THE SST IN COMMERCIAL OPERATION

THE BOEING COMPANY COMMERCIAL AIRPLANE GROUP
SUPERSONIC TRANSPORT DIVISION

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May, 1969

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INTRODUCTION

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This document is a description of two recent studies of Supersonic Transport (SST) commercial operations in the 1980 decade.

The first of these is a comprehensive and detailed study, on a route by route basis, of the introduction of the SST to commercial service. It is based upon generally accepted airline traffic levels forecasted through 1990 by the FAA, Boeing and others; and associated traffic growth rates by major route. The basic traffic level forecasts are contained in the FAA "Economic Feasibility Reports" and "The SST Program and Related National Benefits" also available from the FAA/SST Project Office. In contrast with other studies, which have analyzed SST operation and economics assuming a static environment throughout the life of the program; the study reported herein emphasizes the early years of SST penetration of a market now dominated entirely by subsonic jets. The dynamics of SST introduction are simulated in considerable detail based upon the history of the introduction of subsonic jets into the market dominated by propeller airplanes. The analysis continued several years beyond the introductory period to illustrate the development of a long-term situation from the introductory period. This detailed study assumes no cost escalation.

This study is based on today's air route structure. The application of the SST to the route structure is illustrated in a large foldout map inside the back cover of this document. New major SST international airports and routes will undoubtedly be added to accommodate the projected increases in traffic. Some of the possible new SST international terminals are also indicated on the map. The addition of these terminals and routes will make the SST travel more accessible and attractive to a large part of the free-world population than this current study would indicate.

The second study reported on is a projection of operating economics into the advanced time period (1980 decade) using historical escalation rates for each element of cost.

Both studies are predicated on the basis of no supersonic flight over land areas south of the Arctic Circle and no fare surcharge, although the effect on Return on Investment of a 10% increase is shown for comparison purposes.

SUMMARY

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Summary

There is a remarkable similarity between the commonly-held view of SST economics and the belief expressed in the early 1950's that the subsonic jet airplane would not be able to compete with piston engine and turbine-propeller airplanes. The jet transport promised more speed and airplane productivity than piston and turbo-prop types, but early studies projected its operating economics to be marginal or inferior. Developments of the past 15 years, however, have proved the decision to pursue the superior jet technology to have been a wise one. Jet transport speed, productivity, reliability, and economic return have far outstripped the potential of the other machines. Today, the SST faces the same challenge as the jet did two decades ago. It promises great increases in speed and productivity, but is commonly believed to have marginal or inferior operating economics.

A new comprehensive study for the 12-year period 1978 through 1989, drawing on the jet experience, shows that the economics of SST operation are attractive and that the airplane is competitive with even the new generation of large jets. The high speed combined with the large capacity of the SST promises high productivity, through carrying more paying passengers in a given period of time over the competitive routes of the world. Within the available subsonic fare options on these routes there will be ample opportunity to establish competitive and profitable SST passenger service. *The new study concludes that restriction of the SST to supersonic flying over water and unpopulated areas, will not impair the viability of the program; that a fleet of 500 airplanes operating in conjunction with subsonic jets is entirely feasible and advantageous; and that there is nothing in the technology of operating the currently defined SST in commercial service that will demand increases in the relative fare structure.*

The study focuses on conditions projected for the air transportation market in the 1980's rather than those existing today. This is the period in which the SST's will be current. With prototype construction beginning now, the time required for completion of the prototypes, flight testing, production, and airline introduction will reach into the late '70's and operational numbers will not be large until the '80's. By comparison, the first American jet transport prototype was started in 1952 and did not reach airline service until late 1958. Large increases in fleet numbers did not come until the mid and later 1960's. *In assessing program economics for such a major development, it is necessary to project both air transport market dimensions and operating cost considerations into a time period of from 10 to 20 years from start.*

Conditions validating the previously estimated 500-airplane market for the U.S. SST on international routes prior to 1990, and confirming the airplane's economic competitiveness, are summarized below.

Size of Travel Market

Passenger market growth has followed a pattern closely related to population growth and average personal income growth as compared with fare levels. International travel has been growing even more rapidly than domestic. Projections indicate that by 1978, when the SST is introduced, international traffic will approximate today's total free world air traffic. By 1990, when total world traffic is expected to have increased six-fold, the intercontinental portion will have increased to eight times its 1968 level. *Before 1990, the SST can be expected to carry more traffic, in international service, than the current free world total.*

Reduced Flight Times

The cutting of long distance terminal-to-terminal times to less than half present jet times will significantly increase overseas travel. With subsonic jets on domestic routes and supersonic jets on international routes, overseas points will, in many cases, seem closer than domestic destinations. The SST will put Europe as close to the East Coast as Minneapolis is to New York by subsonic jet. *The domestic traveler of today, both U.S. and foreign, will be the international traveler of tomorrow.*

Makeup of Travel Market

At present, nearly 56% of air travelers, according to the Survey Research Center, University of Michigan, are business and professional people. With a backlog of obligations to be attended to, reduced trip time and fatigue are important to these travelers. For the tourist, point of destination attractions and the desirability of increased times at a destination are likewise important. A 3-hour-trip, as compared with one of 7 hours, can mean a full day's difference in scheduling activities. A recent Louis Harris survey indicated that 87% of air travelers preferred that means of travel because of the time saved. Asked if they would like to fly on the SST, 58% of experienced air travelers were enthusiastically affirmative, as were 32% of persons who had never flown.

Travel market surveys (Survey Research Center) also show that persons between the ages of 25 and 45 have had the greatest exposure to air travel. In 10 years these individuals will be in higher income brackets with increased travel potential. Increased vacation lengths and more retirement programs coming into effect will further enlarge the air travel demand and add greatly to the international dimension.

Twenty percent of the U.S. adult population had flown in 1955; 39% in 1964. A projection of trends indicates that 60% or more will have experienced air travel by 1980. The flying public is not a "jet set," it is becoming the majority of American citizens.

Fleet Considerations

With the increase in air travel, air transport fleets have become divided into various specialized aircraft to fit the requirements of different segments of the market. The much larger traffic volume of the '80's will lead to still more specialization. In the overall structure, the SST will be ideally suited to long-range international operations. Its shorter trip times will permit greater schedule flexibility and more trip completions outside the midnight to 6 a.m. curfews being observed at certain major airports. In keeping with its enroute speed, the airplane is being designed for minimum-time station stops, with advantage to the passenger and increased air-aircraft use.

A six-fold growth in traffic will make it possible to offer more SST nonstop flights from major U.S. cities to major cities in Europe. This will cut the travel time to destination and, in many cases, the travel cost also. The somewhat smaller seating capacity of the SST than that of the large economy jets will make nonstop operation feasible between additional city pairs where traffic is more limited. This increased emphasis on point-to-point service will help relieve major airport congestion.

Incorporation of automatic flight management equipment in the SST, and the parallel development of advanced air traffic control equipment on the ground, will also relieve airway and terminal traffic problems, bringing increased safety and important freedom from weather interruptions. The SST program provides a focal point for the needed substantial effort to bring these major developments to early completion. The results will benefit all commercial aviation.

Transportation Productivity

Each major advancement in air transport equipment has increased equipment productivity and has thereby made possible the expansion that has taken place. This productivity is expressed in terms of seat-miles per hour per airplane; and can be increased either by increasing the number of seats, or by increasing the number of miles per hour. There has been a history of increase in both directions. The earlier smaller and slower equipment would be utterly incapable of handling today's traffic.

The largest single jump in productivity has been from the 707-DC-8 class to the 747, which increases seat-miles per hour from 100,000 to approximately 200,000. *The U.S. SST, by virtue of its large step-up in speed, will further increase productivity by some 75%, although it has 30% fewer seats than the 747.* This increase in productivity is appropriate to the forthcoming increase in total air traffic. It will not only be timely from an operational standpoint—it also has an important bearing on transport economics.

The Economics of Speed

Traditionally, air transport equipment has been evaluated primarily in terms of direct operating cost of the airplane, including depreciation, maintenance, and fuel and flight crew expense. Such an evaluation generally assumes that other factors, such as load factors, fare yield, and indirect operating costs, will remain relatively constant. *For an airplane that is essentially different from its predecessors in capability, however, these other factors may not remain constant. Total operating cost, or perhaps return on investment, become more meaningful criteria.*

The direct operating cost of the U.S. SST has been calculated to be about equal to that of current subsonic equipment but substantially higher than the coming large body subsonic aircraft. However, if total operating cost is used as the criteria, the SST is found to be more economical than present jets, and positioned about halfway between present equipment and the advanced large-body equipment in terms of today's costs. Its relative gain results primarily from the fact that several elements of ground support system cost decrease in proportion to the increase in seat-mile productivity per hour. This significant result stems from the economics of speed. The SST's increase in speed over previous equipment is so marked that the effect is significant.

Time Period Economics

The economic effect of this speed advantage becomes greater with the passage of time, bringing total operating costs of the U.S. SST to a level competitive with those of the advanced, large-body subsonic jets in the 1980's. Each year there is a percentage increase in both flight crew costs and the applicable ground support labor costs. The amount of this hourly labor rate increase can be applied to the number of seat-miles provided per hour. Because of the difference in miles per hour, this incremental cost increase becomes substantially greater for the slower equipment on a seat-mile basis.

In the more than 25-year time span of the SST, comprising a 10-year development period followed by 15 years of production and several more of airplane useful life, even a relatively small annual increment in these wage and salary costs build to significant proportions. Each element of cost was separately projected through the 1980's in a special study of this aspect. *The SST was found to approximate the total operating cost of the present 747 airplane in its 440-seat economy version by the mid-'80's and appears to offer greater economy than the latter from the late '80's onward.*

Load Factor Influence

Other revenue producing advantages apply in an earlier time period. In the years following the introduction of the jet transport, while these airplanes were in short supply and demand was high because of passenger preference, the load factors, or percentage of seats occupied, were unusually high. A similar introductory period bonus is expected to accrue for the SST. This new equipment will offer an even greater reduction in trip times, a higher and smoother ride, and once again, the dramatic appeal of a new form of flight. It is estimated that this added introductory load factor influence will extend over a 5-year period. Thereafter, as long as slower equipment is offered on competitive routes at similar fares, the SST will attain a higher load factor and hence will have an income advantage.

Fare Structure

In the operational simulation study, a current fare structure was assumed and the airplane was found to be economically viable without surcharge. Given an equivalent fare structure, the passenger preference for speed will result in the SST's capturing the bulk of the traffic on the transocean international routes.

Overall Profitability

The combination of the above factors is found to be appropriately compensating through the operating life of the SST. The apparent disadvantage in operating economics will be more than offset in the early years by passenger preference and high load factors, and in later years, by the labor cost escalation advantage. Travel at three times the present speed can be accomplished at relatively the same cost per seat mile as for the subsonic equipment. It is significant that the gains in productivity accomplished by both the advanced large-body subsonic jets and the SST over present jet equipment will offer the capability of maintaining a relatively stable fare structure in air transportation throughout the period under study. Concurrently, average personal income will continue to increase. These same conditions prevailed during the past two decades, with advanced equipment coming into use, and helped to make possible the remarkable growth of air transportation that has taken place. The elements exist to assure the continuance of that growth. The SST will help make it possible. This growth, in turn, will call for the added productivity of the U.S. SST on international airways.

The operational appropriateness of the SST and its economic earning power assure it a solid and increasingly important place in the world air transportation network. There is every indication it will become the international workhorse airplane of the 1980's.

SST OPERATIONS – GENERAL CONSIDERATIONS

SST OPERATIONS—GENERAL CONSIDERATIONS

Dramatic improvements in air transport capability during the last 25 years have made it physically possible and convenient for vast numbers of people to engage in many activities requiring long distance travel. Utilization of these new capabilities by the public at large has been truly phenomenal. Almost half of the U.S. population has used scheduled air service at least once, and more than 10% have used it regularly. Although the population continues to increase, the number of people using air transportation is increasing at a much faster rate. By 1980 almost 20% of the people will have become regular airline customers and more than 60% will have traveled by air at least occasionally.

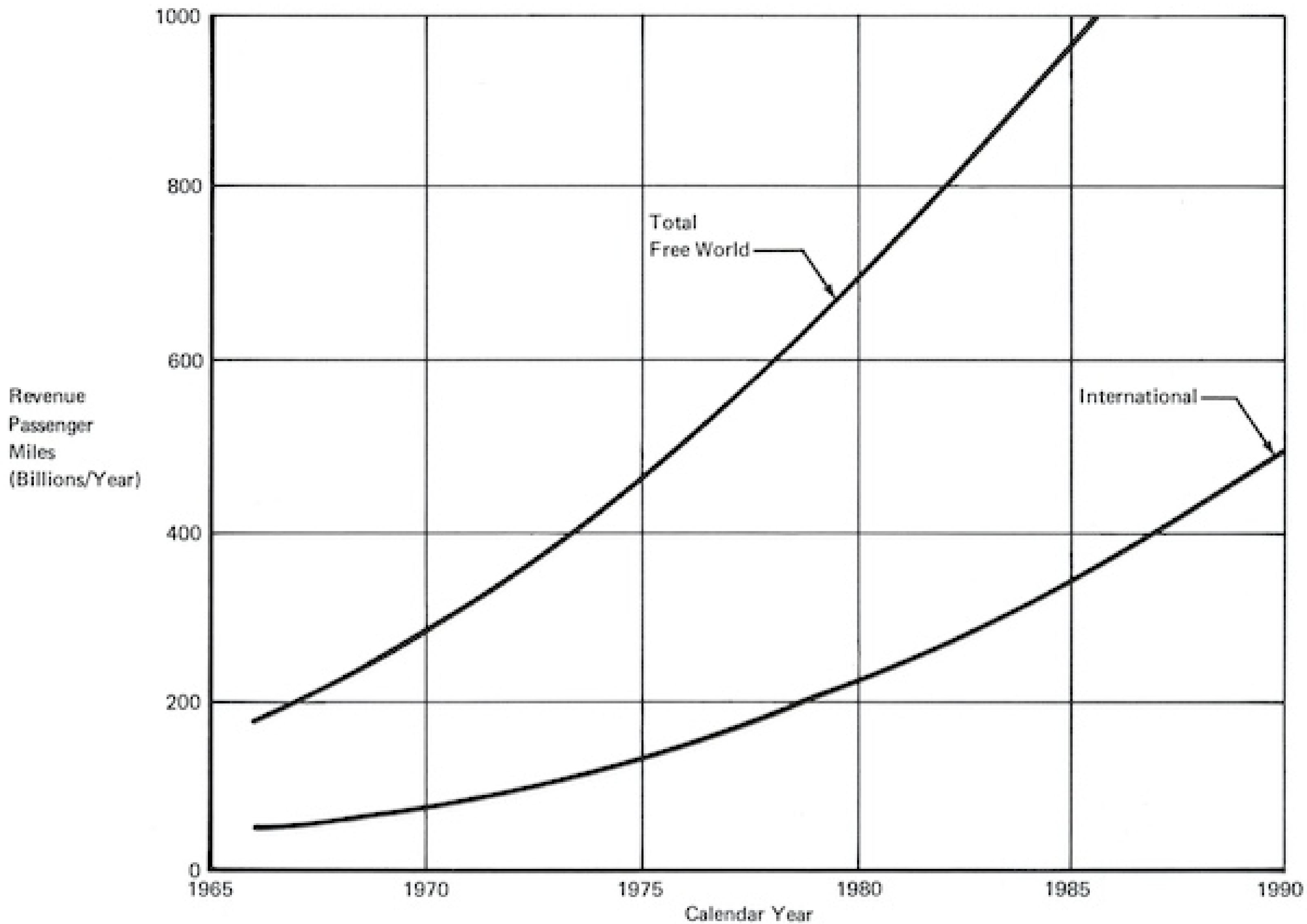
The diversity of needs to be served by the air transport industry requires a wide selection of aircraft of various sizes, speeds and ranges flying a comprehensive air-route network. A large travel demand exists within this network that will be uniquely filled by the SST. The operational utility of the SST will be characterized by shorter trip times, significantly better schedules, and congestion relief on the fast growing airways. Economic gains will result principally from its speed, and accompanying productivity.

An intensive study of SST introduction to the air transport system, using the environment of today's route structure, has substantiated that the projected benefits of the SST can be realized in practice. A large map illustrating the wide distribution of SST's on airline routes in 1990 is contained inside the back cover of this document. Further development of the world air route system and improvements in the method of SST operation will augment the actual distribution of SST's when they are introduced into service.

Travel Demand and Growth

Using forecast methods that have proven conservative in the past, the passenger traffic on international routes is expected to increase nearly eight-fold by 1990. By 1978, it will be almost as large as today's total free-world traffic (Fig. 3-A).

The rapid growth in air transportation can be attributed to several factors. For the U.S. alone the population growth during the years 1958 to 1968 has been about 1.5% per year while during the same period the annual growth in air transportation has been over 14% in passenger miles each year. The keys to this air traffic growth become evident when one considers that GNP increased at more than 6% each year. The consumer price index has increased an average 2% per year since 1958, but air fares in 1968 were actually below the 1958 level after peaking in the early 1960 time period. With the introduction of better and faster aircraft, air transportation has become more and more competitive with other types of transportation. Since 1956, service improvements such as smoother and quieter ride, more scheduled air service, over 95% schedule reliability, and halved flying times have contributed to make air travel the most attractive transportation means of the modern era.



Source: The Boeing Company

Figure 3-A. Free World Traffic Forecast

The supersonic transport will continue the trend of offering more and better service while reducing flight times again by one-half. The high productivity of the increased speed will maintain the trend toward decreasing or stabilized passenger fares.

Type of Traffic and New Market

Air travel owes most of its popularity to the time savings offered over other modes of transportation. Out of a representative group of air travelers contacted, 87% preferred air travel because of the time saved. The reduction of international air travel times by the SST will be especially appealing for business travel, which presently makes up the largest segment of air traffic.

By SST, Europe will be as close to the U.S. as New York is to Minneapolis today, and international commuting for the businessman will become a reality. Relatively short trip times and flight in high altitude turbulence-free air will provide the passengers a means of transportation unequaled in comfort and convenience. At the same time growth in air traffic will create new demands for air service and radical changes in airline route patterns. History showed that as the traffic volume increased, more and more direct point-to-point service was offered to meet the demands of the traveling public. The improved service resulting from more direct point-to-point SST schedules are expected to generate a whole new business travel market.

The SST is certainly the forerunner of a new family of high speed transports whose high productivity will be a major factor in keeping operating costs from increasing during the next two decades. Stabilized fares combined with rising incomes will continue to broaden the base of the passenger market which, when combined with the new traffic patterns, will make international air travel accessible to more people than ever before.

Historical Trend

The piston-engine era began to decline in the late 1950's with the advent of the swept wing subsonic jet commercial transport. A 50 percent increase in cruise speed coupled with increased airplane size, resulted in a two-fold increase in productivity. The subsonic transport speed plateau has remained relatively fixed during the 1960's. Although the propeller driven commercial transports are rapidly disappearing from the air transport systems due to the superiority of the subsonic jets, current studies show that subsonic jets will complement the SST fleets for many years to come.

The SST can best fill a special role in the world air transportation system and should not now be considered as total replacement for the subsonic jets. The most meaningful perspective of the worth of the SST is gained by considering its contribution to the efficiency and operations of the total air transportation system of which it will be an integral part.

SST Capability

The diversity of air transport requirements has led to the development of several specialized airplane types, such as short range, intermediate range, and long range, each of which has been optimized to provide the lowest fares for the passenger while providing a reasonable profit for the airlines. Very large capacity airplanes in the long and intermediate range categories are now under construction, offering the airlines further equipment choices to meet their needs. Most airlines already have two types of specialized aircraft in their fleets and large capacity airplanes on order. The SST, with 298 passengers and 1800 mph speed is designed to handle increasingly diverse traffic patterns as well as increased traffic volume. The Supersonic Transport fulfills the specific requirement for a very high speed long range transport of moderate size.

