAI-LON	2171	8	6	13026	1920	31	4168	280	427	226	387	385
FRA-GIG	FRA-RIO	5942	5	5	29710	1919	60	11405	329	192	227	205	142
AMS-PBM	AMS-PBM	4674	4	7	32718	1909	68	8924	179	172	228	169	190
FDF-ORY	FDF-PAR	4255	4	4	17020	1908	32	8120	391	352	229	378	215
ORY-PTP	PAR-PTP	4193	4	4	16772	1908	32	8000	417	358	230	386	220
HND-HNL	TYO-HNL	3845	10	5	19225	1900	35	7306	336	310	231	358	244
LHR-RUH	LON-RUH	3080	8	6	18480	1895	39	5835	305	321	232	321	300
DEL-FCO	DEL-ROM	3685	9	6	22110	1891	48	6967	286	282	233	267	258
LAX-PPT	LAX-PPT	4105	11	6	24630	1889	48	7756	303	259	234	271	226
ATL-MUC	ATL-MUC	4786	3	7	33502	1883	62	9012	185	166	235	195	186
BNE-NRT	BNE-TYO	4472	18	6	26832	1883	54	8422	277	234	236	239	203
CVG-FRA	CVG-FRA	4347	3	7	30429	1883	57	8185	212	184	237	219	212
CVG-LGW	CVG-LON	3969	3	7	27783	1883	53	7474	213	224	238	244	239
NRT-PDX	TYO-PDX	4810	10	7	33670	1883	61	9057	262	165	239	201	185
PDX-SEL	PDX-SEL	5252	10	7	36764	1883	81	9890	266	146	240	139	166
DUS-JFK	DUS-NYC	3736	3	8	29888	1877	65	7012	167	188	241	183	256
BOS-BRU	BOS-BRU	3468	3	6	20808	1872	38	6492	279	291	242	323	276
JFK-SVO	NYC-MOW	4646	3	5	23230	1870	46	8688	340	272	243	282	195
KHG-SHA	KHG-SHA	2592	18	7	18144	1869	15	4844	250	329	244	616	354
MAD-SDQ	MAD-SDQ	4154	4	7	29078	1862	56	7735	258	200	245	229	230
GIG-LHR	RIO-LON	5746	5	5	28730	1857	55	10670	331	211	246	233	156
FRA-YVR	FRA-YVR	5007	3	8	40056	1856	82	9293	170	132	247	137	176
FRA-THR	FRA-THR	2339	8	7	16373	1833	36	4288	237	363	248	344	380
DPS-MEL	DPS-MEL	2726	18	7	19082	1830	37	4988	223	313	249	327	342
DTW-SEL	DTT-SEL	6603	10	4	26412	1800	58	11885	386	242	250	214	131

