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ECONOMIC STUDY OF MULTIPURPOSE ADVANCED HIGH-SPEED TRANSPORT CONFIGURATIONS

Boeing Commercial Airplane Company
P.O. Box 3707 Seattle, WA 98124

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

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1.0 SUMMARY

A non-dimensional economic examination of a parametrically-derived set of supersonic transport aircraft has been conducted. The measure of economic value was surcharge relative to subsonic airplane tourist-class yield.

The supersonic airplanes differed from each other in size, payload, range capability, and speed. A special version designed to operate overland at supersonic speeds with very low sonic boom overpressure was also examined.

For one of the study configurations, economic factors such as utilization, maintenance cost, airplane price, load factor, fuel price and crew pay were varied non-dimensionally and the impact of these variations upon the nominal surcharge was determined.

Looking at the different airplanes, the lowest values of surcharge occurred for those airplanes with the highest seating capacity. Under the ground rules of the study, payload capacity increase for some of these airplanes was obtained by sacrificing range capability, down to the lowest range capability studied; one just adequate for the Paris-New York route.

The parameter with the most noticeable influence on nominal surcharge was found to be real (constant dollars) fuel price increase. This parameter was varied to determine what would happen if fuel prices increased at a rate substantially different from general inflation rate and other costs. For example, on a mission typical of North Atlantic operations, a 44-percent increase in fuel price ratio needs an additional 12-percent surcharge. This makes the supersonic transport (SST) sensitive but not critically vulnerable to fuel price increases. The sensitivity of surcharge to changes in the other operating factors that were examined was found to be less than increased fuel price and no single factor was found to be particularly critical.

A change in SST design mach number from 2.4 to mach 2.7 showed a very small surcharge advantage (on the order of 1 percent) for the faster airplane. For an airplane to operate overland at supersonic speeds without causing sonic boom annoyance, certain configuration design compromises are necessary. The consequences of the compromises assumed in this study resulted in severe performance penalties. This, in turn, required high (more than 100 percent) surcharges.

2.0 INTRODUCTION

This document describes an Economic Analysis Study which was conducted in the context of a larger National Aeronautics and Space Administration Supersonic Cruise Research (NASA SCR) Program designed to identify and develop technology that may make it possible to define advanced supersonic airplanes. As part of this program system studies which integrate and assess technology advancements are being conducted at the Boeing Company. To support such studies, the economic aspects that affect the research direction were examined. The Economic Analysis Study described in this report developed sensitivity data necessary to determine such research directions.

This report is comprised of two major sections. The airplane definitions, cost estimating, and economic analysis are described in Section 4 while the results of this analysis are described in Section 5. All figures and tables have been compiled at the end of the report. The NASA technical monitor for this study was Dal Maddalon.

3.0 ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

Alt	altitude
ATA	Air Transport Association
B.S.	body station
C_D	drag coefficient
cg	center of gravity
C_L	lift coefficient
FAR	Federal Air Regulations
h	altitude
hr	hour
K_E	induced drag factor
kg	kilogram
km	kilometer
LSB/HS	low sonic boom (model designation)
M	mach number
MAC	mean aerodynamic chord
min	minute
MTW	maximum taxi weight
N	newton
nmi	nautical mile
OEW	operating weight empty
ref	reference
ROI	discounted cash flow return on investment
sec	second
SLS	sea level static thrust
Sref	wing reference area
SST	supersonic transport
sym	symmetric
yr	year
ZFW	zero fuel weight

SYMBOLS

	angle of attack
	wing leading edge sweep angle
%	percent
°C	degree centigrade

4.0 STUDY APPROACH

The objective of this study was to conduct an economic analysis and to determine the surcharge sensitivities of advanced high-speed transport airplane configurations. Ten airplanes were defined according to size, payload, and speed. The price, range capability, fuel burned, and block time were determined for each configuration; that task is described in Subsection 4.1. The operating costs were then calculated and used to determine the tourist class yield surcharge required for each supersonic airplane to achieve the same return on investment as the subsonic airplane. This analysis is detailed in Subsection 4.3.

4.1 AIRPLANE DEFINITION

Over the last 5 years, several supersonic transport airplane concepts were studied in detail at the Boeing Company. These airplanes were developed to study different technical aspects including effects of wing planform, passenger payload, design mach number, family commonality, and design for low sonic boom. Information from these studies was used to define ten airplane configurations in sufficient detail to estimate operational empty weight, lift-to-drag ratio and the required power plant size and thrust; Table 1 lists the design characteristics of these ten airplanes. One of these ten configurations was a subsonic reference airplane, eight were supersonic configurations designed for a speed of mach 2.4, and one was designed for a speed of mach 2.7. Of the mach 2.4 configurations, one was designed for low sonic boom, domestic operations.

All supersonic configurations were derived from Model 733-633 illustrated in Figure 1 and described in detail in Reference 1, Model 733-636 (fig. 2, ref 2) and Model 733-632 (fig. 3). Special design characteristics and geometry data for the low sonic boom configuration are based on those developed for model LSB/HS-3 (fig. 4, ref 3).

A payload range matrix (fig. 5) showing number of passengers versus distance flown was developed for this study. The points in the matrix for which the ten aircraft were designed roughly correspond to the geographic areas now served by airlines (fig. 6) and the route density anticipated. Airplanes 1, 2, 3, and 8 are supersonic airplanes designed to mach 2.4 at a gross weight of 340 000 kg (750 000 lb) with different payload-range design goals. Airplanes 1, 2, and 3 form a high commonality family (ref. 2). Similarly, Airplanes No. 9, 6, and 5, form a set of mach 2.4 airplanes at a gross weight of 272 000 kg (600 000 lb). Airplane No. 10 is a mach 2.7 airplane designed to the same objectives as the mach 2.4 Airplane No. 1. Airplane No. 4 is a mach 2.4 airplane constrained to operate with a low sonic boom pressure. The reference subsonic airplane is designated Airplane No. 7 and has a range comparable with that of supersonic Airplane No. 3. Figure 7 shows the configuration development scheme as well as the airplanes relationships to each other and to the base and base reference airplanes.

An operational empty mass, airplane mass, maximum zero fuel mass, and propulsion mass was calculated for each of the ten airplanes. An interior passenger floor plan was developed for each configuration using the rules for international tourist class comfort level: 86-cm (34-in) seat spacing, 46-cm (18-in) aisle width, 0.8-cm (0.31-in) linear coat space, and 32 to 38 passengers per lavatory. Because of shorter flying times, the galley space was reduced proportionately to the space common on subsonic transcontinental airliners. All interiors meet FAA emergency egress regulations.

The technology for all supersonic configuration includes the variable-cycle engine, fly-by-wire digital electronics, titanium sandwich, and a small amount of composites on selected components. Based on wind tunnel tests performed on Model 733-633 (ref 1), a lift-to-drag ratio was estimated for each of the ten airplane configurations and the performance was calculated using the ground rules shown in Figure 8. Performance data for each airplane at maximum design range and full payload is tabulated in Table 2. Block time and block fuel versus average range is listed for 100-, 62- and 55-percent payload in Table 3 and illustrated versus range for payloads of 100 and 55 percent in Figure 9. The proximity of lines for all mach 2.4 airplanes indicates block times are within 5 minutes for each configuration, regardless of payload. Block fuel versus range for all airplanes and all missions at 100- and 55-percent payload is shown in Figure 10, top left graph shows block fuel for 340 000-kg (750 000-lb) Airplanes No. 1, 2 and 3 and the subsonic reference Airplane No. 7; while the top right graph shows the block fuel for the 272 000-kg (600 000-lb) Airplanes No. 5 and 6. The center row shows block fuel versus range for the short-range Airplanes No. 8 and 9 and the bottom graphs show the block fuel for the domestic Airplane No. 4 and the mach 2.7 Airplane No. 10.

All of the airplanes considered in this study have been constrained implicitly to meet all pertinent Federal Air Regulations (FAR). The status of supersonic transport legal noise requirements in this country is still unclear, but, in any case, the state-of-the-art does not allow accurate quantitative predictions of community noise for the type of airplane considered here. Whatever data are available suggest, however, that these airplanes in general would be quieter than the 1971 SST concept. It had been hoped in 1971 that the airplane would eventually be able to meet FAR 36 (1969).

4.1.1 AIRPLANE NO. 1

Airplane No. 1 is illustrated in Figure 11. The design gross mass is 340 000 kg (750 000 lb) and the nominal payload is 273 passengers, tourist class at international comfort level. The seats are four, five and six abreast, arranged as shown in Figure 11. The body is area ruled with the wing for low wave drag. The propulsion system includes four variable-cycle engines with an airflow of 318 $kg \cdot s^{-1}$ (700 $lb.s^{-1}$) each. The airplane is configured for a design range of 8834 km (4500 nmi), at full payload on a hot day, and the lift-to-drag ratio was estimated at 9.2; configuration characteristics are listed in Figure 11.

4.1.2 AIRPLANE NO. 2

Airplane No. 2 (fig. 12) is a derivative of Airplane No. 1 using the family concept detailed in ref. 2. Figure 13 shows the general concept while Figure 14 shows the concept relative to payload/range, and Figure 7 shows the concept with respect to the other airplanes used in the study. The gross mass is 340 000 kg (750 000 lb) and the payload is 34 128 kg (75 240 lb) which is equivalent to 360 passengers, tourist class. Volume was increased by lengthening and widening the body as shown in Figure 13. The body was lengthened 1550 cm (610 in), rebalanced, and area-ruled with the wing of Airplane No. 1. Empennage and propulsion are identical to those of Airplane No. 1. The lift-to-drag ratio was estimated at 9.2 and the full-payload range was calculated to 7034 km (3800 nmi).

4.1.3 AIRPLANE NO. 3

Airplane No. 3 (fig. 15) represents the smaller, family derivative of Airplane No. 1 similar to airplane "C" of Figures 13 and 14. The derivative principle is identical to that described in Subsection 4.1.1. Wing, propulsion and empennage remained the same as those of Airplane No. 1. The body was shortened 695 cm (274 in) and made narrower by one seat width. The gross mass is 340 000 kg (750 000 lb) and the payload is 18 960 kg (41 800 lb) which is equivalent to 200 passengers, tourist class. The full payload range is 9260 km (5000 nmi) and the lift-to-drag ratio was estimated at 9.2. Additional data are listed in Figure 15.

4.1.4 AIRPLANE NO. 4

Airplane No. 4 (fig. 16) is based on model LSB/HS-3 (ref. 3) and represents the low sonic boom, domestic airplane. Its relationship to the study airplanes with respect to configuration differences and sonic boom overpressure is shown in Figure 17. The low sonic boom requirement of 36 N/m^2 (0.75 lb/ft^2) at midcruise weights, limits the gross weight to about 295 000 kg (650 000 lb). This resulted in a maximum payload of 180 passengers for the New York-San Francisco range of 5185 kg (2800 nmi). The configuration requires a long, slender body which led to the 4-abreast, constant cross-section design shown, non-dimensionally, in Figure 18.

Model LSB/HS-3 (fig. 4) was used for structural detail and the weight statement of Table 4 served as the base for the operational empty weight estimate. The lift-to-drag ratio was estimated at 8.6 and was incremented from Figure 19 to reflect payload and wing area changes.

4.1.5 AIRPLANE NO. 5

Airplane No. 5 (fig. 20) represents the small version within the family of 272 000-kg (600 000-lb) gross mass airplanes. The derivative principle is the same as that for Airplanes No. 2 and 3 described in Subections 4.1.2 and 4.1.3. The airplane is designed for a "thin" 8148-km (4400-nmi) range Pacific route with a full payload of 200 passengers, tourist class on a hot day. The wing planform is identical to that of Airplane No. 1, but smaller by 144 m^2 (1550 ft^2). The cabin interior is similar to that of Airplane No. 3. The lift-to-drag ratio was estimated at 8.8 and the operational empty weight was estimated at 113 717 kg (250 700 lb).

4.1.6 AIRPLANE NO. 6

Airplane No. 6 (fig. 21) represents the lower gross mass alternate to Airplane No. 1. It also is the base airplane for the family of 272 000-kg (600 000-lb) gross mass airplanes of which Airplanes No. 5 and 9 are derivatives. The airplane is designed to fly 6852 kg (3700 nmi) on a hot day with a full payload of 273 passengers, tourist class. The fuselage is similar to that of Airplane No. 1 and the wing is identical to that of Airplane No. 5. The operational empty weight was estimated at 120 748 kg (266 200 lb) and the lift-to-drag ratio at 8.8.

4.1.7 AIRPLANE NO. 7

Airplane No. 7 (fig. 22) shows the general arrangement of a three-engine wide-body subsonic airliner, designed for a cruise speed of mach 0.83. The cabin interior is designed for international comfort level with 86-cm (34-in) seat spacing and 51-cm (20-in) aisle width. It accommodates 295 passengers, tourist class. Doors and emergency exit provisions meet FAA egress regulations. There are eight lavatories, seven galleys and approximately 0.85 cm (0.33 in) of linear coat space per passenger in the aircraft. The propulsion system consists of three pod-mounted, high-bypass-ratio engines. The wing area is 343 m^2 (3700 ft^2) and the design gross mass 261 000 kg (575 000 lb). The design range with full payload is 9485 kg (5119 nmi) and the operational empty mass was estimated at 123 379 kg (272 000 lb) with a lift-to-drag ratio of 16.05.

4.1.8 AIRPLANES NO. 8 AND 9

To cover the economics of airplanes closer to the average airline network range, two airplanes (No. 8 and 9) with lower range capability were also considered. A design range of 6019 km (3250 nmi) was chosen for both airplanes and fuel was traded for payload and payload-related components. Airplane No. 8 (fig. 23) belongs to the set of 340 000-kg (750 000-lb) gross mass airplanes for which Airplane No. 1 is the base. The range reduction of 2316 km (1250 nmi) resulted in a fuel reduction of 30 047 kg (66 370 lb) which was used to increase the payload from 273 passengers to 430 passengers. Because of the body size required to accommodate this payload, Airplane No. 8 falls outside the specific family concept described in Reference 2. But it could be a member of some other family. With a maximum of eight seats abreast, the body was area-ruled with the 715 m^2 (7700 ft^2) reference wing at mach 2.2. The fuselage is 114.52m (375 ft) long. The anticipated weight and drag penalties for this configuration are reflected in the performance. With respect to its base Airplane No. 1, the operating weight was increased 15 150 kg (33 400 lb) to 158 821 kg (350 600 lb) and the lift-to-drag ratio was decreased from 9.2 to 9.12.

Airplane No. 9 (fig. 24) belongs to the set of 272 000-kg (600 000-lb) gross mass airplanes and represents the alternate to Airplane No. 8. Similarly, it no longer fits the family concept of Airplanes No. 5 and 6 because of its size. With respect to its base, Airplane No. 6, 8811 kg (19 429 lb) of fuel were traded for an increase in payload from 273 passengers to 320 passengers. The operational empty weight increased 4264 kg (9400 lb) to 125 012 kg (275 600 lb) and the lift-to-drag ratio was decreased from 8.8 to 8.7.

4.1.9 AIRPLANE NO. 10

Airplane No. 10 (fig. 25) represents the mach 2.7 version of base Airplane No. 1 with identical wing planform, size, gross mass, and payload. The fuselage is area-ruled with the wing at mach 2.7. The engine air intakes and the rotating machinery of the propulsion system are adjusted for mach 2.62 hot day cruise. For reasons of directional stability during cruise, a folding ventral with an area of 20 m^2 (215 ft^2) was added to the airplane. The aft body was redesigned to take the additional ventral load and to accommodate the folding mechanism. The operational empty weight increased by 1927 kg (4250 lb) over that of the mach 2.4 airplane. The mid-cruise lift-to-drag ratio was estimated at 8.88. Those were the only changes needed to account for design mach number changes from mach 2.4 to 2.7. The two airplanes are defined to the same requirements.

4.2 COST ESTIMATING

Before an economic analysis could be made for each airplane configuration, estimations of the cost of a commercial transport production program and the purchase price of each airplane were necessary.

4.2.1 PRODUCTION PROGRAM COST

Thirteen program assumptions were used to estimate the cost of a commercial transport production program; see Table 5 for these assumptions. Time tables and production schedules were then established for all 13 program assumptions and sale prices were calculated for all airplane configurations from information gathered during previous studies (like ref. 2). Based on these studies, Production Programs 1, 5, 9 and 13 were selected as being most representative of the airplane configurations used in this study.

According to those assumptions, typical 10-year production and sale schedules were selected for airplane configurations having similar gross weights (see Table 6). The production and sale of 500 airplanes of a single configuration over a 10-year period was assumed for Airplanes No. 4 and 7 (fig. 26). For the low gross weight airplanes (fig. 27) a total of 300 Airplanes No. 5 and 200 Airplanes No. 6 was considered typical. A total of 350 Airplanes No. 1, 150 Airplanes No. 2, and 50 Airplanes No. 3 was considered typical for the airplanes having a gross weight of 340 000 kg (750 000 lb) (fig. 28).

4.2.2 AIRPLANE COST

A cost estimate was developed for Airplane Model 733-633A (ref. 1 and 2) using data from the airplane description, three view drawings, weight statement (by structure section and system), part card estimate and development/production schedules. Complexity adjustments were then applied to cost element major airplane sections based on extensive conceptual drawings and material descriptions as well as fabrication methods analysis. These adjustments used previous "in-house" studies and/or judgmental assessments involving the Finance, Engineering and Manufacturing departments of Boeing Commercial Airplane Company.

Model 733-633A, together with derivative Models 733-633B and C, formed the basis for a comprehensive family commonality and cost study as reported in Reference 1. Using Model 733-633A as the baseline, the cost effect of commonality on the derivative airplanes was assessed by applying the benefits of lower costs due to the increased production to the common parts.