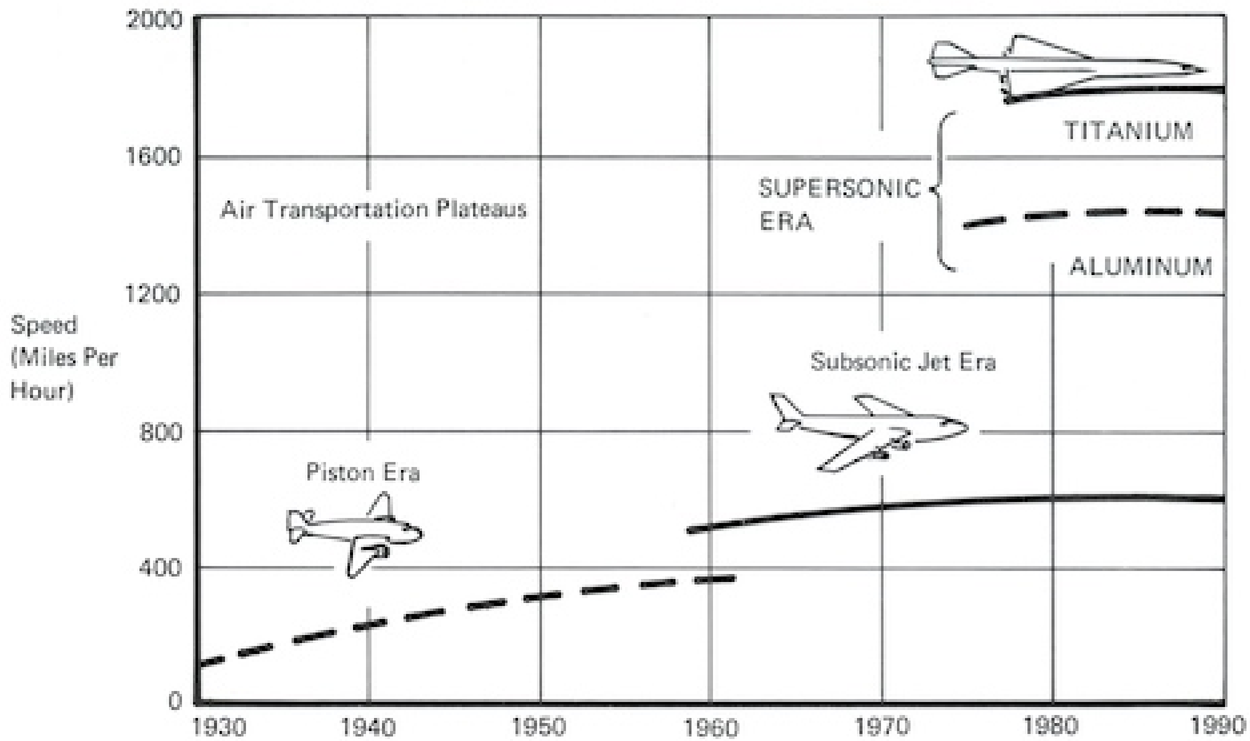
Productivity

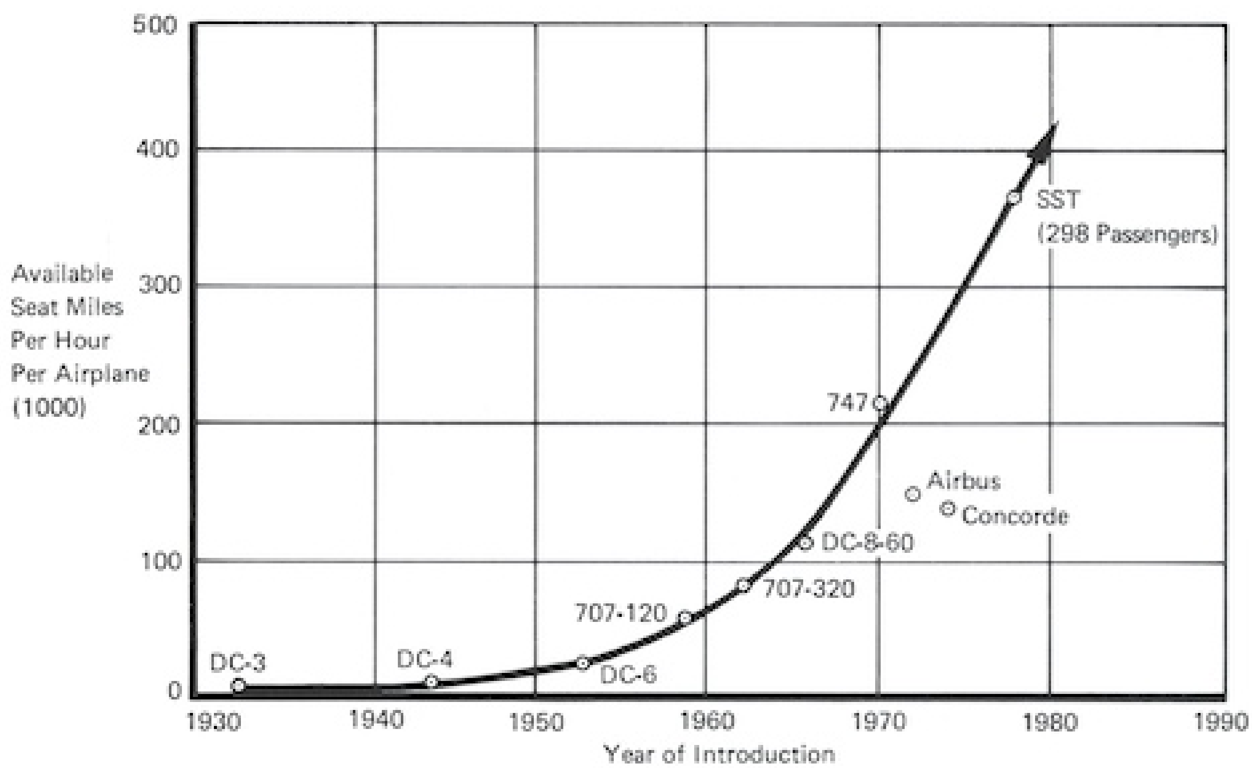
Productivity is measured by average speed multiplied by the number of seats carried over a given range. The payload-range capability of an airplane is a function of the efficiency of its aerodynamic design, its propulsion system, and its structure. Appendix A contains a brief explanation of this relationship and other supersonic flight phenomena. The production airplane configuration is briefly described in Appendix B. The SST is designed to achieve the optimum combination of productivity factors at supersonic cruise speed as well as during subsonic flight.

Continuing air traffic growth demands airplanes of ever increasing productivity so that the air transportation fleet size and airline manpower requirements can remain within reasonable limits. More than 5 current subsonic transports or 500 Douglas DC-3's would be required to move the volume of air traffic that can be handled by one SST.

A work force of millions would be required as compared to about 300,000 people employed by the airlines in 1968 if aircraft of increased productivity were not introduced into the air transportation system. The airlines faced with ever growing traffic will need to rely on highly productive aircraft such as the jumbo jets and SST's to meet future traffic demands.

By virtue of its greater speed, the production model SST, with 298 passengers, is nearly 75 percent more productive than the 747 with 440 seats. A subsonic 747 would have to carry 750 passengers to match the productivity of the 298 passenger SST (Fig. 3-B).





Source: The Boeing Company

Figure 3-B. Airplane Productivity (2500 Mile Route Typical International Seat Density)

Schedule Reliability

Changes in route patterns to offer more point-to-point service will tend to decentralize airport terminals helping to relieve the congestion due to passenger traffic growth. Furthermore, advanced automatic flight systems, and all-weather landing capability will result in more efficient use of the airports.

Currently, airline operations are dependent on the weather conditions at the terminals. Restricted visibility may cancel a flight or divert it to an alternate airport, however, the major problem results from delays caused by the limited airport flight handling capacities during bad weather. Improvements programmed for the SST will attain bad weather airport capacities close to present good weather capability.

The dispersion of the SST operation to meet the requirements for more point-to-point non-stop traffic, more accurate navigation provided by the automatic flight management system, and increased airport capacity resulting from all-weather instrumentation will improve schedule reliability by reducing flight delays.

Improved Scheduling

In addition to improving speed and comfort for the traveler, the SST will offer new schedule options of special value to the businessman. For example, it will be possible to depart from New York at 6 a.m., arrive in Paris at 3 p.m. Paris time, spend the afternoon and evening in Paris, return on a flight leaving Paris at midnight and be back in New York by 9 p.m. the same day. The total time elapsed would be 15 hours, with 9 of them spent in Paris. As another example, a round trip leaving Los Angeles at 8:00 a.m. and returning at 11:00 p.m. could provide a full business day in Honolulu (Fig. 3-C).

For very long trips, the improved scheduling will be a major enhancement to travel. On a London-Sydney trip, the present total elapsed time exceeds 22 hours by subsonic transports, while the SST will take about 13 hours (see Fig. 3-D).

For the airlines, the operation of a mixed fleet, SST's and long range subsonic jets on the same route, will offer the possibility of more hours of operation per day. As an illustration, SST's or subsonic transports can each depart during 12 hour periods on the Paris-New York route without breaking self-imposed midnight to 6 a.m. airport curfew. However, a combined fleet can offer departure times covering 16 hours of the day.

Utilization of the early-morning hours (6-8 a.m.) for SST departures from the U.S. to Europe, and late (8-11 p.m.) departures for the return trip will be stimulated by a demand from business travelers making short duration transatlantic round trips. Similarly, expansion of scheduled operations between the West Coast and Honolulu will be enhanced by the time saved by SST travel.

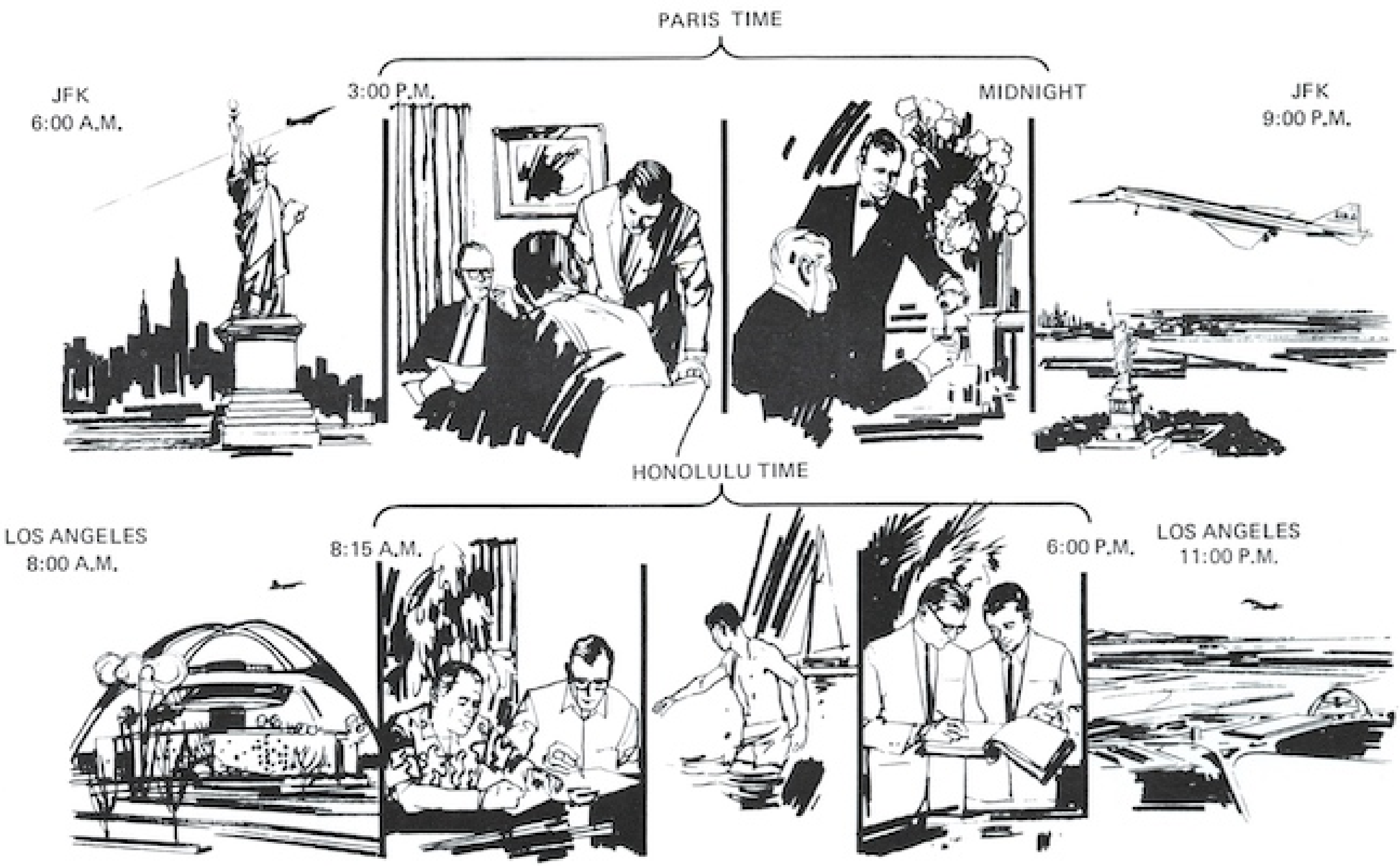


Figure 3-C. SST Commuting Opportunities

	Subsonic Jet Transport Elapsed Time (Hrs & Mins)	SST Elapsed Time (Hrs & Mins)	Time Saved (Hrs & Mins)
London, Sydney (West)	28:20	15:00	13:20
London, Sydney (East)	22:11	13:30	8:41
London, Tokyo	15:48	7:36	8:12
New York, Copenhagen	7:30	4:48	2:42
New York, Zurich	7:36	4:30	3:06
New York, Rome	8:12	4:48	3:24
New York, Athens	9:12	5:18	3:54
New York, Frankfurt	7:30	4:18	3:12
New York, Rio de Janiero	9:06	5:00	4:06
New York, Johannesburg	18:24	9:24	9:00
Seattle, Tokyo	9:12	4:42	4:30
San Francisco, Tokyo	9:48	5:24	4:24
Sydney, Tokyo	12:48	7:54	4:54
New York, Tokyo	13:54	5:00	8:54
San Francisco, London	11:54	7:30	4:24

Notes:

1. 30-minute stop time assumed for both aircraft.
2. SST elapsed time includes fuel stops and speeds below sonic boom threshold over populated areas.
3. Maximum SST range 3380 nautical miles
4. Maximum subsonic transport range 4250 nautical miles
5. SST cruise Mach = 2.7
6. Subsonic cruise Mach = 0.85
7. SST 298-passenger payload
8. Subsonic transport 441 passengers
9. SST/Subsonic Routing not identical due to Range differences

Source: The Boeing Company

Figure 3-D. SST/Subsonic Transport Elapsed Time Comparison (Representative Routes)

These new schedule opportunities will not only serve to level off traffic peaks at the busy terminals, but will offer the intercontinental traveler originating at an inland city the opportunity of reaching his overseas destination in one day. A traveler could depart Dallas during mid-morning, arrive in New York during mid-afternoon, and take an SST arriving in London late-evening the same day.

The eight-fold growth in traffic will make it economically feasible for the airlines to offer SST non-stop direct flights from most major U.S. cities to most major European cities. For example, a traveler going to Oslo or Stockholm will be able to fly directly from any of several U.S. cities instead of having to go to Copenhagen, and/or Stockholm before getting to Oslo, as he now must. Point-to-point, non-stop type service is ideally suited to the size and speed of the Supersonic Transport. The combination of direct non-stop service to many of the major U.S. cities, and short haul commuter type shuttles to many others will provide better service than has ever been possible. This will provide a large stable business traffic base for the international travel market.

Utilization

The speed of the SST will have an appreciable effect on schedule flexibility, although the total impact on airline operations has not been evaluated. Typical schedule elapsed time comparisons shown in Figure 3-D illustrate that the longer range non-stop capability of the newer subsonic airplanes will not give them a schedule advantage over the currently defined SST at any range.

Operationally, the supersonic transport has many of the characteristics and requirements of the short haul transports such as the DC-9 and 737. Short flight times make it mandatory to keep ground time to a minimum if the full advantages of speed are to be realized. The SST is being designed to meet this kind of requirement. The SST has an advantage over the short haul subsonic transports because the change in time zones permits a degree of schedule flexibility unavailable to the short haul jet transport. This schedule flexibility combined with the short ground times and the advanced maintenance techniques being used in the design will permit utilizations of 12 hours per day or more even with self-imposed midnight to 6 a.m. curfews at most airports.

Results of a detailed study confirmed that SST utilization of 12 hours per day could be realistically achieved on representative international route systems while respecting curfews and maintenance requirements. (Appendix C)

Operating Costs

A fundamental consideration in air transportation economics is operating cost. When the jet transport was introduced in 1958, its principal advantage was believed to be travel time saved due to increased speed. In 1950 it was not recognized that the jet operating cost could ever be less than that of the piston-engine airplane, or even the turbo-prop transport. And now a decade before the introduction of the first generation SST's, estimates show that their direct operating costs will be slightly higher than for today's jets. However, economic studies show that as a result of improved technology, actual load factors, wage trends, and escalation, the SST will achieve equal or lower total operating costs than the next generation of subsonic transports.

Airport and Airways Decongestion

The SST will relieve both airport and airways traffic congestion. The travel demands for supersonic flight and the scheduling flexibility of the SST will spread the air traffic throughout a greater part of the day thereby effecting a general reduction in airport and airways congestion. The automatic flight management system, under development for the SST but with application to all commercial aircraft, will further relieve the air traffic congestion by improving navigation accuracy and schedule reliability.

The higher cruise altitude of the SST will increase the number of air traffic corridors effectively increasing the amount of airspace. An analysis of the airspace problem shows that the number of daily North Atlantic crossings will increase from 240 in 1967, to about 2100 in 1989 if current airplane types are used, or to about 700 if all flights are by jumbo jets. If the world air transport transatlantic fleet is divided between SST's and jumbo jets there would be about 200 crossings by the subsonic jets and about 600 crossings by SST's. The SST will cruise at altitudes up to 72,000 feet while subsonic jets are limited to altitudes below 41,000 feet. The cruise speed of the SST is about three times faster than the subsonic jet, hence an SST will utilize the airspace only one-third as long as a subsonic jet. It can be concluded therefore, that despite the projected traffic growth, with a mixed fleet of subsonic and supersonic airplanes, the airways traffic density on the North Atlantic would be at about today's density level.

SST OPERATING ECONOMICS STUDY (1968 COSTS)

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During the past several years, the relative merit of competing air transports has been assessed primarily in terms of direct operating cost (DOC). This has been a valid comparison because the various airplanes had similar characteristics and investment requirements. This is not necessarily a valid method of assessment when comparing SST's to subsonic jets, because of the high speed and unique operating characteristics of the SST. An assessment at a higher economic level involving operational simulation, load factors, fare structures, and direct and indirect costs, leading to a Return on Investment (ROI) comparison is required (see Fig. 4-A). This section describes such a study. It indicates that the currently defined production SST can compete economically on the routes for which it is intended, in a fleet size of 500 or more airplanes.

Standard Operating Costs Assessment

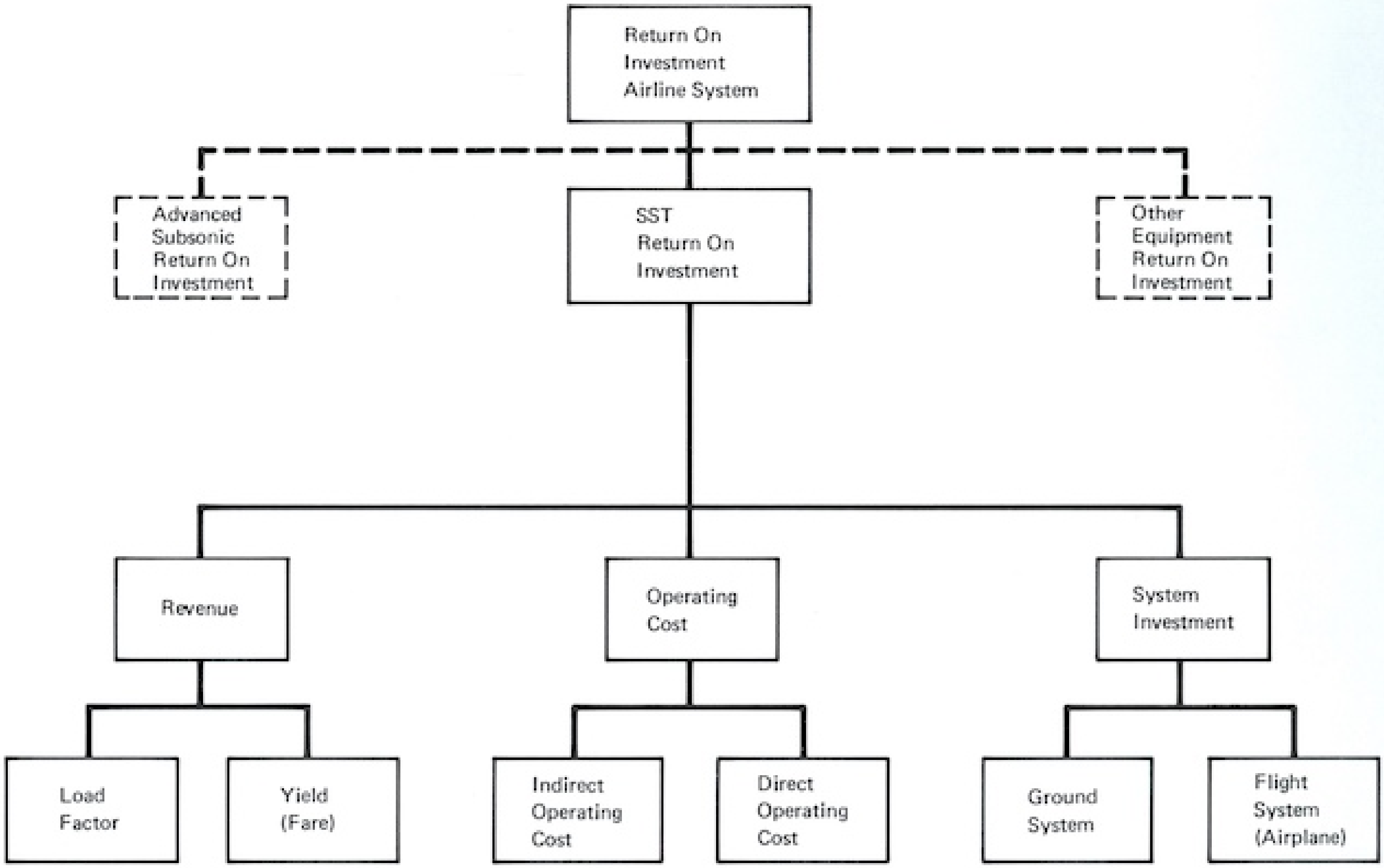
Figure 4-B is a typical plot of direct operating costs showing the relative DOC's for advanced subsonic airplanes, current subsonic airplanes, and an estimate for the first generation production SST's based on 1967 ATA standard day rules. These data have been calculated in terms of 1968 costs and reveal that the SST is expected to achieve DOC's slightly above current subsonic equipment, but somewhat higher than advanced subsonic equipment. The difference between the supersonic airplane and advanced large-body subsonic airplane DOC's is attributed primarily to an increase in fuel consumption, rather than other factors, such as maintenance, labor, and depreciation.

Recent studies at Boeing indicate that the indirect operating costs per seat mile of the SST tend to be somewhat less than for subsonic aircraft because of the high productivity of the supersonic airplane. By combining the indirect operating costs and the direct operating costs, the relative picture tends to become more favorable to the SST as illustrated in Figure 4-C. In comparing the total operating costs, it appears that the SST is only slightly more costly than the advanced subsonic jet and slightly less costly than current subsonic jets.

Operational Simulation Economic Assessment—1968 Costs

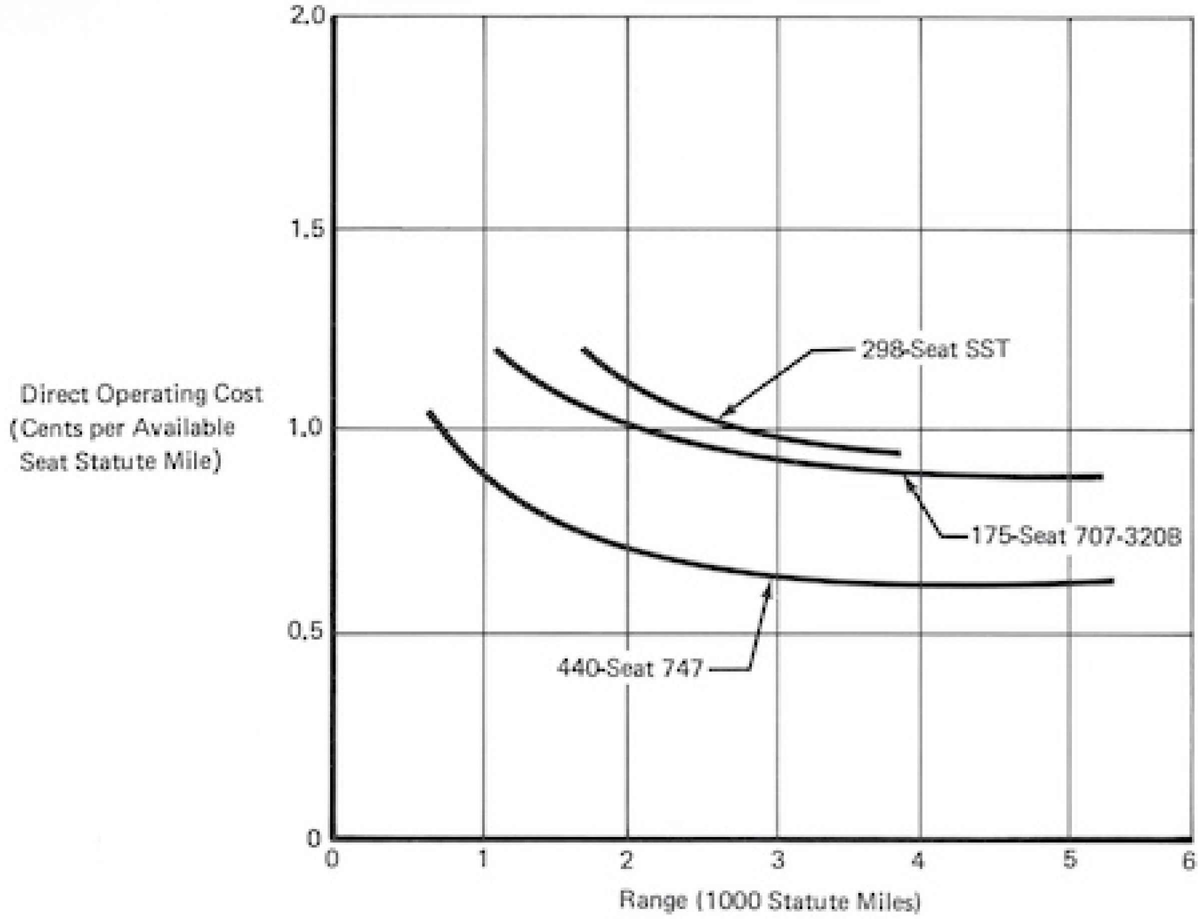
An economic assessment of SST introduction in 1978-1990 was accomplished in considerable detail by evaluating the various factors discussed in Figure 4-A. A list of the key assumptions for this study is continaed in Appendix D. The objective of the study was to calculate the variation in annual ROI of the SST fleet to determine the probable number of aircraft desired in the transoceanic system and the extent at which the SST would penetrate the international market.