APPENDIX B

GREAT CIRCLE VERSUS DIVERTED DISTANCES STRIP CHARTS FOR TOP 20 CITY-PAIRS

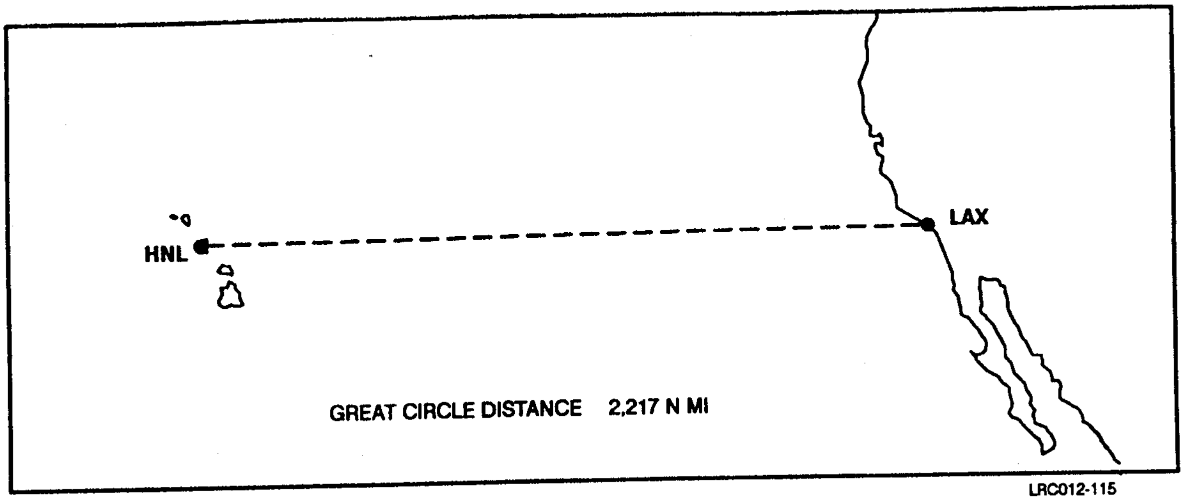


FIGURE B-1. HSCT ROUTE CHART FOR HNL-LAX

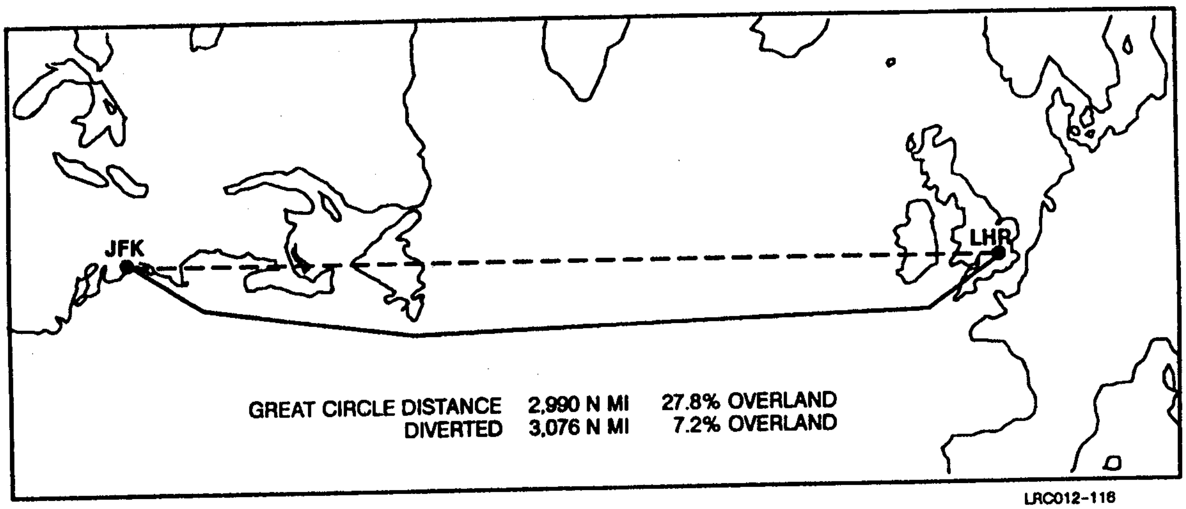


FIGURE B-2. HSCT ROUTE CHART FOR JFK-LHR

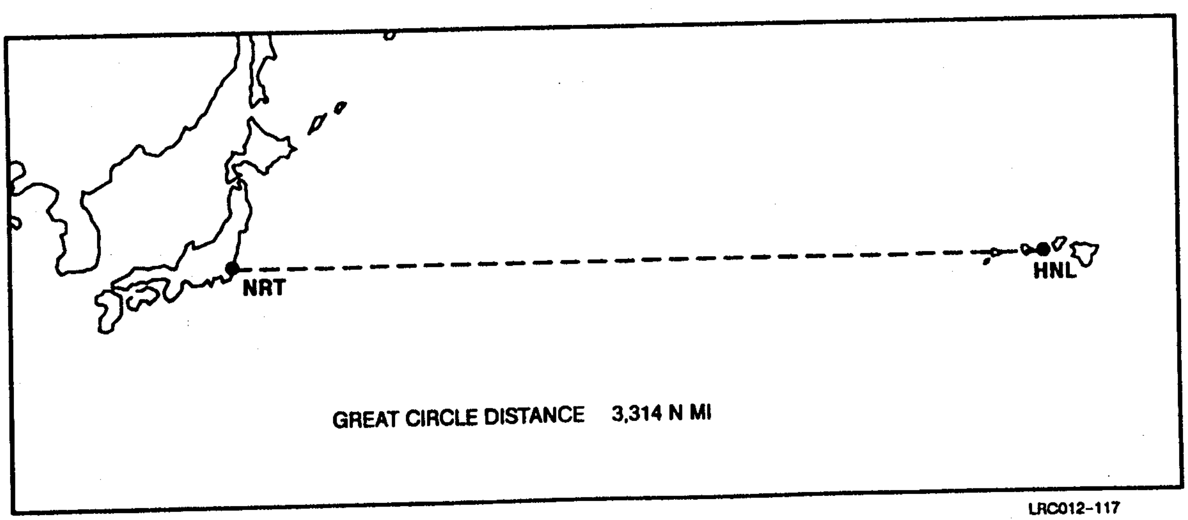


FIGURE B-3. HSCT ROUTE CHART FOR HNL-NRT

LRC018-B

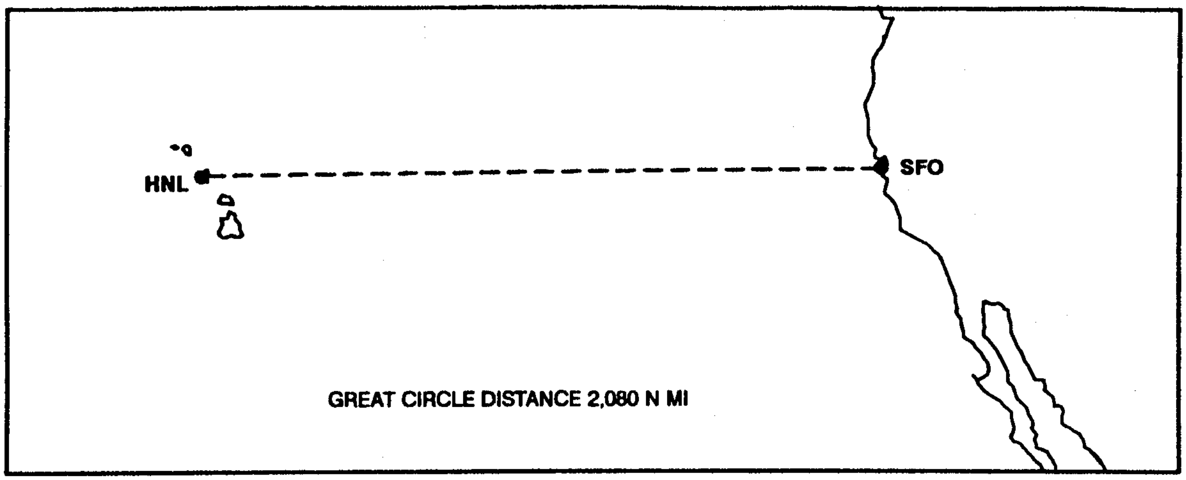


FIGURE B-4. HSCT ROUTE CHART FOR HNL-SFO

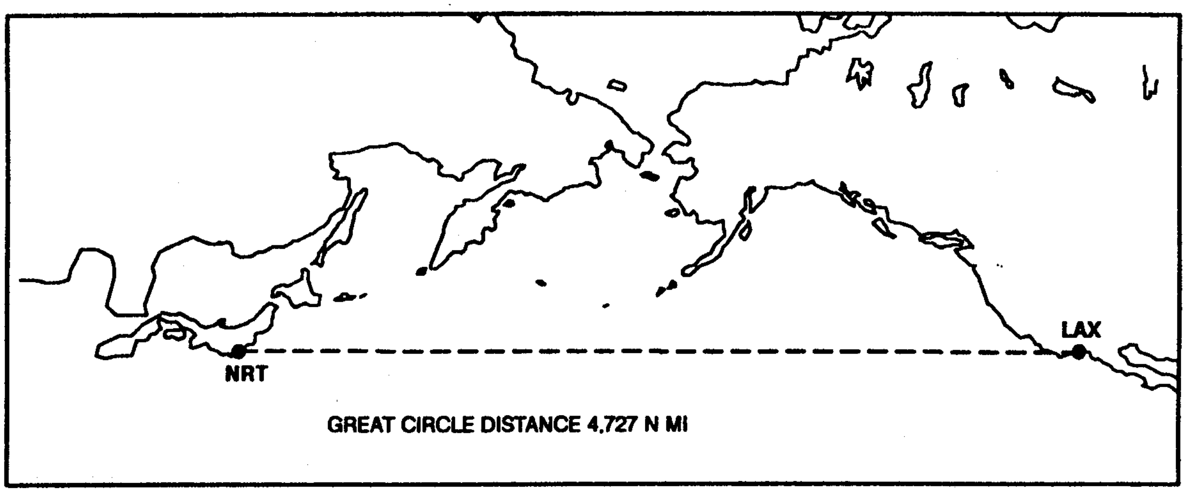


FIGURE B-5. HSCT ROUTE CHART FOR LAX-NRT

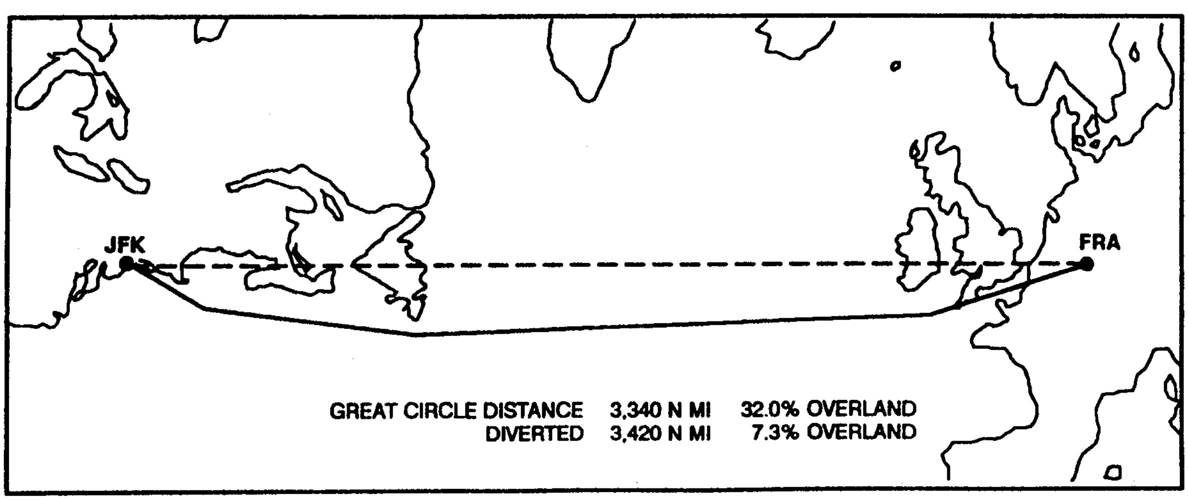
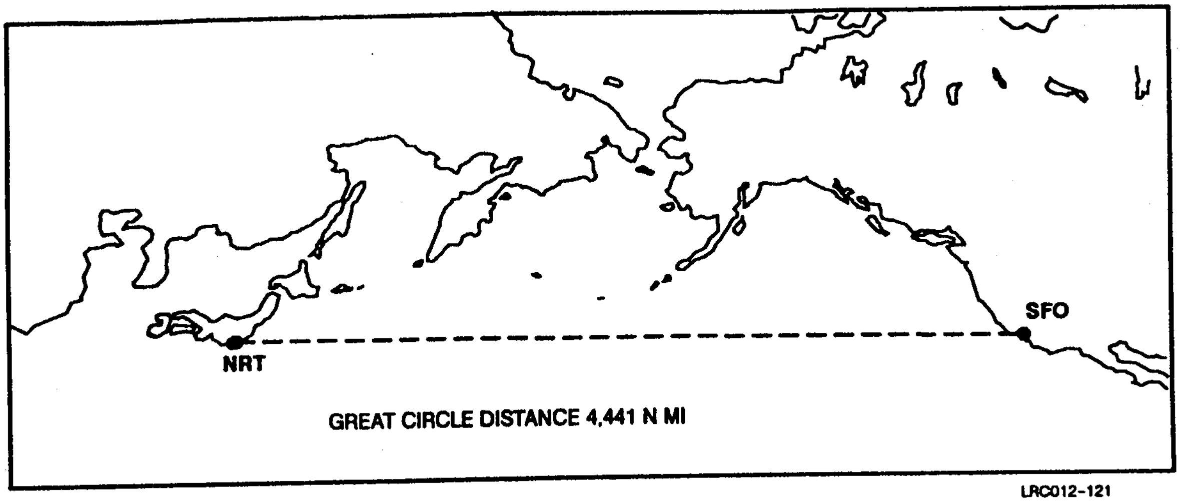


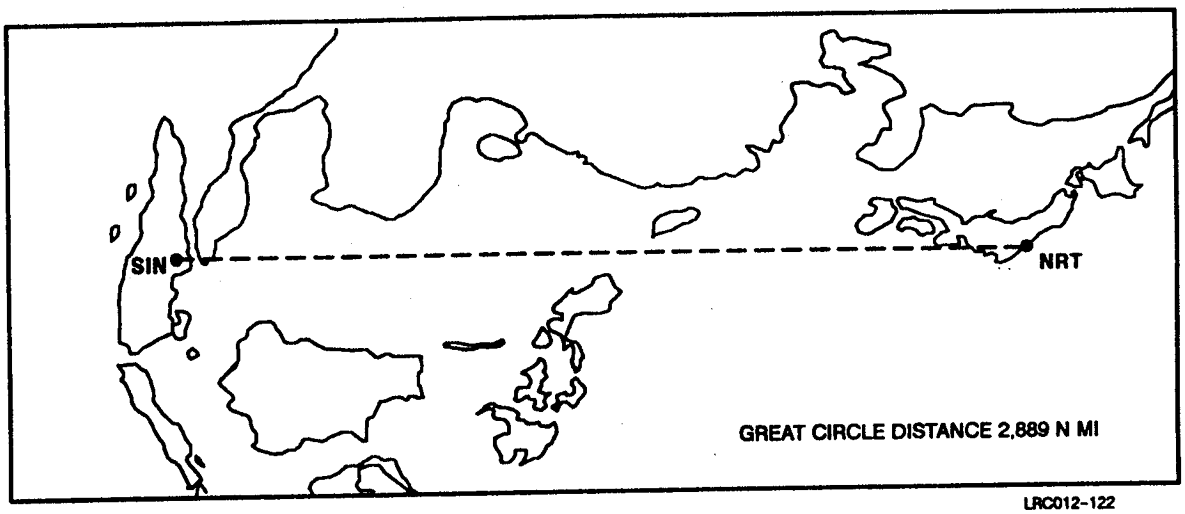
FIGURE B-6. HSCT ROUTE CHART FOR FRA-JFK

LRC018-B



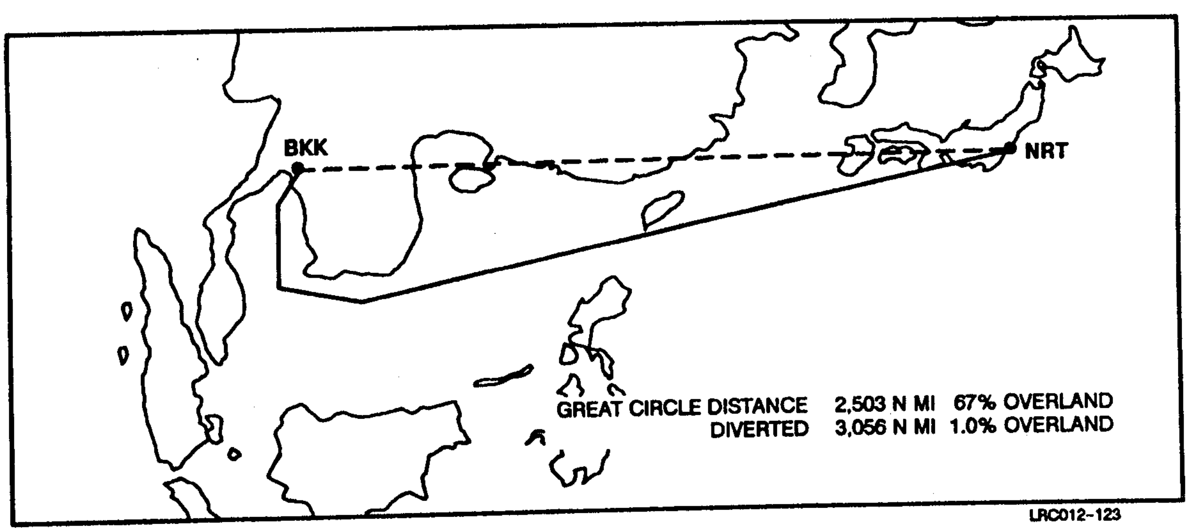
LRC012-121

FIGURE B-7. HSCT ROUTE CHART FOR NRT-SFO



LRC012-122

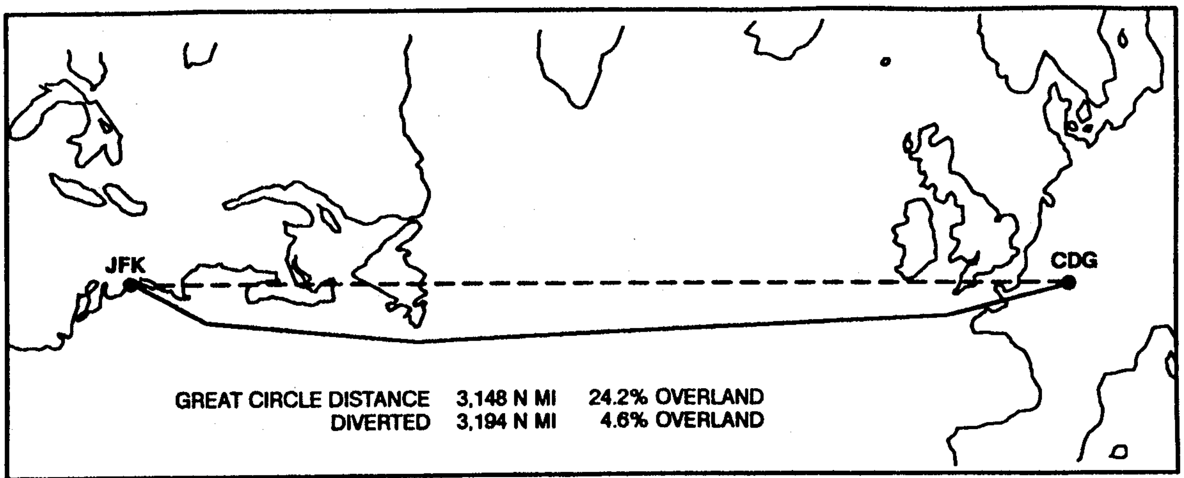
FIGURE B-8. HSCT ROUTE CHART FOR NRT-SIN