4.2.2.1 Economics Study Cost Estimating Methodology—The data for the airplanes shown in Table 1 (Airplane No. 1 through No. 10) were then estimated based on the parameters developed from the 733-633A, B and C family commonality cost study. The 340 000-kg (750 000-lb) gross weight family (Airplanes No. 1, 2 and 3) and the 272 000-kg (600 000-lb) gross weight family (Airplanes No. 5 and 6) relative prices are based on the required quantities and schedule assumptions outlined in Subsection 4.2.1. Airplanes No. 4 and 10 were estimated as single model programs of 500 units. Airplane No. 8 was an alternative to Airplane No. 2 (150 units). Airplane No. 9 was an alternative to Airplane No. 6 (200 units). The reference subsonic airplane (Airplane No. 7) was estimated as a single model program of 500 units and the price was based on historical aluminum skin and stringer cost history.

Figure 29 demonstrates the flow of cost information, as described above, from the Model 733-633A, B and C estimates as the basis for the parameters used to estimate the costs of Airplanes No. 1 through 10.

4.2.2.2 Pricing—Study prices for the single model programs (Airplanes No. 4, 7 and 10) were for a specified return on investment (ROI) to the airframe manufacturer. The estimated costs and program schedule for each model was used to determine program expenditures and cash receipts to calculate a price that resulted in the predetermined manufacturer's ROI. Study prices for the family concept programs (Airplanes No. 1, 2, 3, 5 and 6) were determined in a similar manner except that a total program ROI was calculated to achieve the same ROI as the single model program. The study prices, however, for the individual models within the family were based on the number of passenger seats and range. The study prices are tabulated in Table 13 and the effect of quantity is shown in Figure 30. The study price of each supersonic airplane is shown non-dimensionally, having been divided by the price of the subsonic airplane determined using consistent assumptions. The prices of current subsonic airplanes are published occasionally in connection with sales. At the time this work was being conducted (1978) announced prices of passenger versions of the Boeing Model 747-200B ranged from about 54 to 56 million dollars, and prices of the Boeing Model 727's from about 14 to 16 million dollars.

4.2.2.3 Results of Family Concept on Pricing—The favorable effects on costs and prices can be illustrated by comparing a single model program with a family program. Figure 31 is a comparison of the program schedules for each of these programs. The total program length, production rate per month and quantity of airplanes produced are identical for a family of airplanes and for a single model point design in order that cost and price comparisons between the two programs can be directly compared.

Figure 32 illustrates the cost advantage of the family concept. It demonstrates that by maintaining a high degree of commonality between models, the relatively minor incremental average cost increase is more than offset by increased market size. Figure 33 demonstrates the cost effect of extending the market from 300 airplanes to 500 airplanes. The 500 airplane single program price is shown for reference only.

This comparison between the single model program and the family program illustrates the possible benefits of designing for a family program with minimum differences between derivative models at the very early stages of the program.

The study prices used in the economic analysis are sensitive to the assumed production quantities and delivery rates. Additionally, the family concept program is sensitive to the extent of commonality achieved and is applicable only to families developed under this study's ground rules. As stated above, the prices are quoted in form of a price ratio with the price of the subsonic reference airplane being unity.

4.3 ECONOMIC ANALYSIS

After the airplane configurations were defined, priced, and evaluated with respect to payload range capability, the block time and fuel used, and system average ranges expected for large subsonic and supersonic fleets were established (see Subsection 4.3.1). The economics of the subsonic aircraft operations were determined using 1978 Boeing Company operating cost methods (ref 4). A discounted cash flow ROI to the airplane operator was computed as the economic figure of merit.

The economics of the supersonic transport family were also computed using economic analysis procedures which are similar to the Boeing Company's standard economic procedures. The economics involve two sets of calculations: operating costs consisting of direct (DOC) and indirect (IOC) costs, and airline ROI. The economic assumptions are listed in Table 7. All operating cost items were examined and incremented, where necessary, to reflect supersonic operating conditions (Subsection 4.3.2). The surcharge (relative to tourist class yield) necessary to obtain the subsonic ROI was then calculated for each of the supersonic commercial transport configurations. Finally, the surcharge sensitivity to variations in key economic factors was developed. This was accomplished by establishing a range of possible variations in airline utilization, maintenance cost, airplane acquisition cost, load factor, fuel price and crew pay. The surcharge required to obtain the target ROI was then recomputed for each variation holding all other factors constant. The base reference airplane, for the economic analysis, was Airplane No. 2 having a range of 7034 km (3800 nmi) on a hot day with a maximum payload of 360 tourist class passengers.

4.3.1 SYSTEM AVERAGE RANGES

An assessment of the economics of a particular type of new aircraft requires knowledge of the manner in which this aircraft will be operated. This information is necessary because both costs and revenue vary according to the average distance over which a fleet is operated. For this study current airline operational practices used in scheduling the world's fleet of 747 wide-body aircraft were assumed to constitute the type of in-service use that would be most representative of the way a large fleet of SST aircraft would be used. The annual 1978 worldwide 747 flight itineraries were separated into groups corresponding to the geographic operational areas of the SST family of configurations. Weighted average system operational ranges for these areas were then computed, providing the results listed in Table 8. These ranges were used for economic analysis of the nine SST configurations according to their respective operational areas. The average range of worldwide operations of subsonic aircraft was assumed to be the same as the current in-service experience of all wide-body transport aircraft, as shown in Table 8. A world map defining the particular geographic operational areas is shown in Figure 6.

4.3.2 SENSITIVITY ANALYSIS

The sensitivity of surcharge to variations in important economic factors was examined by first establishing a range of possible variations in each economic quantity, then for each factor, using values within this range to recompute the required surcharge; all other variables remain the same. Included in the economic items are annual fleet utilization, maintenance costs, other operating costs and load factor. Each of these items is discussed in the following subsections.

4.3.2.1 Annual Fleet Utilization—The annual utilization of an SST fleet is subject to the same variety of factors that affects subsonic fleets. Airport curfews, airline fleet size, route structure restrictions and increased turn-around times are among the factors often considered likely to affect the utilization of commercial supersonic airplanes. While a comprehensive examination of these factors was beyond the scope of this study, some were briefly examined. This examination indicated that no influences, neither benefiting nor restricting fleet utilization, could be attributed to any of these factors. For example, it was determined that the ground time available for servicing the flight items (structure, engines, systems) on current subsonic aircraft between scheduled flights was typically more than needed for that purpose. Turn-around time is usually determined by totaling the time required to service the passenger cabin, to load and unload passengers, cargo and baggage, and to schedule connecting flights. It was concluded that reasonable increases in aircraft servicing, due to increased complexity of supersonic airplanes, could occur without affecting turn around time or utilization.

The potential impact on utilization imposed by aircraft curfews was examined by establishing potential flight itineraries for a selected sample of economically-attractive routes. The sample indicated that potential increases in utilization through "curfew avoidance" scheduling were insignificant. An additional (and more important) limit on improvements in utilization is the particular times of day airline travelers prefer to travel. An SST airliner that departs one airport just prior to the end-of-day curfew and arrives at the end of the day at another airport would not, in general, attract sufficient passengers to be economically sound. The few special city pairs in the world where this could be done will not add up to a significant improvement in the utilization of a large fleet of supersonic transports. As a result, the subsonic utilization formula, which predicts annual utilization in units of block hours per year, as function of block time, per trip, was used to predict the nominal annual utilization of each of the supersonic transport configurations. Reasonably expected upper and lower limits for use in the sensitivity analyses were calculated from the dispersion in currently reported subsonic fleet utilization data. This dispersion is large because the route authority of some airlines enables them to schedule much more efficiently than others. Table 9 shows the predicted utilizations selected for this analysis.

4.3.2.2 Maintenance Costs—To evaluate maintenance costs for supersonic airliners maintenance costs calculated from several different cost estimating models were analyzed. Analytical judgement and experience was then used to select appropriate average maintenance cost estimates for each configuration, plus high and low values for the North Atlantic configuration.

- Airframe Maintenance—The two principal methods available for comparing airframe cost estimates were an updated version of the 1971 ATA formula, and a system-by-system comparison of the study airplanes with the maintenance costs of the 1971 U.S. supersonic transport. Another analytical method that relates airframe maintenance costs to airplane characteristics was developed by American Airlines under contract to NASA (ref 5). This method was used to estimate engine costs, as is discussed in the following section, but sufficiently detailed information was not available to use it in estimating airframe maintenance. The 1971 formula (ref 6) was updated by substituting historical experience for the formula's material escalation factors. Applying this revised formula to Airplane No. 2 resulted in a total airframe maintenance cost that was 183 percent higher than that experienced by the reference subsonic aircraft as operated on its reference mission. To account for a more extensive use of advanced structural materials in the study airplanes, this predicted total maintenance cost was arbitrarily increased to about 210 percent above the reference subsonic aircraft maintenance. This value was subsequently found to represent the upper boundary of the group of airframe cost estimates. The Air Transport Association (ATA) subsystem method compared the current makeup and use of each ATA system with those of the 1971 airplane. Such factors as changes in system complexity, quantities, operating requirements and application were considered in making these comparisons. On the basis of these comparisons the 1971 subsystems maintenance estimates were adjusted to 1978 levels resulting in total SST airframe maintenance costs of about 25 percent greater than those of the reference subsonic aircraft. The total costs were approximately 60 percent attributable to airframe structure (primary structure, landing gear, flight controls) and 40 percent attributable to airframe subsystems. The costs estimated by this method were the lowest values determined for airframe maintenance. Analytical judgement was then used to select the most reasonably expected maintenance costs from the estimated range of values. A similar procedure was followed for the nine supersonic study configurations. The selected airframe maintenance values are tabulated in Table 10.

- Engine Maintenance—Three methods were used to evaluate the engine maintenance costs of the SST's variable cycle engine. Two of these methods were the same as those previously described for the airframe comparison: an ATA system-by-system comparison and an updated 1971 ATA formula. The revised 1971 formula estimated total engine maintenance costs for Airplane No. 2 to be approximately 2.2 times those of the reference subsonic airplane. The ATA subsystems' comparison estimated engine maintenance costs to be about 75 percent higher than the reference subsonic airplane's engine maintenance costs. About 60 percent of the later cost estimate was attributable to the engine core components (turbine, compressor, combustor, etc.) with the remaining 40 percent attributable to the engine's controls and support systems. Additionally, an empirically based method developed by American Airlines under contract to NASA (ref 5) was also available. The results of this method, which was developed primarily for application to large 222 400 N (50 000 lb) subsonic fanjet engines, were slightly increased to account for the complexity of the supersonic inlet and other engine parts. This method indicates that total engine maintenance costs for the Airplane No. 2 engine would be 65 percent greater than those of the reference subsonic airplane. The estimates obtained from these analytical methods were judged by experienced engine maintenance analysts as being too low, considering the complexity of the variable cycle, supersonic engine. Consequently, analytical judgement was used to select appropriately higher average engine maintenance costs and an upper limit for the sensitivity analysis. The selected values are tabulated in Table 10.

4.3.2.3 Other Operating Costs—Included in operating costs are fuel price, crew pay, and food expense. A single fuel price of 45 cents per U.S. gallon was used throughout this analysis for both subsonic and supersonic aircraft as well as for domestic and international missions. Two possible price increases of 22 and 44 percent also were considered for use in the sensitivity analysis. The 1978 Boeing crew expense formula, which is based on reported airline expenses, was used for the analysis of supersonic operations. This formula results in crew salaries 20 percent higher than those paid currently to 747 crews. An additional 20 percent was arbitrarily added as an upper bound. The cost of providing food for passengers traveling at supersonic speed was reduced by 40 percent from the value predicted by the Boeing indirect operating cost formula. This adjustment was made to account for the elimination of one meal that may occur as a result of the SST's shorter flight times.

4.3.2.4 Load Factor—In this study the load factor expressed in percent is the ratio of passengers occupying the airplane during flight to the total number of seats available. A nominal load factor of 62 percent was selected for all aircraft and operational areas. To conduct the sensitivity analysis it was assumed that load factors for supersonic operations may vary between a low of 55 percent and a high of 70 percent. The load factor for the subsonic operations was kept at 62 percent.

5.0 ECONOMIC RESULTS

The surcharges required by each of the nine supersonic configurations are listed in Table 11. The most attractive configurations in terms of surcharge are those with the most seats relative to airplane empty weight. Although limited in range capability, Airplanes No. 8 and 9 are the best. Airplanes No. 2 and 6 are the next best with full North Atlantic range capability. The surcharges on these four configurations (Airplanes No. 2, 6, 8 and 9) are sufficiently low to enable them to capture a significant market share in competition with subsonic airplanes. The domestic, overland airplane, however, does not seem to have a favorable number of seats to empty weight ratio and appears to be uneconomical. For all the configurations, surcharge alone does not measure the market benefits or performance penalties, thus market-route studies are required to reliably assess overall viability of the study configurations.

The results of the sensitivity analysis performed on Airplane No. 2 are displayed in Figure 34. The ranges of variations in the economic factors (utilization, maintenance, airplane price, fuel costs, crew pay and load factors) that were used in the calculations of these curves are summarized in Table 12. The factors are expressed as a ratio, the subsonic factor being equal to 1.0.

Graph A of Figure 34 shows the sensitivity of surcharge to the low, nominal, and high utilization ratio for Airplane No. 2. Surcharges approach zero at utilizations 8 percent above that for the subsonic airplane. Nominal utilization ratios for all airplanes are tabulated, for reference, in Table 9.

Graph B of Figure 34 shows the surcharge sensitivity to airplane maintenance ratio with low, nominal and high values indicated; maintenance includes airframe and engine maintenance. Table 10 shows both airplane and engine maintenance cost ratios as well as the total costs for all airplanes except No. 7.

The surcharge sensitivity to airplane price ratio (acquisition cost ratio) is shown in Graph C Figure 34. The surcharge approaches zero for a price ratio of 2.2, while the nominal price ratio is 2.7 and the high price ratio is about 3.2. The price ratios for the other study airplanes are listed in Table 13. The price ratios range betwen 2.0 and 3.0, depending on cost and productivity.

Graph D of Figure 34 displays the load factor sensitivity with low, nominal and high load factors of 55, 62 and 70 percent respectively. Zero surcharge is obtained at 66 percent.

The sensitivity of surcharge to fuel price ratio for supersonic travel with reference to subsonic travel is displayed in Graph E of Figure 34. The nominal 1978 fuel price ratio is indicated as unity, while the two values that correspond to the selected fuel increases are identified as "high" and "highest". The graph also indicates, that a surcharge for subsonic travel would be necessary if fuel prices increase as indicated. But the surcharge would be less than half of that for supersonic travel.

Graph F of Figure 34 shows a graph of surcharge sensitivity to crew pay ratio. The crew pay for the subsonic reference Airplane No. 7 equals unity. The crew pay ratios, generally less than unity, reflect the higher rate of crew pay for supersonic travel but shorter flying times. The curve is nearly flat indicating relatively low sensitivity to crew pay.

This analysis indicates that the required level of surcharge is not substantially altered by excursions in any one of the selected parameters. Of all the selected items, surcharge is most influenced by the potential variations in the price of fuel and in load factor, thus indicating the importance of an accurate assessment of jet fuel price and air travel market conditions. The combined effect on surcharge of changes in more than one of the selected parameters is cumulative. However, as shown in Table 14, the combination of changes in operating costs that could reasonably be expected to occur would decrease the surcharge by about 8 percent; on the other hand, if all events were unfavorable they would potentially increase it by about 15 percent from the most likely values.

6.0 CONCLUSIONS

Under the ground rules of the study the following conclusions can be drawn. First, Airplanes No. 2, 6, 8 and 9 were found to have surcharges that could be economically attractive. Airplanes 1 and 10 are on the borderline of sound economics and Airplanes 3, 4 and 5 suffer under a payload too small for the price of the airplane. Also, the prime configuration parameter influencing the surcharge is design payload. Maximum payload results in minimum surcharge, minimum payload results in maximum surcharge, points in between are not linear. Finally, sensitivities of surcharge with respect to airplane utilization, maintenance purchase price, load factor, fuel price and crew pay are now available for future economic and market predictions.

7.0 REFERENCES

1. "Advanced Concept Studies for Supersonic Vehicles," NASA CR-145286, February 1978.

2. "Advanced Concept Studies for Supersonic Vehicles", NASA CR 159028, April 1979.

3. "A Study to Determine the Feasibility of a Low Sonic Boom Supersonic Transport," by Edward T. Kane - NASA CR-2332, December 1973.

4. "Boeing 1978 Operating Cost Methods," Boeing Document 6-1445-S-310.

5. "A New Method for Estimating Current and Future Transport Aircraft Operating Economics," NASA CR-145190, March 1978.

6. "The U.S.-SST in Commercial Operation," Boeing Document D6A-11788-2, May 1969.