The study assumes operation in conjunction with a large subsonic jet fleet on world-wide air routes. It was based on detailed analyses of the airplane-by-airplane introduction of 515 SST's on 142 existing airline routes that comprised the major part of the world-wide network served by 25 airlines.



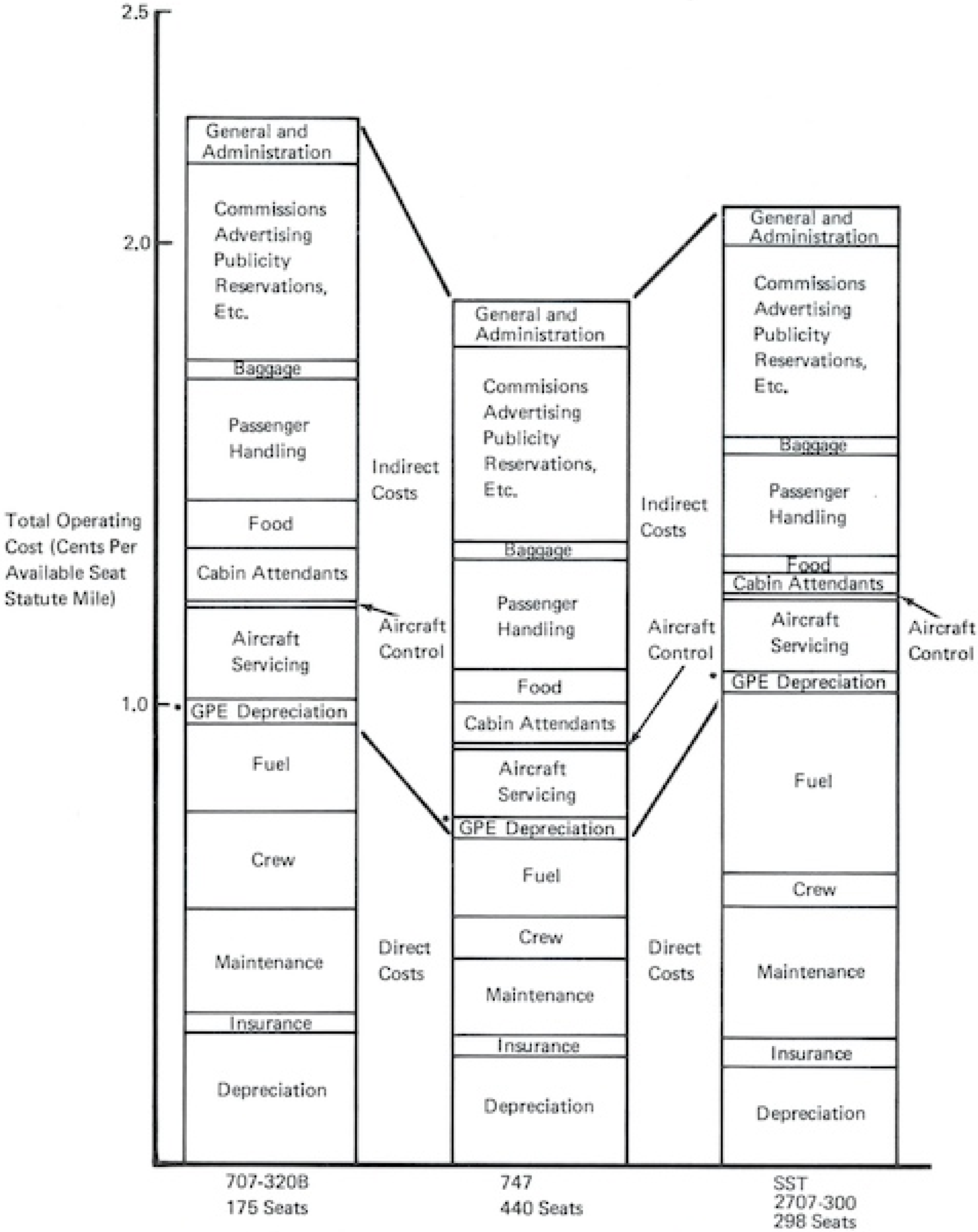
Source: The Boeing Company

Figure 4-A. Airline Economic Elements



Source: The Boeing Company

Figure 4-B. Direct Operating Cost (1967 ATA Rules Standard Day All-Economy Payloads)



Source: The Boeing Company

*Ground Property and Equipment

Figure 4-C. Total Operating Cost Comparison — 1968 Costs (All-Economy Payloads)

The operationg of the 515 currently defined production SST's in the world-wide network was simulated by the Boeing study. The economic impact on the total SST fleet was analyzed, and in addition, the economics for several individual airline SST fleets were examined. The study was based on allowing sonic boom only over water and north of the Arctic Circle. Even though flight operations at subsonic speed cost more per mile than at supersonic speed, this world route analysis shows the practicality of using the SST on routes requiring combinations of subsonic and supersonic flying. These flight operations are compatible with the needs of passenger traffic, individual airline route structures, and subsonic jet operations. The study also shows that the use of circuitous supersonic flying to avoid populated areas can be practical for airline operators. The SST introductory market study was simple in concept and was conducted as follows:

1. Method

An SST production airplane delivery schedule was assumed. The airplanes were then introduced into the route structure of each individual airline according to the delivery schedule. The operations and economic performance on each route and for the total system was calculated annually in a computer program. The program also permits calculating the economic performance of the individual SST fleets assigned to each of the 25 airlines covered by the study.

2. Passenger Traffic

The world international passenger traffic forecast for the period 1978 through 1990 was used (Fig. 3-A). The traffic was broken down to annual intercontinental traffic and finally into monthly point-to-point traffic that reflected both the seasonal variation of the particular region and its growth rate.

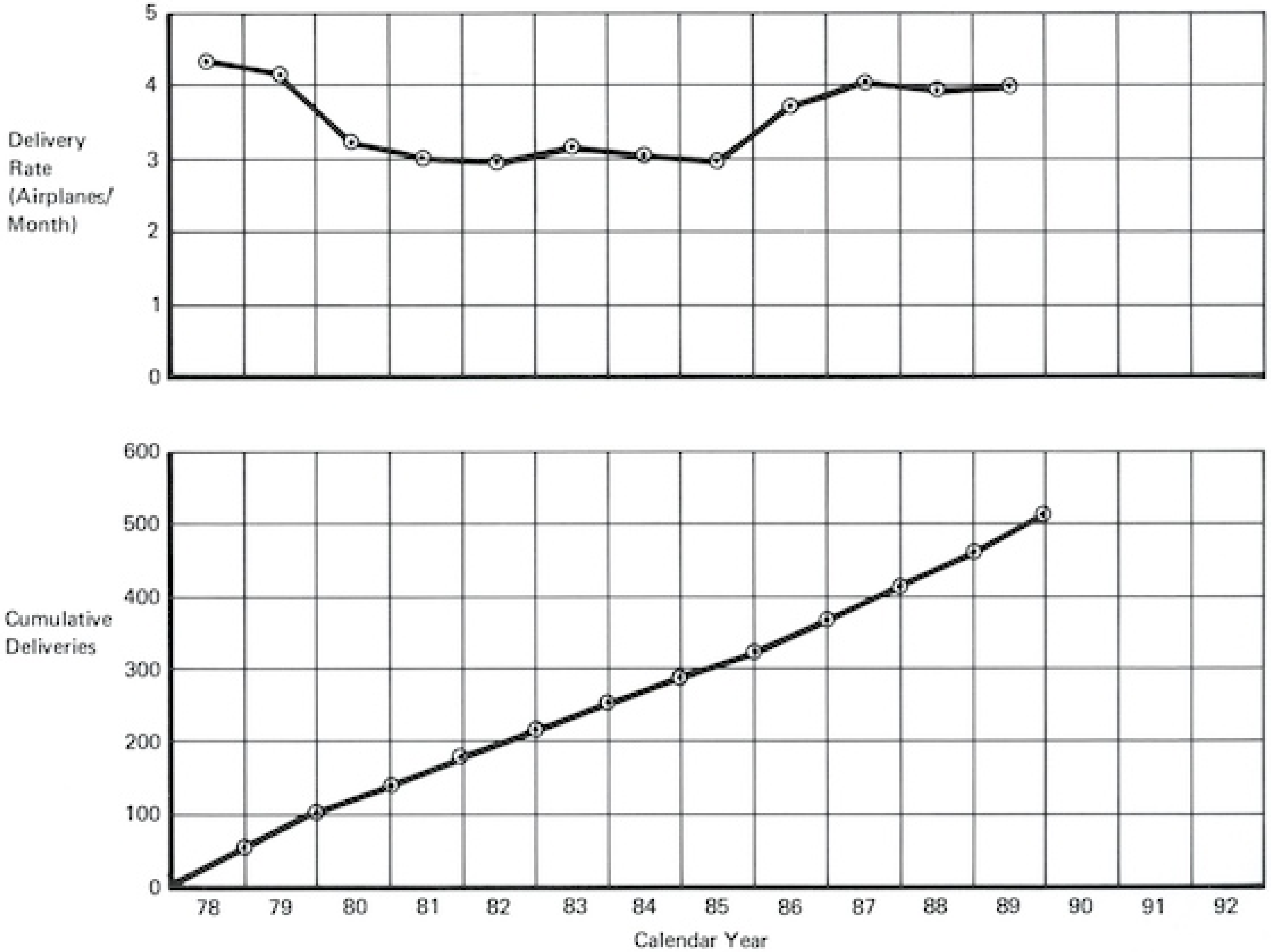
3. Airplane Production and Assignment

The airplane production rate during the 12 years covered by the study is shown in Figure 4-D. The first 100 SST's were assigned to individual airlines in accordance with the FAA reservation schedule (Fig. 4-E). Subsequent deliveries were assigned in an order that would effectively maintain the 1967 fleet size proportions between airlines. A total of 515 airplanes were assigned.

The individual airplane routes were assigned considering the airline competitive viewpoint. This resulted in the very rapid spread of SST's on the major international air routes as illustrated in Figures 4-F and 4-G. See the map inside the back cover for complete route picture.

4. Operating Costs

Operating costs used in the introductory market study were estimated using standard methods of computation. Direct costs were based on the 1967 ATA method and indirect costs using the Boeing-Lockheed method (see Appendix D).



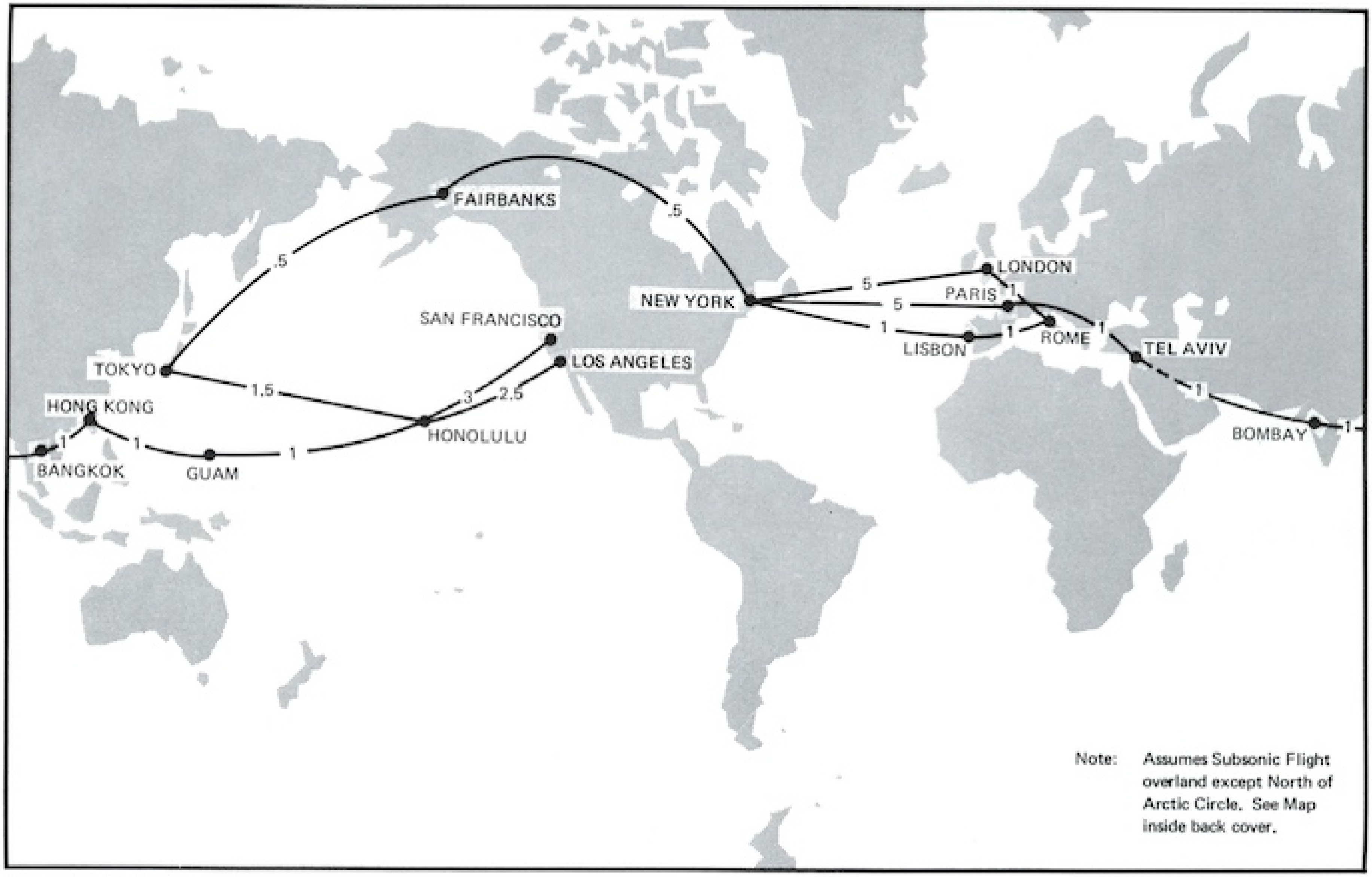
Source: The Boeing Company

Figure 4-D. SST Deliveries (Used in 515 Airplane Study)

Airline	1978												1979												1980	
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F
TWA	1	3 6	11	15		26		33			47	52 55											116		125	
PAA		2 4	7	12 16			27	32		43	50	54	58 61	64 65 67												
AZ		5	9		21													91	96	101						
AAL			8	13	20		31		40		48															
EL AL			10	14																						
BOAC					17	24			41					66	69 74											
NWA					18	22	29					56												119	127	
JAL					19	23	30			46		57														
QEA						25	28	34			49		60	68												
AF								35 36			51		62		71	75										
AII									37	42																
BNF									38	44																
DAL									39	45			63													
T–A															70	79										
CPAL															72	78	82									
IAL																76	81									
DLH																77	80 85									
IBERIA																	84	88	92							
KLM																		86 90	95					121	128	134
PIA																		89	93							
EAL																			94		102			118	126	132
WORLD																				97	104	109				
UAL																				98 100	103 105	107 108	113			
CAL																				99	106		112	120		
AC																						110	114 117	123		
AIRLIFT																						111				
Deliveries	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5		
Cum. Del.	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101	106	111	116		

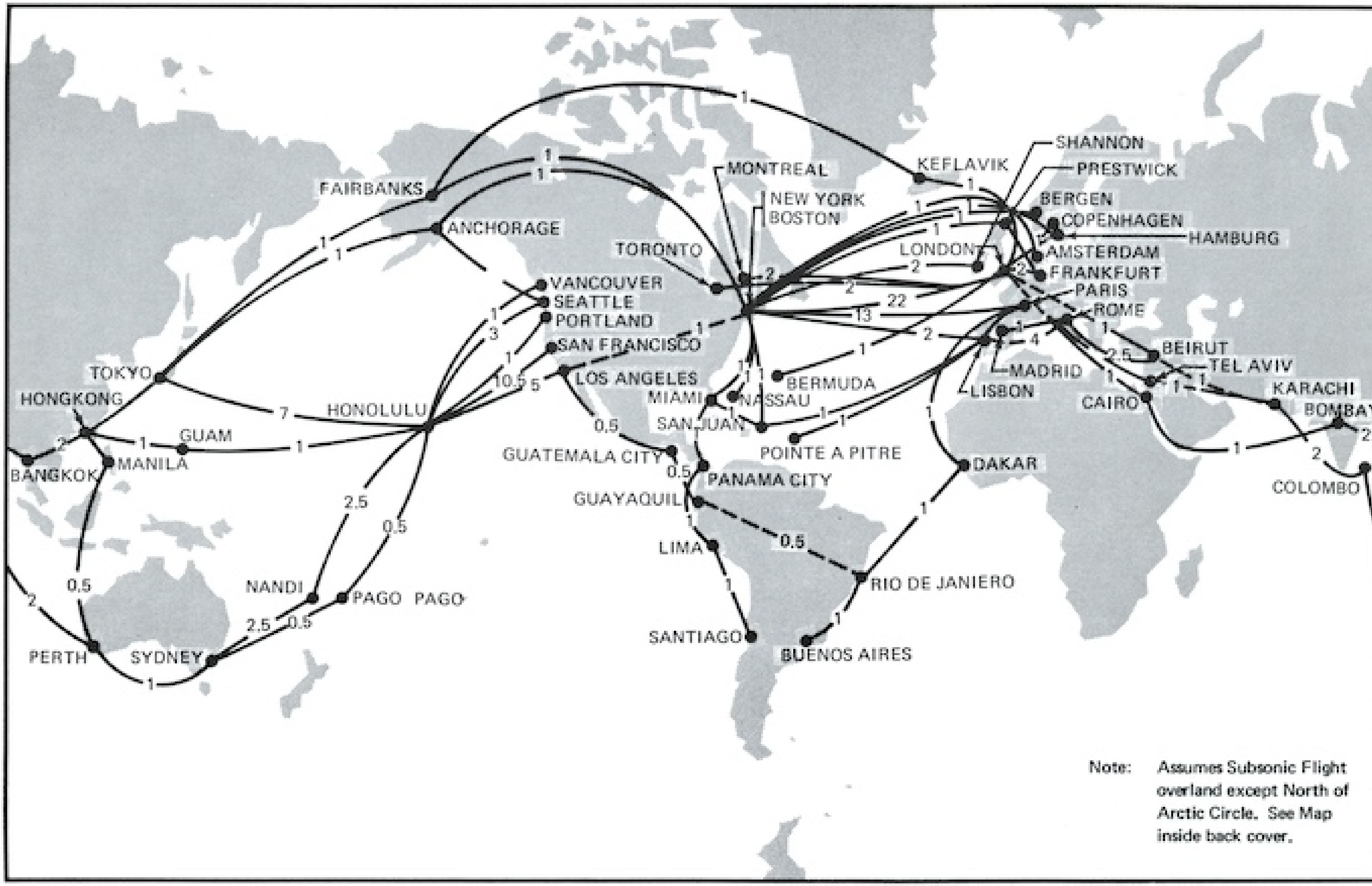
Source: The Boeing Company

Figure 4-E. Assumed SST Delivery Positions



Source: The Boeing Company

Figure 4-F. SST Routes (3 Months After First Delivery)



Source: The Boeing Company

Figure 4-G. SST Routes (15 Months After First Delivery)

5. Load Factor

Several independent surveys have indicated that there will be a very high passenger preference for the SST over the subsonic jets. These preferences vary depending on conditions imposed, but generally indicate a preference of 50% or more. Similar studies conducted in 1958 indicated that the passenger preference for the jet airplane over the piston would be only 37%. There is strong evidence that the predicted SST preference will be realized. Data show that the supersonic transport will be as comfortable as the subsonic jet airplanes and all indications are that the ride will be even smoother. There are minor pros and cons for each airplane type, but the overwhelming consideration is that the SST flight time will be half the subsonic jet flying time.

The reaction of the public to a particular type of transportation service can be measured by the number of people using it. This is generally expressed as "load factor" which is the ratio of the number of passengers using the mode of transportation to the number of seats available. The similarity in situations of the jet airplane introduction into piston-engine aircraft market and the SST introduction into the jet market is unmistakable and it is very probable that the reaction of the public will be similar. The public reaction to the jet airplane introduction is documented in CAB and ATA statistics (Fig. 4-H) and this historical data was used as the basis for the introductory market study (Fig. 4-I).