LRC012-123

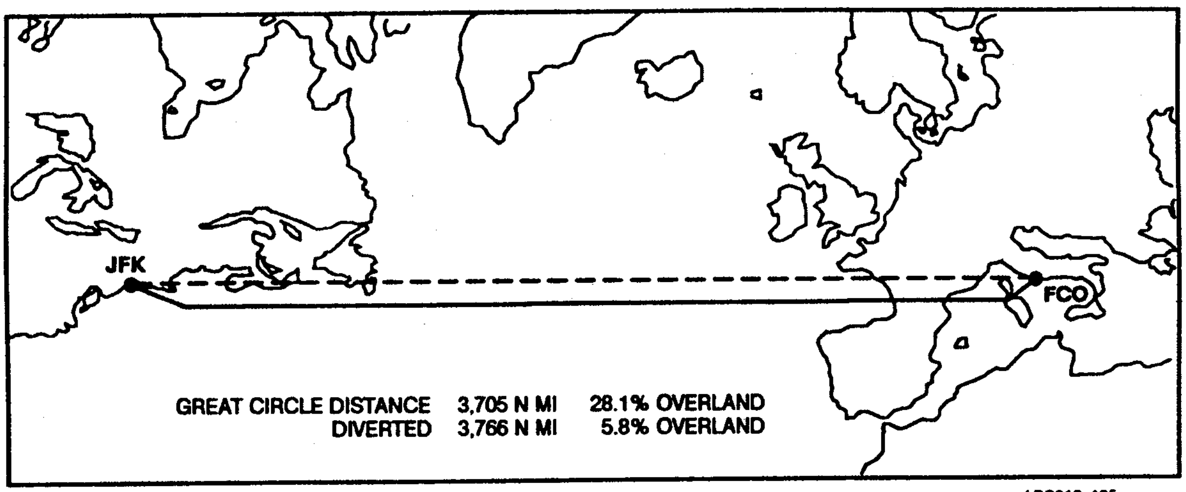
FIGURE B-9. HSCT ROUTE CHART FOR BKK-NRT

LRC018-B



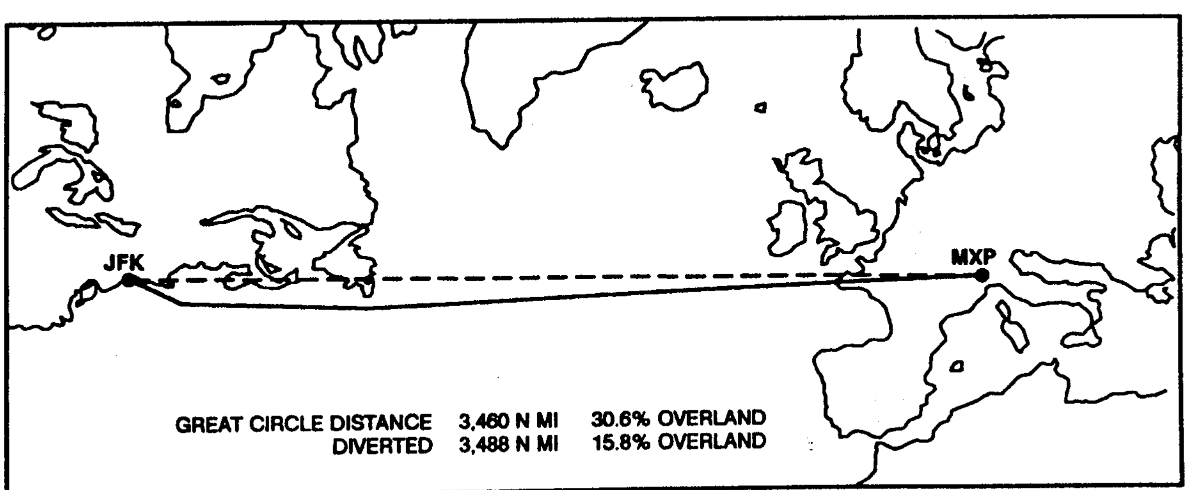
LRC012-124

FIGURE B-10. HSCT ROUTE CHART FOR CDG-JFK



LRC012-125

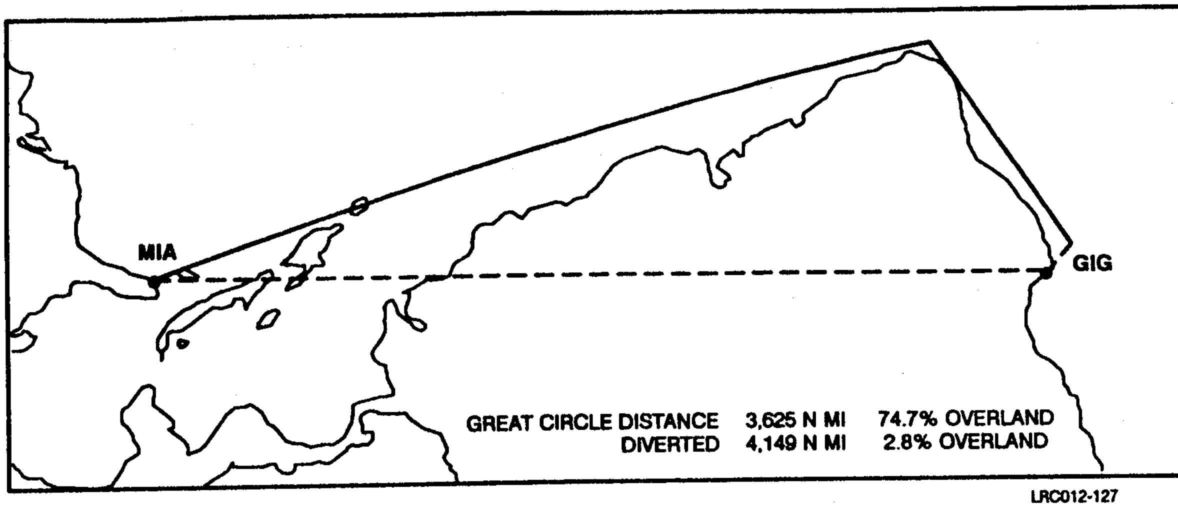
FIGURE B-11. HSCT ROUTE CHART FOR FCO-JFK



LRC012-126

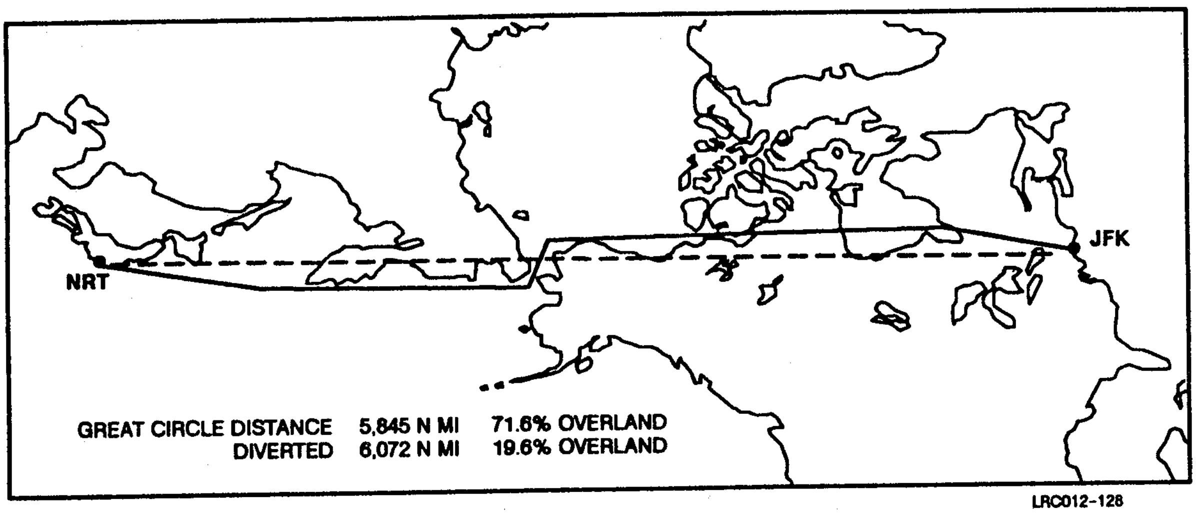
FIGURE B-12. HSCT ROUTE CHART FOR JFK-MXP