Table 1. Configuration Characteristics

Airplane no.	Mission	Takeoff gross mass, kg (lb)	Design range, km (nmi)	Thrust to mass, N/kg (lb/lb)	Engine thrust— SLS, N (lb)	Wing area, m^2 (ft^2)	Body length, m (in)	Abreast seating	Wing loading, Nm^{-2} (lb/ft^2)	Operating empty mass, kg (lb)	Propulsion mass, kg (lb)	[1] Airframe mass, kg (lb)	Maximum zero fuel mass, kg (lb)
1	Basic Pacific	340 000 (750 000)	8 834 (4 500)	2.826 (0.288)	240 200 (54 000)	715 (7 700)	89.30 (3516)	4, 5, 6	4 664 (97)	143 882 (317 200)	26 717 (58 900)	118 294 (260 790)	169 782 (374 300)
2	North Atlantic + Central Pacific	340 000 (750 000)	7 034 (3 800)	2.826 (0.288)	240 200 (54 000)	715 (7 700)	104.80 (4126)	4, 5, 6	4 664 (97)	152 137 (335 400)	26 717 (58 900)	125 416 (276 490)	186 248 (410 600)
3	Long range	340 000 (750 000)	9 260 (5 000)	2.826 (0.288)	240 200 (54 000)	715 (7 700)	82.32 (3241)	4, 5	4 664 (97)	137 259 (302 600)	26 717 (58 900)	112 579 (248 190)	156 220 (344 400)
4	Basic overland	295 000 (650 000)	5 185 (2 800)	3.257 (0.330)	240 200 (54 000)	805 (8 670)	79.91 (3146)	4	3590 (75)	158 805 (350 100)	26 717 (58 900)	134 401 (296 300)	175 860 (387 700)
5	Small Pacific	272 000 (600 000)	8 148 (4 400)	2.826 (0.288)	192 150 (43 200)	571 (6 150)	82.32 (3241)	4, 5	4 664 (97)	113 717 (250 700)	20 366 (44 900)	93 441 (206 000)	132 678 (292 500)
6	Small Atlantic + Central Pacific	272 000 (600 000)	6 852 (3 700)	2.826 (0.288)	192 150 (43 200)	571 (6 150)	89.30 (3516)	4, 5, 6	4 664 (97)	120 748 (266 200)	20 366 (44 900)	99 565 (219 500)	146 649 (323 300)
7	Subsonic reference	261 000 (575 000)	9 485 (5 119)	2.710 (0.276)	235 750 (53 000)	343 (3 700)	51.99 (2046)	9	7 441 (155)	125 093 (275 840)	18 (40 000)	100 100 (220 680)	153 084 (337 495)
8	North Atlantic	340 000 (750 000)	6 019 (3 250)	2.826 (0.288)	240 200 (54 000)	715 (7 700)	114.52 (4509)	4, 5, 6, 8	4 664 (97)	159 032 (350 600)	26 717 (58 900)	130 936 (288 660)	199 810 (440 500)
9	Special North Atlantic	272 000 (600 000)	6 019 (3 250)	2.826 (0.288)	192 150 (43 200)	571 (6 150)	100.93 (3974)	4, 5, 6	4664 (97)	125 012 (275 600)	20 366 (44 900)	103 361 (277 870)	155 358 (342 500)
10	M = 2.7 Pacific	340 000 (750 000)	7 936 (4 300)	2.826 (0.288)	240 200 (54 000)	715 (7 700)	89.30 (3516)	4, 5, 6	4 664 (97)	145 809 (321 450)	27 714 (61 100)	120 240 (265 080)	171 687 (378 500)

[1] Manufacturers empty mass less engines

Table 2. Primary Characteristics of Study Configurations at 100% Payload

Airplane no.	Cruise speed, M	Takeoff gross mass, kg (lb)	Passenger payload	Range, km (nmi)	Takeoff field length, m (ft)	Block fuel, liter (lb)	Block time, hr
1	2.32	340 000 (750 000)	273	8 834 (4 500)	3300 (10 900)	181 300 (331 200)	3.98
2	2.32	340 000 (750 000)	360	7 034 (3 800)	3300 (10 900)	166 400 (294 900)	3.46
3	2.32	340 000 (750 000)	200	9 260 (5 000)	3300 (10 900)	203 300 (360 200)	4.42
4	2.32	295 000 (650 000)	180	5 185 (2 800)	2600 (8 400)	125 500 (222 300)	2.72
5	2.32	272 000 (600 000)	200	8 148 (4 400)	3300 (10 900)	153 100 (271 300)	3.89
6	2.32	272 000 (600 000)	273	6 852 (3 700)	3300 (10 900)	135 800 (240 600)	3.38
7	0.83	261 000 (575 000)	295	9 485 (5 119)	3300 (10 900)	111 200 (197 020)	11.03
8	2.32	340 000 (750 000)	430	6 019 (3 250)	3300 (10 900)	149 500 (264 870)	3.07
9	2.32	272 000 (600 000)	320	6 019 (3 250)	3300 (10 900)	124 840 (221 170)	3.07
10	2.62	340 000 (750 000)	273	7 936 (4 300)	3280 (10 750)	184 600 (327 000)	3.54

Table 3. Block Fuel and Block Time for 100, 62, and 55% Payload at System Average Ranges

Airplane no.	Payload 100% Block fuel, liter	(lb)	Time, hr	Payload 62% Block fuel, liter	(lb)	Time, hr	Payload 55% Block fuel, liter	(lb)	Time, hr	System average range, km	(nmi)
1	88 600	(157 000)	2.25	82 200	(145 600)	2.25	81 300	(144 000)	2.25	4170	(2250)
2	105 800	(187 500)	2.47	99 700	(176 700)	2.47	98 500	(174 500)	2.47	4630	(2500)
3	99 900	(177 000)	2.61	95 000	(168 300)	2.61	94 300	(167 000)	2.61	5100	(2750)
4	55 300	(98 000)	1.43	52 300	(92 700)	1.43	52 000	(92 000)	1.43	2130	(1150)
5	74 000	(131 000)	2.25	71 500	(126 600)	2.25	71 100	(126 000)	2.25	4170	(2250)
6	89 200	(158 000)	2.47	84 000	(148 800)	2.47	83 300	(147 500)	2.47	4630	(2500)
7	33 489 17 717	(73 830) (39 060)	4.78 2.59	31 162 16 465	(68 700) (36 300)	4.78 2.59	30 844 16 284	(68 000) (35 900)	4.78 2.59	3700 1850	(2000) (1000)
8	113 500	(201 000)	2.47	106 000	(187 000)	2.47	104 000	(185 000)	2.47	4630	(2500)
9	93 700	(166 000)	2.47	87 800	(155 500)	2.47	87 000	(154 000)	2.47	4630	(2500)
10	102 700	(182 000)	2.26	98 000	(173 600)	2.26	97 000	(172 000)	2.26	4630	(2500)

Table 4. Weight and Balance Summary—LSB/HS-3

Item	Weight kg	Weight (lb)	C.G. Body station m	C.G. Body station (in)	C.G. % MAC
Nose to wing front spar					
Station 5.08 (200) to 70.358 (2770)	(38 692)	(85 300)	(44.145)	(1738)	
Body and contents	36 605	80 700	45.187	1779	
Nose landing gear (up)	726	1 600	32.512	1280	
Canard (out)	1361	3 000	22.301	878	
Wing front spar to rear spar					
Station 70.358 (2770) to 80.518 (3170)	(112 808)	(248 700)	(75.844)	(2986)	
Body and contents	13 336	29 400	75.438	2970	
Wing structure	41 821	92 200	71.653	2821	
Wing contents	12 610	27 800	69.596	2740	
Propulsion pod	29 710	65 500	86.868	3420	
Main landing gear (up)	11 748	25 900	66.802	2630	
Vertical tail and contents	3583	7900	86.868	3420	
Aft body					
Station 80.518 (3170) to 96.520 (3800)	(1814)	(4000)	(85.090)	(3350)	
OEW (gears up)—1975 technology	[153 314]	[338 000]	[67.945]	[2675]	[50.9]
Advanced technology increments	(-12 700)	(-28 000)	(67.107)	(2642)	
Decrease engine airflow 15%	-3402	-7500	86.868	3420	
Design concepts on airplane less propulsion pod (-7.5%)	-9298	-20 500	59.868	2357	
OEW (gears up)—1985 technology	[140 614]	[310 000]	[68.021]	[2678]	[51.1]
Payload	(14 040)	(30 955)	(51.765)	(2038)	
Passengers (151)	11 300	24 915	47.803	1882	
Baggage	2740	6040	68.072	2680	
Zero fuel weight (ZFW)—1985 technology	[154 654]	[340 955]	[66.548]	[2620]	[47.3]
C.G. tolerance			-.254	-10	
Forward C.G. limit (low speed)			66.29	2610	46.6

Table 5. *Production Program Assumptions*

Production program no.	Production and deliveries	
	Quantity	Airplane no.
1	500	7
2	500	1
3	120 60 20	1 2 3
4	240 120 40	1 2 3
5	300 150 50	1 2 3
6	360 180 60	1 2 3
7	120 80	5 6
8	240 160	5 6
9	300 200	5 6
10	360 240	5 6
11	200	4
12	400	4
13	500	4

Table 6. *Typical 10-Year Production and Sale Schedule for Airplane Configurations Having Similar Gross Mass Weights*

<table>
<tr><td rowspan="4">Airplane takeoff gross weight, kg (lb)</td><td colspan="6">Airplane configuration no.</td></tr>
<tr><td colspan="3">High gross weight</td><td colspan="3">Low gross weight</td></tr>
<tr><td>No. 1</td><td>No. 2</td><td>No. 3</td><td>No. 4</td><td>No. 5</td><td>No. 6</td></tr>
<tr><td>340 000 (750 000)</td><td>340 000 (750 000)</td><td>340 000 (750 000)</td><td>295 000 (650 000)</td><td>272 000 (600 000)</td><td>272 000 (600 000)</td></tr>
<tr><td>Quantity (family)</td><td colspan="3">500</td><td rowspan="2">500</td><td colspan="2">500</td></tr>
<tr><td>Quantity (each)</td><td>300</td><td>150</td><td>50</td><td>300</td><td>200</td></tr>
</table>

Table 7. Economic Analysis Methodology

Direct operating costs per 1978 Boeing formula	
Mission profile:	Still-air range + SST reserves
Crew expense:	Function of gross weight, speed, and airplane utilization
Insurance:	0.5% flyaway price per year
Depreciation:	15 years to 10% residual value on airplane and spares
Utilization:	
Fuel price:	Per detailed analysis
Maintenance:	
Indirect operating costs per 1978 Boeing formulas	
Ground property and equipment:	Function of landing weight
Airplane related:	Function of landing weight, flight time, and seating capacity
Passenger related:	Function of enplaned passengers, flight distance, flight time, and class of service
General and administrative:	Function of direct cash operating costs, other indirect costs, and landing weight
Return on investment	
Discounted cash flow method	
Prepayments:	35%
Investment tax credit:	10%
Tax depreciation:	10 years, sum of year's digits
Tax rate:	48%

Table 8. System Average Ranges

Geographical operational area	System average range, km	(nmi)
Supersonic		
North Atlantic	4630	(2500)
Pacific	4167	(2250)
Long range	5093	(2750)
U.S. domestic	2130	(1150)
Subsonic		
International	3704	(2000)
U.S. domestic	1852	(1000)

Table 9. Nominal Utilization (Ratios Relative to Reference Subsonic)

Airplane no.	Utilization ratio
1	0.88
2	0.89
3	0.90
4	0.90
5	0.88
6	0.89
7	1.00
8	0.88
9	0.88
10	0.87

Table 10. Nominal Maintenance Costs (Ratios Relative to Reference Subsonic)

Airplane no.	Maintenance ratios		
	Airframe	Engine	Total
1	1.3	2.4	1.8
2	1.5	2.6	2.0
3	1.3	2.8	2.0
4	1.7	2.7	2.1
5	1.2	1.8	1.5
6	1.3	2.0	1.6
8	1.6	2.6	2.0
9	1.4	2.0	1.7
10	1.3	2.2	1.7

Table 11. Surcharge

Airplane no.	Seats (all tourist)	Surcharge (%)
1	273	26
2	360	6
3	200	47
4	180	107
5	200	40
6	273	15
7	295	Reference
8	430	0
9	320	5
10	273	25

Table 12. Estimated Variations in Economic Factors (Ratios Relative to Reference Subsonic)

Item	Estimated variation		
	Low	Nominal	High
Utilization, hr/yr	0.82	0.89	0.97
Maintenance cost, $/trip	1.25	2.00	3.12
Airplane price, $	2.27	2.73	3.19
Fuel price, $/gal	–	1.0	1.44
Crew pay, $/trip	–	0.72	0.86
Load factor, %	55	62	70

Table 13. Nominal Airplane Purchase Prices (Ratios Relative to Reference Subsonic)

Airplane configuration	Price ratio
1	2.4
2	2.7
3	2.0
4	2.5
5	2.0
6	2.3
7	1.0
8	3.0
9	2.4
10	2.4

Table 14. Surcharge Uncertainty Estimates, Airplane No. 2

Operating cost element	Incremental change in nominal surcharge (%)	
	Best case	Worst case
Utilization, hr/yr	-2.8	3.3
Maintenance, $/trip	-4.2	6.3
Airplane price, $	-5.8	5.8
Fuel price, $/gal	0	12.4
Crew pay, $/trip	0	0.7
Total change from nominal	-12.8	28.4
Root-sum-square average change	7.7	15.4
Reasonably anticipated surcharge	0% ⩽ S	⩽ 21%