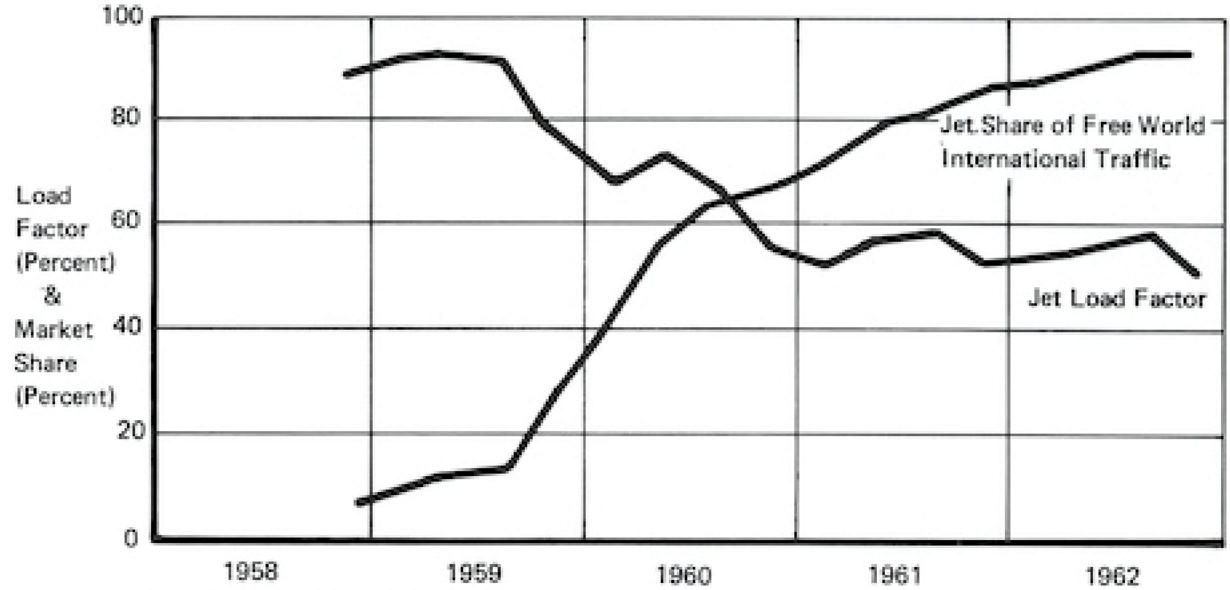
6. Yield*

Historical data indicate the initial yield on jet airplanes was approximately equal to the fare, but that as jets penetrated more deeply into the passenger market, the yields were reduced, probably through incentive fares (see Fig. 4-J). To duplicate the historical evidence, current fare levels on each route were used. The yields were then varied as a function of the market penetration (Fig. 4-K). After the fifth year, the yield on each route was decreased at a uniform rate of 2% per year in accordance with the average historical decline in yield.

7. Subsonic Operations

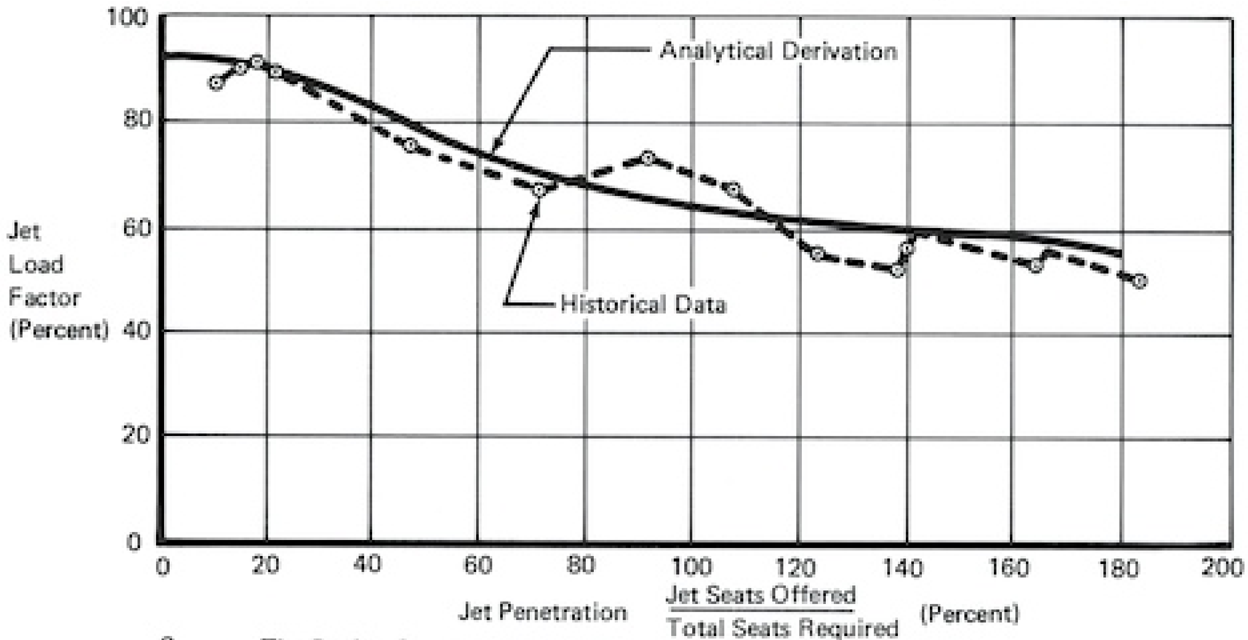
Efficient subsonic operation is one of design objectives of the SST. In normal operation, the SST will not accelerate to supersonic speed until it is at least 50 miles from takeoff. The speed will be subsonic prior to landing approach at least 75 miles from the airport. These subsonic legs may be extended as required to eliminate overland sonic boom. In the introductory market study the flight operation is planned around this characteristic, and no sonic booms are created

* Yield is the actual revenue received per passenger seat mile. It is not the same as published fares because of special discounts and fares. (Half fare for children, family fare plans, excursions, fares, etc.)



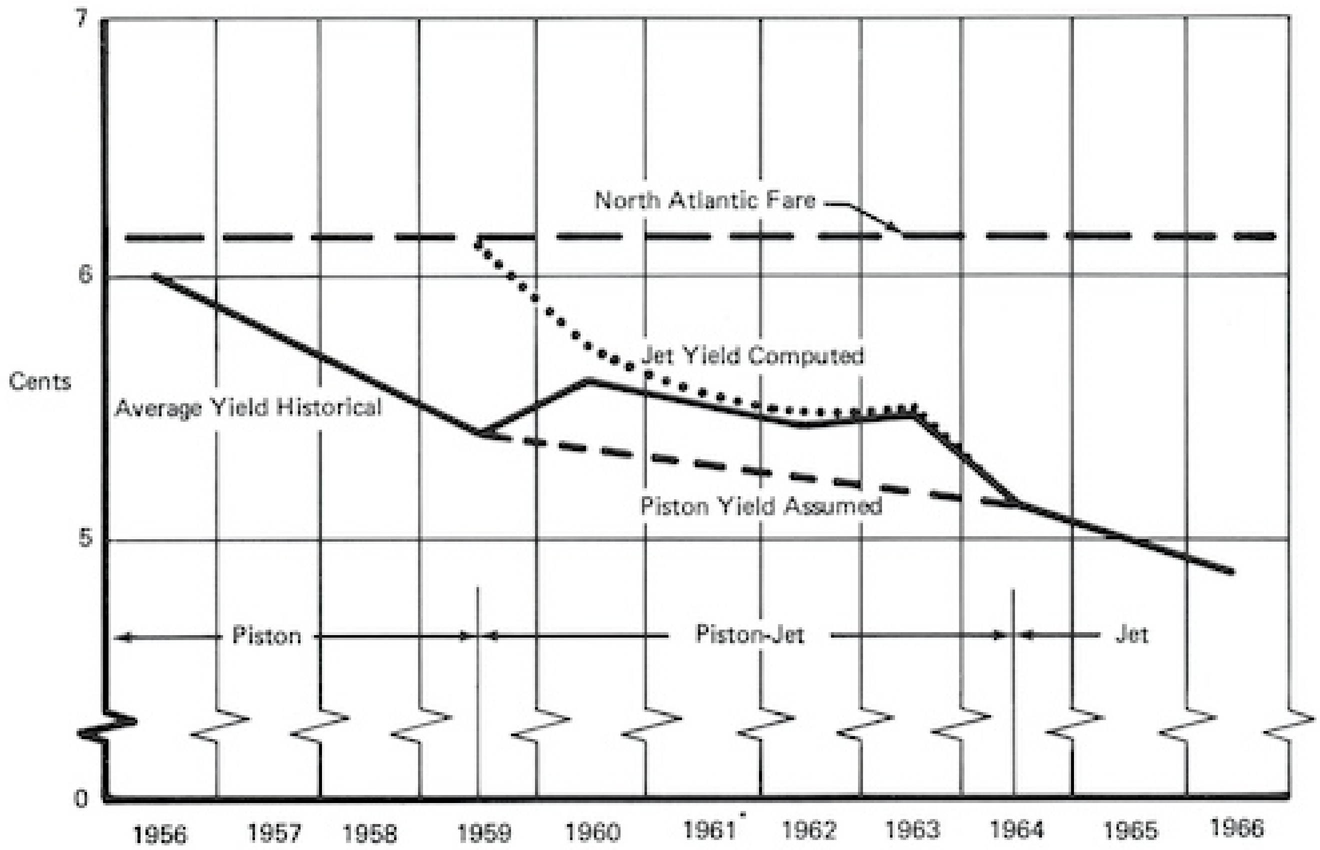
Source: The Boeing Company

Figure 4-H. Subsonic Jet Introduction Impact (Load Factor and Traffic Share)



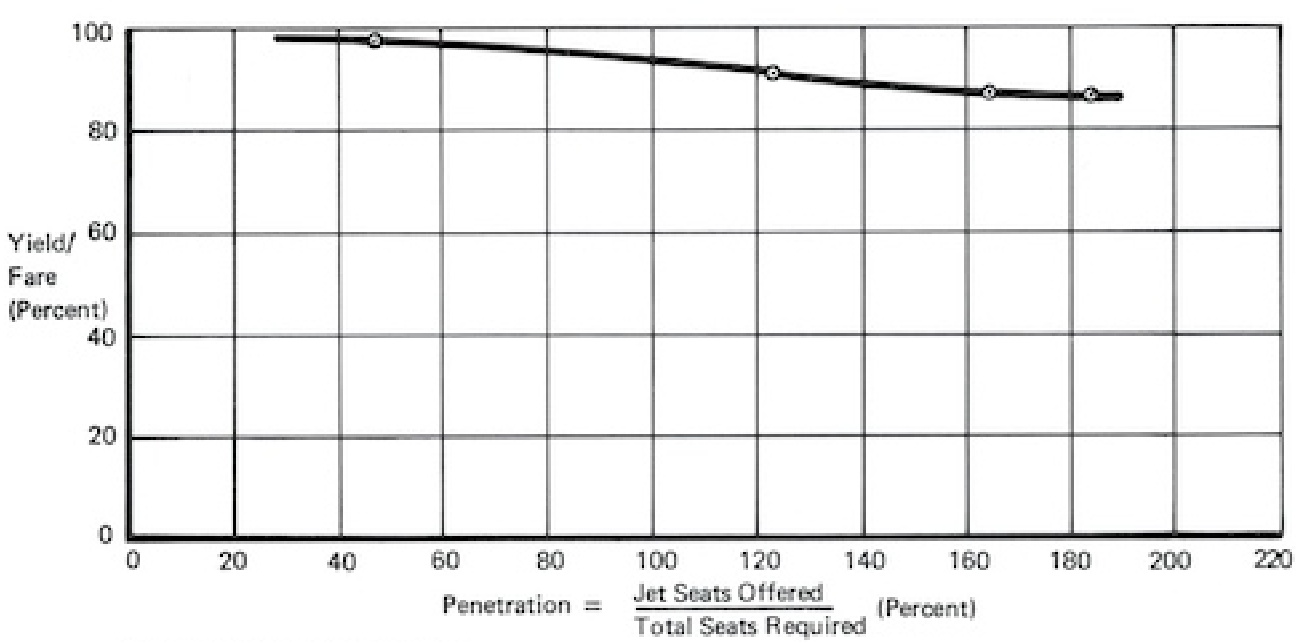
Source: The Boeing Company

Figure 4-I. Historical Jet Load Factor Related to Penetration



Source: The Boeing Company

Figure 4-J. Subsonic Jet Introduction Impact (Fare and Yield)



Source: The Boeing Company

Figure 4-K. Historical Jet Yield Related to Fare and Penetration

over land except north of the Arctic Circle. The international route structure is such that over 90% of SST flight mileage will be at supersonic speeds over water.

During flight over populated areas, the SST will be able to cruise from 100 to 150 mph faster than current jet transports without causing sonic boom.

STUDY RESULTS,

1. SST Routes and Traffic

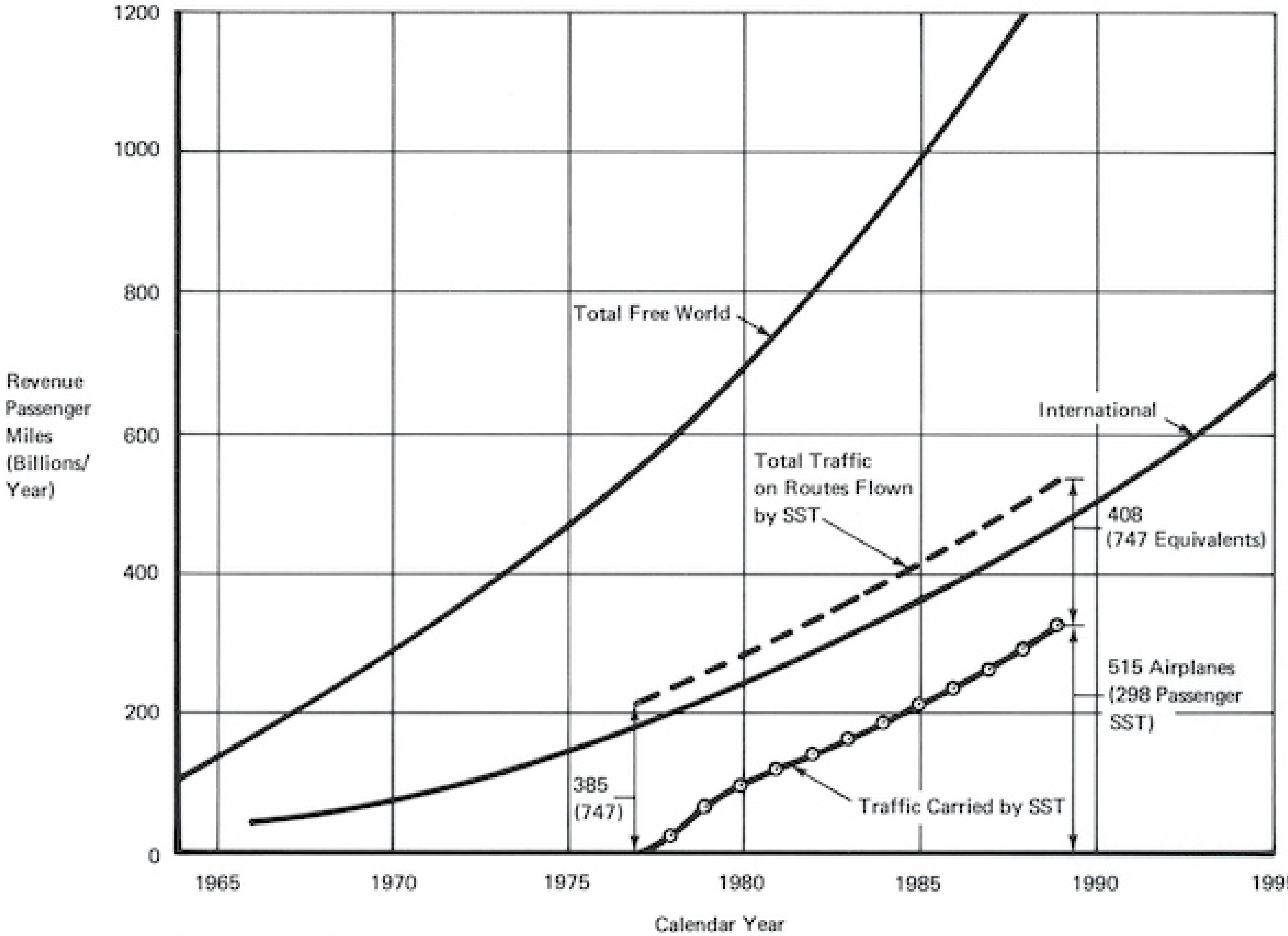
The results of the study indicate that the delivery rate of slightly less than four airplanes per month will serve about 75% of the projected international market by 1990 (515 airplanes). The passenger miles flown by the 515 SST fleet in 1990 represents about 25% of the projected total world traffic at that time (see Fig. 4-L). It is significant to note that the SST fleet, while limited to essentially over-water routes, will handle more traffic than the total free world traffic of today.

It should be noted that the total traffic forecasts on the specific SST routes exceeds the international traffic estimate. This is attributed to the fact that many of the SST routes in the European network must "tag-end" into the various countries to service the principal cities such as Copenhagen, Frankfurt, Bergen, Milan, and Rome. Further, the SST route traffic is the result of a detailed build-up of city-pair traffic rather than the more general approach used in estimating the international traffic.

It is significant to note that the traffic on the SST candidate routes in 1978 requires the equivalent of 385 747 type subsonic airplanes and after introduction of 515 SST's, the routes still require the equivalent of 408 747 types. In effect, the SST introduction into the international system matches the traffic growth rate and a large subsonic requirement will continue. This study was limited to an analysis of airline route structures that exist today and only the major gateway cities were considered. It is probable that the route structure will change by the 1980 decade to take advantage of the SST capabilities and that many more cities will be serviced by the SST than were assumed in this study. The large chart in the back cover of this document identifies some of the most probable cities that will eventually be serviced by the SST.

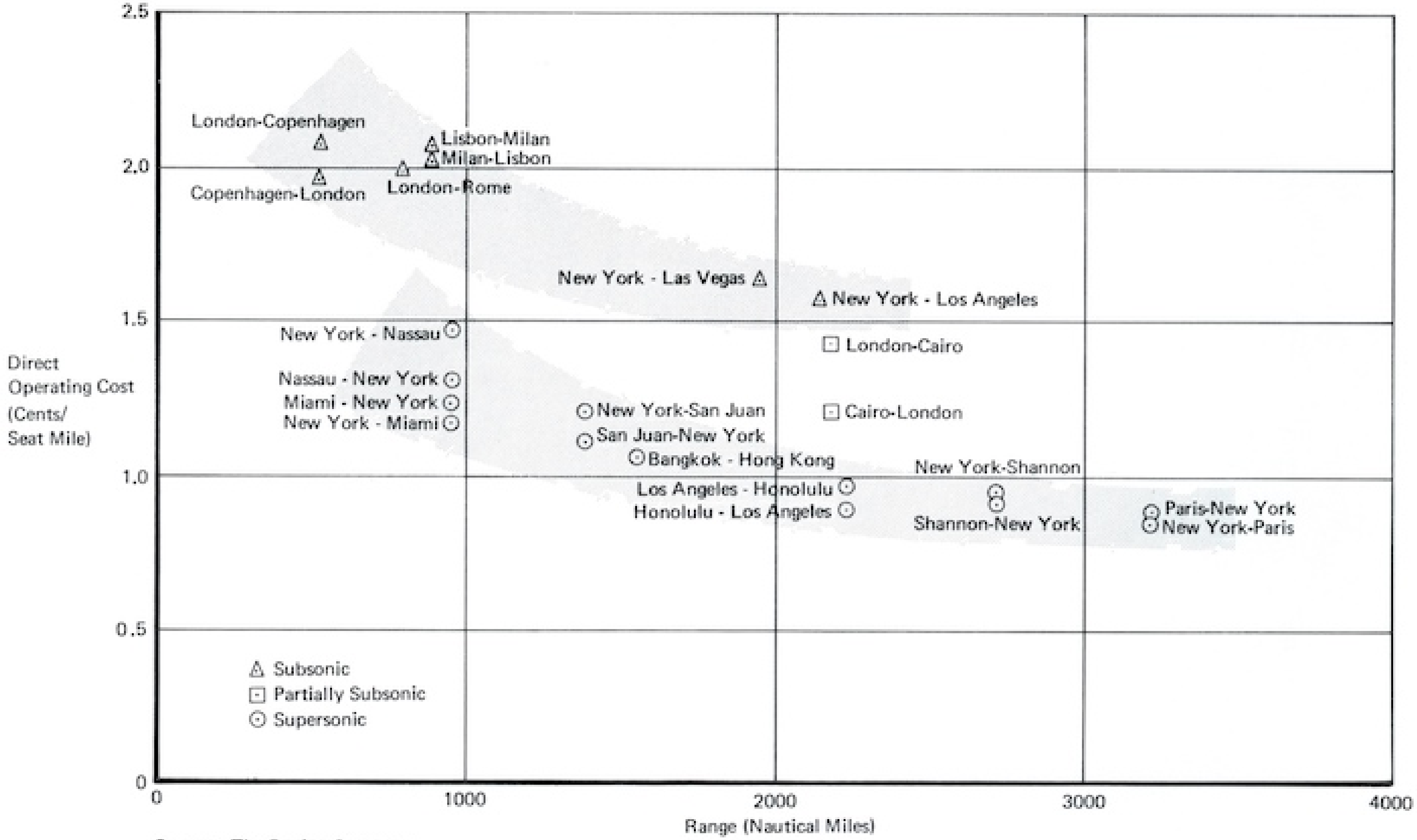
2. Direct Operating Costs

Representative DOC's calculated on the basis of city-pair simulated flight operations are shown in Figure 4-M. These costs are based on actual route mileage, fuel costs, route utilization, and fuel reserves rather than assumed average conditions (see Fig. 4-B). The lower band of data points indicates the range of DOC's on unrestricted supersonic routes, while the upper band



Source: The Boeing Company

Figure 4-L. Free World Traffic Forecast (SST Traffic)



Source: The Boeing Company

Figure 4-M. Calculated Direct Operating Costs for Typical Routes (1980)

indicates DOC's resulting from over-land flying at speeds below the sonic boom threshold. The London-to-Cairo data is representative of a combination of subsonic and supersonic operation. Since the DOC's that an SST achieves vary greatly depending upon the characteristics of the actual route system and the extent of supersonic flying that is available, the DOC parameter has limited value as an economic indicator.

3. Load Factor, Fare, and Yield

In order to assess return on investment, the load factors and yield achieved on each route were assessed on an annual basis. The results are shown in Figures 4-N and 4-O. The average load factors were initially high due to passenger preference and limited penetration, but declined to a stable value of about 50% as penetration increased.

The yield is shown to decline below the economy fare as penetration increases, simulating the history of jet transport penetration of the piston transport market.

It is important to note that this yield does not correspond to a surcharge but rather, it corresponds to the economy class fare structure of today that offers special rates for families, students, and tours. It is this fare/yield relationship that will allow the SST to attract the large amount of international traffic discussed above.