LRC018-B



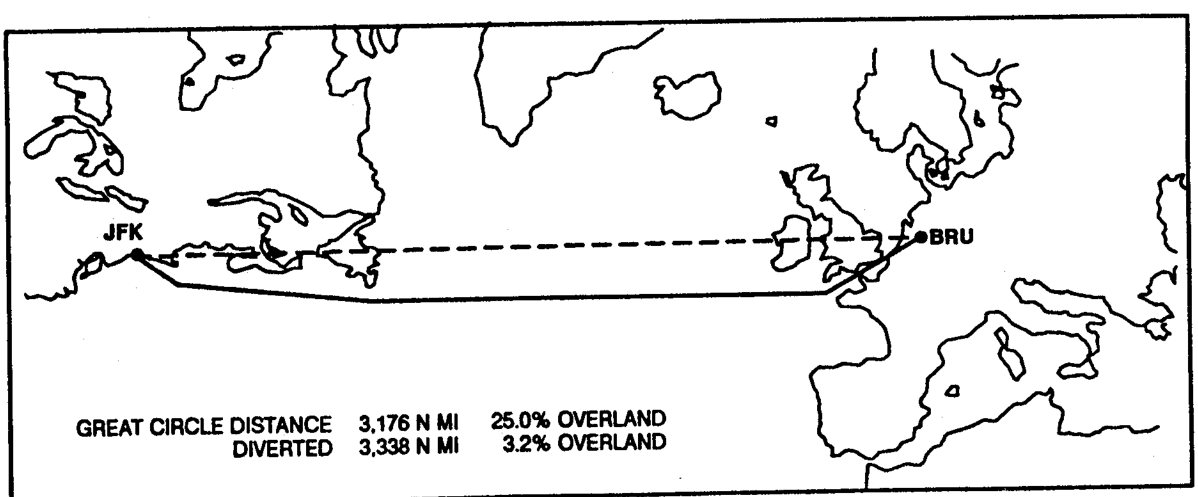
LRC012-127

FIGURE B-13. HSCT ROUTE CHART FOR GIG-MIA



LRC012-128

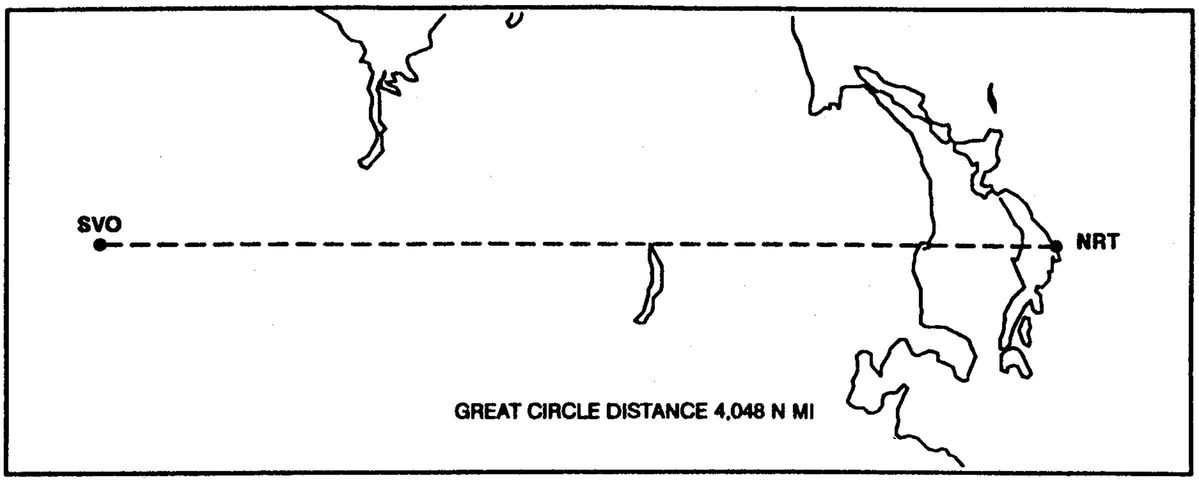
FIGURE B-14. HSCT ROUTE CHART FOR JFK-NRT



LRC012-129

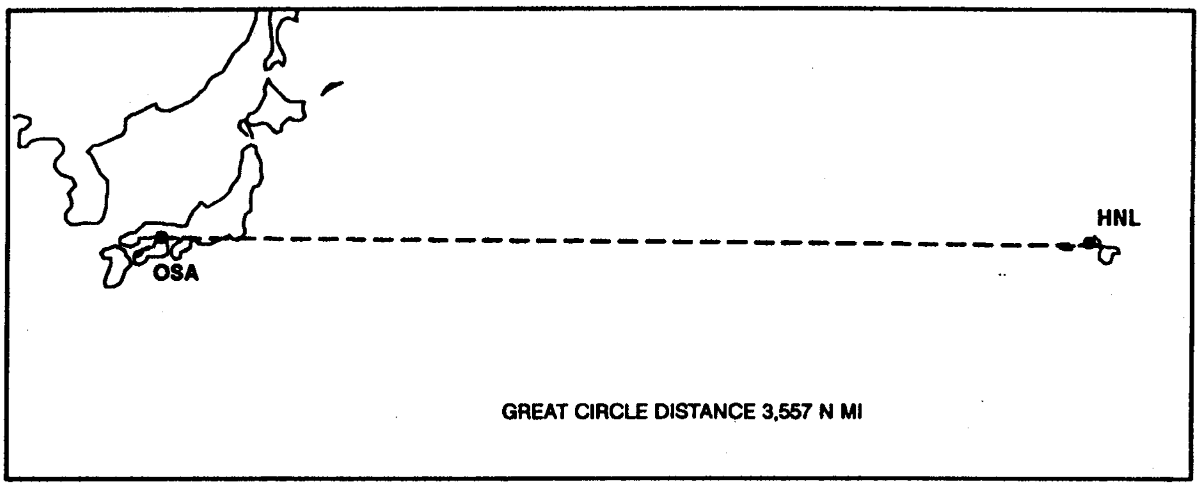
FIGURE B-15. HSCT ROUTE CHART FOR BRU-JFK