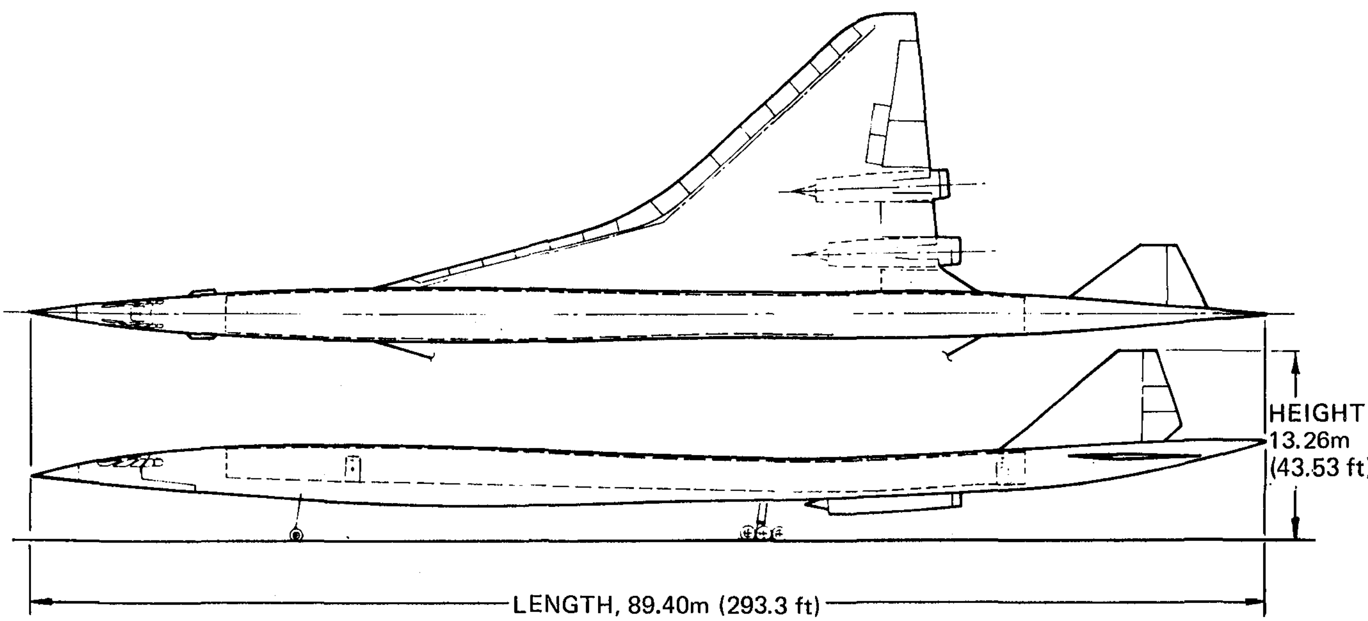


Figure 1. General Arrangement, Model 733-633

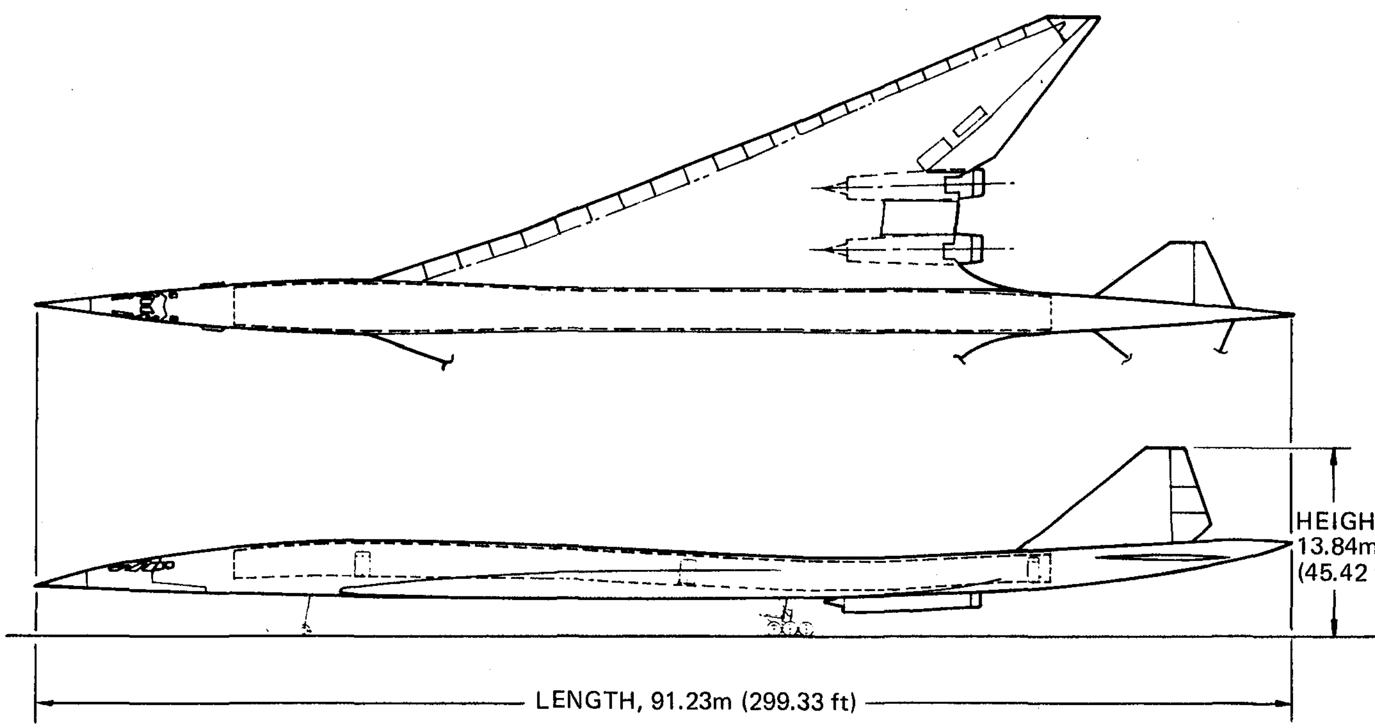


Figure 2. Advanced Technology Arrow Wing, Model 733-636

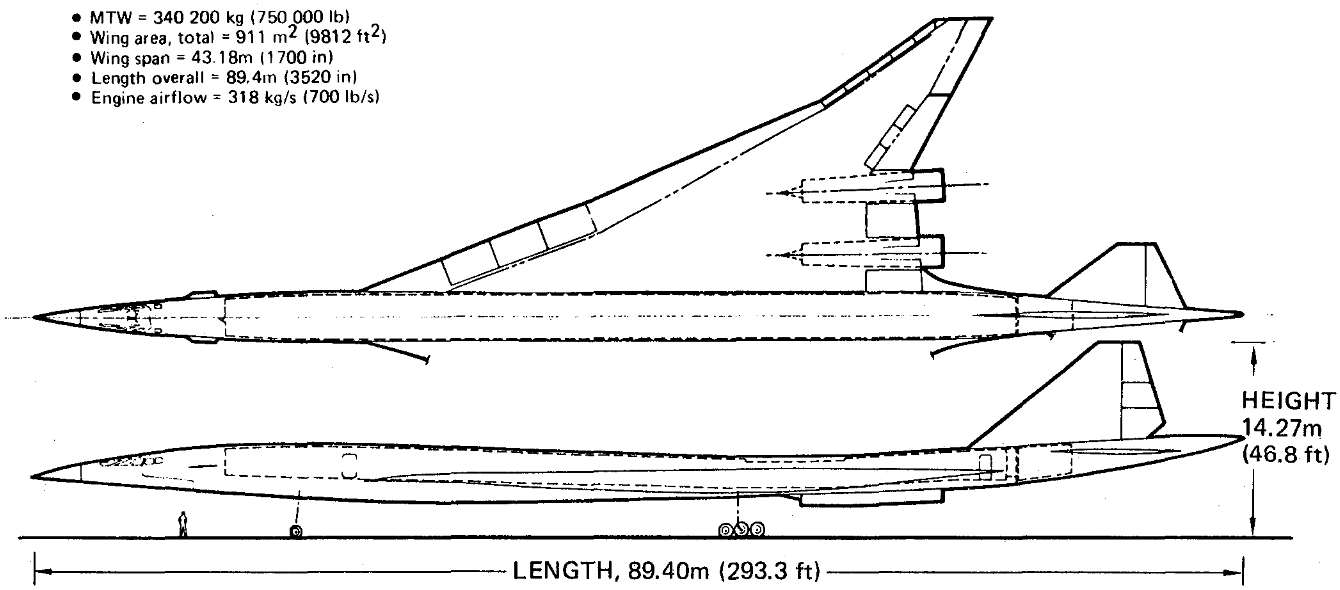


Figure 3. General Arrangement, Model 733-632

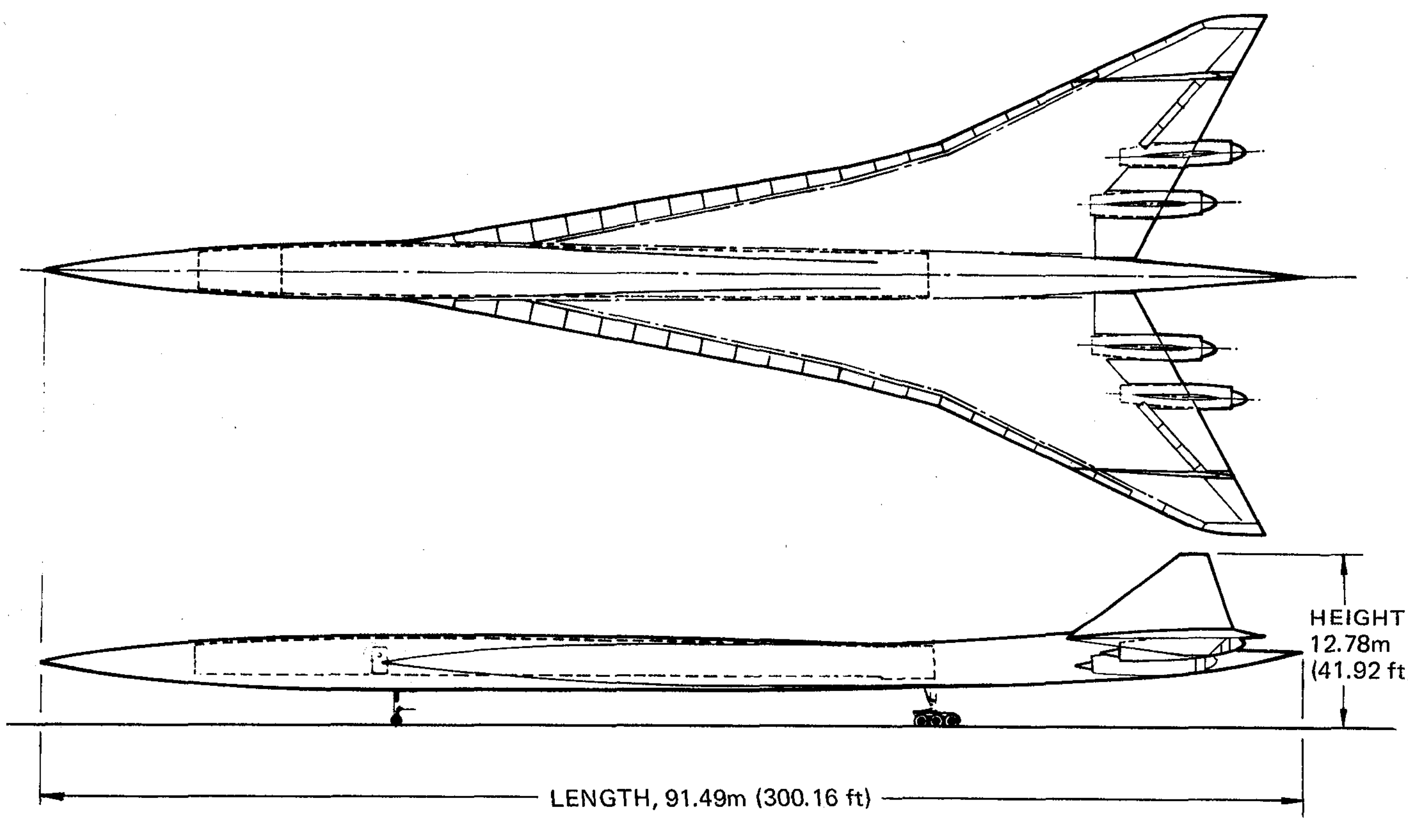


Figure 4. Low, Sonic Boom Configuration LSB/HS-3

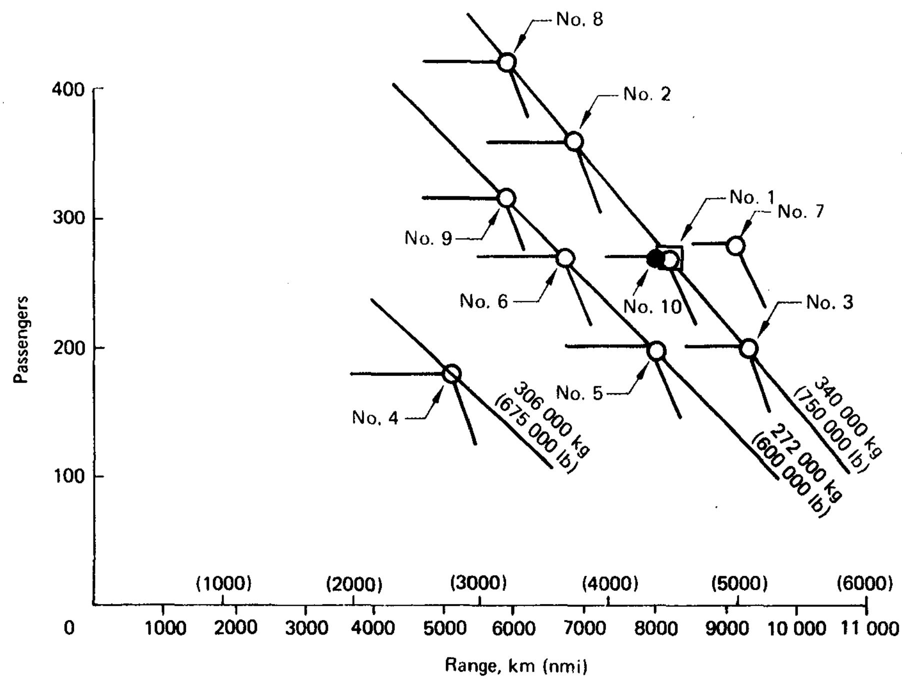
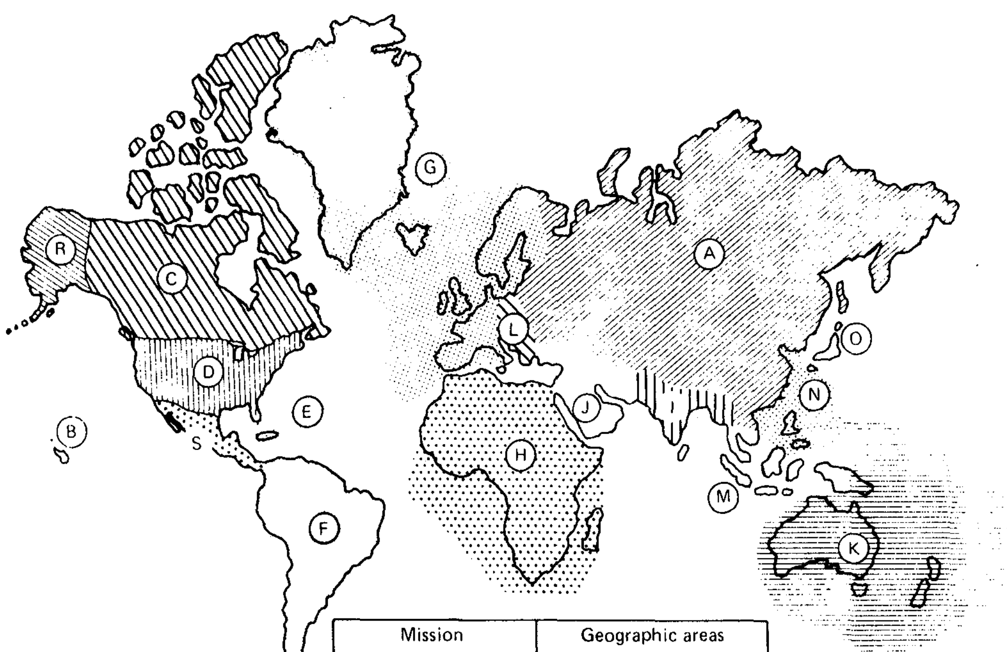


Figure 5. Payload Range Matrix



Mission	Geographic areas
North Atlantic	CDG
Pacific	BCDKMNOR
Long range	BCDEFGHIJKLMNORS
Domestic	DC

Figure 6. Geographic Areas

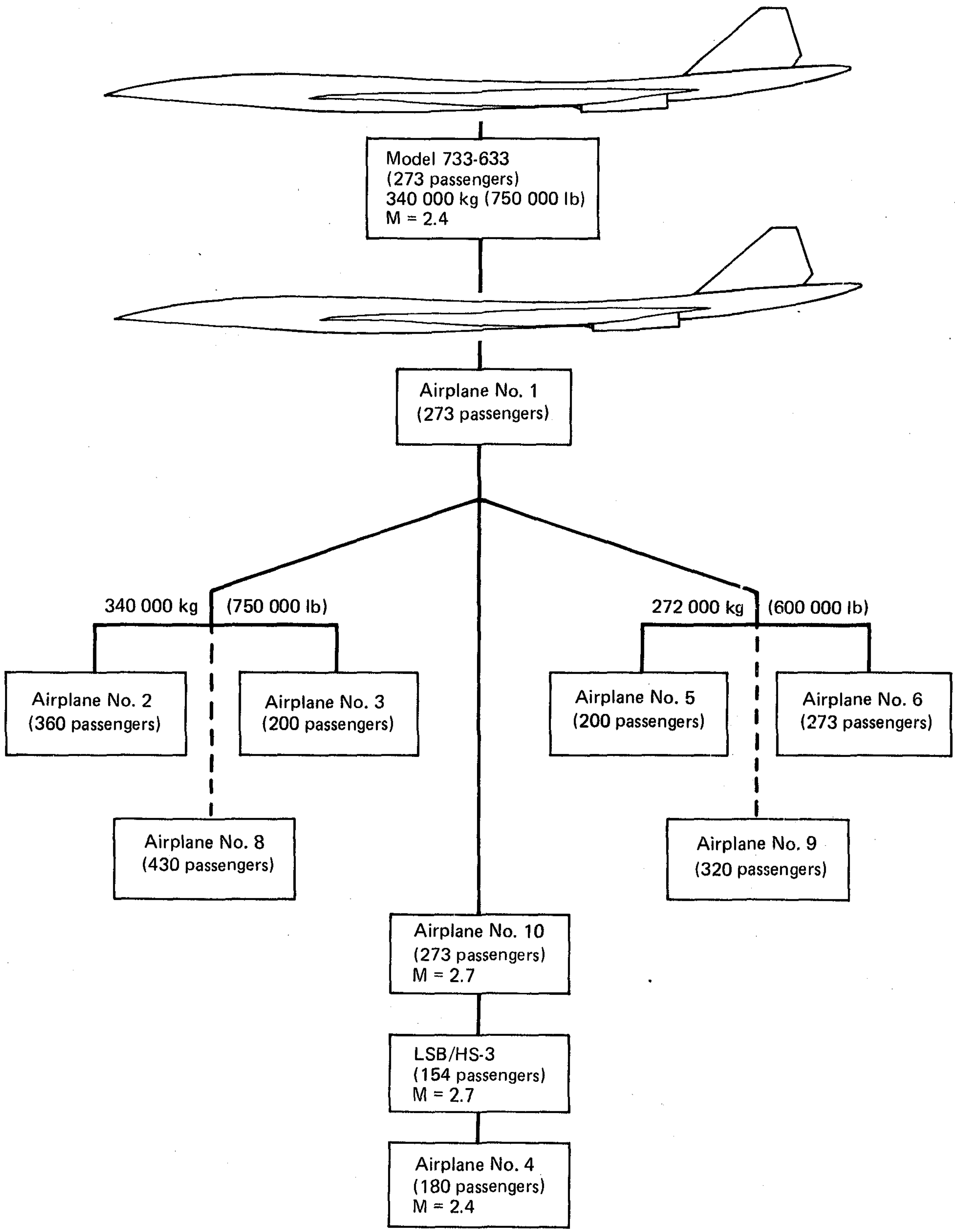
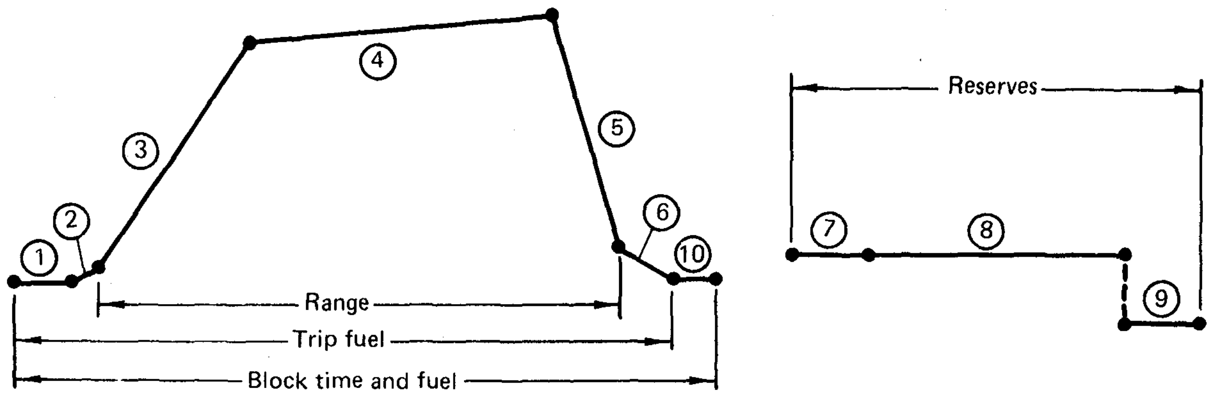


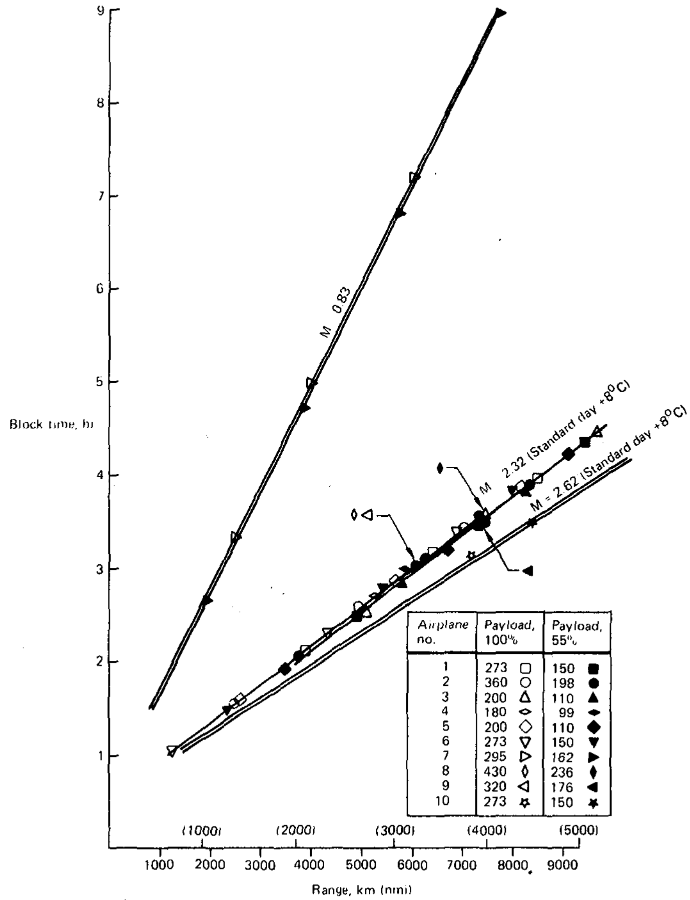
Figure 7. Study Airplane Development Scheme