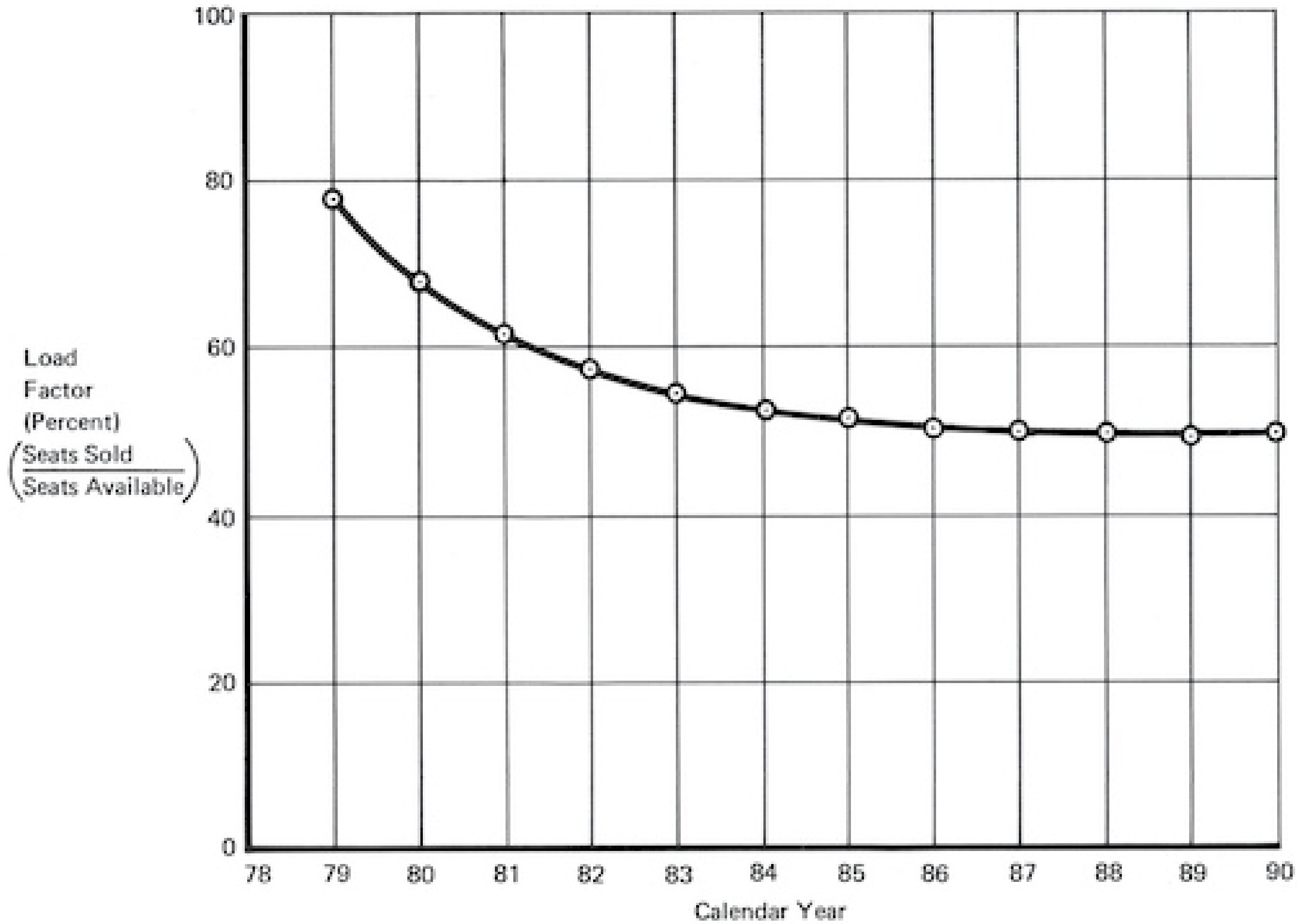
The average yield achieved by 1989 is shown to be 5.6¢ per passenger mile. This yield is a weighted average of the specific world-wide SST routes and includes low yield routes (such as the North Atlantic) as well as high yield routes (such as the South Pacific and Mid-East).

4. Return on Investment (ROI)

The operating costs, load factor, and yield data discussed above formed the basis for a simplified calculation of annual ROI as shown in Figure 4-P.

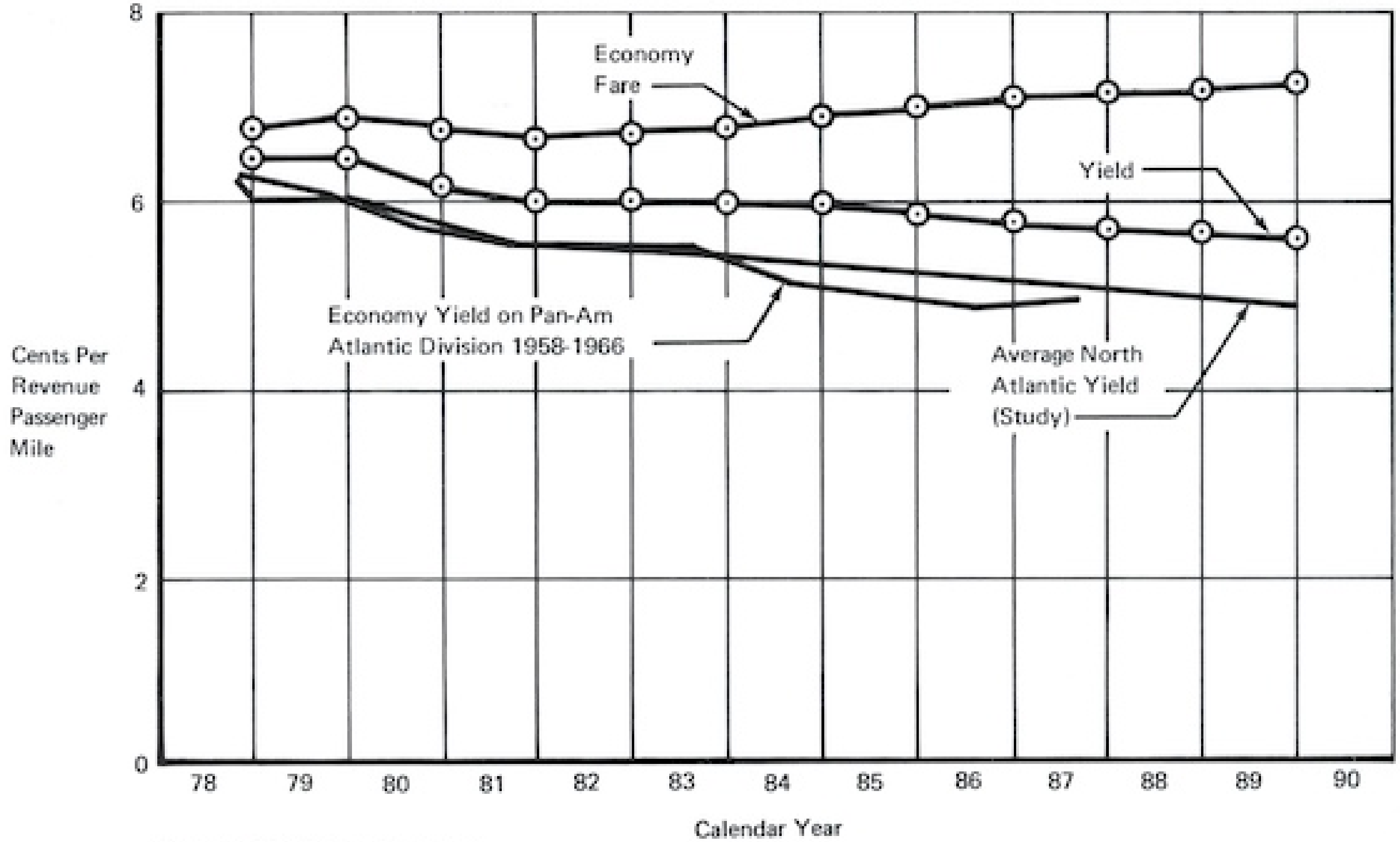
This calculation was accomplished annually to reflect the dynamics of SST introduction taking into account the variations in load factor, yield, traffic growth, airplane deliveries, and route assignments. This dynamic effect is revealed in high profitability in the first several years with a stabilizing ROI of 18% (after taxes-economy fare) occurring toward the end of the 1980 decade.

Based on a CAB regulatory guideline the FAA Economic Feasibility Report suggests a return of approximately 15% (after taxes) on the long-haul equipment is required to assure an adequate return to the carrier on total system investment taking into account the associated short-haul equipment.



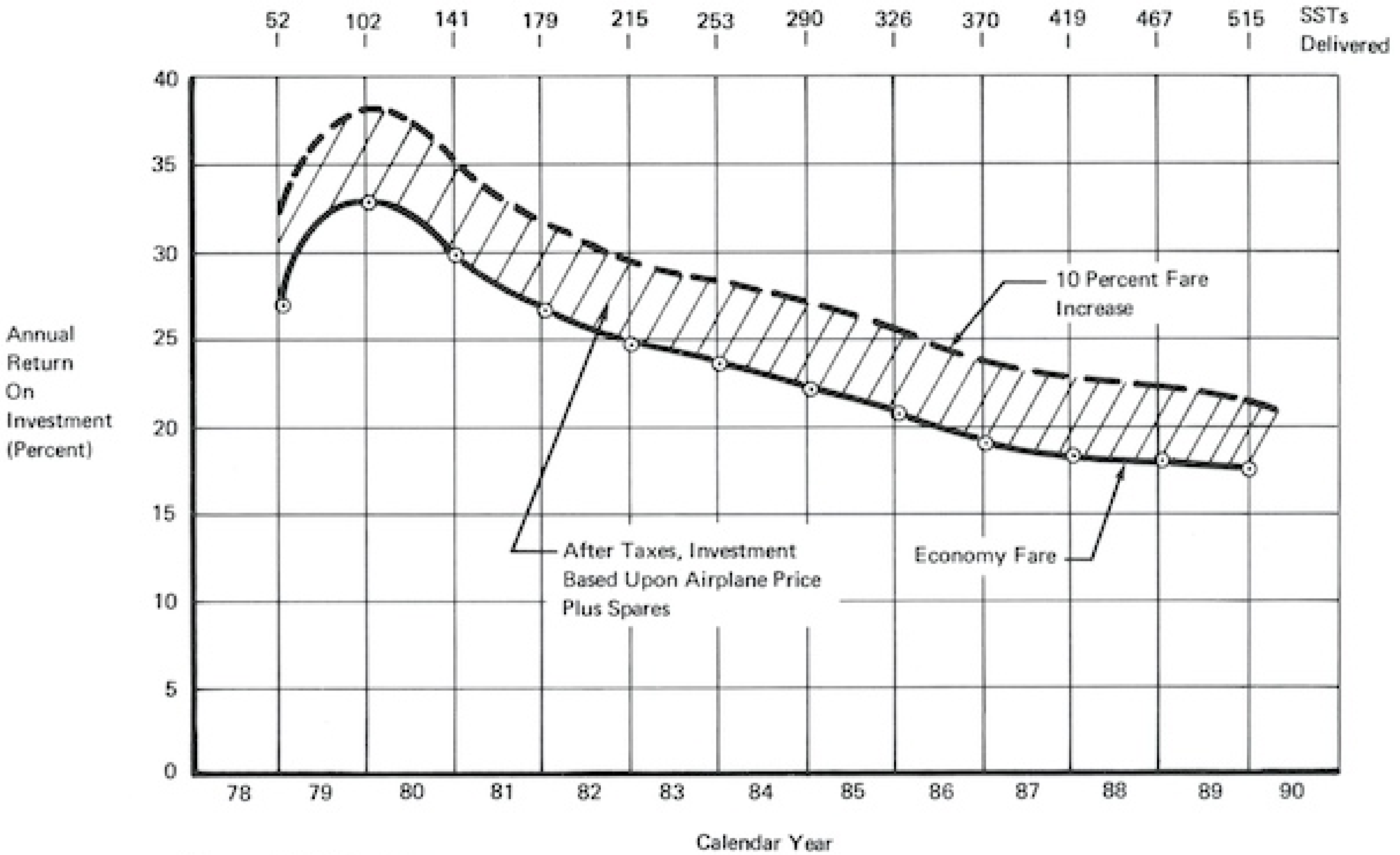
Source: The Boeing Company

Figure 4-N. SST Fleet Average Load Factor (Computed)



Source: The Boeing Company

Figure 4-O. SST Fleet Average Yield/Fare Comparison (Computed)



Source: The Boeing Company

$$\text{Annual Return on Investment (ROI)} = \frac{\text{Annual Cash Flow}}{\text{Cumulative Investment}}$$

Figure 4-P. Return on Investment

The data based upon existing economy class fare structure clearly exceeds the CAB guideline level. The sensitivity of ROI to a 10% fare increase is also shown for reference.

The principal conclusions resulting from the study are:

- The transoceanic type of operation was projected to be an extremely large market by the SST time period. (1978-1990)
- The economic aspects of the projected SST operations appear promising when based upon standardized industry operating cost methods and applied to a detailed route and traffic situation.
- The existing fare structure on the selected routes coupled with the long segment lengths, and high initial load factors promise high profitability in the introductory years and reasonable profitability in the later years.
- Restricting supersonic flight to over-water and unpopulated areas (Overland sonic boom North of Arctic Circle only) does not seriously impair SST operations. Combinations of subsonic flight over land and circuitous routing permits SST service to all free-world major traffic centers.
- Reasonable airplane utilization can be achieved within the existing airline operating and maintenance structures.
- Introduction of the SST followed by a buildup to an operational fleet of 515 airplanes operating in conjunction with subsonic jets appears feasible and would be advantageous to a large segment of the traveling population.

The results discussed above were based on standardized costing methods and do not take into account the historical and projected changes in the various elements of cost. This aspect is discussed in the following section.

OPERATING COST PROJECTION (ESCALATED)

OPERATING COST PROJECTION (ESCALATED)

OPERATING COST PROJECTION (ESCALATED)

The composition of SST total operating costs is such that it is less sensitive to labor cost escalation than are subsonic jets operating costs. This characteristic, which has been generally overlooked, will have a large, favorable effect on the SST's comparative economics when it is operational, and may even result in its having an operating cost advantage.

The air transportation industry has experienced a remarkable growth because the cost of a given air trip has actually declined, while both population and per capita disposable income have steadily increased. This counterinflationary trend has existed even though there has been a steady increase in the cost of nearly every item the airline is required to buy. Figure 5-A shows these aspects of air transportation since the introduction of the 707/DC-8 generation of subsonic jets began in 1958. Figure 5-B illustrates the increasing labor productivity of the airline system and the increasing productivity in terms of seat miles per year of the airplanes in operation for the same period. These increases in productivity are undoubtedly the basis for the declining cost of air travel in the face of inflation.

If the operating cost of an individual type of airplane is investigated, it is found to gradually increase with time, since the employees that operate and maintain the equipment are being paid more as time goes on, and the price of airplane type is gradually increasing due to inflation while its productivity is relatively fixed.

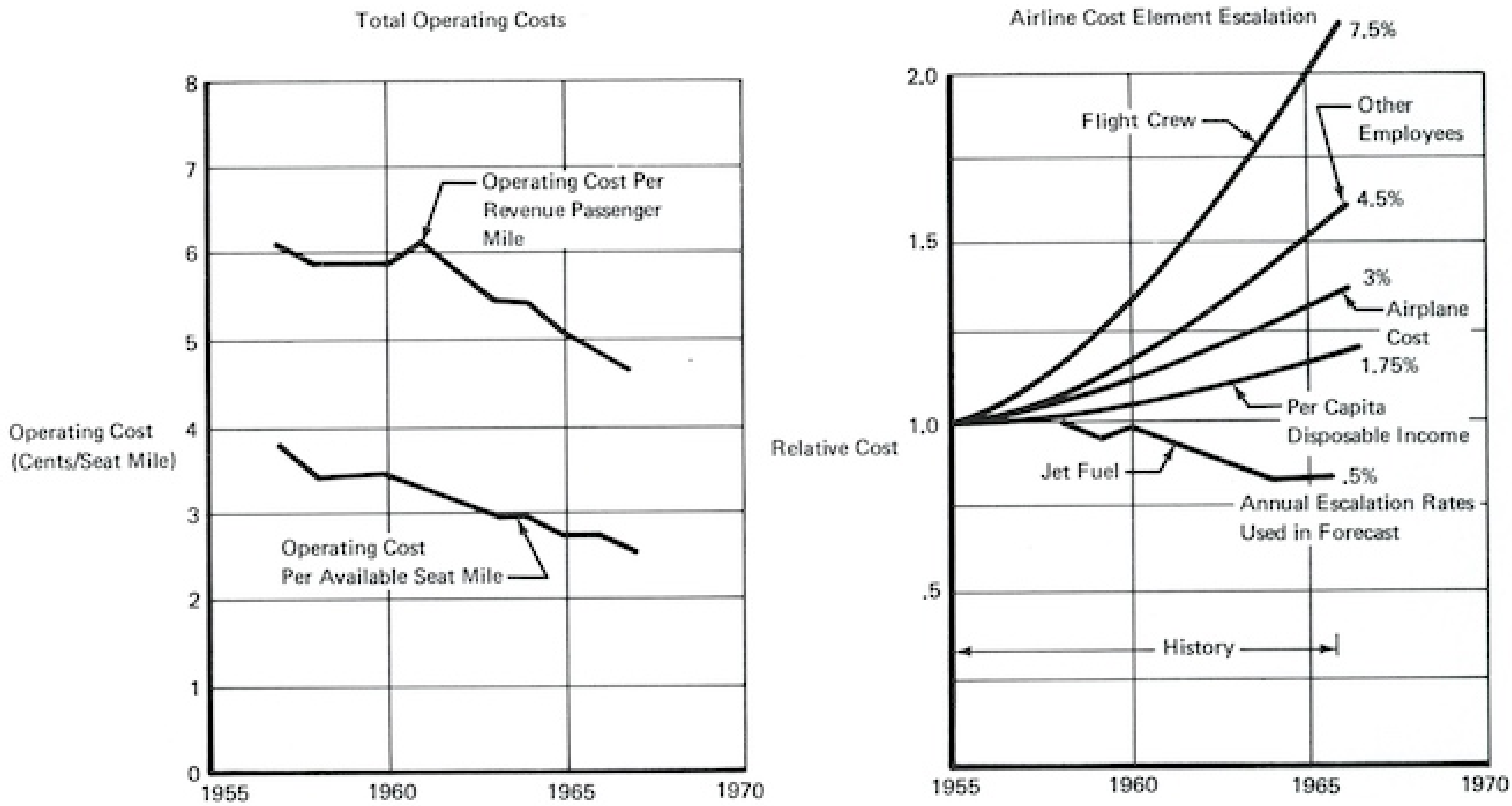
Using Figure 4-C as a starting point, and considering historical cost escalation rates of each of the cost elements, forecasts of the operating cost of the 707-320B, 747, and SST in 1978 and 1988 were developed as shown in Figure 5-C for comparison with the 1968 cost basis. In 1968, the SST would have a total operating cost higher than that of the 747. However, the SST is more productive per hour of labor. Therefore, the SST is less sensitive to wage escalation pressures, and by 1978 (estimated SST introduction) the total operating differential cost will be reduced from an apparent 16% to 4%. The difference continues to narrow and disappears by the latter 1980's after which the SST appears to have a total operating cost advantage over the 747-type subsonic equipment.

The total operating costs discussed above have been expressed in the traditional terms of cost per available seat mile. A more significant parameter is cost per revenue passenger mile since it relates not only to the passengers carried (load factor) but also relates to the actual revenue per passenger mile (yield).

Figure 5-D was developed assuming a load factor of 55% for all equipment in order to be consistent with historical load factors. Cost escalation pressures discussed above result in a trend that tends to close the gap between advanced subsonic aircraft and supersonic airplanes. The predicted influence of high introductory load factors that the SST should achieve because of passenger preference and limited equipment availability is shown in dashed lines. Load factors are anticipated to be initially high and to reduce over a period of about 5 years, while the SST penetrates and captures the transoceanic traffic on the appropriate routes (see Fig. 4-N).

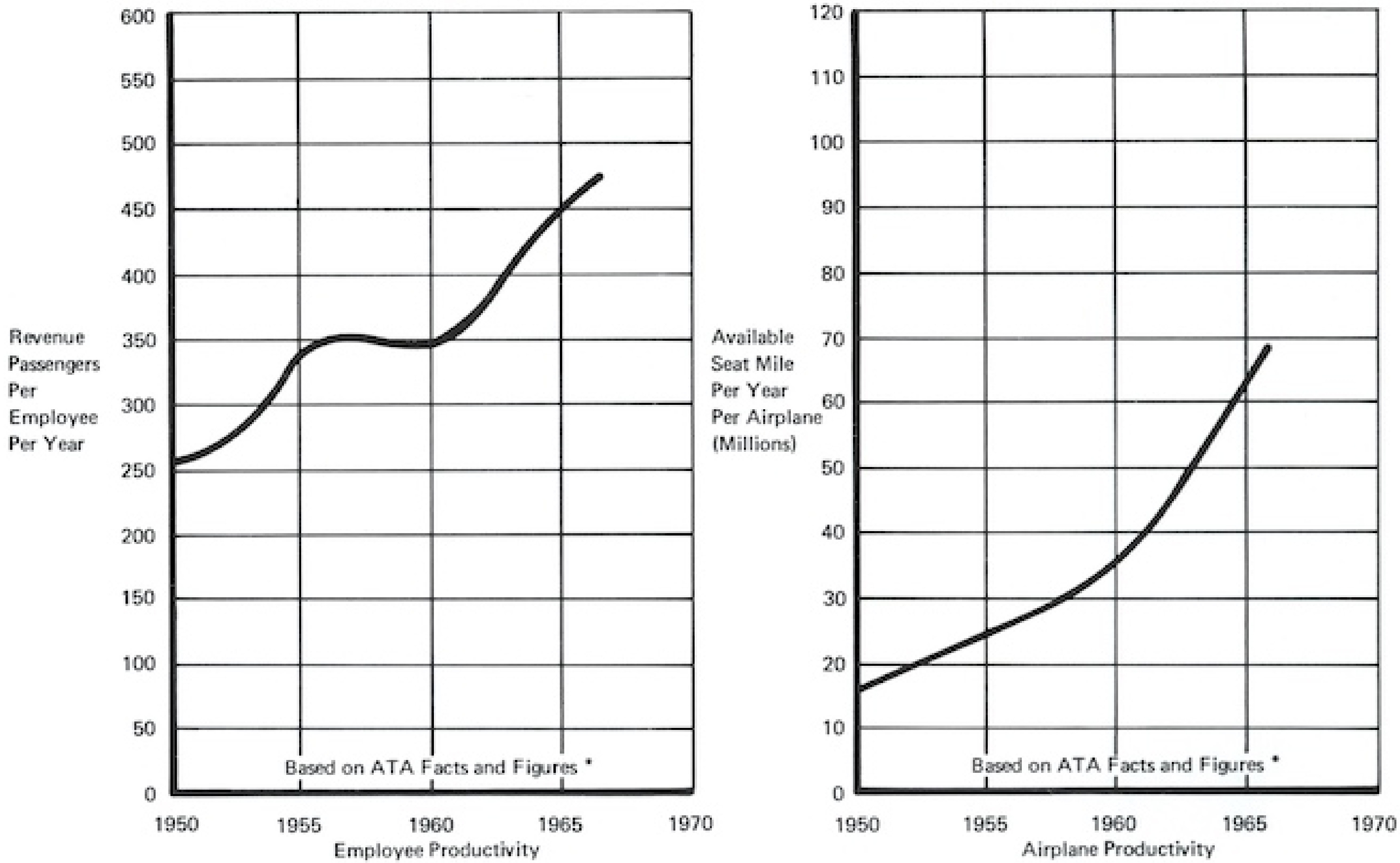
Figure 5-D relates an extension of the current average fare level and a projection of per capita disposable income growth to the operating costs discussed above. It illustrates that operating costs can remain relatively stable while passenger disposable income continues to increase, thereby enlarging the market. Additional data and assumptions for this study are listed in Appendix D.