LRC018-B



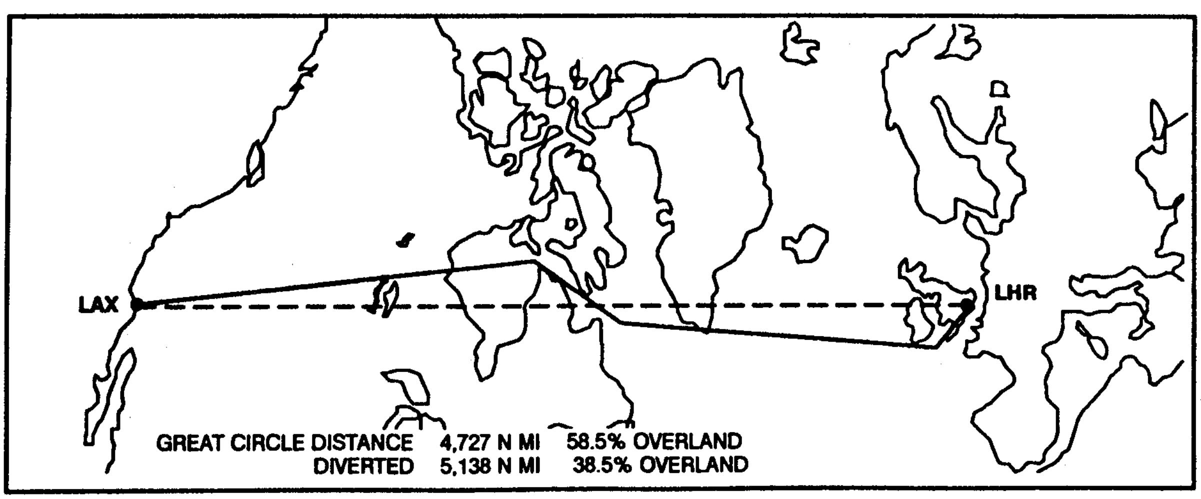
LRC012-130

FIGURE B-16. HSCT ROUTE CHART FOR NRT-SVO



LRC012-131

FIGURE B-17. HSCT ROUTE CHART FOR HNL-OSA



LRC012-132

FIGURE B-18. HSCT ROUTE CHART FOR LAX-LHR

LRC018-B

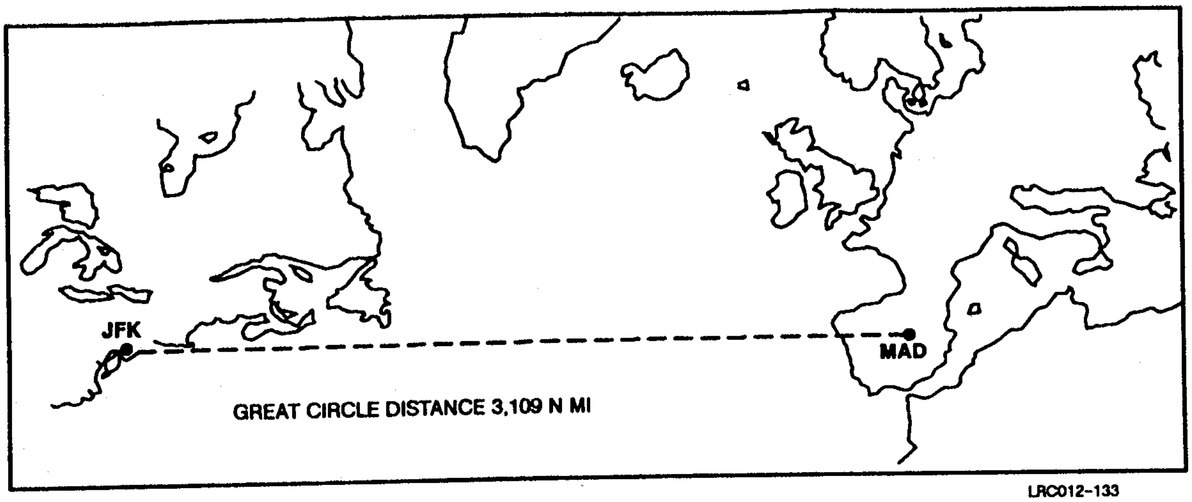


FIGURE B-19. HSCT ROUTE CHART FOR JFK-MAD

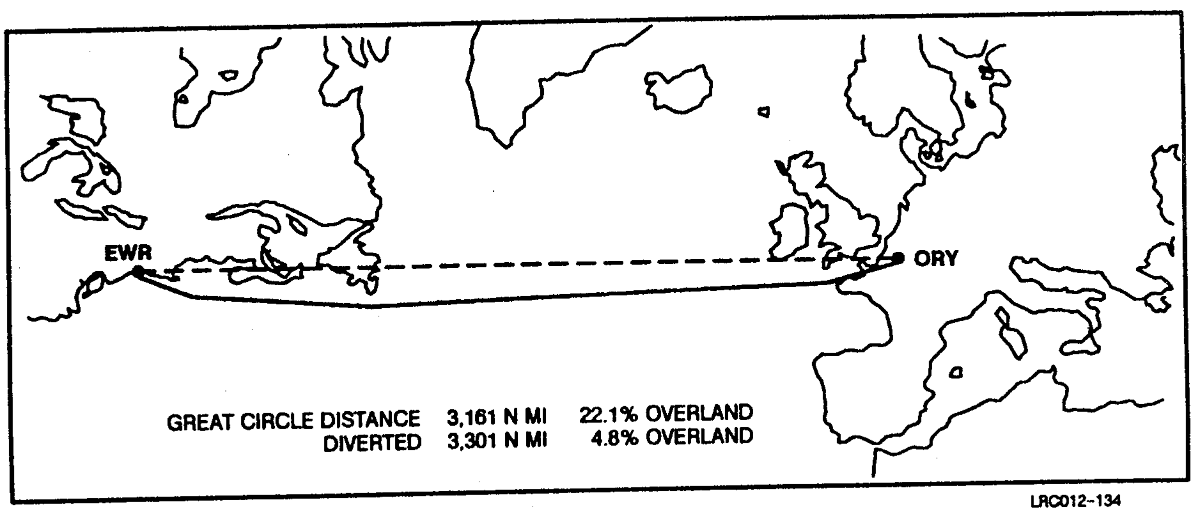


FIGURE B-20. HSCT ROUTE CHART FOR EWR-ORY

LRC018-B

APPENDIX C

GROUND TRACK PROFILE DISPLAY

250 CITY-PAIRS

LRC018-82

#	AIRPORT CODES	IATA CODE	RT TYP	DIST (SM)	GC Range (N.Mi.)	Overland Dist	Overland %	Diverted Range	Overlan Dist	Overlan %	Cum %	Ground Track Length % 0 10 20 30 40 50 60 70 80 90 100
1	HNL-LAX*	12	1	2551	2217	0	0.0	2217	0	0.0	0.00	
2	HNL-NRT*	10	1	3813	3314	0	0.0	3314	0	0.0	0.00	
3	HNL-SFO*	12	1	2394	2080	0	0.0	2080	0	0.0	0.00	
4	LAX-NRT*	10	1	5440	4727	0	0.0	4727	0	0.0	0.00	
5	NRT-SFO*	10	1	5112	4441	0	0.0	4441	0	0.0	0.00	
6	NRT-SIN*	18	1	3324	2889	0	0.0	2889	0	0.0	0.00	
7	SIN-SYD*	18	1	3908	3360	1892	56.3	5364	0	0.0	0.00	
8	SIN-TPE*	18	1	2012	1748	0	0.0	1748	0	0.0	0.00	
9	HNL-SEL*	10	1	4538	3944	181	4.6	4592	0	0.0	0.00	
10	AKL-HNL*	11	1	4403	3826	0	0.0	3826	0	0.0	0.00	
11	HNL-SYD*	11	1	5074	4409	66	1.5	4416	0	0.0	0.00	
12	LAX-SEL*	10	1	5956	5175	0	0.0	5175	0	0.0	0.00	
13	BKK-SYD*	18	1	4684	4070	2389	58.7	5649	0	0.0	0.00	
14	HKG-SFO*	10	1	6898	5994	851	14.2	6181	0	0.0	0.00	
15	LAX-SYD*	11	1	7490	6508	0	0.0	6508	0	0.0	0.00	
16	GIG-JFK*	1	1	4800	4171	1852	44.4	4796	0	0.0	0.00	
17	LAX-OGG	12	1	2481	2156	0	0.0	2156	0	0.0	0.00	
18	PER-SYD*	18	1	2035	1768	1360	76.9	2302	0	0.0	0.00	
19	BGI-JFK*	2	1	2091	1816	0	0.0	1816	0	0.0	0.00	
20	CCS-JFK*	1	1	2115	1837	0	0.0	1837	0	0.0	0.00	
21	OSA-SIN*	18	1	3069	2667	0	0.0	2667	0	0.0	0.00	
22	OGG-SFO	12	1	2335	2029	0	0.0	2029	0	0.0	0.00	
23	BOM-SIN*	18	1	2435	2115	632	29.9	3601	0	0.0	0.00	
24	HNL-MNL*	10	1	5290	4597	0	0.0	4597	0	0.0	0.00	
25	JFK-LIS*	3	1	3357	2917	0	0.0	2917	0	0.0	0.00	
26	AKL-LAX*	11	1	6512	5685	0	0.0	5685	0	0.0	0.00	
27	HKG-SEA*	10	1	6474	5588	1743	31.2	5907	0	0.0	0.00	
28	GUM-HNL*	10	1	3797	3300	0	0.0	3300	0	0.0	0.00	
29	BOS-SNN*	3	1	2885	2507	521	20.8	2548	0	0.0	0.00	
30	SEA-SEL	10	1	5180	4501	900	20.0	4566	0	0.0	0.00	
31	HNL-NAN*	11	1	3171	2755	0	0.0	2755	0	0.0	0.00	
32	CGK-NRT	18	1	3623	3148	466	14.8	3245	0	0.0	0.00	
33	KUL-MEL	18	1	3946	3429	2500	72.9	4782	0	0.0	0.00	
34	SFO-TPE*	10	1	6439	5596	716	12.8	5633	0	0.0	0.00	
35	AKL-SIN*	18	1	5222	4556	1904	41.8	4867	0	0.0	0.00	
36	MEL-NAN*	18	1	2401	2086	309	14.8	2255	0	0.0	0.00	
37	HKG-SYD	18	1	4581	3983	2410	60.5	4497	0	0.0	0.00	
38	AMS-AUA*	4	1	4893	4252	272	6.4	4278	0	0.0	0.00	
39	AMS-IAH*	3	1	4998	4343	2662	61.3	5055	0	0.0	0.00	
40	CNS-NRT*	18	1	3653	3174	225	7.1	3435	0	0.0	0.00	
41	AKL-NRT*	18	1	5490	4771	0	0.0	4771	0	0.0	0.00	
42	KUL-NRT*	18	1	3337	2900	0	0.0	2900	0	0.0	0.00	
43	HNL-SAN	12	1	2609	2267	0	0.0	2267	0	0.0	0.00	
44	FCO-GIG*	5	1	5694	4984	2367	47.5	5330	0	0.0	0.00	
45	HNL-SJC	12	1	2413	2096	0	0.0	2096	0	0.0	0.00	
46	HNL-NGO	10	1	4006	3481	0	0.0	3481	0	0.0	0.00	
47	BOS-GLA*	3	1	3020	2624	585	22.3	2693	0	0.0	0.00	
48	AMS-BOS*	3	1	3445	2993	1266	42.3	3141	0	0.0	0.00	
49	HND-HNL	10	1	3845	3983	0	0.0	3983	0	0.0	0.00	
50	LAX-PPT*	11	1	4105	3569	0	0.0	3569	0	0.0	0.00	
52	BNE-NRT*	18	1	4472	3886	323	8.3	3940	0	0.0	0.00	
51	PDX-SEL	10	1	5252	4564	393	8.6	4606	0	0.0	0.00	
53	NRT-PDX	10	1	4810	4180	0	0.0	4180	0	0.0	0.00	
54	DPS-MEL*	18	1	2726	2262	1421	62.8	3134	0	0.0	0.00	
55	JFK-KEF*	3	1	2586	2247	1038	46.2	2451	0	0.0	0.00	

#	AIRPORT CODES	IATA CODE	RT TYP	DIST (SM)	GC Range (N.Mi.)	Overland Dist	Overland %	Diverted Range	Dist	Overlan %	Cum %	Ground Track Length % 0 10 20 30 40 50 60 70 80 90 100
56	NRT-SYD*	18	1	4863	4226	1040	24.6	4388	22	0.5	0.04	|....|....|....|....|....|....|....|....|....|....|
57	BKK-NRT*	18	1	2881	2503	1695	67.7	3056	31	1.0	0.10	*....|....|....|....|....|....|....|....|....|....*
58	AMS-JFK*	3	1	3632	3156	814	25.8	3353	34	1.0	0.15	|....|....|....|....|....|....|....|....|....|....*
59	JFK-TLV*	3	1	5663	4921	2746	55.8	5178	52	1.0	0.23	|....|....|....|....|....|....|....|....|....|....*
60	JFK-SNN*	3	1	3072	2669	544	20.4	2716	27	1.0	0.26	|....|....|....|....|....|....|....|....|....|....*
61	LAX-TPE*	10	1	6770	5883	682	11.6	5898	59	1.0	0.32	*....|....|....|....|....|....|....|....|....|....|
62	LHR-MIA*	4	1	4414	3836	361	9.4	3842	85	2.2	0.42	*....|....|....|....|....|....|....|....|....|....|
63	JFK-MAN*	3	1	3330	2894	1210	41.8	3030	70	2.3	0.50	|....|....|....|....|....|....|....|....|....|....*
64	BKK-SEL*	18	1	2294	1994	1603	80.4	2816	68	2.4	0.56	*....|....|....|....|....|....|....|....|....|....*
65	CMB-DXB*	19	1	2043	1776	455	25.6	1897	46	2.4	0.61	|....|....|....|....|....|....|....|....|....|....*
66	BOS-LHR*	3	1	3254	2827	591	20.9	2956	74	2.5	0.67	|....|....|....|....|....|....|....|....|....|...**
67	NRT-SEA*	10	1	4757	4133	174	4.2	4144	108	2.6	0.76	|....|....|....|....|....|....|....|....|....|....*
68	DXB-KUL*	19	1	3434	2984	534	17.9	3340	87	2.6	0.83	*....|....|....|....|....|....|....|....|....|....*
69	GIG-MIA*	1	2	4172	3625	2708	74.7	4149	116	2.8	0.92	|....|....|*...|....|....|....|....|....|....|....|
70	HNL-SEA*	12	1	2675	2325	72	3.1	2325	72	3.1	0.97	|....|....|....|....|....|....|....|....|....|...**
71	BRU-JFK*	3	1	3655	3176	794	25.0	3338	107	3.2	1.04	**...|....|....|....|....|....|....|....|....|....|
72	AUH-SIN	19	1	3672	3190	935	29.3	3486	112	3.2	1.11	**...|....|....|....|....|....|....|....|....|....|
73	EWR-LHR*	3	1	3454	3002	1324	44.1	3070	98	3.2	1.17	|....|....|....|....|....|....|....|....|....|...**
74	BOS-LGW*	3	1	3272	2843	847	29.8	2889	95	3.3	1.23	|....|....|....|....|....|....|....|....|....|...**
75	BOS-BRU*	3	1	3468	3013	1338	44.4	3097	111	3.6	1.29	|....|....|....|....|....|....|....|....|....|...**
76	HKG-YVR*	10	1	6368	5534	2308	41.7	5832	216	3.7	1.41	|....|....|....|....|....|....|....|....|....|...**
77	MIA-SCL*	1	2	4146	3603	1802	50.0	3945	150	3.8	1.49	|....|....|**..|....|....|....|....|....|....|....|
78	ANC-SFO	12	1	2014	1750	67	3.8	1750	67	3.8	1.52	**...|....|....|....|....|....|....|....|....|....|
79	ATH-JFK*	3	2	4919	4274	1607	37.6	4889	220	4.5	1.63	|....**...|....|....|....|....|....|....|....|....|
80	CDG-JFK*	3	1	3623	3148	762	24.2	3194	147	4.6	1.70	***..|....|....|....|....|....|....|....|....|....|
81	EWR-LGW*	3	1	3472	3018	803	26.6	3183	146	4.6	1.77	|....|....|....|....|....|....|....|....|....|...**
82	AMS-ATL*	3	1	4388	3812	1395	36.6	4157	191	4.6	1.85	|....|....|....|....|....|....|....|....|....|....*
83	CDG-MIA*	4	1	4577	3977	183	4.6	3977	183	4.6	1.93	***..|....|....|....|....|....|....|....|....|....|
84	EZE-MAD*	5	1	6257	5437	2409	44.3	5712	263	4.6	2.03	|....|....|....|....|....|....|....|....|....|..***
85	GUA-LAX*	2	1	2193	1905	1905	100.0	2111	99	4.7	2.07	**...|....|....|....|....|....|....|....|....|....|
86	EWR-ORY*	3	1	3638	3161	699	22.1	3301	158	4.8	2.12	|....|....|....|....|....|....|....|....|....|...**
87	GIG-MAD*	5	1	5058	4396	725	16.5	4444	213	4.8	2.20	|....|....|....|....|....|....|....|....|....|..***
88	LGW-MIA*	4	1	4429	3849	362	9.4	3859	185	4.8	2.26	***..|....|....|....|....|....|....|....|....|....|
89	JFK-MEX*	2	2	2090	1816	1115	61.4	2022	99	4.9	2.29	|....|....|....|....**...|....|....|....|....|..***
90	CPH-JFK*	3	1	3843	3340	792	23.7	3451	169	4.9	2.34	***..|....|....|....|....|....|....|....|....|....|
91	NRT-YVR*	10	1	4663	4052	288	7.1	4069	208	5.1	2.41	|....|....|....|....|....|....|....|....|....|..***
92	AUH-CGK	19	1	4101	3563	1290	36.2	3689	192	5.2	2.47	**...|....|....|....|....|....|....|....|....|....*
93	IAH-LGW*	3	1	4840	4210	2404	57.1	4826	256	5.3	2.54	|....|....|....|....|....|....|....|....|....|..***
94	GIG-LHR*	5	1	5746	4893	1316	26.9	5062	268	5.3	2.62	|....|....|....|....|....|....|....|....|....|.****
95	JFK-ORY*	3	1	3623	3148	711	22.6	3181	172	5.4	2.66	|....|....|....|....|....|....|....|....|....|..***
96	BOS-CDG*	3	1	3436	2967	629	21.2	3022	169	5.6	2.71	|....|....|....|....|....|....|....|....|....|..***
97	FCO-JFK*	3	2	4264	3705	1041	28.1	3766	218	5.8	2.77	|....|***.|....|....|....|....|....|....|....|....|
98	FRA-GIG*	5	1	5942	5164	1513	29.3	5370	311	5.8	2.85	***..|....|....|....|....|....|....|....|....|....|
99	MAD-MIA*	4	1	4413	3834	238	6.2	3834	238	6.2	2.91	***..|....|....|....|....|....|....|....|....|....|
100	LHR-PHL*	3	1	3533	3070	1461	47.6	3145	198	6.3	2.96	**...|....|....|....|....|....|....|....|....|....*
101	BCN-JFK*	3	1	3820	3319	461	13.9	3458	218	6.3	3.02	***..|....|....|....|....|....|....|....|....|....|
102	AMS-PBM*	4	1	4674	4061	256	6.3	4061	256	6.3	3.08	***..|....|....|....|....|....|....|....|....|....|
103	DUS-JFK	3	1	3736	3247	1555	47.9	3364	212	6.3	3.13	***..|....|....|....|....|....|....|....|....|....|
104	CCS-MAD*	4	1	4349	3779	242	6.4	3779	242	6.4	3.18	|....|....|....|....|....|....|....|....|....|..***
105	FRA-MIA*	4	1	4820	4188	725	17.3	4210	274	6.5	3.24	***..|....|....|....|....|....|....|....|....|....|
106	BKK-OSA*	18	1	2601	2264	1598	70.6	2789	181	6.5	3.28	**...|....|....|....|....|....|....|....|....|..***
107	HAV-YQX	2	1	2345	2037	139	6.8	2037	139	6.8	3.31	|....|....|....|....|....|....|....|....|....|..***
108	ATL-LGW*	3	1	4216	3664	1718	46.9	3826	264	6.9	3.37	**...|....|....|....|....|....|....|....|....|....*
109	LIM-MIA*	1	2	2620	2277	1025	45.0	2647	183	6.9	3.41	*....|....|...***...|....|....|....|....|....|....|
110	MAD-MEX*	4	1	5631	4893	499	10.2	4970	353	7.1	3.48	***..|....|....|....|....|....|....|....|....|...**