(1) Taxi = 10 min, h = 0, ground idle fuel flow
(2) Takeoff = over 11m (35 ft) obstacle
(3) Acceleration and climb to BCA[a] and cruise Mach no.
(4) Supersonic cruise climb at constant Mach no.
(5) Descent and deceleration at flight idle fuel flow
(6) ILS approach until touchdown
(7) Allowance = 6% trip fuel
(8) Subsonic cruise to alternate at M = 0.9, h = 11 521m (37 800 ft)
(9) Hold = 30 min, h = 4572m (15 000 ft), M = optimum
(10) Taxi = 5 min, h = 0 at ground idle fuel flow

[a]BCA = Best cruise altitude

Figure 8. Ground Rules: Flight Profile and Reserves



Airplane no.	Payload, 100%	Payload, 55%
1	273 □	150 ■
2	360 ○	198 ●
3	200 △	110 ▲
4	180 ⬭	99 ⬬
5	200 ◇	110 ◆
6	273 ▽	150 ▼
7	295 ▷	162 ▶
8	430 ◊	236 ⧫
9	320 ◁	176 ◀
10	273 ✡	150 ✶

Figure 9. Block Time Versus Range—All Missions

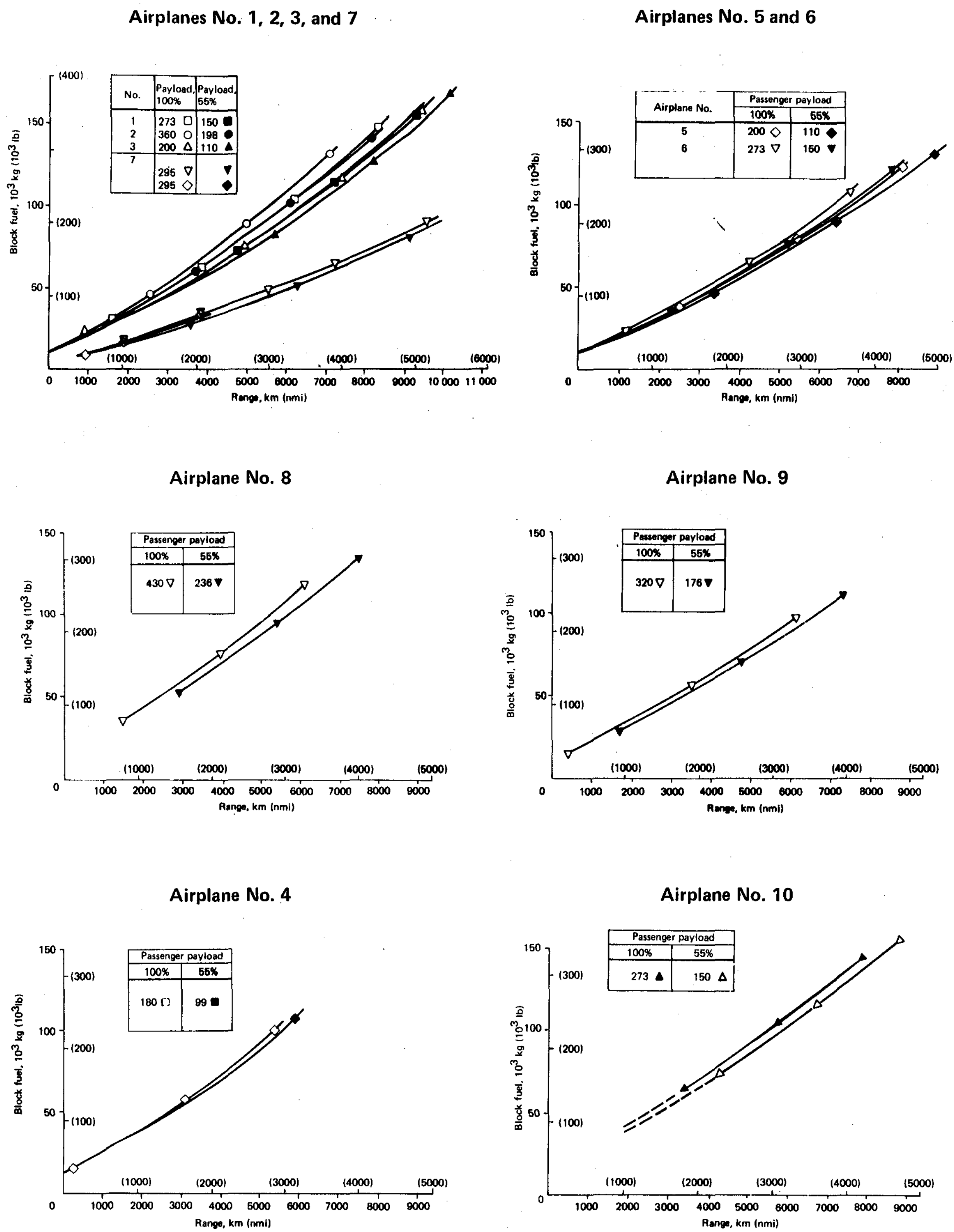
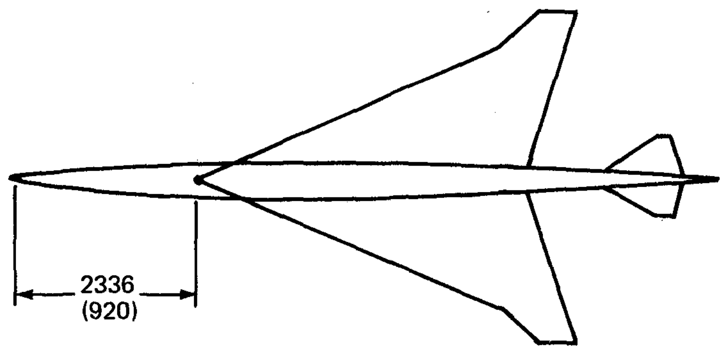


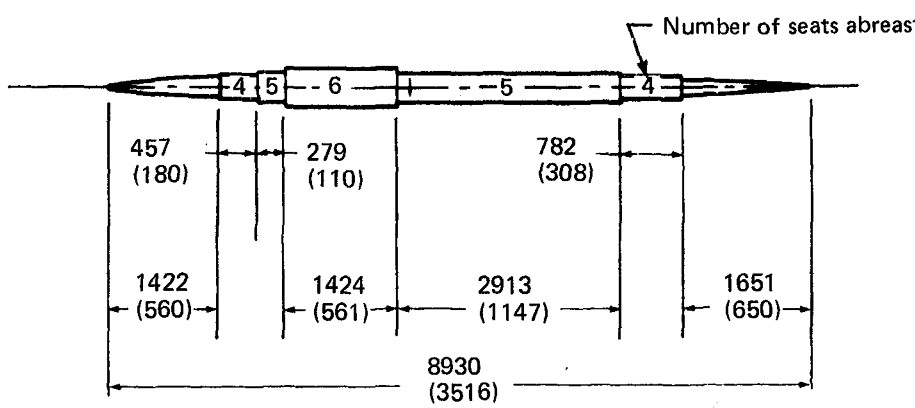
Figure 10. Block Fuel Versus Range (M = 2.32; Standard Day +8^{o}C)

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	340 000 (750 000)
Design range, km (nmi)	8834 (4500)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust–SLS, N (lb)	240 200 (54 000)
Wing area, M^2 (ft^2)	715 (7700)
Body length, m (in)	89.306 (3516)
Abreast seating	4,5,6
Wing loading, (Nm^{-2}) (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	143 882 (317 200)
Propulsion mass, kg (lb)	26 717 (58 900)
Airframe mass, kg (lb)	118 294 (260 790)
Maximum zero fuel mass, kg (lb)	109 782 (374 300)



Passenger Seating Arrangement
273 Passengers

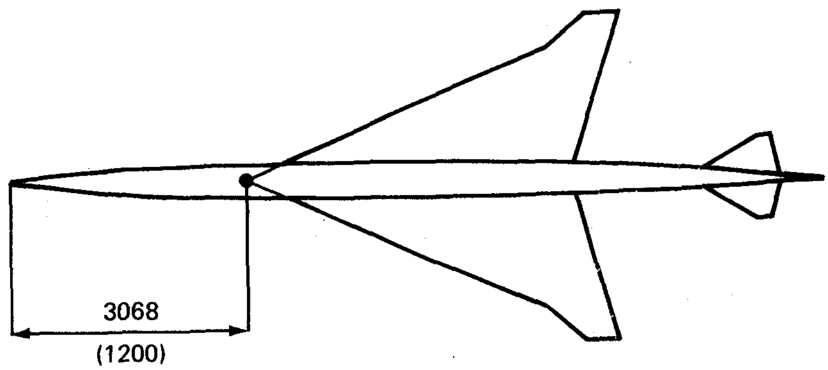


Dimensions, cm (in)

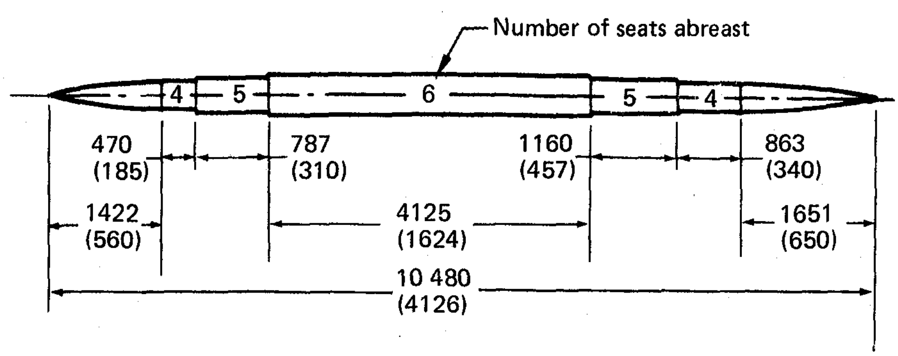
Figure 11. Airplane No. 1

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	340 000 (750 000)
Design range, km (nmi)	7034 (3800)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust–SLS, N (lb)	240 200 (54 000)
Wing area, m^2 (ft^2)	715 (7700)
Body length, m (in)	104.800 (4126)
Abreast seating	4,5,6
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	152 137 (335 400)
Propulsion mass, kg (lb)	26 717 (58 900)
Airframe mass, kg (lb)	125 416 (276 490)
Maximum zero fuel mass, kg (lb)	186 248 (412 600)



Passenger Seating Arrangement
360 Passengers



Dimensions, cm (in)

Figure 12. Airplane No. 2

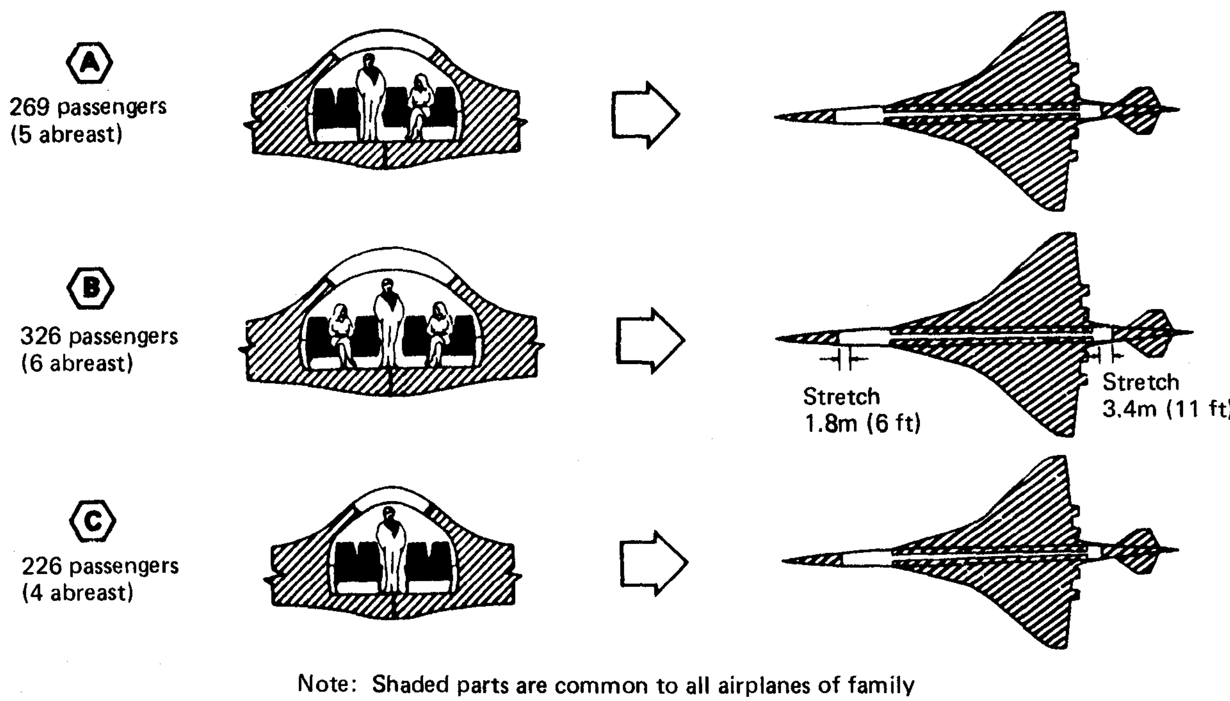


Figure 13. Derivative Concept

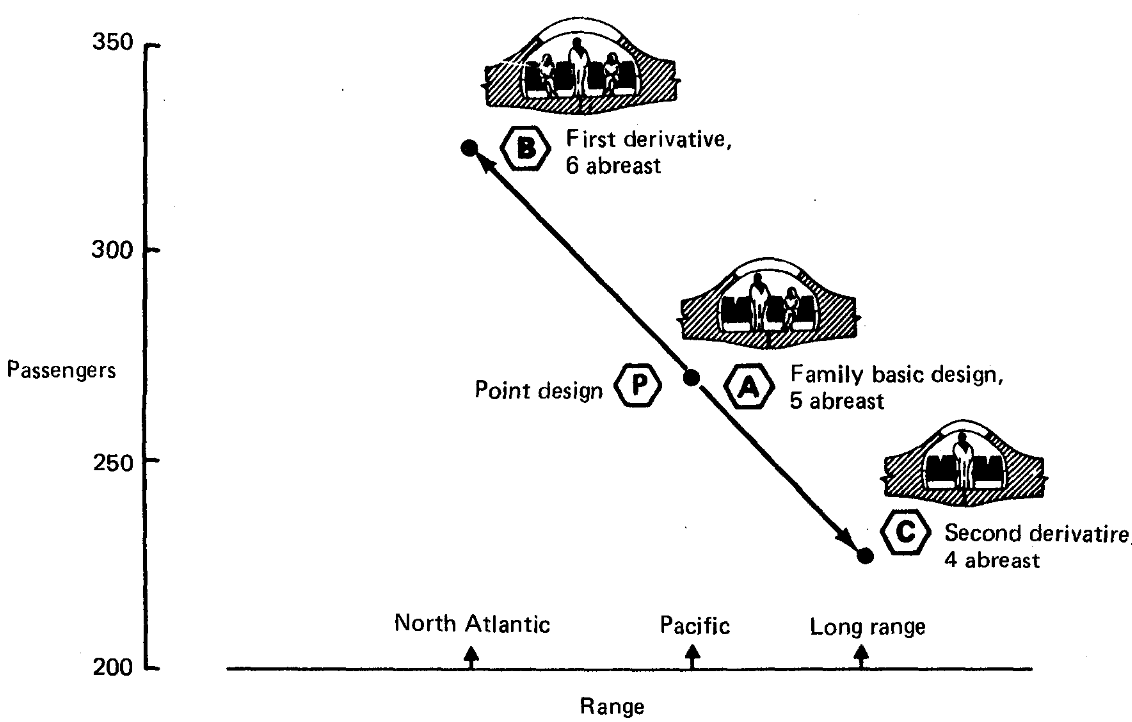
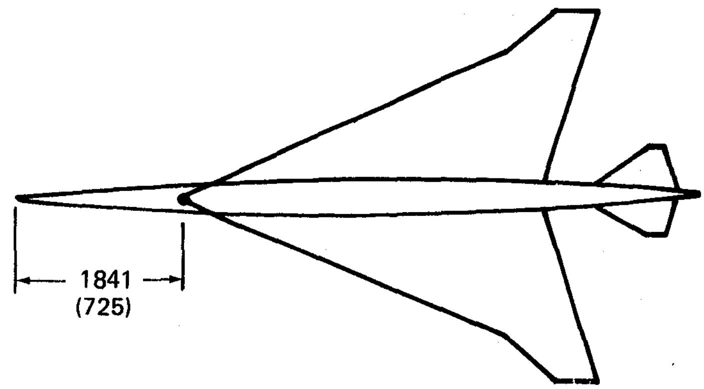


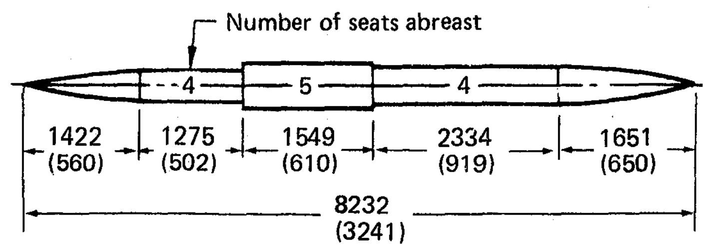
Figure 14. Payload Range, Derivative Concept