In summary, the apparent disadvantage in operating economics in the early years will be more than offset by passenger preference and high load factors, and in later years by labor cost escalation trends. Thus, transportation at three times the speed can be supplied at approximately the same cost per passenger mile as the currently planned large-body subsonic aircraft.



Source: The Boeing Company

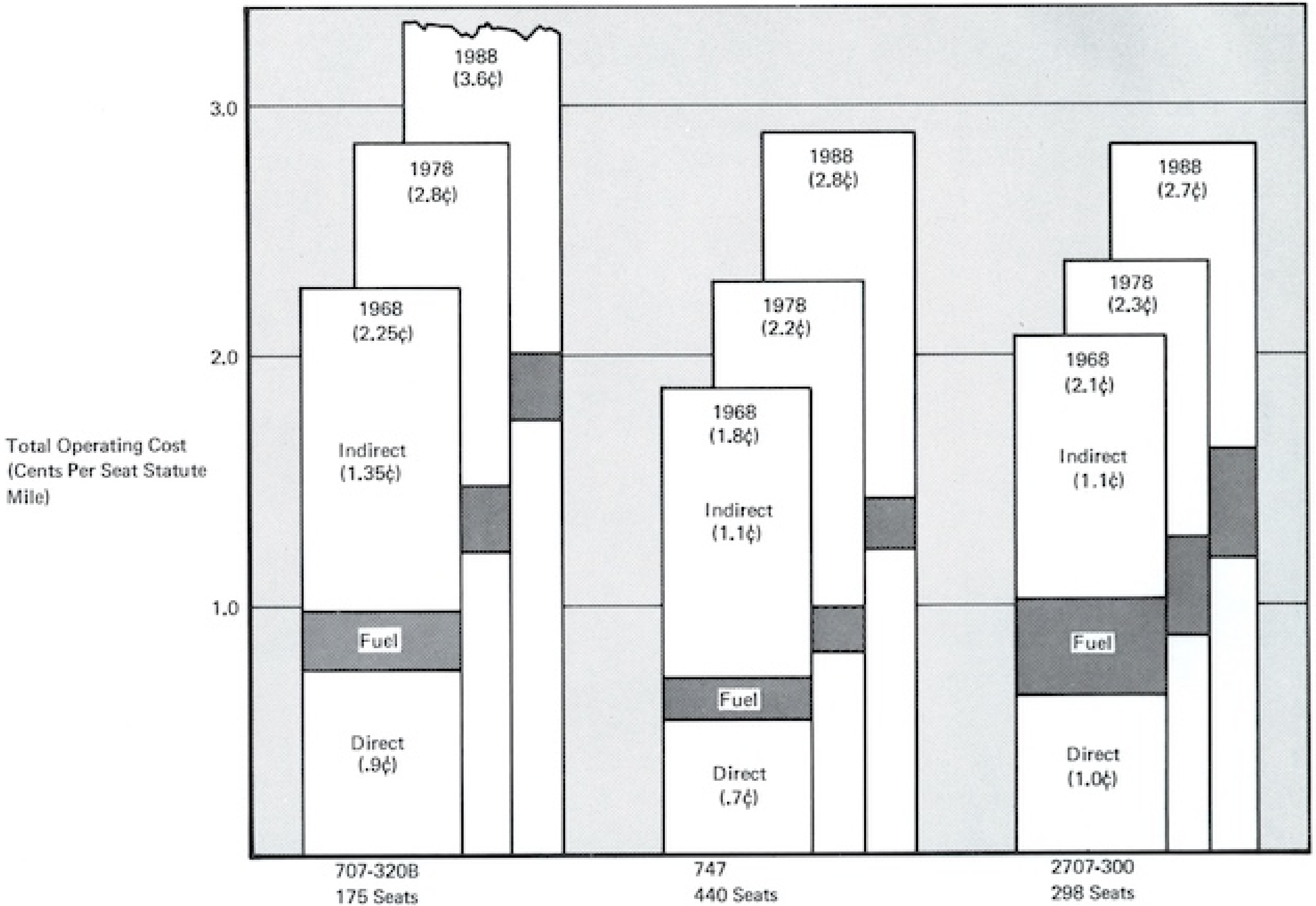
Figure 5-A. Operating Cost Trends



Source: The Boeing Company

* Periodical published annually

Figure 5-B. Productivity Growth



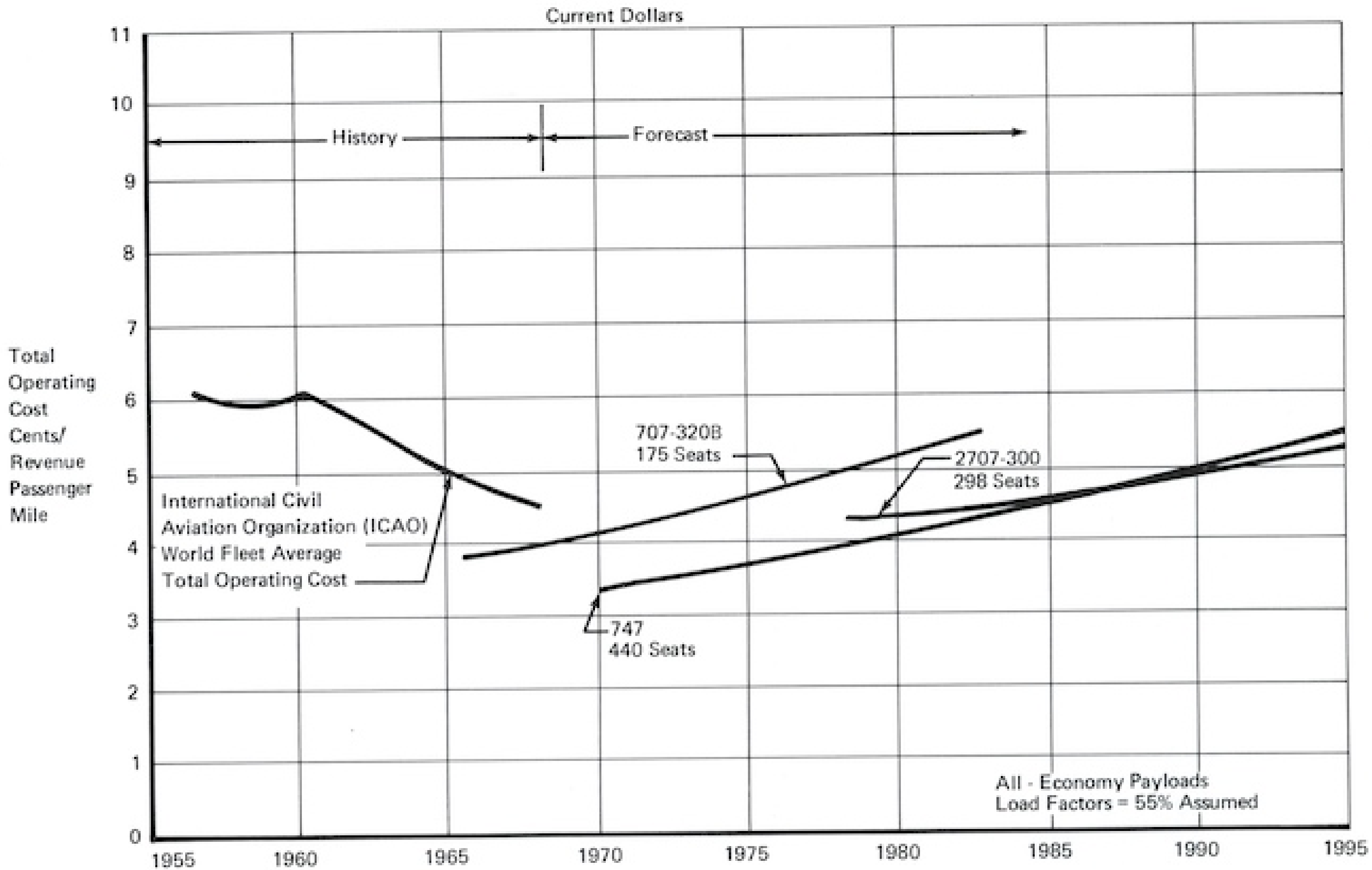
Source: The Boeing Company

Figure 5-C. Total Operating Cost Escalation Comparison (All-Economy Class)

*Weighted Average International Economy Fare on SST Routes


SST With
Introductory
Load Factors


Adv. SST
(400 Seats)
Adv. Subsonic
(600 Seats)



Source: The Boeing Company

Figure 5-D. Total Operating Cost Trends (All-Economy Class)

APPENDIX A FLIGHT FUNDAMENTALS

APPENDIX A

FLIGHT FUNDAMENTALS

Several physical phenomena are unique to supersonic flight. Factors affecting the efficiency of an airplane are changed; productivity is increased, a sonic boom is created and the high-thrust jet engines force attention to potential airport and community noise problems.

Supersonic Flight Efficiency

The flight efficiency of an airplane designed to fly at a given speed, is measured in terms of its payload-range capability. Payload-range is the product of three factors; aerodynamic efficiency, propulsive efficiency, and structural efficiency. The effect of design speed on these three factors is discussed below.

Aerodynamic Efficiency

The aerodynamic efficiency of an airplane is measured by the ratio of lift (upward force) to drag (retarding force), commonly called L/D. During subsonic flight, drag results from air friction and a retarding force associated with the downward deflection of the air by the wing in producing lift. During supersonic flight, an additional retarding force exists called "wave," or "pressure" drag. The additional energy required to overcome wave drag results in the formation of "shock waves" surrounding the airplane. A lower aerodynamic efficiency results as compared to subsonic airplanes.

Propulsive Efficiency

The propulsive efficiency of an airplane is measured in terms of the airplane speed divided by the amount of fuel burned for each pound of continuous thrust generated by the engines. The rate of fuel burned for each pound of thrust is called specific fuel consumption (SFC). Generally, the faster an airplane travels, the higher its SFC. This trend, however, is more than offset by the higher velocity term (V) in the propulsive efficiency factor, V/SFC.

For supersonic flight, the increase of propulsive efficiency with speed makes it economically attractive to go as fast as materials technology permits because speed more than offsets the decrease in aerodynamic efficiency.

Structural Efficiency

The structural efficiency of an airplane is measured by the ratio of its maximum takeoff weight to its operating empty weight. The airplane operating empty weight is maximum weight minus usable fuel, reserve fuel, and payload. While the major component of the empty weight is structure, other operating items such as the engines, crew, unavailable fuel, and emergency gear are all included in operating empty weight.

The structural weight tends to increase with speed as a result of a number of related factors. Most significant of these are additional structure required to offset aerodynamic heating, wing thinness, and body slenderness. Structural efficiency tends to decrease as design speed increases.

Payload-Range

As mentioned previously, the payload-range capability of an airplane is the product of aerodynamic, propulsive, and structural efficiencies. Generally, an airplane is designed to meet specific speed and range requirements, while having satisfactory handling qualities, flight safety provisions, and other characteristics compatible with traffic and terminal facilities. Thus, the optimized end product of design is a best compromise to accomplish these requirements while carrying the maximum payload. Figure A-A illustrates how the three flight efficiency factors vary with the design speed (Mach number) of airplanes, and how payload, the result of these efficiencies, varies with speed.

Productivity

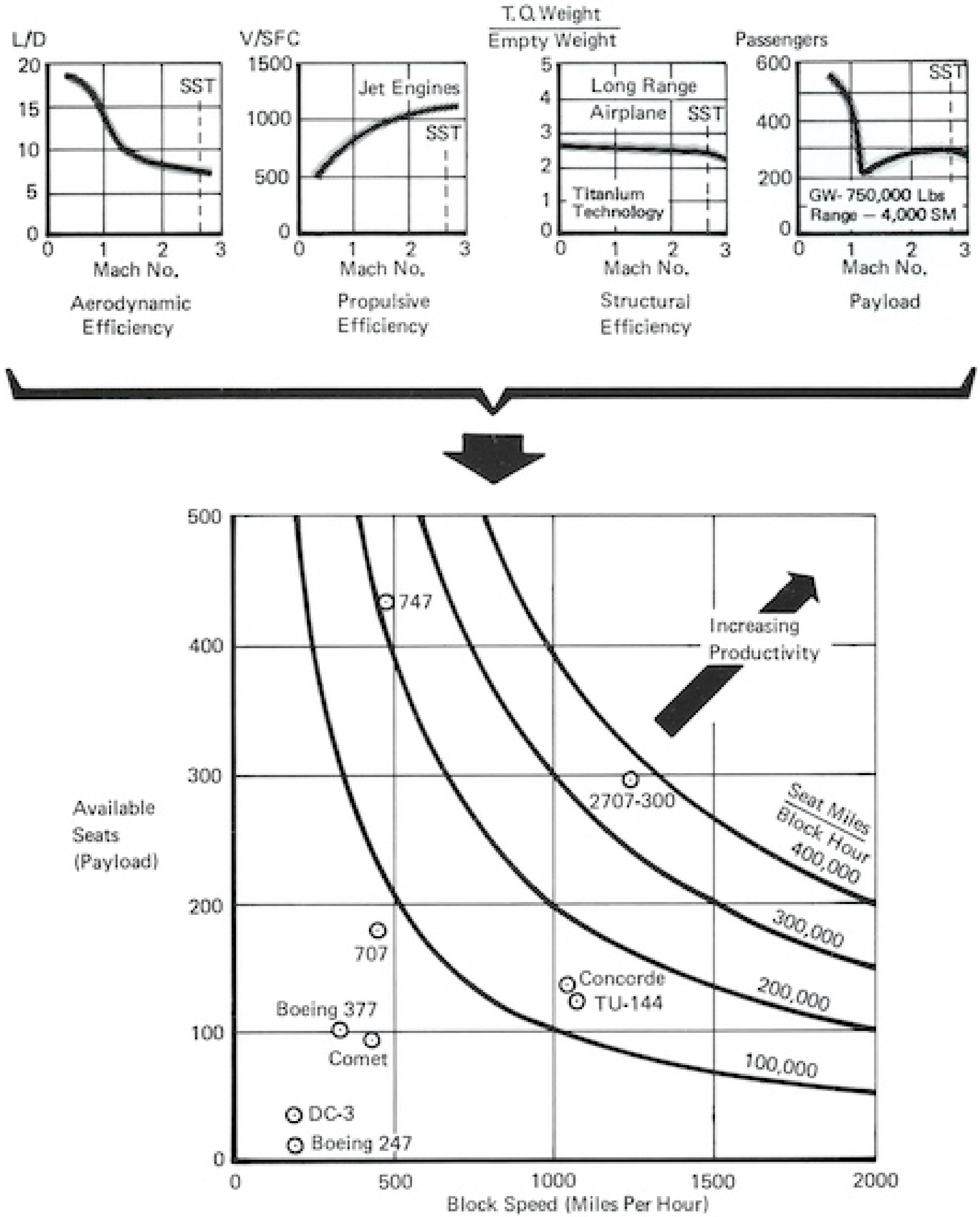
Productivity, which is the index of transportation system performance, is shown in the lower portion of the figure. The importance of speed in air transport productivity is pointed out in the comparison of the SST with several current and future subsonic jets. The productivity of the SST is shown to be 75% greater than the large-body subsonic despite 32% less seats.

Sonic Boom

SST economic studies are based on the premise that the SST will not operate supersonically over land. The cruise speed over land and for operations near airports will be subsonic, producing no boom. Economic feasibility of this operation policy has been confirmed by indepth studies. The characteristics of sonic boom during supersonic cruise are discussed below to provide the reader with a clearer understanding of this unique supersonic phenomenom.

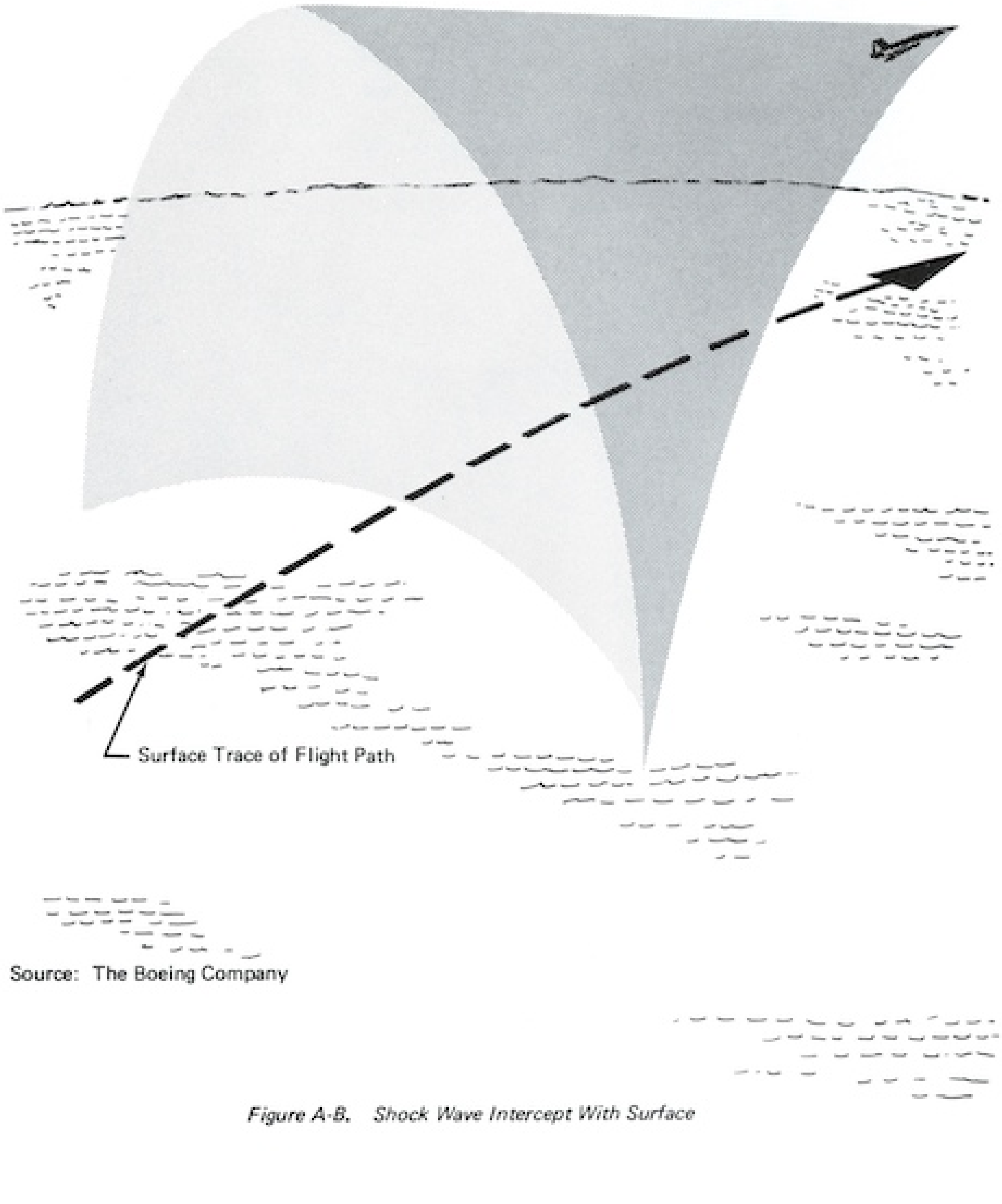
During supersonic flight, air pressure waves are generated similar to the bow wave of a ship. These pressure disturbances join and lag behind the airplane, forming a conical shock wave (Fig. A-B), with the airplane at the apex. This shock wave represents a concentration of pressure waves. The pressure change on the surface across a shock wave from a supersonic airplane at high altitude is about 1/1,000 of the normal pressure of the atmosphere. This is the sonic boom. Figure A-B illustrates the intercept of the shock wave with the surface for an airplane flying supersonically at high altitude.

A typical plot of the sonic boom track on the water for a flight from New York to London is shown in Figure A-C. After takeoff from JFK, the SST flies 90 miles during acceleration to boom producing speed. It proceeds to a point about 30 miles



Source: The Boeing Company

Figure A-A. Flight Efficiency and Productivity



Source: The Boeing Company

Figure A-B. Shock Wave Intercept With Surface

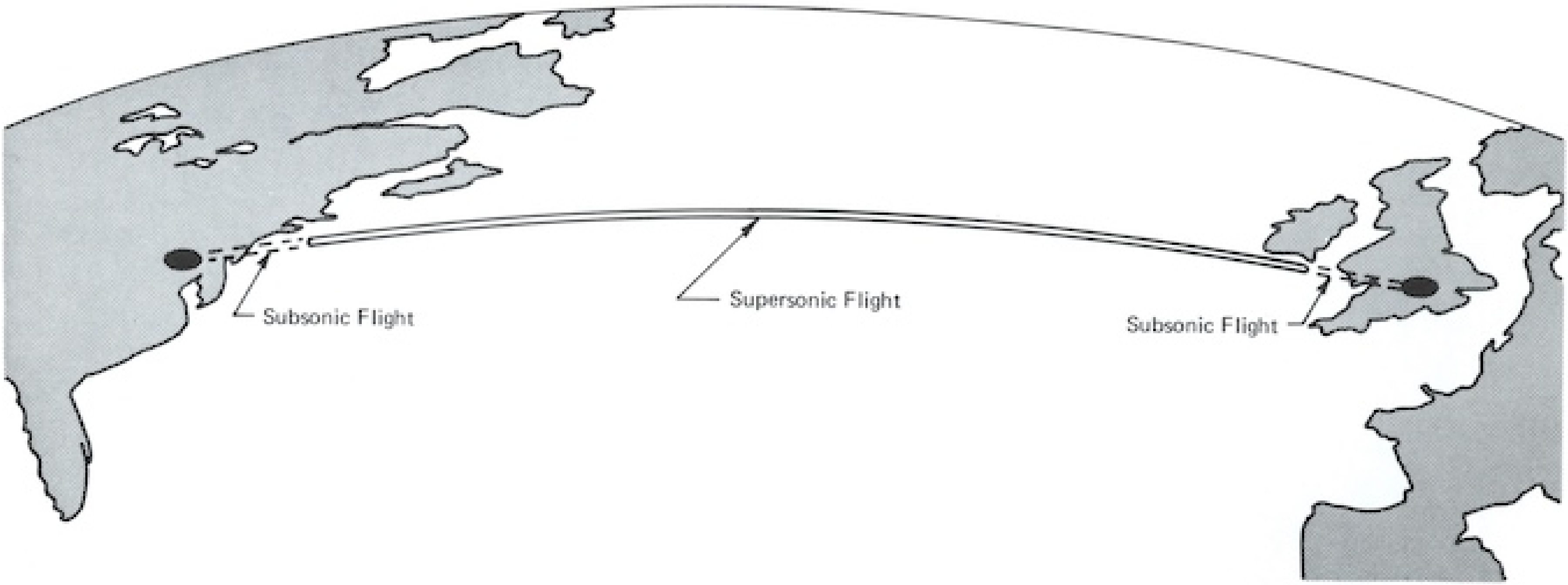


Figure A-C. Typical North Atlantic Flight south of the tip of Newfoundland, then follows a great circle route toward London. It decelerates below boom producing speed prior to arrival at the coastline of England and continues on to London. The route thus flown takes only 2 minutes longer than the most direct (great circle) route.