#	AIRPORT CODES	IATA CODE	RT TYP	DIST (SM)	GC Range (N.Mi.)	Overland Dist	Overland %	Diverted Range	Overlan Dist	Overlan %	Cum %	Ground Track Length % (0 10 20 30 40 50 60 70 80 90 100)
111	FDF-ORY*	4	1	4255	3697	262	7.1	3697	262	7.1	3.54	|....|....|....|....|....|....|....|....|....|.****
112	JFK-LHR*	3	1	3441	2990	831	27.8	3076	221	7.2	3.58	**...|....|....|....|....|....|....|....|....|...**
113	JFK-LGW*	3	1	3459	2996	833	27.8	3082	222	7.2	3.63	**...|....|....|....|....|....|....|....|....|...**
114	FRA-JFK*	3	1	3844	3340	1069	32.0	3420	250	7.3	3.68	***..|....|....|....|....|....|....|....|....|....*
115	OSA-SFO	10	1	5374	3643	270	7.4	3643	270	7.4	3.73	****.|....|....|....|....|....|....|....|....|....|
116	HNL-OSA*	10	1	4093	3557	263	7.4	3557	263	7.4	3.78	|....|....|....|....|....|....|....|....|....|..***
117	AMS-YMX*	3	1	3429	2979	1341	45.0	3312	255	7.7	3.82	|....|....|....|....|....|....|....|....|....|.****
118	ORY-PTP	4	1	4193	4670	369	7.9	4670	369	7.9	3.89	****.|....|....|....|....|....|....|....|....|....|
119	BOS-FRA*	3	1	3657	3178	953	30.0	3312	265	8.0	3.94	|....|....|....|....|....|....|....|....|....|.****
120	JFK-MAD*	3	1	3578	3109	255	8.2	3109	255	8.2	3.99	|....|....|....|....|....|....|....|....|....|.****
121	CDG-FDF*	4	1	4266	3707	308	8.3	3707	308	8.3	4.05	****.|....|....|....|....|....|....|....|....|....|
122	ANC-NRT*	10	1	3426	2977	444	14.9	3031	255	8.4	4.09	****.|....|....|....|....|....|....|....|....|....|
123	MAD-SDQ*	4	1	4154	3609	303	8.4	3609	303	8.4	4.15	*****|....|....|....|....|....|....|....|....|....|
124	CDG-PTP*	4	1	4204	3653	321	8.8	3653	321	8.8	4.21	*****|....|....|....|....|....|....|....|....|....|
125	CDG-IAD*	3	1	3848	3344	883	26.4	3376	300	8.9	4.26	**...|....|....|....|....|....|....|....|....|..***
126	FRA-IAD*	3	1	4067	3534	1428	40.4	3619	362	10.0	4.33	***..|....|....|....|....|....|....|....|....|...**
127	IAD-LHR*	3	1	3665	3185	1271	39.9	3260	339	10.4	4.39	**...|....|....|....|....|....|....|....|....|..***
128	BOS-ZRH*	3	1	3732	3243	1281	39.5	3290	345	10.5	4.46	|....|....|....|....|....|....|....|....|....******
129	BRU-YMX*	3	1	3461	3007	1320	43.9	3269	350	10.7	4.52	**...|....|....|....|....|....|....|....|....|.****
130	ANC-SEL*	10	1	3769	3275	874	26.7	3417	372	10.9	4.59	****.|....|....|....|....|....|....|....|....|....*
131	HNL-LAS*	12	1	2757	2395	266	11.1	2395	266	11.1	4.64	|....|....|....|....|....|....|....|....|....******
132	ARN-JFK*	3	1	3908	3382	1383	40.9	3536	392	11.1	4.71	*****|....|....|....|....|....|....|....|....|....|
133	HNL-PHX	12	1	2910	2529	281	11.1	2529	281	11.1	4.76	|....|....|....|....|....|....|....|........*******
134	ATL-FRA*	3	1	4600	3998	1915	47.9	4179	485	11.6	4.85	**...|....|....|....|....|....|....|....|....|.****
135	CVG-LGW	3	1	3969	3450	1846	53.5	3653	424	11.6	4.93	******....|....|....|....|....|....|....|....|....*
136	LHR-YMX*	3	1	3251	2825	1212	42.9	3200	384	12.0	4.99	***..|....|....|....|....|....|....|....|....|..***
137	AMS-YYZ*	3	1	3720	3232	1587	49.1	3625	442	12.2	5.07	|....|....|....|....|....|....|....|.......********
138	CPH-SEA*	3	2	4849	4214	2748	65.2	5074	624	12.3	5.18	**...|....|....|....|....|....|....****.|....|....*
139	CDG-YMX*	3	1	3444	2993	1116	37.3	3203	400	12.5	5.25	***..|....|....|....|....|....|....|....|....|.****
140	GVA-JFK*	3	1	3852	3347	1406	42.0	3377	422	12.5	5.32	*******...|....|....|....|....|....|....|....|....|
141	DFW-SJU*	2	1	2163	1879	586	31.2	1941	247	12.7	5.36	*******...|....|....|....|....|....|....|....|....|
142	LHR-NRT*	9	2	5954	5147	3829	74.4	5880	759	12.9	5.48	*....|....|....|....|....|....|.*****...|....|....*
143	JFK-WAW*	3	1	4253	3695	1655	44.8	3828	532	13.9	5.57	|....|....|....|....|....|....|....|....|..********
144	FRA-YMX*	3	1	3647	3169	1534	48.4	3425	493	14.4	5.65	****.|....|....|....|....|....|....|....|....|....|
145	PER-SIN*	18	1	2428	2110	306	14.5	2110	306	14.5	5.71	*******...|....|....|....|....|....|....|....|....|
146	ATL-MUC	3	1	4786	4159	2583	62.1	4376	639	14.6	5.81	***..|....|....|....|....|....|....|....|....|*****
147	FRA-YYZ*	3	1	3939	3423	1089	31.8	3699	544	14.7	5.90	***..|....|....|....|....|....|....|....|....|.****
148	HEL-JFK*	3	1	4103	3566	1562	43.8	3746	566	15.1	5.99	********..|....|....|....|....|....|....|....|....|
149	LGW-NRT	9	2	5967	5149	4289	83.3	5448	844	15.5	6.13	*....|....|....|....|....|....|...******|....|....*
150	AMS-ORD	3	1	4106	3568	1745	48.9	4028	628	15.6	6.22	********..|....|....|....|....|....|....|....|....|
151	JFK-MXP*	3	1	3983	3460	1059	30.6	3488	551	15.8	6.31	|....|....|....|....|....|....|....|....|..********
152	ATH-SIN	9	2	5626	4889	3545	72.5	5232	832	15.9	6.44	|....|.*******.|...*|....|....|....|....|....|....|
153	JFK-MUC*	3	1	4028	3501	1390	39.7	3549	568	16.0	6.52	********..|....|....|....|....|....|....|....|....|
154	CVG-FRA	3	1	4347	3778	2059	54.5	4194	688	16.4	6.62	******....|....|....|....|....|....|....|....|..***
155	EZE-MIA*	1	2	4409	3831	2984	77.9	4137	691	16.7	6.73	********..|....|....|....|....|....|..*.|....|*...|
156	FRA-NRT*	9	2	5814	5053	4073	80.6	5211	917	17.6	6.86	*....|....|....|....|....|....|.********|....|....*
157	CVG-ORY*	3	1	4144	3601	1426	39.6	3700	651	17.6	6.96	********..|....|....|....|....|....|....|....|...**
158	DTW-NRT	10	2	6380	5544	3321	59.9	6083	1077	17.7	7.11	*****|....|..*****..|....|....|....|....|....|....|
159	DTW-SEL	10	2	6603	5737	4211	73.4	6314	1124	17.8	7.27	*****|....|..*****..|....|....|....|....|....|....|
160	LGW-MSP	3	1	4022	3495	1754	50.2	3942	706	17.9	7.37	|....|....|....|....|....|....|....|....|**********
161	CDG-DTW	3	1	3948	3431	1791	52.2	3575	651	18.2	7.46	********..|....|....|....|....|....|....|....|...**
162	JFK-ZRH*	3	1	3919	3405	1611	47.3	3441	630	18.3	7.54	|....|....|....|....|....|....|....|....|.*********
163	BOG-JFK	1	1	2481	2156	395	18.3	2156	395	18.3	7.59	**********|....|....|....|....|....|....|....|....|
164	BRU-ORD*	3	1	4145	3602	1740	48.3	3966	738	18.6	7.69	**...|....|....|....|....|....|....|....|..********
165	LGW-YYZ*	3	1	3564	3097	1505	48.6	3347	653	19.5	7.78	***..|....|....|....|....|....|....|....|..********

Configuration: Mach 3.2-Subsonic Overland, 6Hr Curfew, 2hr Turnaround.