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	340 000 (750 000)
Design range, km (nmi)	9260 (5000)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust—SLS, N (lb)	240 200 (54 000)
Wing area, m^2 (ft^2)	715 (7700)
Body length, m (in)	82 320 (3241)
Abreast seating	4,5
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	137 259 (302 600)
Propulsion mass, kg (lb)	26 717 (58 900)
Airframe mass, kg (lb)	112 579 (248 190)
Maximum zero fuel mass, kg (lb)	156 220 (344 400)



Passenger Seating Arrangement
200 Passengers

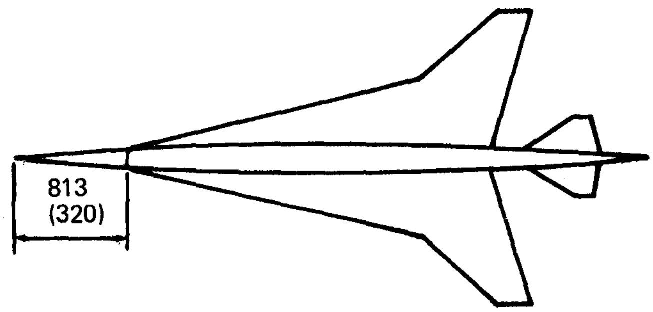


Dimensions, cm (in)

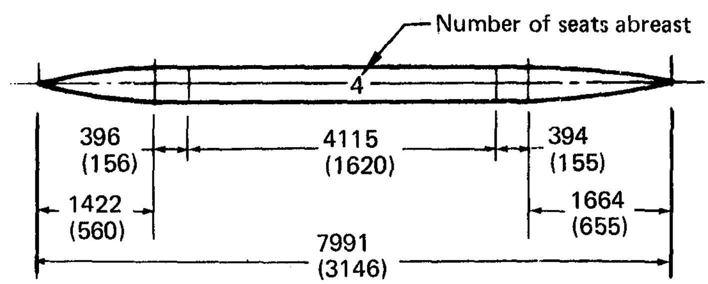
Figure 15. Airplane No. 3

Configuration Characteristics

Mach. Number	2.4
Takeoff gross mass, kg (lb)	295 000 (650 000)
Design range, km (nmi)	5185 (2800)
Thrust to mass, N/kg (lb/lb)	3.257 (0.330)
Engine thrust—SLS, N (lb)	240 200 (54 000)
Wing area, m^2 (ft^2)	805 (8670)
Body length, m (in)	79.908 (3146)
Abreast seating	4
Wing loading, Nm^{-2} (lb/ft^2)	3590 (75)
Operating empty mass, kg (lb)	158 805 (350 100)
Propulsion mass, kg (lb)	26 717 (58 900)
Airframe mass, kg (lb)	134 401 (296 300)
Maximum zero fuel mass, kg (lb)	175 860 (387 700)



Passenger Seating Arrangement
180 Passengers



Dimensions, cm (in)

Figure 16. Airplane No. 4

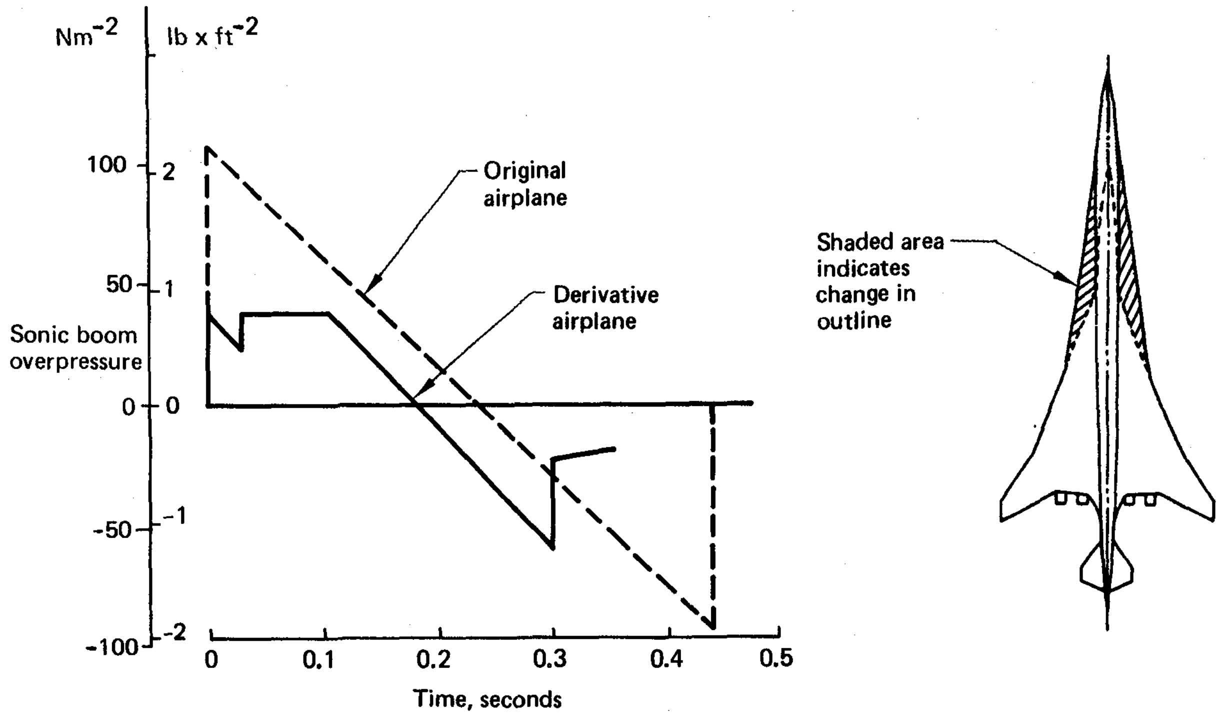


Figure 17. Sonic Boom Signature vs. Airplane Design

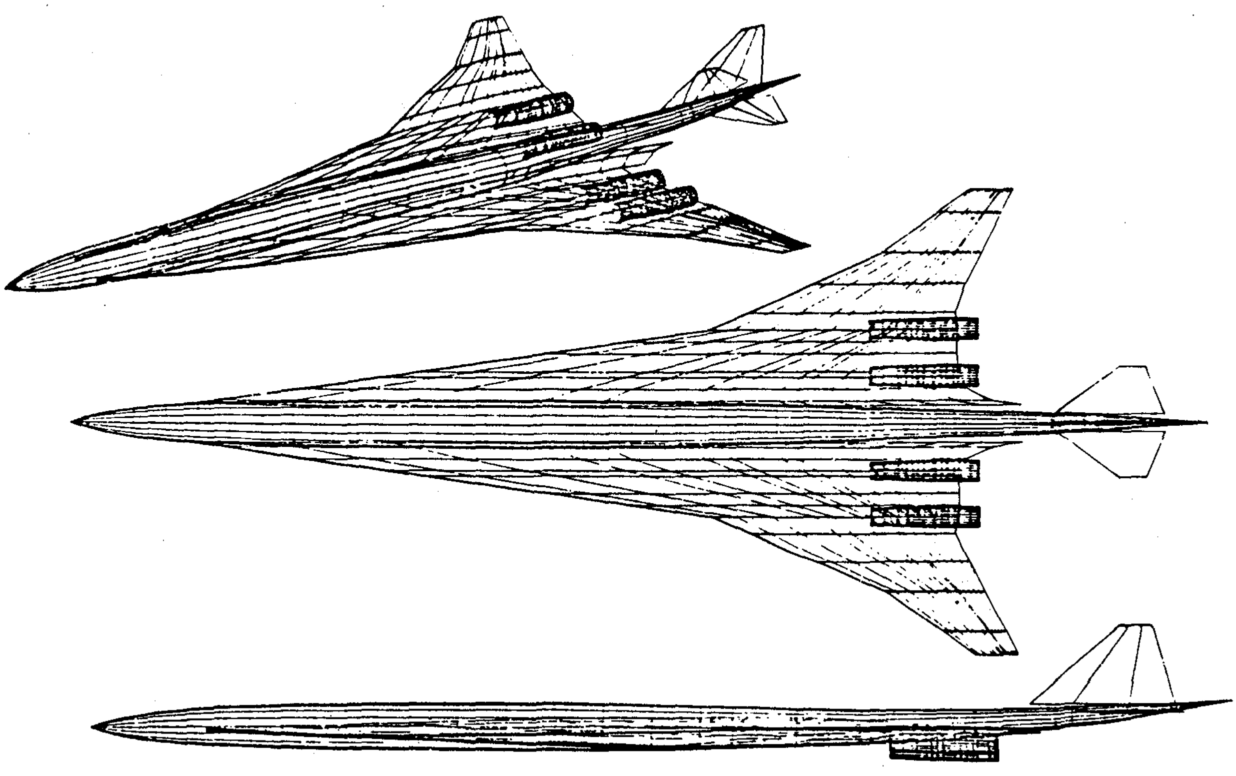


Figure 18. Nondimensional Computer Model, Low Sonic Boom

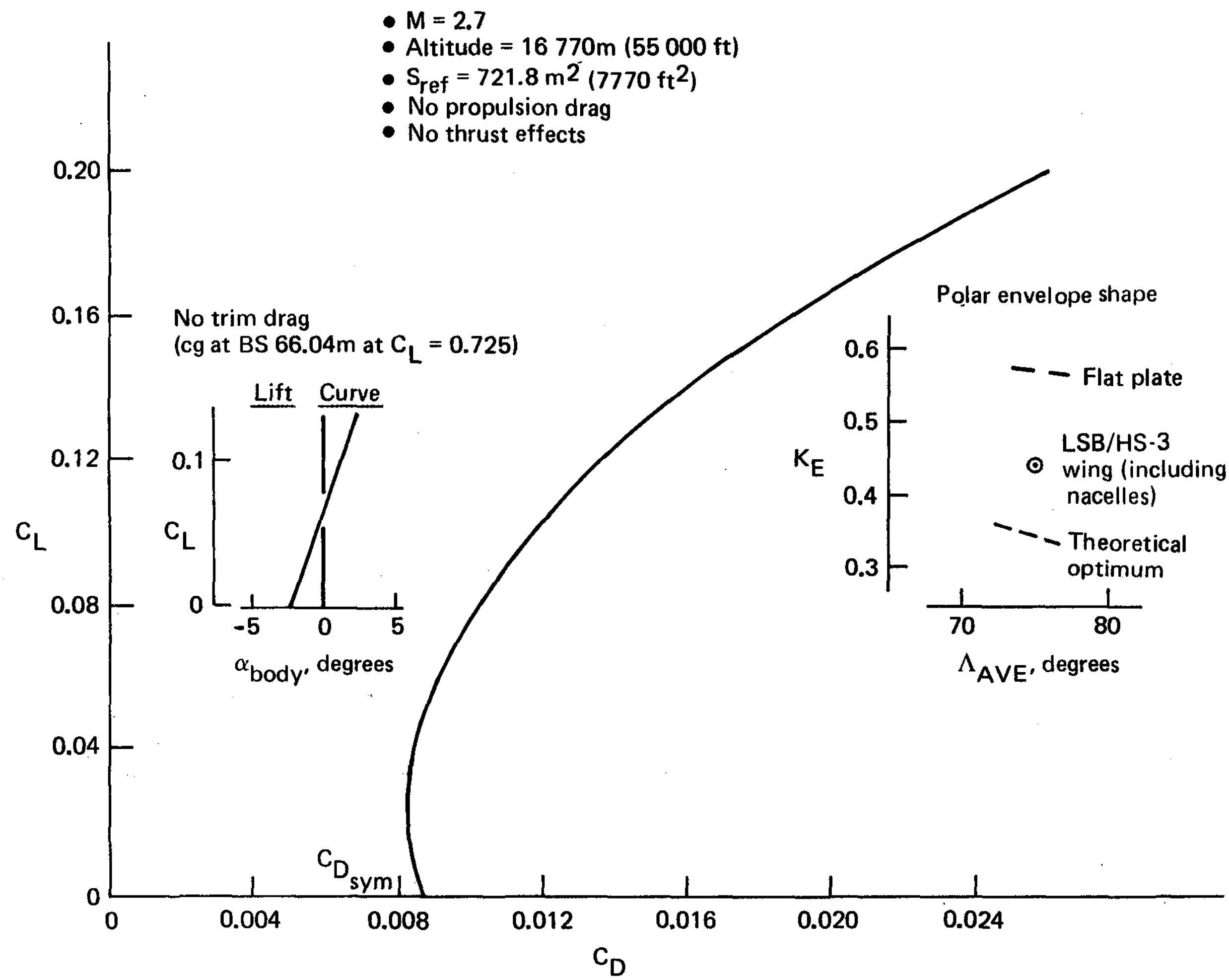
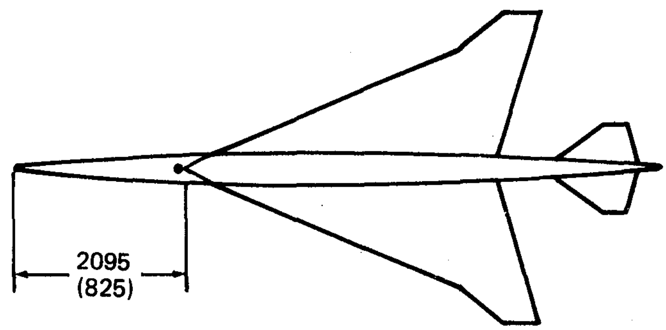


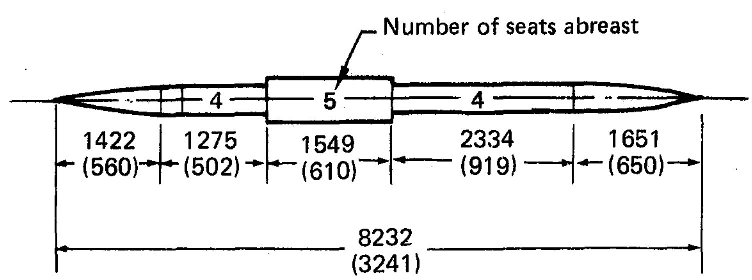
Figure 19. Cruise Lift–Drag Characteristics–LSB/HS-3

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	272 000 (600 000)
Design range, km (nmi)	8148 (4400)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust–SLS, N (lb)	192 150 (43 200)
Wing area, m^2 (ft^2)	571 (6150)
Body length, m (in)	82.321 (3241)
Abreast seating	4,5
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	113 717 (250 700)
Propulsion mass, kg (lb)	20 366 (44 900)
Airframe mass, kg (lb)	93 441 (206 000)
Maximun zero fuel mass, kg (lb)	132 678 (292 500)



Passenger Seating Arrangement
200 Passengers

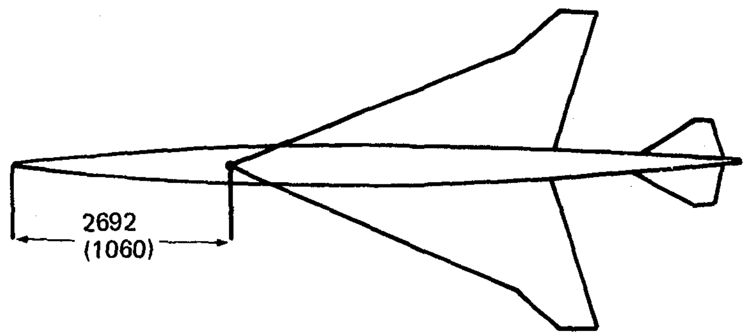


Dimensions, cm (in)

Figure 20. Airplane No. 5

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	272 000 (600 000)
Design range, km (nmi)	6852 (3700)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust–SLS, N (lb)	196 150 (43 200)
Wing area, m^2 (ft^2)	571 (6150)
Body length, m (in)	89.306 (3516)
Abreast seating	4,5,6
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	120 748 (266 200)
Propulsion mass, kg (lb)	20 366 (44 900)
Airframe mass, kg (lb)	99 565 (219 500)
Maximum zero fuel mass, kg (lb)	146 649 (323 300)



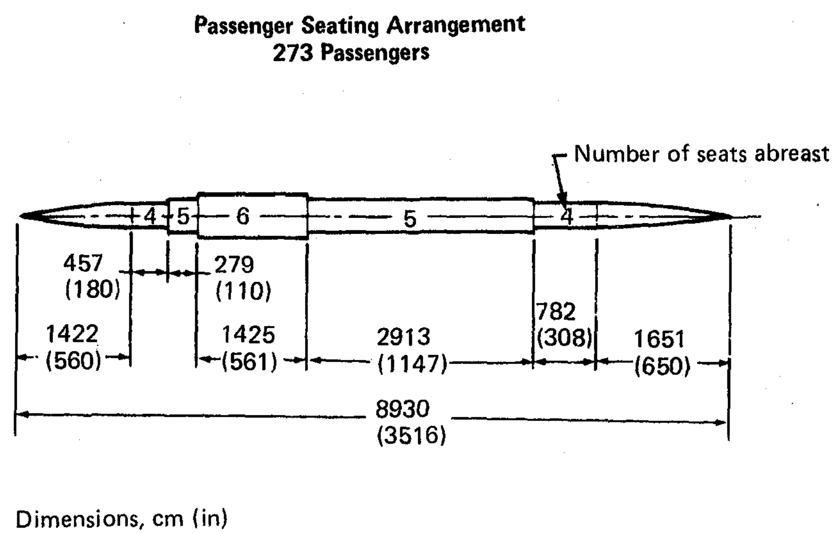


Figure 21. Airplane No. 6

Configuration Characteristics

Mach number	0.83
Takeoff gross mass, kg (lb)	261 000 (575 000)
Design range, km (nmi)	9485 (5119)
Thrust to mass, N/kg (lb/lb)	2.710 (0.276)
Engine thrust—SLS, N (lb)	235 750 (53 000)
Wing area, m^2 (ft^2)	343 (3700)
Body length, m (in)	51.968 (2046)
Abreast seating	9
Wing loading, Nm^{-2} (lb/ft^2)	7441 (155)
Operating empty mass, kg (lb)	125 093 (275 840)
Propulsion mass, kg (lb)	18 144 (40 000)
Airframe mass, kg (lb)	100 100 (220 680)
Maximum zero fuel mass, kg (lb)	177 318 (391 000)