Airport and Community Noise

Sound, as perceived by the ear, can be defined by its pitch and loudness. Pitch is measured by frequency of vibrations or cycles per second (cps); annoyance is measured in units of perceived noise levels in units of PNdB.

Because of greater thrust, the SST will gain altitude after takeoff more rapidly than current and proposed subsonic jets and, following power cutback for noise abatement, will be quieter over communities near airports.

A smaller-diameter propulsion system with a relatively high jet velocity is required to accelerate through the transonic speed range and maintain efficient supersonic cruise at altitudes above 60,000 feet. The required thrust is obtained by means of a turbojet with an augmentor or modulated afterburner. Figure A-D shows the configuration differences between the augmeted turbojet for the SST and a turbofan engine suitable for subsonic jets.

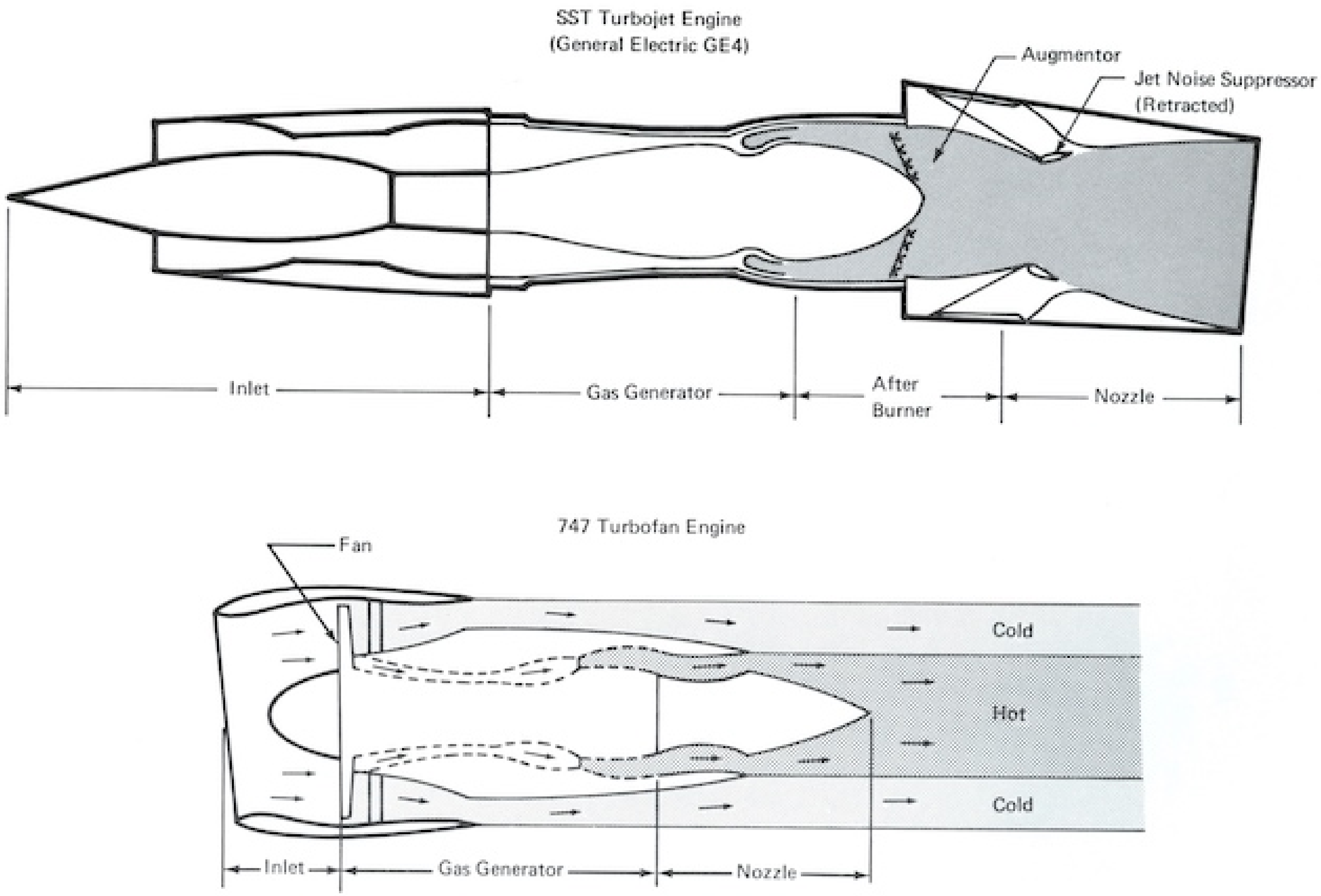
The SST noise objectives established jointly by Boeing and General Electric for the initial production SST are:

- Achieve community noise standards under the flight path comparable to subsonic intercontinental aircraft in the same production period.
- Achieve sufficient sideline noise reduction so that outside the airport boundary the SST will be as quiet as the existing subsonic jets.

Based on extensive design, development, and tests completed to date, these objectives have been achieved in experimental models, and airplane hardware is technically feasible for initial production deliveries. These objectives are consistent with proposed airport noise regulations and land use.

Using a background of many years study in the design of noise suppressors for subsonic as well as supersonic airplanes, Boeing and General Electric are developing a multi-tube nozzle to be used during takeoff to suppress noise and to shift the noise energy spectrum to higher frequencies, which results in a more rapid noise reduction with increased distance.

Figure A-E shows the takeoff noise contours for a production SST with design objective suppression. Corresponding values are shown for a Boeing 707 for comparison with an airplane familiar to the general public. The 747 is expected to be noticeably quieter than the 707. Figure A-F shows the production SST landing



Source: The Boeing Company

Figure A-D. SST and 747 Engine Configurations

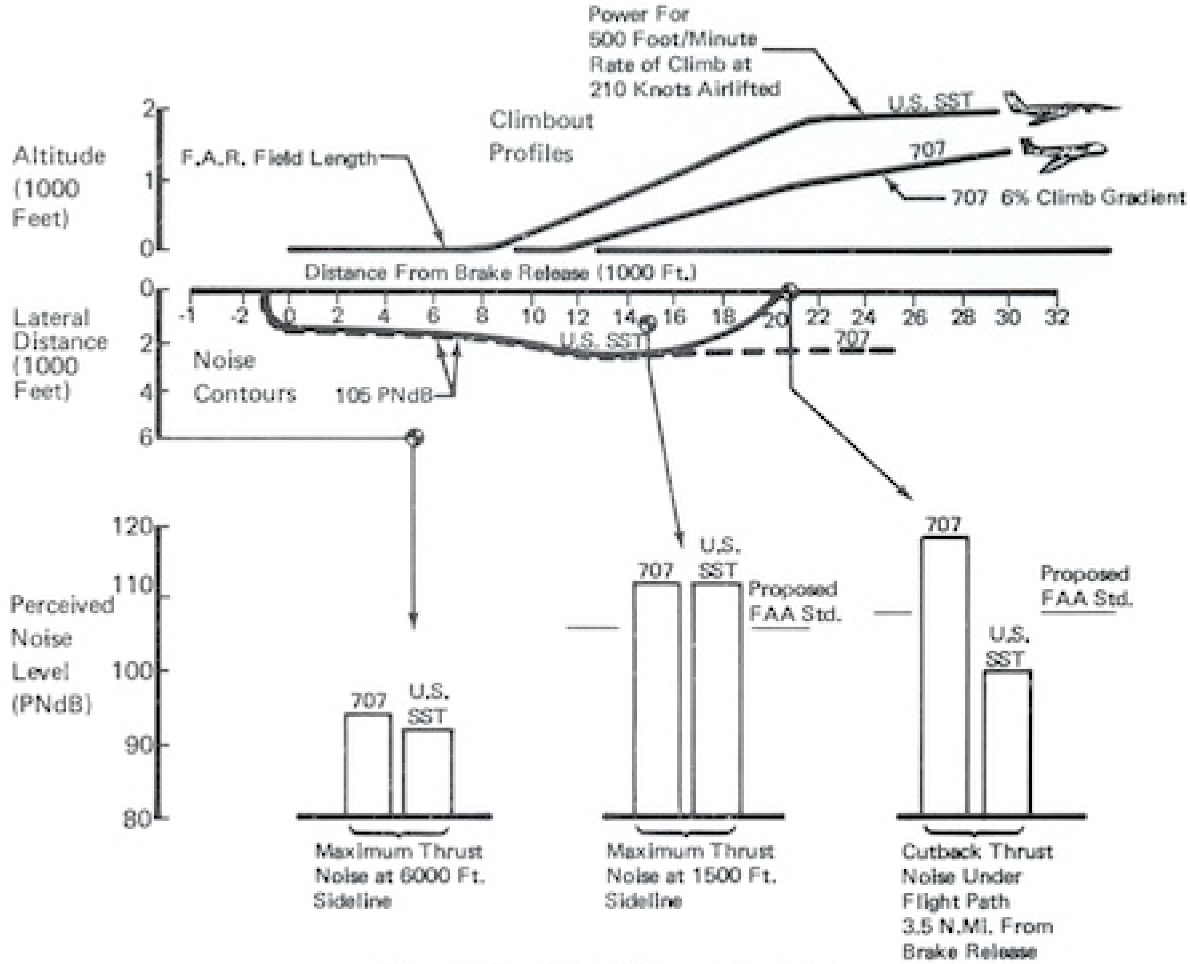
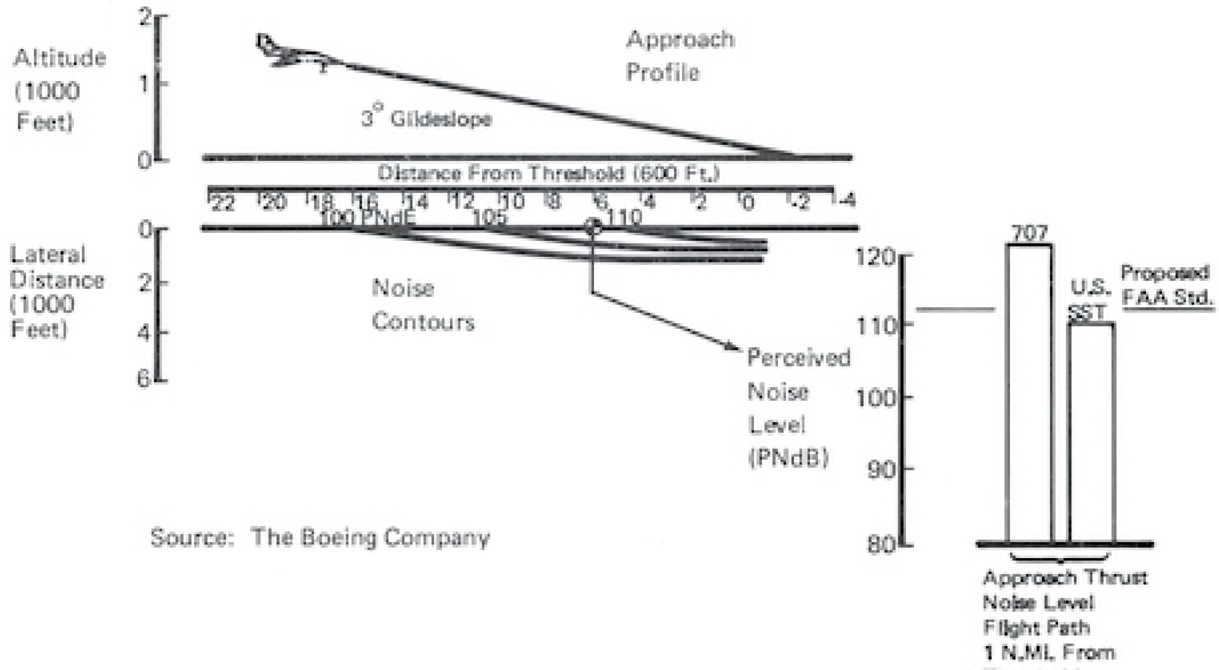


Figure A-E. Takeoff Community Noise



Source: The Boeing Company

Figure A-F. Landing Community Noise

noise contours with values compared with a Boeing 707. These figures show that the SST will generate less noise on the airport during takeoff as well as being quieter over the community during climbout. The SST will also be quieter during airport approach and landing.

APPENDIX B AIRPLANE DESCRIPTION & PERFORMANCE

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APPENDIX B

AIRPLANE DESCRIPTION AND PERFORMANCE

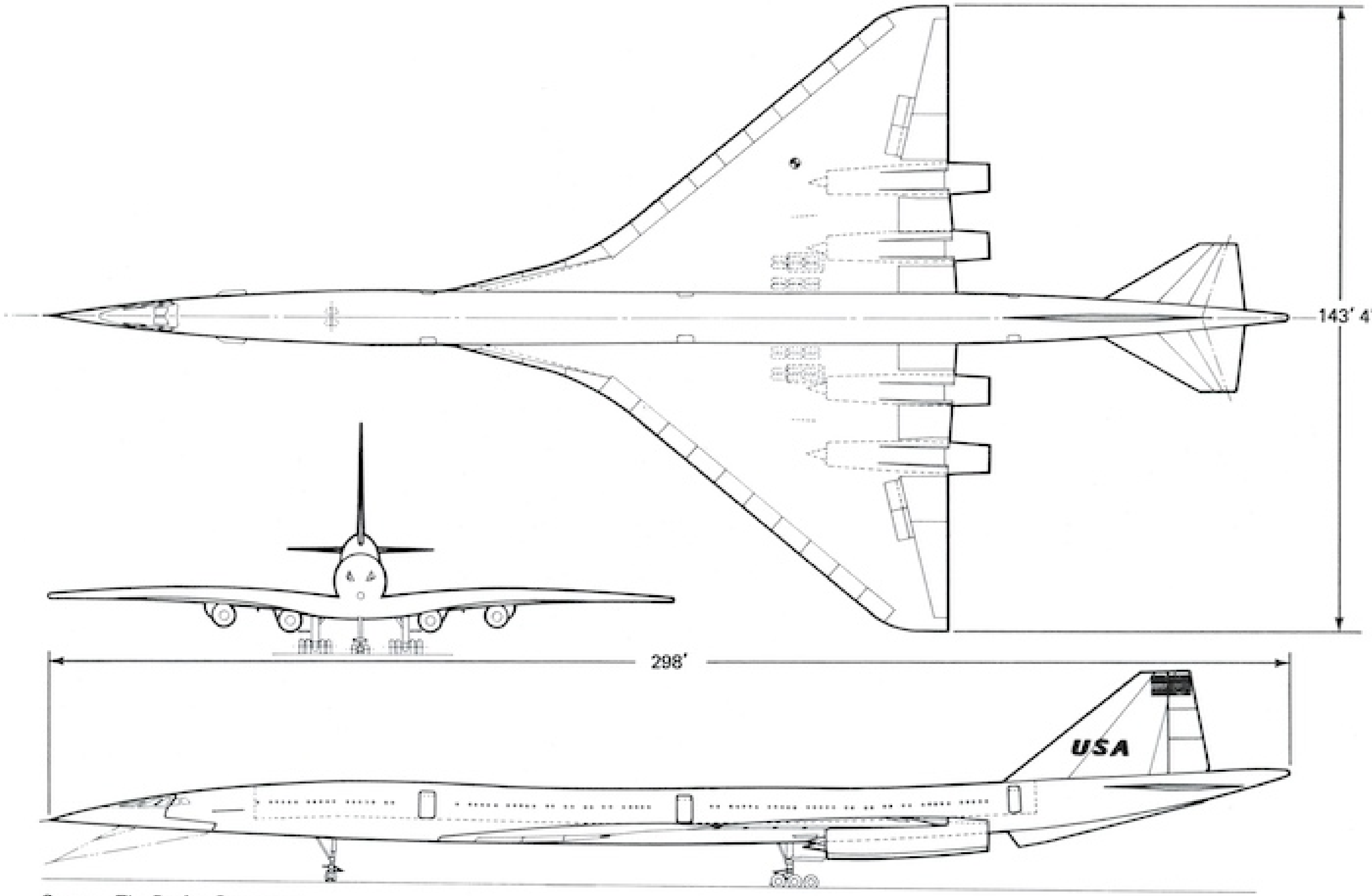
The 2707-300 airplane provides a balanced combination of performance, flying qualities, and operational characteristics. Its delta wing, with aft tail design, meets performance goals specified by the FAA and airlines. A general arrangement of the airplane is shown in Figure B-A and an economy class interior arrangement is shown in Figure B-B.

Figure B-C shows estimated range capability with a maximum payload of 298 economy class (tourist) passengers. Range available with full payload is over 4,000 statute miles. For lesser payloads, the range is increased as additional fuel is substituted for payload.

Figure B-D illustrates the Approximate Range Capability at various cruise speeds. The design permits efficient operation at high subsonic Mach number, as well as at the design point of M 2.7. Its range at M 0.95 is approximately 3,500 statute miles.

Other design data of interest are given below:

Maximum Design Taxi Weight	750,000 pounds
Engine – General Electric GE4/J	67,000 pound thrust
Passenger Capacity	298 Seats (economy)



Source: The Boeing Company

Figure B-A. General Arrangement

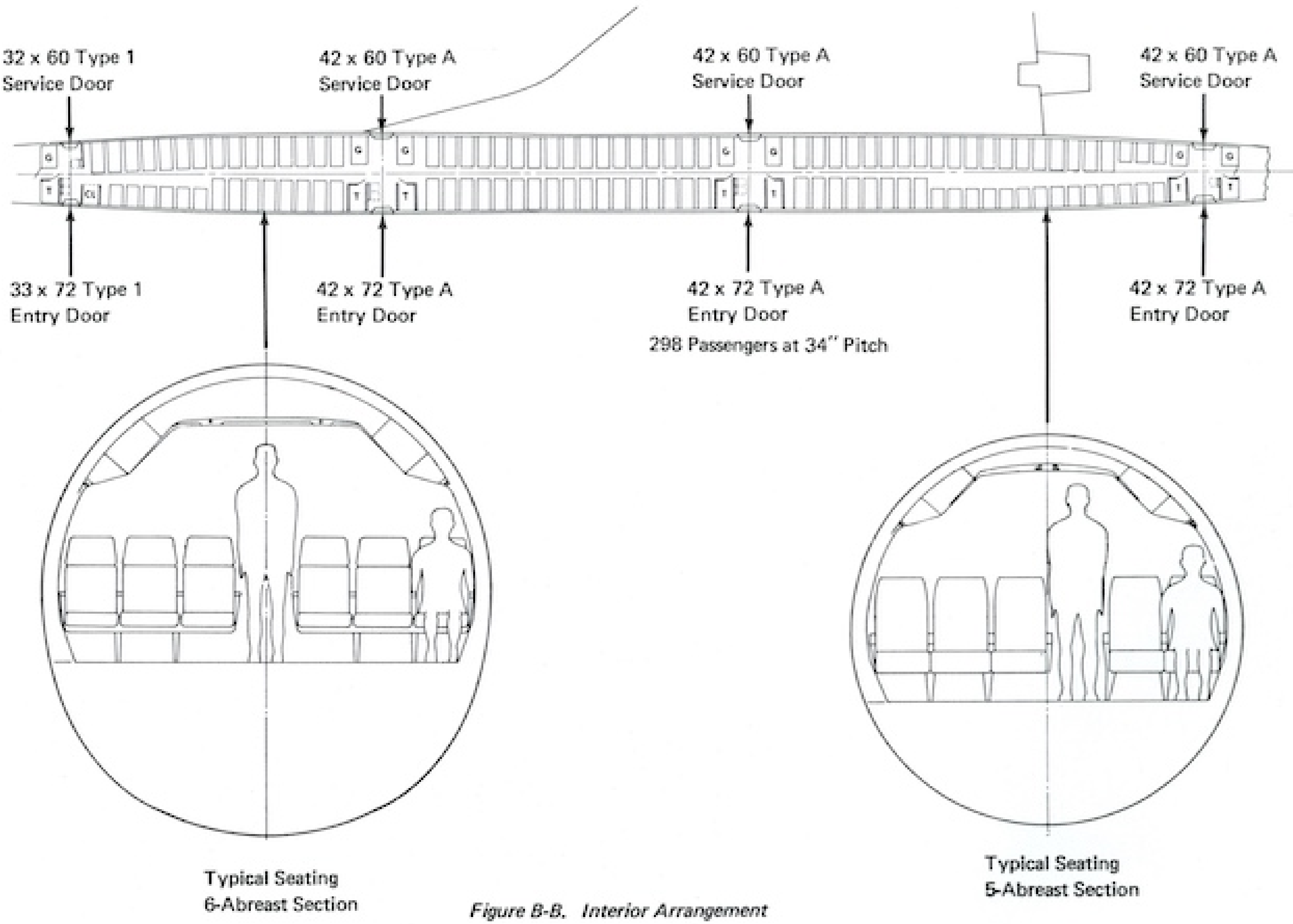


Figure B-B. Interior Arrangement

APPENDIX C AIRPLANE UTILIZATION

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APPENDIX C

AIRPLANE UTILIZATION

A study of a twenty-airplane fleet was performed on a segment of a major airline's route structure in an effort to realistically assess the SST scheduling and utilization capabilities.

This study was based on the following:

- Assumed airport curfew from midnight to 6 a.m. at all airports except Asia on round-the-world flights.

- Although the SST has the capability of 30 minute station time for turn-around as shown in Figure C-A, the station time was extended where practicable, and as required to permit executing the necessary 50- and 300-hour periodic checks.

- Twenty airplanes were used in the study. Nineteen airplanes were actually scheduled in service with the twentieth held in reserve as a backup for unscheduled maintenance and other contingencies.