<table>
<tr><th>#</th><th>AIRPORT CODES</th><th>IATA CODE</th><th>RT TYP</th><th>DIST (SM)</th><th>GC Range (N.Mi.)</th><th>Overland Dist</th><th>Overland %</th><th>Diverted Range</th><th>Diverted Dist</th><th>Overlan %</th><th>Cum %</th><th>Ground Track Length % (0 10 20 30 40 50 60 70 80 90 100)</th></tr>
<tr><td>166</td><td>JFK-NRT*</td><td>10</td><td>2</td><td>6727</td><td>5845</td><td>4185</td><td>71.6</td><td>6072</td><td>1190</td><td>19.6</td><td>7.94</td><td>******....|****|....|....|....|....|....|....|....|</td></tr>
<tr><td>167</td><td>CDG-NRT*</td><td>9</td><td>2</td><td>6027</td><td>5237</td><td>4509</td><td>86.1</td><td>5607</td><td>1110</td><td>19.8</td><td>8.08</td><td>*....|....|....|....|....|....********..|....|...**</td></tr>
<tr><td>168</td><td>IAD-NRT</td><td>10</td><td>2</td><td>6736</td><td>5853</td><td>4624</td><td>79.0</td><td>6171</td><td>1271</td><td>20.6</td><td>8.25</td><td>******....|..****..|....|....|....|....|....|....|....|</td></tr>
<tr><td>169</td><td>DTW-FRA</td><td>3</td><td>1</td><td>4147</td><td>3604</td><td>1971</td><td>54.7</td><td>3802</td><td>810</td><td>21.3</td><td>8.35</td><td>********..|....|....|....|....|....|....|....|....|</td></tr>
<tr><td>170</td><td>JFK-SVO</td><td>3</td><td>1</td><td>4646</td><td>4037</td><td>2176</td><td>53.9</td><td>4198</td><td>924</td><td>22.0</td><td>8.47</td><td>************...|....|....|....|....|....|....|....|</td></tr>
<tr><td>171</td><td>DUS-ORD*</td><td>3</td><td>1</td><td>4214</td><td>3663</td><td>1648</td><td>45.0</td><td>3988</td><td>897</td><td>22.5</td><td>8.59</td><td>**...|....|....|....|....|....|....|....|.*********</td></tr>
<tr><td>172</td><td>DFW-FRA*</td><td>3</td><td>1</td><td>5125</td><td>4453</td><td>2672</td><td>60.0</td><td>4807</td><td>1139</td><td>23.7</td><td>8.74</td><td>*********.|....|....|....|....|....|....|....|..***</td></tr>
<tr><td>173</td><td>CDG-TLV*</td><td>8</td><td>1</td><td>2041</td><td>1773</td><td>1183</td><td>66.7</td><td>1859</td><td>446</td><td>24.0</td><td>8.80</td><td>************...|....|....|....|....|....|....|....|</td></tr>
<tr><td>174</td><td>LHR-YYZ*</td><td>3</td><td>1</td><td>3544</td><td>3079</td><td>1512</td><td>49.1</td><td>3341</td><td>809</td><td>24.2</td><td>8.90</td><td>***..|....|....|....|....|....|....|....|**********</td></tr>
<tr><td>175</td><td>JFK-VIE*</td><td>3</td><td>1</td><td>4224</td><td>3670</td><td>2007</td><td>54.7</td><td>3736</td><td>919</td><td>24.6</td><td>9.02</td><td>|....|....|....|....|....|....|....|...************</td></tr>
<tr><td>176</td><td>FRA-YVR</td><td>3</td><td>1</td><td>5007</td><td>4351</td><td>3263</td><td>75.0</td><td>4671</td><td>1224</td><td>26.2</td><td>9.18</td><td>*....|....|....|....|....|....|....|..*************</td></tr>
<tr><td>177</td><td>JIB-RUN</td><td>16</td><td>1</td><td>2392</td><td>2078</td><td>547</td><td>26.3</td><td>2078</td><td>547</td><td>26.3</td><td>9.25</td><td>**************.|....|....|....|....|....|....|....|</td></tr>
<tr><td>178</td><td>LHR-SEA</td><td>3</td><td>1</td><td>4783</td><td>4156</td><td>3051</td><td>73.4</td><td>4746</td><td>1253</td><td>26.4</td><td>9.41</td><td>*....|....|....|....|....|....|....|..*************</td></tr>
<tr><td>179</td><td>FRA-ORD*</td><td>3</td><td>1</td><td>4328</td><td>3761</td><td>1809</td><td>48.1</td><td>4055</td><td>1087</td><td>26.8</td><td>9.55</td><td>****.|....|....|....|....|....|....|....|**********</td></tr>
<tr><td>180</td><td>LHR-TLV*</td><td>8</td><td>1</td><td>2229</td><td>1937</td><td>1395</td><td>72.0</td><td>2383</td><td>670</td><td>28.1</td><td>9.64</td><td>*************..|....|....|....|....|....|....|....|</td></tr>
<tr><td>181</td><td>AMS-LAX</td><td>3</td><td>1</td><td>5562</td><td>4833</td><td>3025</td><td>62.6</td><td>5111</td><td>1452</td><td>28.4</td><td>9.83</td><td>***************|....|....|....|....|....|....|....|</td></tr>
<tr><td>182</td><td>DEN-HNL</td><td>12</td><td>1</td><td>3347</td><td>2908</td><td>846</td><td>29.1</td><td>2908</td><td>846</td><td>29.1</td><td>9.93</td><td>***************|....|....|....|....|....|....|.****</td></tr>
<tr><td>183</td><td>ORD-ZRH*</td><td>3</td><td>1</td><td>4428</td><td>3848</td><td>2213</td><td>57.5</td><td>4073</td><td>1250</td><td>30.7</td><td>10.10</td><td>***********....|....|....|....|....|....|....|*****</td></tr>
<tr><td>184</td><td>LHR-ORD*</td><td>3</td><td>1</td><td>3939</td><td>3423</td><td>1807</td><td>52.8</td><td>3702</td><td>1140</td><td>30.8</td><td>10.24</td><td>**...|....|....|....|....|....|....|...************</td></tr>
<tr><td>185</td><td>DFW-HNL*</td><td>12</td><td>1</td><td>3776</td><td>3281</td><td>1014</td><td>30.9</td><td>3281</td><td>1014</td><td>30.9</td><td>10.37</td><td>****************...|....|....|....|....|....|....|</td></tr>
<tr><td>186</td><td>LCA-LHR*</td><td>8</td><td>1</td><td>2035</td><td>1768</td><td>1660</td><td>93.9</td><td>2296</td><td>709</td><td>30.9</td><td>10.46</td><td>****************...|....|....|....|....|....|....|</td></tr>
<tr><td>187</td><td>NRT-ORD*</td><td>10</td><td>1</td><td>6257</td><td>5437</td><td>2876</td><td>52.9</td><td>5537</td><td>1744</td><td>31.5</td><td>10.67</td><td>|....|....|....|....|....|....|..******************</td></tr>
<tr><td>188</td><td>DFW-LGW*</td><td>3</td><td>1</td><td>4754</td><td>4121</td><td>2415</td><td>58.6</td><td>4279</td><td>1356</td><td>31.7</td><td>10.84</td><td>**************.|....|....|....|....|....|....|...**</td></tr>
<tr><td>189</td><td>LHR-YVR*</td><td>3</td><td>1</td><td>4707</td><td>4090</td><td>2597</td><td>63.5</td><td>4512</td><td>1430</td><td>31.7</td><td>11.01</td><td>***..|....|....|....|....|....|....|.**************</td></tr>
<tr><td>190</td><td>HNL-IAH</td><td>12</td><td>1</td><td>3896</td><td>3385</td><td>1090</td><td>32.2</td><td>3385</td><td>1090</td><td>32.2</td><td>11.14</td><td>|....|....|....|....|....|....|...*****************</td></tr>
<tr><td>191</td><td>FRA-SFO</td><td>3</td><td>1</td><td>5681</td><td>4937</td><td>3767</td><td>76.3</td><td>5204</td><td>1681</td><td>32.3</td><td>11.34</td><td>*....|....|....|....|....|....|....|***************</td></tr>
<tr><td>192</td><td>DUS-LAX</td><td>3</td><td>1</td><td>5671</td><td>4929</td><td>3283</td><td>66.6</td><td>5201</td><td>1774</td><td>34.1</td><td>11.55</td><td>**...|....|....|....|....|....|....|***************</td></tr>
<tr><td>193</td><td>CDG-LAX</td><td>3</td><td>1</td><td>5652</td><td>4912</td><td>2869</td><td>58.4</td><td>5132</td><td>1842</td><td>35.9</td><td>11.77</td><td>*****************...|....|....|....|....|....|...**</td></tr>
<tr><td>194</td><td>ORD-SJU*</td><td>2</td><td>1</td><td>2072</td><td>1800</td><td>666</td><td>37.0</td><td>1800</td><td>666</td><td>37.0</td><td>11.85</td><td>***********************..|....|....|....|....|....|</td></tr>
<tr><td>195</td><td>CAI-LHR</td><td>8</td><td>1</td><td>2192</td><td>1887</td><td>1408</td><td>74.6</td><td>1954</td><td>723</td><td>37.0</td><td>11.94</td><td>****************....|....|....|....|....|..***</td></tr>
<tr><td>196</td><td>CAI-LGW</td><td>8</td><td>1</td><td>2171</td><td>1905</td><td>1372</td><td>72.0</td><td>1972</td><td>730</td><td>37.0</td><td>12.03</td><td>****************....|....|....|....|....|..***</td></tr>
<tr><td>197</td><td>LAX-LHR*</td><td>3</td><td>1</td><td>5440</td><td>4727</td><td>2765</td><td>58.5</td><td>5138</td><td>1978</td><td>38.5</td><td>12.26</td><td>****************....|....|....|....|....|*****</td></tr>
<tr><td>198</td><td>LAX-LGW*</td><td>3</td><td>1</td><td>5463</td><td>4747</td><td>2777</td><td>58.5</td><td>5138</td><td>1978</td><td>38.5</td><td>12.49</td><td>****************....|....|....|....|....|*****</td></tr>
<tr><td>199</td><td>LHR-SFO*</td><td>3</td><td>1</td><td>5351</td><td>4650</td><td>2646</td><td>56.9</td><td>5040</td><td>2016</td><td>40.0</td><td>12.73</td><td>***..|....|....|....|....|....|..*******************</td></tr>
<tr><td>200</td><td>HNL-STL</td><td>12</td><td>1</td><td>4120</td><td>3580</td><td>1475</td><td>41.2</td><td>3580</td><td>1475</td><td>41.2</td><td>12.90</td><td>|....|....|....|....|....|...**********************</td></tr>
<tr><td>201</td><td>HKG-MEL</td><td>18</td><td>1</td><td>4601</td><td>3998</td><td>1675</td><td>41.9</td><td>3998</td><td>1675</td><td>41.9</td><td>13.10</td><td>|....|....|....|....|....|...**********************</td></tr>
<tr><td>202</td><td>HNL-ORD*</td><td>12</td><td>1</td><td>4235</td><td>3680</td><td>1623</td><td>44.1</td><td>3680</td><td>1623</td><td>44.1</td><td>13.29</td><td>|....|....|....|....|...***************************</td></tr>
<tr><td>203</td><td>DEL-SIN</td><td>18</td><td>1</td><td>2582</td><td>2243</td><td>998</td><td>44.5</td><td>2243</td><td>998</td><td>44.5</td><td>13.41</td><td>****************....|....|....|....|.......********</td></tr>
<tr><td>204</td><td>KWI-LHR*</td><td>8</td><td>1</td><td>2897</td><td>2517</td><td>2361</td><td>93.8</td><td>2762</td><td>1304</td><td>47.2</td><td>13.56</td><td>************...|....|....|....|....|...************</td></tr>
<tr><td>205</td><td>BKK-DXB*</td><td>19</td><td>3</td><td>3032</td><td>2635</td><td>1415</td><td>53.7</td><td>2635</td><td>1415</td><td>53.7</td><td>13.73</td><td>*******...|....|..*****************|....|....|....*</td></tr>
<tr><td>206</td><td>MEL-SIN*</td><td>18</td><td>2</td><td>3752</td><td>3260</td><td>1757</td><td>53.9</td><td>3260</td><td>1757</td><td>53.9</td><td>13.95</td><td>**************************....|....|..*.|....|....|</td></tr>
<tr><td>207</td><td>JED-LHR</td><td>8</td><td>2</td><td>2960</td><td>2572</td><td>1422</td><td>55.3</td><td>2572</td><td>1422</td><td>55.3</td><td>14.12</td><td>|....******....|....|....|..**********************</td></tr>
<tr><td>208</td><td>BKK-KHI*</td><td>18</td><td>3</td><td>2299</td><td>1998</td><td>1451</td><td>72.6</td><td>1998</td><td>1451</td><td>72.6</td><td>14.31</td><td>*******...|....|....|*****************************</td></tr>
<tr><td>209</td><td>LHR-NBO</td><td>7</td><td>3</td><td>4248</td><td>3691</td><td>2776</td><td>75.2</td><td>3691</td><td>2776</td><td>75.2</td><td>14.68</td><td>*******...|..**********************************</td></tr>
<tr><td>210</td><td>LHR-SIN*</td><td>9</td><td>3</td><td>6757</td><td>5872</td><td>4886</td><td>83.2</td><td>5872</td><td>4886</td><td>83.2</td><td>15.32</td><td>**************************************...|....******</td></tr>
<tr><td>211</td><td>MNL-RUH</td><td>19</td><td>3</td><td>4831</td><td>4199</td><td>3578</td><td>85.2</td><td>4199</td><td>3578</td><td>85.2</td><td>15.79</td><td>|....|..***</td></tr>
<tr><td>212</td><td>NRT-SVO*</td><td>9</td><td>3</td><td>4659</td><td>4048</td><td>3663</td><td>90.5</td><td>4048</td><td>3663</td><td>90.5</td><td>16.27</td><td>**...|.**</td></tr>
<tr><td>213</td><td>BOM-LHR*</td><td>9</td><td>4</td><td>4479</td><td>3892</td><td>3892</td><td>100.0</td><td>3892</td><td>3892</td><td>100.0</td><td>16.78</td><td>***</td></tr>
<tr><td>214</td><td>FRA-HKG*</td><td>9</td><td>4</td><td>5694</td><td>4948</td><td>4948</td><td>100.0</td><td>4948</td><td>4948</td><td>100.0</td><td>17.43</td><td>***</td></tr>
<tr><td>215</td><td>BKK-FRA*</td><td>9</td><td>4</td><td>5570</td><td>4389</td><td>4389</td><td>100.0</td><td>4389</td><td>4389</td><td>100.0</td><td>17.99</td><td>***</td></tr>
<tr><td>216</td><td>BKK-LHR*</td><td>9</td><td>4</td><td>5928</td><td>5151</td><td>5151</td><td>100.0</td><td>5151</td><td>5151</td><td>100.0</td><td>18.64</td><td>***</td></tr>
<tr><td>217</td><td>DXB-LGW*</td><td>8</td><td>4</td><td>3397</td><td>2952</td><td>2952</td><td>100.0</td><td>2952</td><td>2952</td><td>100.0</td><td>19.01</td><td>***</td></tr>
<tr><td>218</td><td>DEL-FRA*</td><td>9</td><td>4</td><td>3801</td><td>3303</td><td>3303</td><td>100.0</td><td>3303</td><td>3303</td><td>100.0</td><td>19.42</td><td>***</td></tr>
<tr><td>219</td><td>DME-KHV*</td><td>9</td><td>4</td><td>3812</td><td>3312</td><td>3312</td><td>100.0</td><td>3312</td><td>3312</td><td>100.0</td><td>19.82</td><td>***</td></tr>
<tr><td>220</td><td>BKK-FCO*</td><td>9</td><td>4</td><td>5495</td><td>4775</td><td>4775</td><td>100.0</td><td>4775</td><td>4775</td><td>100.0</td><td>20.40</td><td>***</td></tr>
</table>