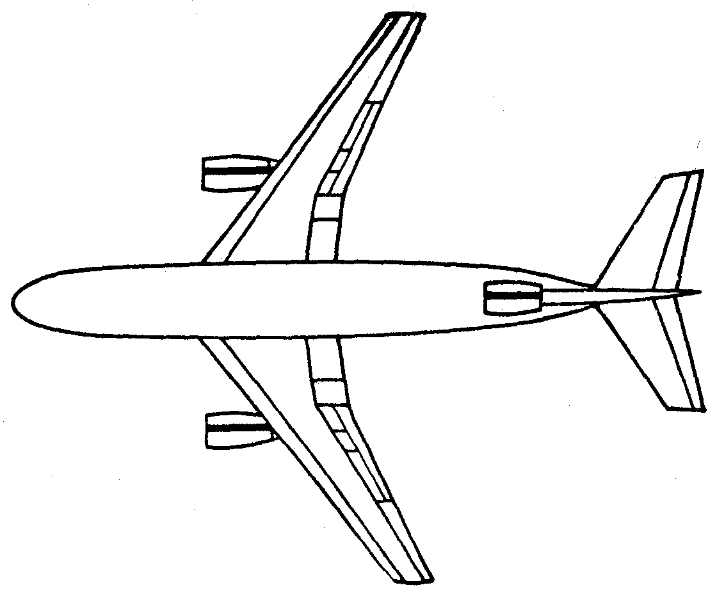
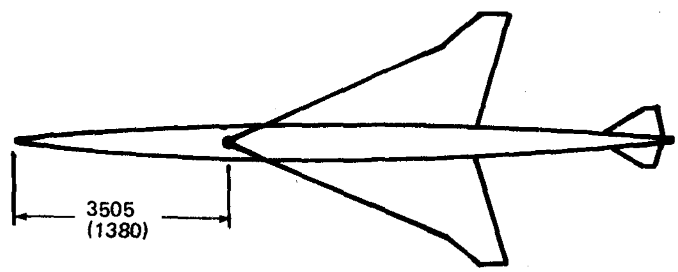


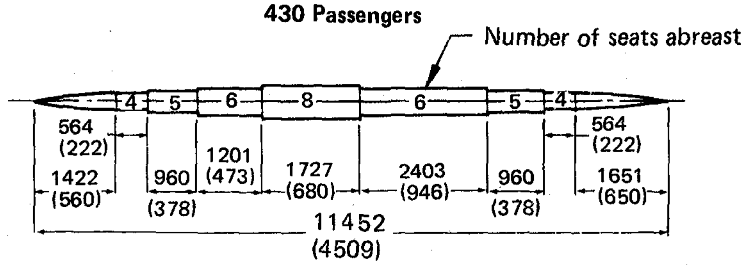
Figure 22. Airplane No. 7

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	340 000 (750 000)
Design range, km (nmi)	6019 (3250)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust—SLS, N (lb)	240 200 (54 000)
Wing area, m^2 (ft^2)	715 (7700)
Body length, m (in)	114 520 (4509)
Abreast seating	4, 5, 6, 8
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	159 032 (350 600)
Propulsion mass, kg (lb)	26 717 (58 900)
Airframe mass, kg (lb)	130 936 (288 660)
Maximun zero fuel mass, kg (lb)	199 810 (440 500)



Passenger Seating Arrangement
430 Passengers



Dimensions, cm (in)

Figure 23. Airplane No. 8

Configuration Characteristics

Mach number	2.4
Takeoff gross mass, kg (lb)	272 000 (600 000)
Design range, km (nmi)	6019 (3250)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust—SLS, N (lb)	192 150 (43 200)
Wing area, m^2 (ft^2)	571 (6150)
Body length, m (in)	100 930 (3974)
Abreast seating	4,5,6
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	125 012 (275 600)
Propulsion mass, kg (lb)	20 366 (44 900)
Airframe mass, kg (lb)	103 361 (277 870)
Maximum zero fuel mass. kg (lb)	155 358 (342 500)

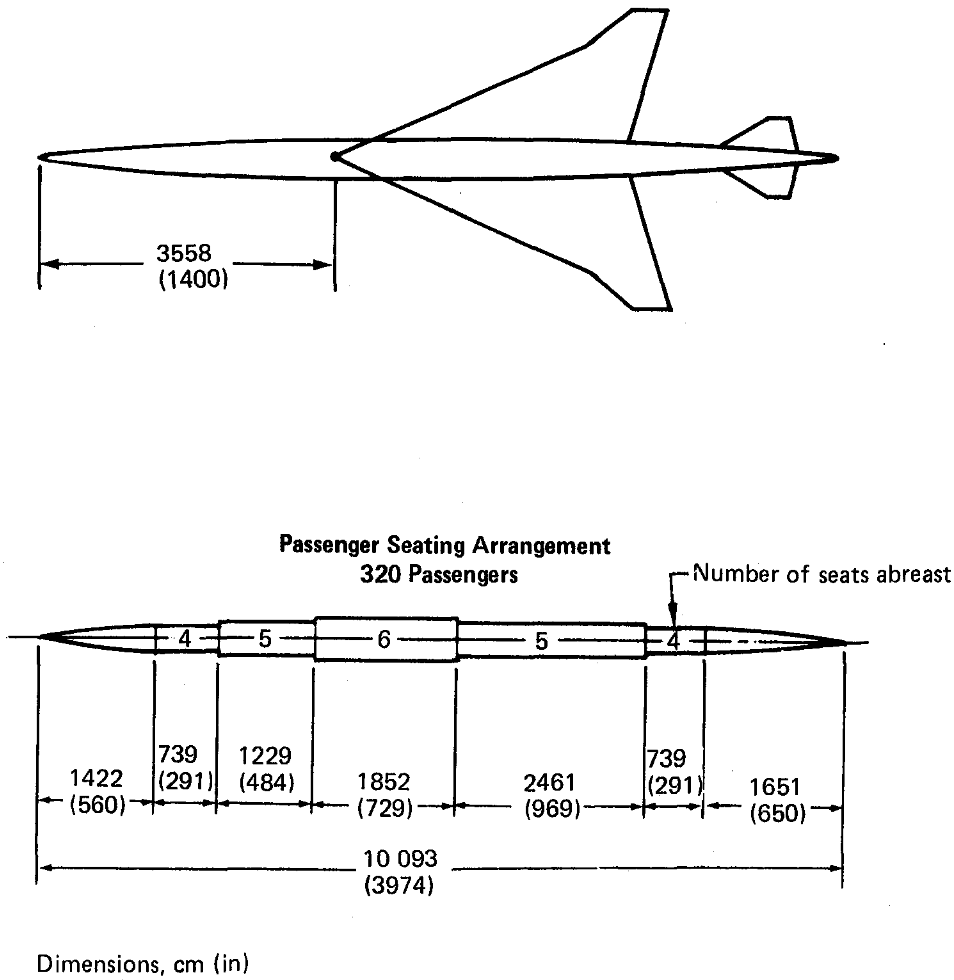
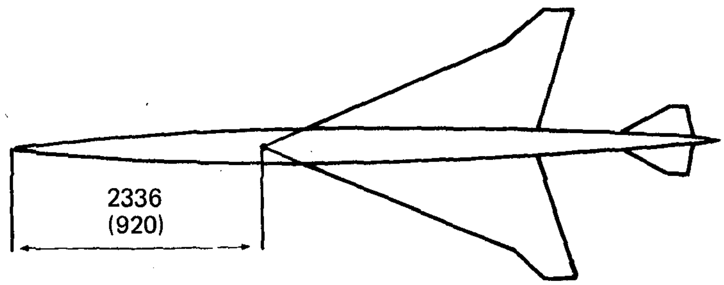


Figure 24. Airplane No. 9

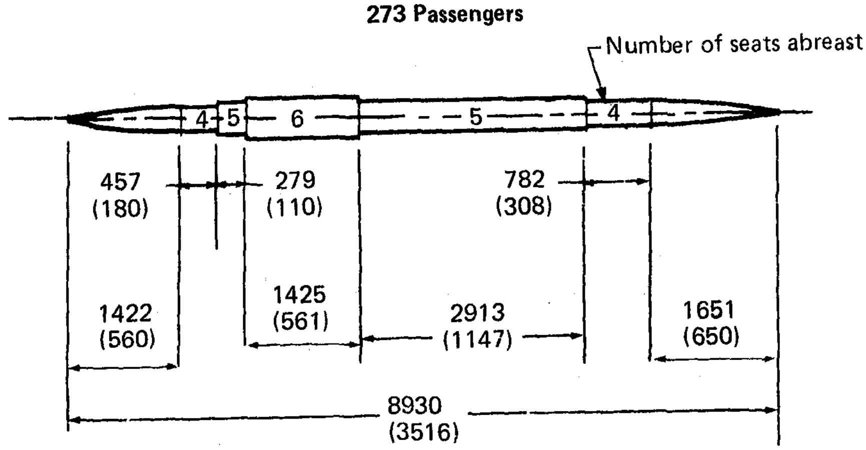
Configuration Characteristics

Mach number	2.7
Takeoff gross mass, kg (lb)	340 000 (750 000)
Design range, km (nmi)	7936 (4300)
Thrust to mass, N/kg (lb/lb)	2.826 (0.288)
Engine thrust—SLS, N (lb)	240 200 (54 000)
Wing area, m^2 (ft^2)	715 (7700)
Body length, m (in)	89.306 (3516)
Abreast seating	4, 5, 6
Wing loading, Nm^{-2} (lb/ft^2)	4664 (97)
Operating empty mass, kg (lb)	145 809) (321 450)
Propulsion mass, kg (lb)	27 714 (61 100)
Airframe mass, kg (lb)	120 240 (265 080)
Maximum zero fuel mass, kg (lb)	171 687 (378 500)



Passenger Seating Arrangement

273 Passengers



Dimensions, cm (in)

Figure 25. Airplane No. 10

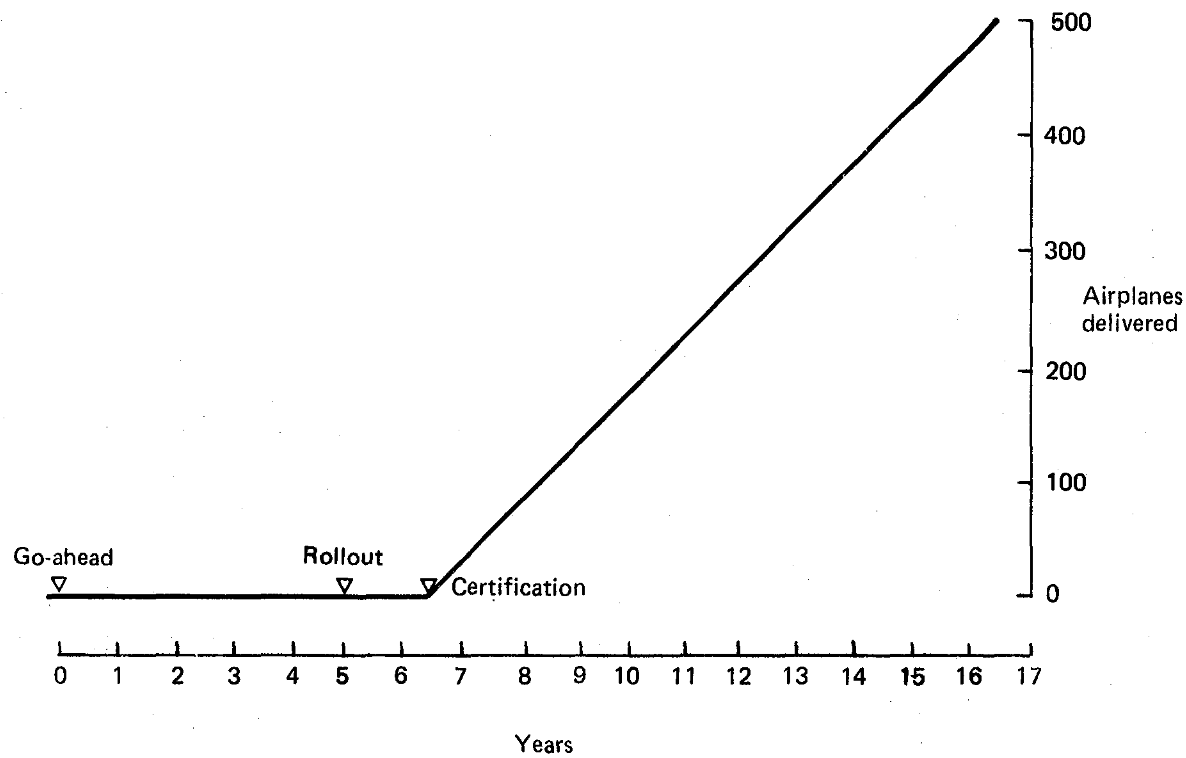


Figure 26. Development and Production Schedules for Airplane No. 4 (or No. 7)

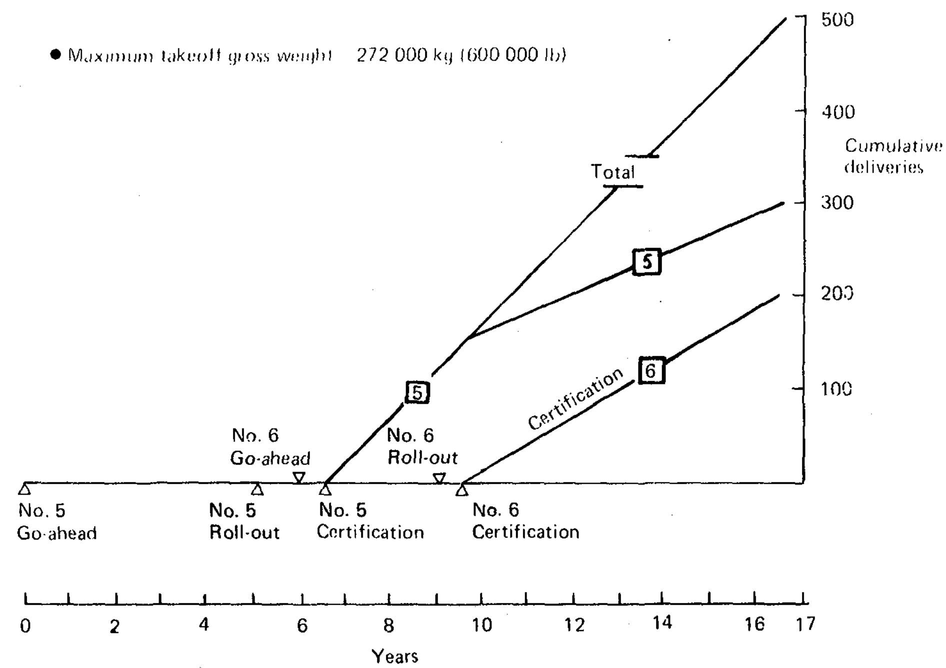


Figure 27. Development and Production Schedules for Airplane Family No. 5 and 6

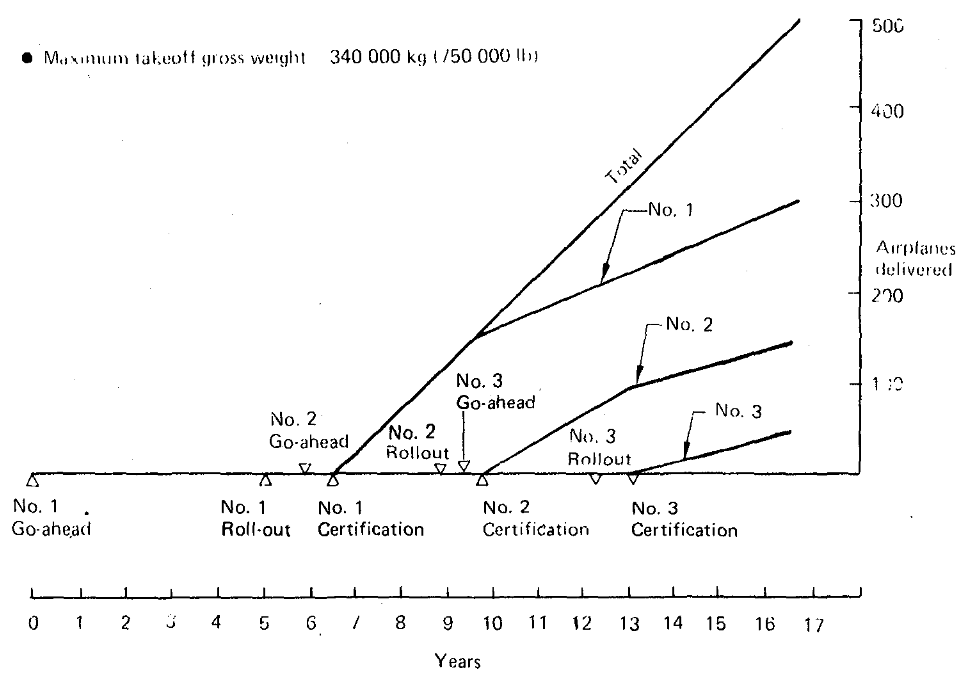


Figure 28. Development and Production Schedules for Airplane Family No. 1, 2, and 3