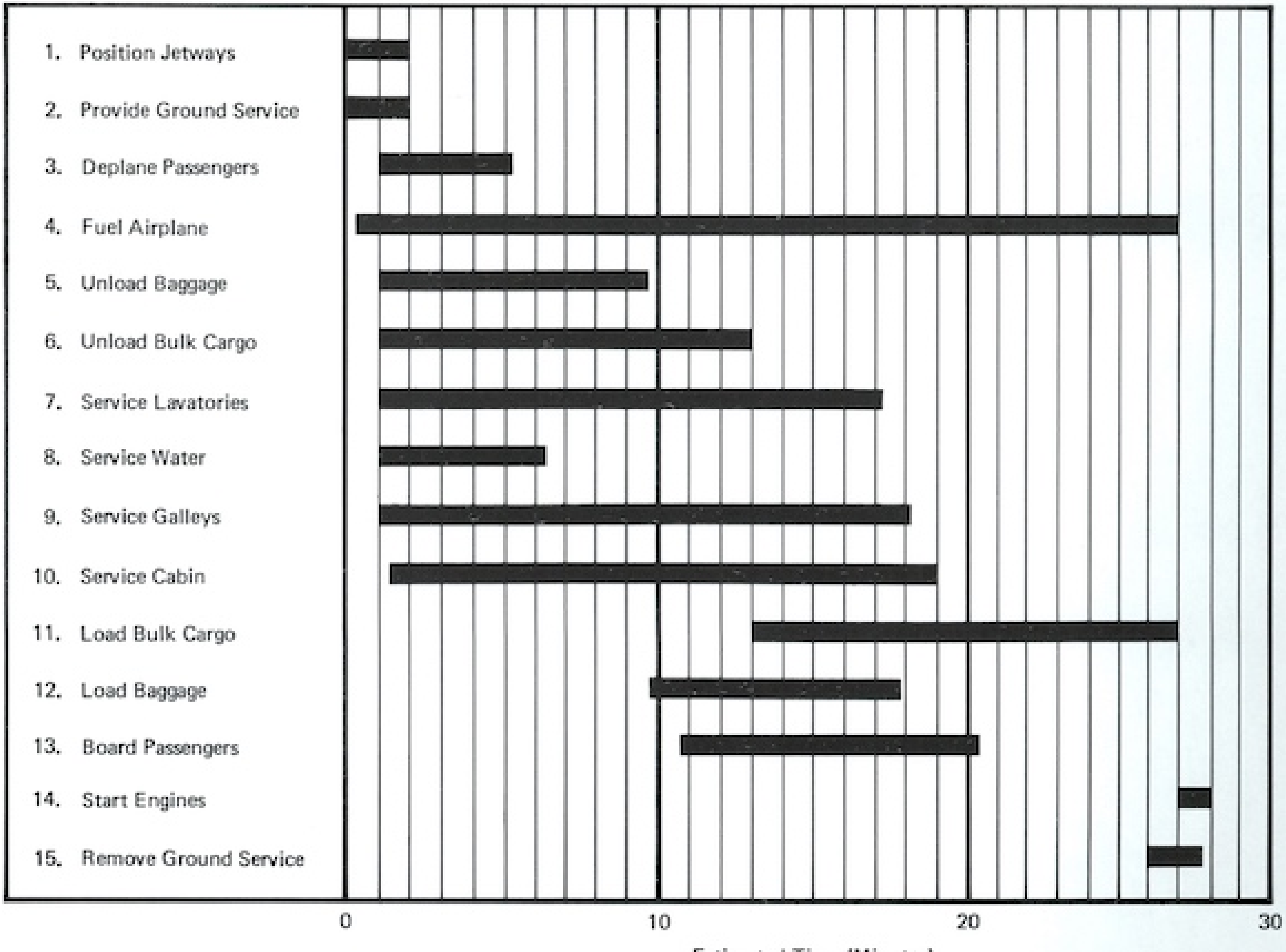
- All airplanes were routed through New York on a periodic cycle, with cycle periods being 48 and 72 hours.

- Two airplanes were always on the circuit for a 48-hour cycle and three airplanes were always on a circuit for a 72-hour cycle.

- Midnight to 6 a.m. curfew at New York permitted time for 300-hour checks and rotate aircraft for the next day's schedule.

In the twenty airplane system, one airplane was held as a backup with 19 airplanes assigned routes on a realistic basis. The flight schedules included actual flight times, realistic stop times and sufficient conservatism to permit unscheduled delays to occur without adversely affecting the complete cycle. This study resulted in an average of 12 hours per day utilization, which was computed by adding the total hours flown by 19 airplanes and then dividing by 20 airplanes for a 20 airplane fleet average. The backup airplane is rotated in such a manner that all 20 aircraft will eventually serve a backup cycle.

The scheduling did not consider connecting flight schedules nor optimized departure times, however the curfew limitation was illustrative of the optimized departure time effect. The conclusion drawn from the study was that contrary to present experience with short average flight time equipment, such as the 727 scheduling would probably not be the limiting factor in SST utilization. The high speed of the SST combined with the change in time zones on the major routes provides the degree of freedom required to achieve utilization comparable with the long haul subsonic jet airplanes of today.



Source: The Boeing Company

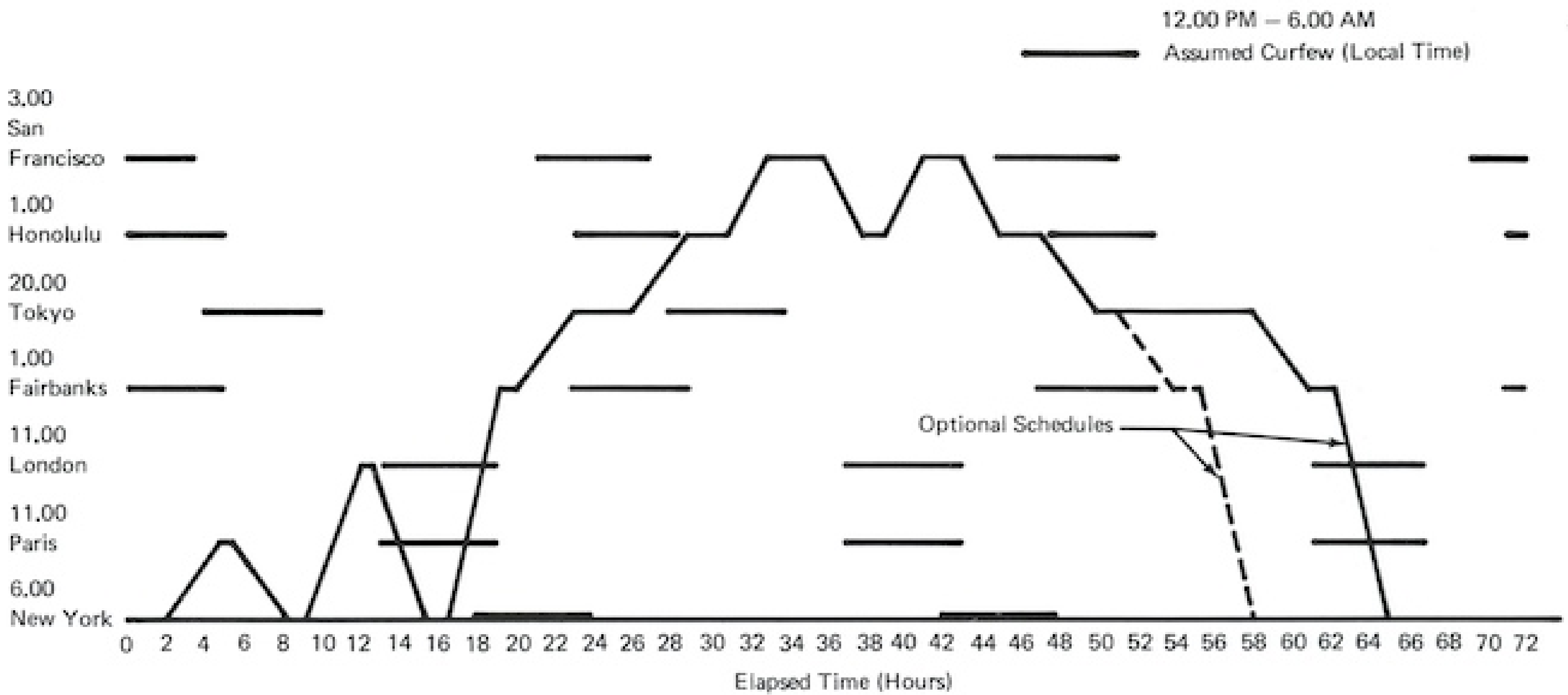
Figure C-A. Turnaround Time – SST Design Objective

Illustrative examples of the SST scheduling capability are shown in Figures C-B and C-C. These figures also illustrate SST speed capabilities. Starting from New York, daylight round-the-world service can be provided in both directions. Also, proper scheduling can provide complete round-the-world service without over-nighting or violating a curfew.

Figure C-B illustrates the round-the-world capability where one SST completes a cycle in three days. Daily service is provided, hence three airplanes are required on the route. Figure C-C illustrates a slightly different SST capability. After spending a day making two North Atlantic crossings, Europe curfews of midnight to 6 a.m. prohibit further SST maneuvering from New York to Europe. The SST can then be turned around and flown west to the Far East.

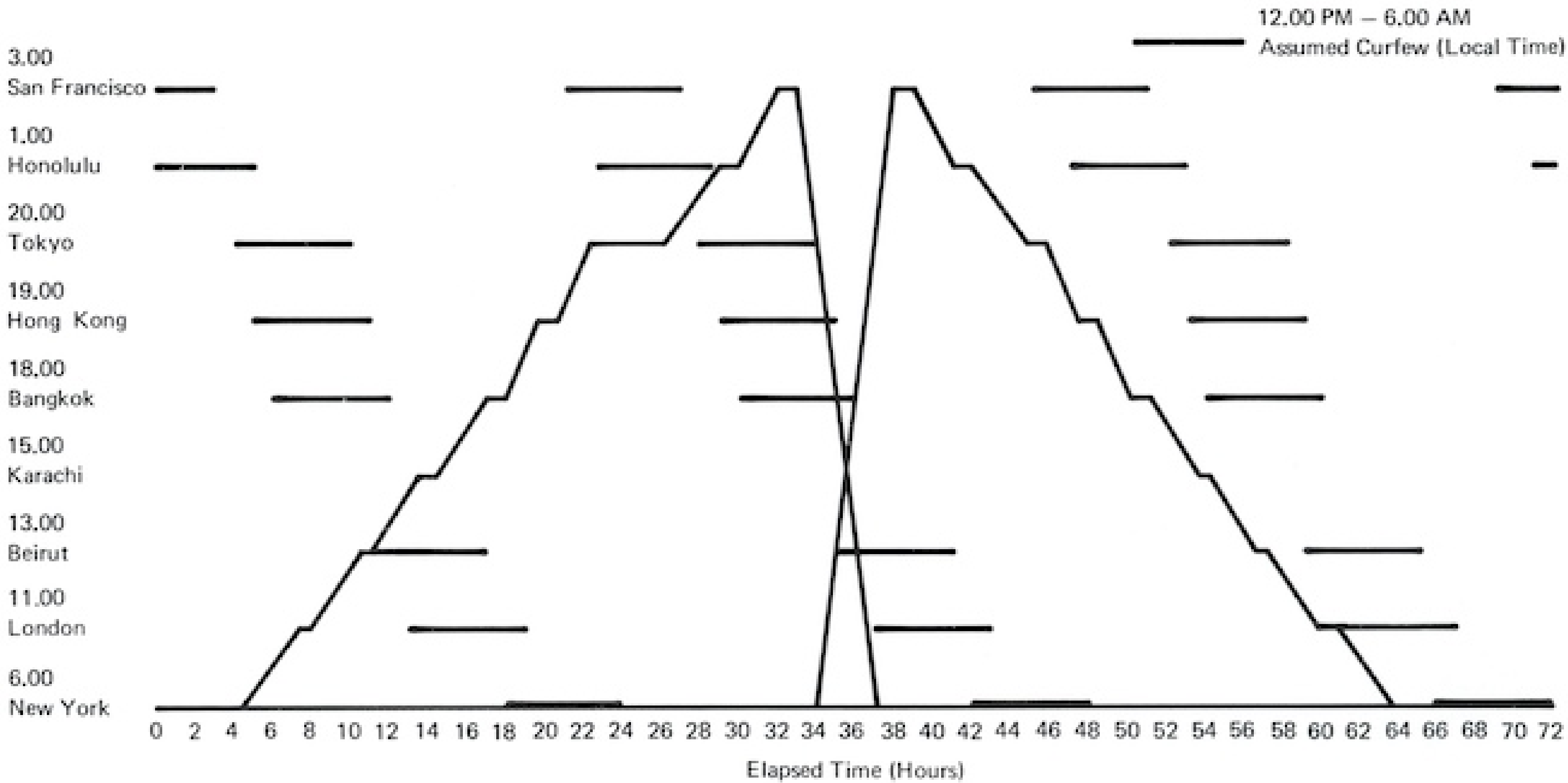
The elapsed time is shown on the abscissa and the airports are shown with their respective local times on the ordinate. Curfews along with elapsed times for arrivals and departures are indicated by horizontal bars. To find the local airport time of arrival and departure, add the local time shown on the ordinate to the elapsed time from the abscissa.

It can be seen that 12-hour utilization can be achieved on routes projected for the SST while respecting curfews and allowing station times longer than the 30 minutes turnaround capability. Within these schedules longer station time is available for the necessary scheduling margin required by unpredictable delays.



Source: The Boeing Company

Figure C-8. Typical SST Schedule (Atlantic and Pacific)



Source: The Boeing Company

Figure C-C. Typical SST Schedule (Around the World)

APPENDIX D STUDY ASSUMPTIONS

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APPENDIX D

STUDY ASSUMPTIONS

Assumptions used in the SST Operating Economics Study and Operating Cost Projection studies are described in the following paragraphs.

SST OPERATING ECONOMICS STUDY (1968 Costs)

The SST introductory market study described in the body of this document was based on a production airplane with characteristics as listed in Appendix B.

Existing international route structures were used with SST networks developed to conform to forecasts of total free world and international traffic. Basic data and restraints employed for operations and economic analyses equations are identified below.

Operations

Routes and Traffic

- The introductory market study traffic forecast is based on a conservative annual growth rate of 10% for total free world traffic from 1970 to 1990. This can be compared to an annual average growth rate of approximately 14% recorded for total free world traffic between 1958 and 1968.
- Traffic between major world areas per Boeing Marketing forecast.
- City-pair traffic proportional to 1967 flight frequencies.
- Route structure used similar to 1967 existing international route structure, except: traffic rerouted as required for sonic boom restrictions and range limitations.
- No supersonic flights over land except north of the Arctic Circle

Deliveries and Assignments

- Delivery Rate

		Airplane in Study
January 1978	1 airplane	1
Feb. 1978-Dec. 1979	approx. 5/mo.	101
Jan. 1980-June 1986	3/mo.	244
July 1986-Dec. 1989	4/mo.	169
SST's in Study		515

- SST Assignments

  1. 1978 and 1979 airplanes assigned to airlines per FAA reservation list.

  2. Subsequent airplanes assigned to airlines on basis of 1967 international fleet sizes.

  3. Route assignments made on basis of traffic and competition.

Scheduling

- Curfew limitations: 12 p.m. to 6 a.m.*

  30 minutes minimum station thru time.

  *except round-the-world trips.

- Scheduled A/C on airline route structures to achieve 11 to 12 hours per day utilization.

- Schedule overnites at existing major bases on 1- or 2-day basis.

- Transonic service limited to trunk route requirements.

- No subsonic legs scheduled except as limited by minimum range.

- Detailed schedule made for first airplane on route. Assumed succeeding A/C could maintain same schedule.

Load Factor

Load factor varies as inverse functions of traffic penetration. Based on load factor history of U.S. carriers in international market during jet introduction into piston market (1959 through 1964). Yield varied in a similar manner.

Yield/Fare

- Economy class fare on each route used as basis for computing yield.

- Yields based on history of U.S. carriers in North Atlantic during jet introductory years of 1958 through 1964. Yield in study reduced as function of market penetration and time, to duplicate historical trend.

Direct Operating Cost (DOC) – 1967 ATA Method

- Cockpit crew cost = (0.05 GW/1000 + 200.00) x Block time
- Fuel cost = (Block fuel) x 1.02 x Fuel price
- Insurance cost = 0.02 x Airplane price x Block time/Utilization
- Maintenance cost

1) Airframe labor

(a) Flight Cycle = $(.05 \frac{Wa}{1000} + 6 - \frac{630}{\frac{Wa}{1000} + 120}) \times R_L \times \sqrt{M}$

where Wa = Airframe weight
M = Cruise mach number
R_L = Labor rate ($4/hr.)

(b) Flight time = $.59 (.05 \frac{Wa}{1000} + 6 - \frac{630}{\frac{Wa}{1000} + 120}) \times$ Flt time $\times R_L \times \sqrt{M}$

2) Engine labor

(a) Flight cycle = $(0.3 + \frac{3 \times \text{Thrust}}{100000}) \times$ No. of Eng $\times R_L$

(b) Flight time = $(0.6 + \frac{2.7 \times \text{Thrust}}{100000}) \times$ No. of Eng $\times R_L \times$ x Flt time

3) Airframe material

(a) Flight cycle = 6.24 x Airframe cost/10^6

(b) Flight hour = (3.08 x Airframe cost/10^6) x Flight time

4) Engine material

(a) Flight cycle = 2.9 x No. of Eng. x Cost/Eng/10^5

(b) Flight hour = (4.2 x No. of Eng. x Cost/Eng/10^5

- Maintenance burden = 1.8 x (Airframe labor + Engine labor)
- Depreciation = Block time x $(\frac{\text{Airplane cost + Spares}}{\text{Depreciation period x Utilization}})$

where SPARES = 10% Airframe cost + 40% Eng. cost x No. of Eng.

- Direct Operating Cost = Summation of above direct costs ($)

- $\text{DOC} = \frac{\text{Direct Operating Cost}}{\text{Seats x Range (st.mi)}}$ (¢ /Avail. Seat Mile)

Indirect Operating Cost (IOC) – Boeing/Lockheed Method

- Ground equipment maintenance = 0.095 x Flight equipment direct maintenance

- Cabin crew = 0.4 x Seats x Block time x (1.0 + % First class)

- Food = (0.75 + 0.32 x Block time) x LF x Seats x (1.0 + 2 x % First class)

- Other passenger services - Seats x LF x Range (St. mi.) x 2/1000

- Aircraft control - 62.40/landing

- Aircraft service = (0.839 + Land fee rate) x GW/1000

- Passenger handling = 3.60 x Seats x LF x $\frac{\text{enplaned}}{\text{onboard}}$

- Passenger baggage = 0.03 x 44 x LF x Seats x $\frac{\text{enplaned}}{\text{onboard}}$ x $(1.0 + \frac{\text{\% First class}}{2})$

- Cargo = 0.0225/LB

- Service administration = 0.093 x (Aircraft Control + Aircraft Service + Passenger Handling + Baggage Handling + Cargo Handling)

- Reservations/sales = 7.80 x LF x Seats x $\frac{\text{enplaned}}{\text{onboard}}$

- Passenger commissions = 3/1000 x Range (St. Miles) x LF x Seats

- Advertising = 2.8/1000 x Range x LF x Seats

- Ground depreciation - 12.2% x Flight equipment depreciation

- Amortization = 9.5% x Flight equipment depreciation

Subtotal = Summation of above Indirect Costs

- General and Administration = 5.4% (DOC + Subtotal)

Indirect Operating Cost = Subtotal + Gen. and Ad. ($)

$\text{IOC} = \frac{\text{Indirect Operating Cost}}{\text{Seats x Range (St. Mi.)}}$ (¢ /Avail. Seat Mile)

ANNUAL RETURN ON INVESTMENT (ROI)

- $\text{Annual ROI} = \dfrac{\text{Annual Cash Flow}}{\text{Cummulative Investment}}$

- Annual Cash Flow = Annual Revenue – Oper. Costs – Taxes

- $\text{Annual Revenue} = \sum_{\text{Flights}} \text{Revenue/Flight}$

- $\text{Operating Costs} = \sum_{\text{Flights}} \text{Direct \& Indirect Costs less Deprec.}$

- $\text{Taxes} = 48\% \sum_{\text{Flights}} \text{Revenue} - \text{Operating Costs} - \text{Deprec.}$

- Cumulative Investment = Cost of all airplanes plus spares in service as of December 31.

- Airplane Cost Assumptions for Study

Airplane	-	$38,000,000 (including engines and customer furnished equipment)
Engines	-	$1,500,000 Each
Cust. Furn. Equip.	-	$850,000/Airplane
Airframe	-	$31,150,000
Airframe Spares	-	$3,115,000/Airplane
Engine Spares	-	$2,400,000/Airplane

Operating Cost Projection (Escalated) Study Assumption

Following are the basic data and escalation forecasts employed to develop the SST advanced time period economics from the outputs of the introductory market study, as described under Operations and Economics.

Airplanes

	SST	707	747
Max. takeoff gross wt - lb	750,000	325,000	710,000
Number of seats	298	175	440
Flight crew	3	3	3
Cabin attendants	(1 attendant per 25 seats - all airplanes)		
Load factor	55%	55%	55%
Utilization	(10 hr/day, 3650 hr/yr - all airplanes)		

Operations

The inflation study was accomplished using a mission which was average from the Fleet Operations Study. The characteristics of this mission are tabulated below:

Distance – 2170 n.mi 2500 statute mi

Atmosphere – ICAO standard day, no wind

Reserves – This mission is well within the maximum range capability of all airplanes, so it was assumed that reserves would not affect operating costs.

Economics

Direct operating cost calculations were based on the October 1967 ATA Rules.

- Maintenance labor and material costs were calculated using the October 1967 ATA Rules,

    1) Labor was assumed to escalate at 4.5% per year (from an initial value of $4.00 per hour)

    2) It was assumed that improvements in component life and techniques would offset the escalation in maintenance material costs.

- Spares costs were estimated as follows:

    Engine Spares – 40% of the estimated cost of the set of engines for each airplane.

    Airframe Spares – 10% of the estimated airframe cost.

- For purposes of calculating operating costs, the following depreciation periods were used:

  707 – 10 years
  747 – 12 years
  SST – 15 years

Indirect operating cost calculations were based on the equations developed in Report RAC-R-20, Cost Analysis of Supersonic Transport in Airline Operation, Research Analysis Corporation, Dec. 31, 1966 modified to adapt to SST advanced time period projections.

Summary of escalation factors used:

Airplane Prices, Engine Prices, Spares Costs	3%
Ground Equipment and Facilities	3%
Flight Crew Labor	7.5%
Cabin Attendant Labor	4.5%
Food Cost	4.0%
Maintenance Labor Cost	4.5%
Jet Fuel (11.1¢/gal, 1978)	.5%
Commissions, Baggage Loss, etc.	No change (per RPM)
Insurance – Escalates with airplane price	

General and Administrative Costs
Baggage Handling
Aircraft Servicing
Aircraft Control
Promotion and Sales

} Increased productivity approximately offsets 3.5% labor cost escalation. (Applied equally to all airplanes)

Passenger Handling – Increased productivity reduces cost approximately 2% per year. (Applied equally to all airplanes)

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