Secondary Sort: Seats   Configuration: Mach 3.2-Subsonic Overland, 6Hr Curfew, 2hr Turnaround.

Primary Sort: Overland %

HSCT Traffic Network: Top 250 Airport-Pairs By Seats

#	AIRPORT CODES	IATA CODE	RT TYP	DIST (SM)	GC Range (N.Mi.)	Overland Dist	Overland %	Diverted Range	Overlan Dist	Overlan %	Cum %	Ground Track Length % (0 10 20 30 40 50 60 70 80 90 100)
221	JNB-LHR*	7	4	5634	4896	4896	100.0	4896	4896	100.0	20.98	***
222	BAH-LHR*	8	4	3160	2746	2746	100.0	2746	2746	100.0	21.30	***
223	DXB-FRA*	8	4	3006	2612	2612	100.0	2612	2612	100.0	21.61	***
224	DEL-LHR*	9	4	4180	3632	3632	100.0	3632	3632	100.0	22.03	***
225	FRA-SIN	9	4	6383	5546	5546	100.0	5546	5546	100.0	22.66	***
226	HKG-LGW	9	4	5991	5206	5206	100.0	5206	5206	100.0	23.25	***
227	DME-IKT*	9	4	2604	2262	2262	100.0	2262	2262	100.0	23.50	***
228	BOM-FRA	9	4	4079	3545	3545	100.0	3545	3545	100.0	23.89	***
229	BKK-CPH*	9	4	5344	4644	4644	100.0	4644	4644	100.0	24.39	***
230	FRA-JNB	7	4	5396	4688	4688	100.0	4688	4688	100.0	24.90	***
232	BAH-HKG	19	4	3978	3457	3457	100.0	3457	3457	100.0	25.55	***
231	BAH-LGW	8	4	3144	2732	2732	100.0	2732	2732	100.0	25.19	***
233	BAH-FRA	8	4	2755	2394	2394	100.0	2394	2394	100.0	25.80	***
236	UUS-VKO	9	4	4146	3603	3603	100.0	3603	3603	100.0	26.70	***
235	KHV-VKO	9	4	3823	3322	3322	100.0	3322	3322	100.0	26.34	***
234	LED-TAS	9	4	2102	1827	1827	100.0	1827	1827	100.0	25.99	***
237	AMS-DXB	8	4	3208	2787	2787	100.0	2787	2787	100.0	26.99	***
238	PEK-SHJ	19	4	3609	3154	3154	100.0	3154	3154	100.0	27.30	***
239	FRA-PEK	9	4	4836	4202	4202	100.0	4202	4202	100.0	27.72	***
240	KHI-PEK	18	4	3003	2610	2610	100.0	2610	2610	100.0	27.98	***
242	UUD-VKO*	9	4	2758	2397	2397	100.0	2397	2397	100.0	28.46	***
241	DME-HTA*	9	4	2937	2552	2552	100.0	2552	2552	100.0	28.23	***
243	DXB-MNL	19	4	4290	3728	3728	100.0	3728	3728	100.0	28.82	***
244	DXB-ZRH	8	4	2959	2571	2571	100.0	2571	2571	100.0	29.06	***
245	HKG-LHR	9	4	5989	5204	5204	100.0	5204	5204	100.0	29.56	***
246	DXB-HKG	19	4	3694	3210	3210	100.0	3210	3210	100.0	29.86	***
247	AMS-DHA	8	4	2946	2560	2560	100.0	2560	2560	100.0	30.09	***
248	BOM-HKG	18	4	2670	2320	2320	100.0	2320	2320	100.0	30.31	***
249	LHR-RUH	8	4	3080	2676	2676	100.0	2676	2676	100.0	30.55	***
250	DEL-FCO	9	4	3685	3203	3203	100.0	3203	3203	100.0	30.84	***
251	KHG-SHA	18	4	2592	2252	2252	100.0	2252	2252	100.0	31.05	***
252	FRA-THR	8	4	2339	2033	2033	100.0	2033	2033	100.0	31.23	***
253	ABA-DME*	9	4	2094	1819	1819	100.0	1819	1819	100.0	31.39	
	Totals				891809	414266		932618	241813		25.93	
	Ratios							1.0457	0.5837			
									0.4162			

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13. ABSTRACT *(Maximum 200 words)*

This report contains the results of the Douglas Aircraft Company system studies related to High-Speed Civil Transports (HSCT's). The tasks were performed under an 18-month extension of NASA Langley Research Center Contract NAS1-18378.

The system studies were conducted to assess the emission impact of HSCT's at design Mach numbers ranging from 1.6 to 3.2. The tasks specifically addressed an HSCT market and economic assessment, development of supersonic route networks, and an atmospheric emissions scenario.

The general results indicated (1) market projections predict sufficient passenger traffic for the 2000 to 2025 time period to support a fleet of economically viable and environmentally compatible HSCT's; (2) the HSCT route structure to minimize supersonic overland traffic can be increased by innovative routing to avoid land masses; and (3) the atmospheric emission impact on ozone would be significantly lower for Mach 1.6 operations than for Mach 3.2 operations.

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