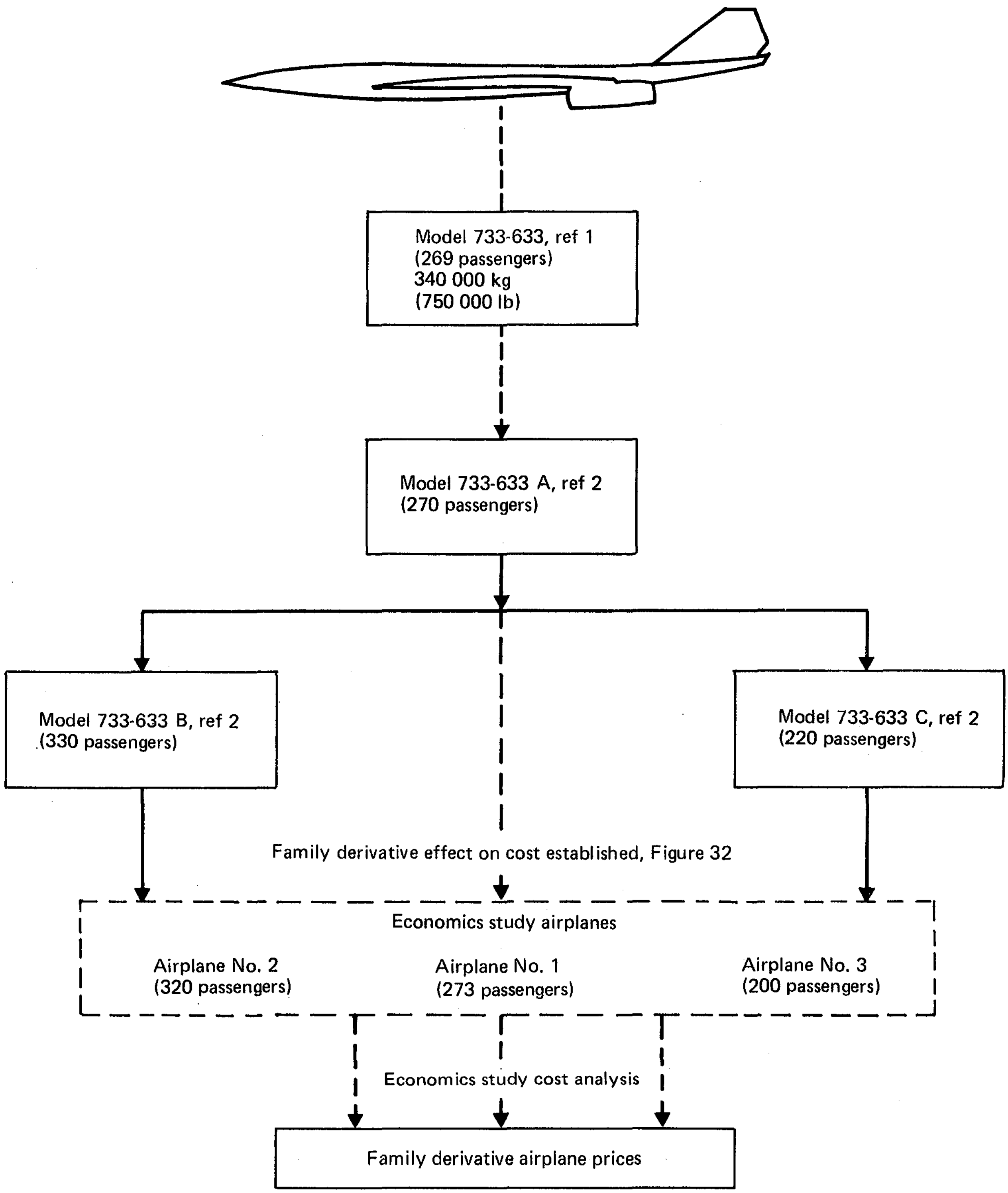


Figure 29. Cost Estimating and Pricing Concept

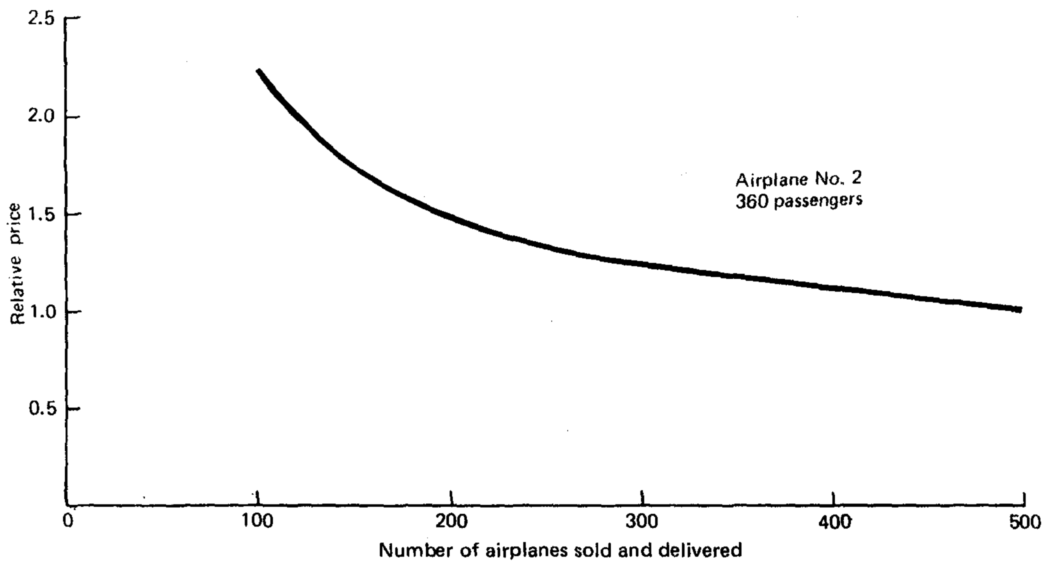


Figure 30. Relative ROI Price vs. Number of Airplanes Sold and Delivered During a 10-Year Time Period

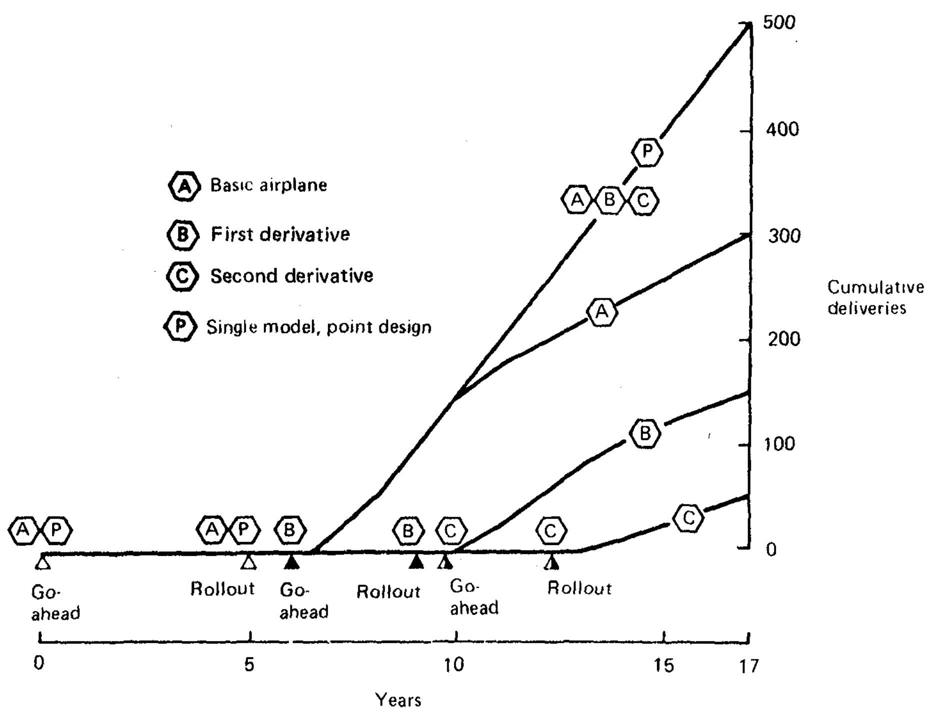


Figure 31. Development and Production Schedules

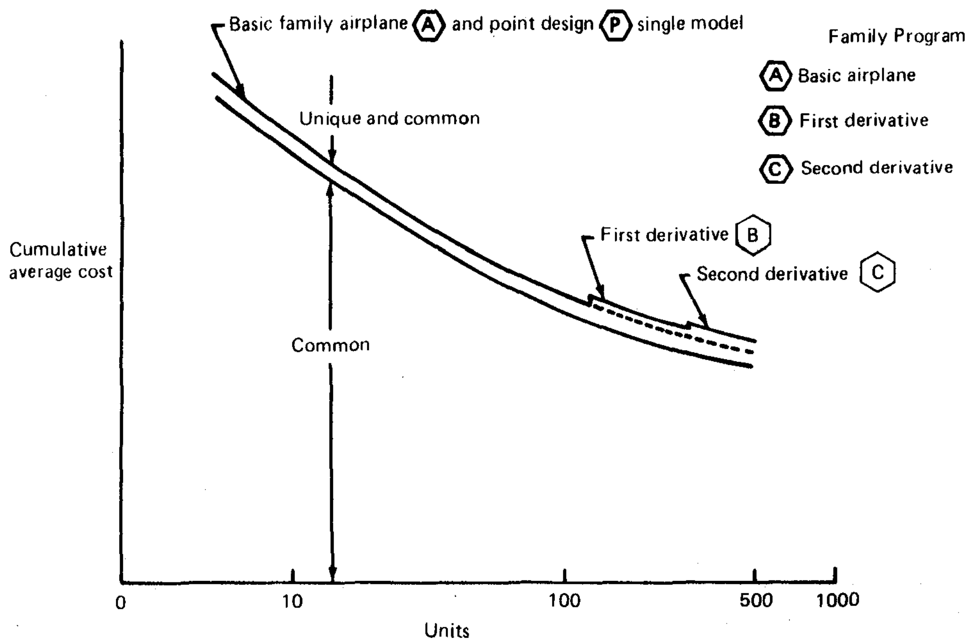


Figure 32. Favorable Effect of Commonality on Cost

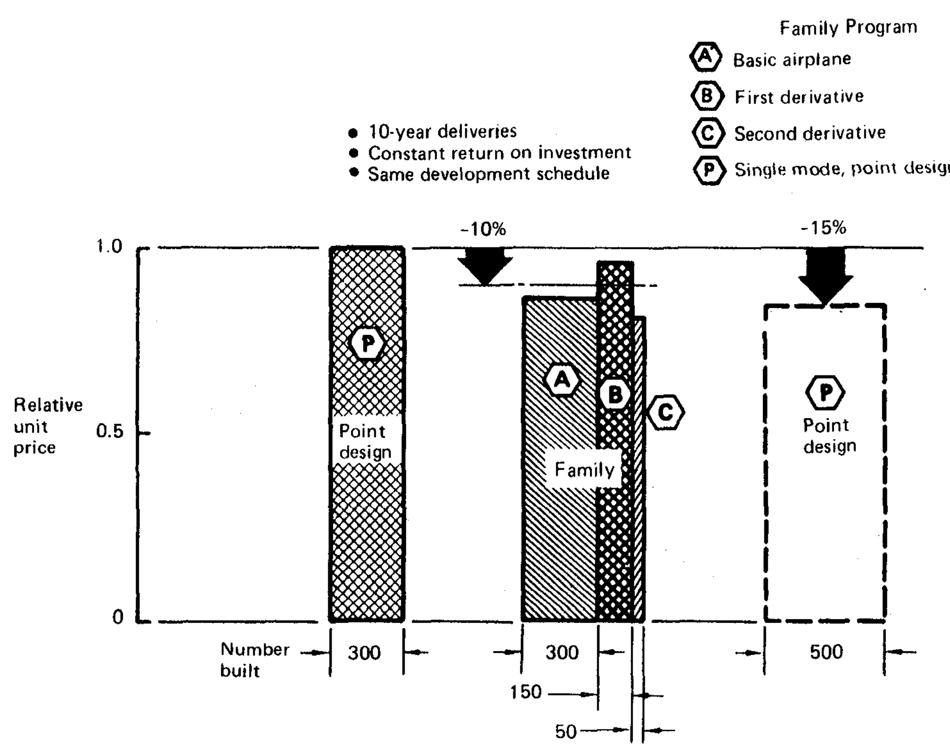
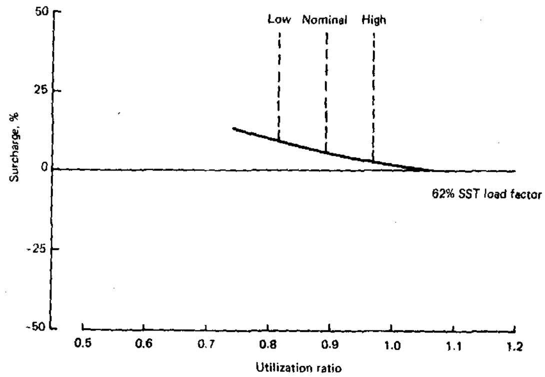
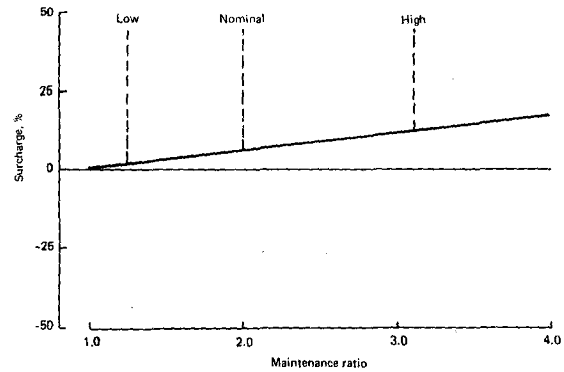


Figure 33. Airplane Price, Family vs. Point Design

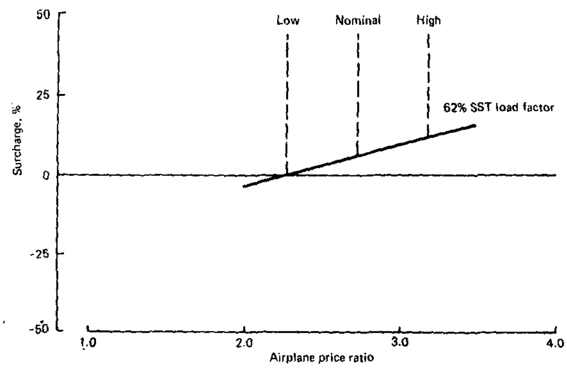
AIRPLANE NO. 2 AT 62% LOAD FACTOR



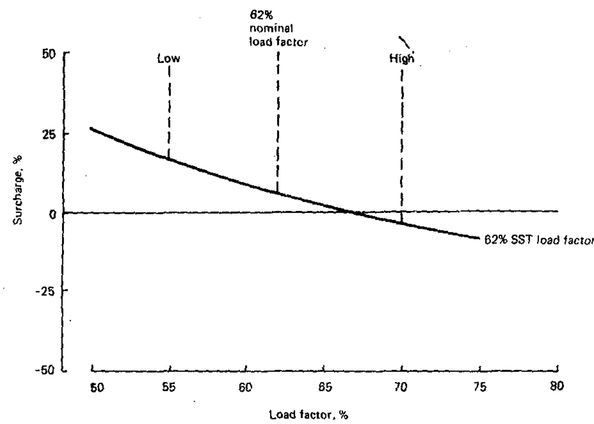
GRAPH A–UTILIZATION RATIO



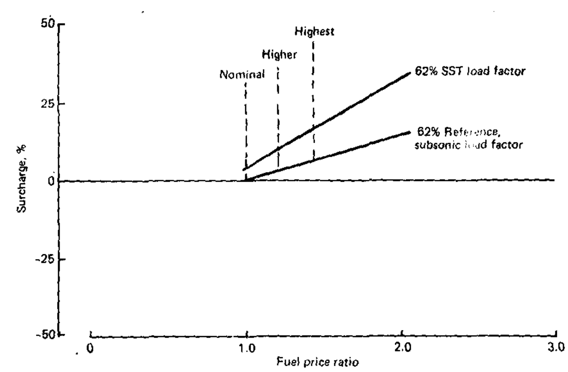
GRAPH B–MAINTENANCE RATIO



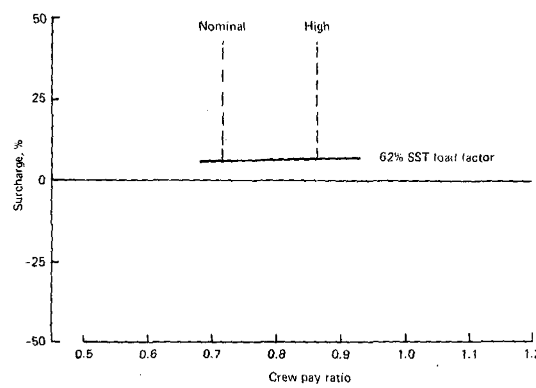
GRAPH C–AIRPLANE PURCHASE PRICE RATIO



GRAPH D–LOAD FACTOR



GRAPH E–FUEL PRICE RATIO



GRAPH F–CREW PAY RATIO

Figure 34. Surcharge Sensitivities

1. Report No. NASA CR-159126	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Economic Study of Multipurpose Advanced High-Speed Transport Configurations		5. Report Date September 1979
		6. Performing Organization Code
7. Author(s) BCAC Preliminary Design Department		8. Performing Organization Report No. D6-48725
9. Performing Organization Name and Address Boeing Commercial Airplane Company P.O. Box 3707 Seattle, WA 98124		10. Work Unit No.
		11. Contract or Grant No. NAS1-14623
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC		13. Type of Report and Period Covered Contractor Report Final (Contract Mod #5)
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This document describes the Economic Analysis Study which is part of a larger National Aeronautics and Space Administration Supersonic Cruise Research (NASA SCR) Program designed to identify and develop technology that may make it possible to define advanced supersonic airplanes. Ten airplanes were defined according to size, payload, and speed. The price, range capability, fuel burned, and block time were determined for each configuration, then operating costs and surcharges were calculated.

17. Key Words (Suggested by Author(s)) Surcharge, Return on Investment, Economics, Maintenance Cost, Airplane Price, Fuel Price, Sensitivity, Direct Operating Cost, Indirect Operating Cost,		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 55	22. Price*

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