BOEING SST

MODEL 733

AVIATION SUBCOMMITTEE - APRIL 19, 1965

This section contains results of economic and market analyses of the SST. Comparisons are made of operating costs of the Boeing supersonic model, 733-290; the Concorde; the current subsonic 707-320B; and a possible future subsonic, the Boeing 707-820. An analysis of the potential market impact of the Concorde is discussed. The effect of a delayed introductory date of the U.S. SST on potential U.S. sales and on the U.S. balance of payments is also discussed.

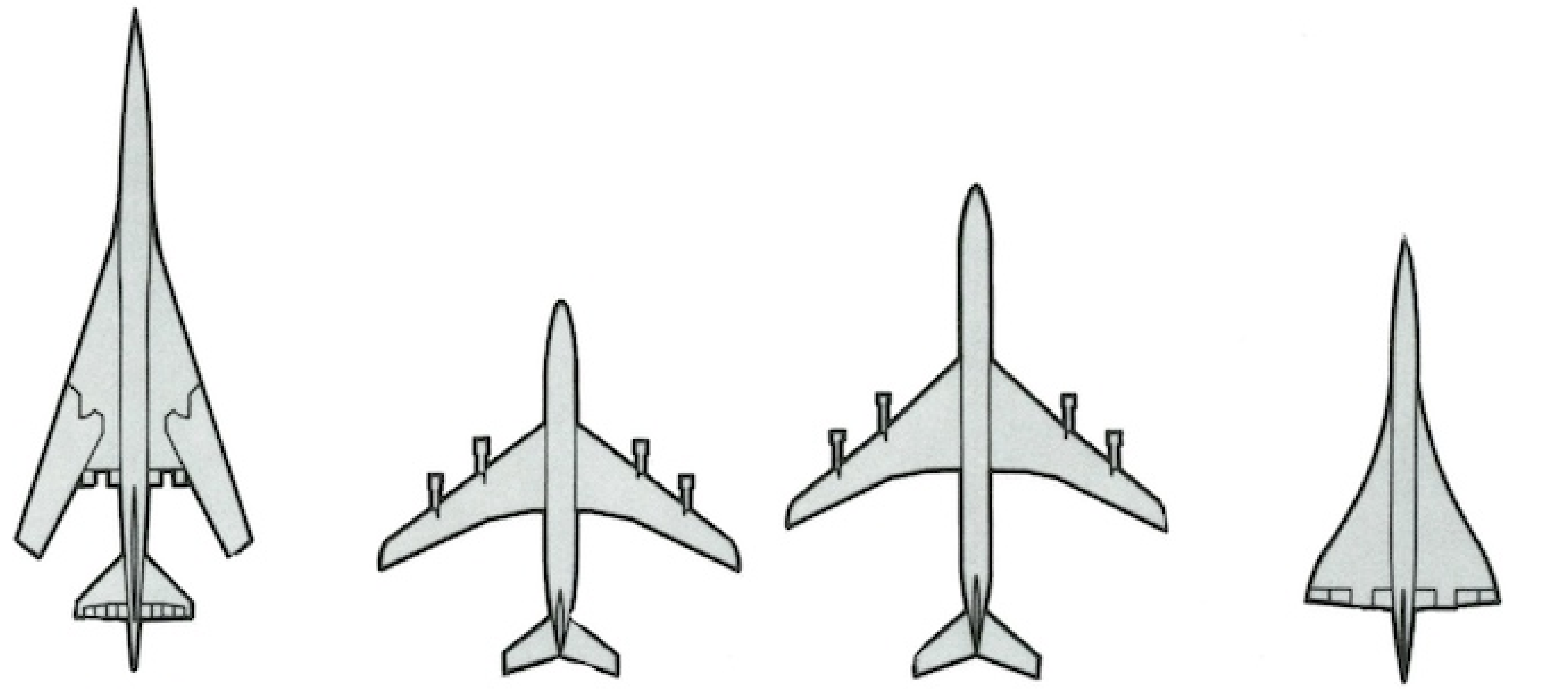
The Boeing 733-290 has economics better than the 707-320B and equal to the 707-820 at the ranges of interest. Although the seat mile costs of the Concorde are higher than any of the other three airplanes, it can be operated profitably with the same number of passengers per trip as are being carried today. This fact, coupled with the marketing appeal for speed, will make it more and more a serious competitive threat to the U.S. SST if the U.S. program is delayed.

SST ECONOMICS

Leading characteristics of the airplanes compared are shown here. The plan views show relative sizes. The sales price for the 733-290 is according to the Phase II-A rules. It does not include 3.45 million dollars per airplane for amortization of R&D. However, amortization of R&D is included as an expense in the operating cost data presented in the following pages.

The seating was according to the FAA Phase II-A international economic model, using a 90 percent coach and a 10 percent first class seating split, with 34 inch seat spacing for coach and 40 inch seat spacing for first class sections. Interior drawings are shown on the following page.

ECONOMIC ANALYSIS ASSUMPTIONS



	SST 733-290	707-320B	707-820	CONCORDE
GROSS WEIGHT - LBS	500,000	328,000	412,000	326,000
AIRPLANE PRICE-MILLIONS $	21.142	6.960	10.750	14.000
ENGINE PRICE-MILLIONS $/ENGINE	.980	.258	.335	.560
NUMBER OF SEATS	230	161	251	112

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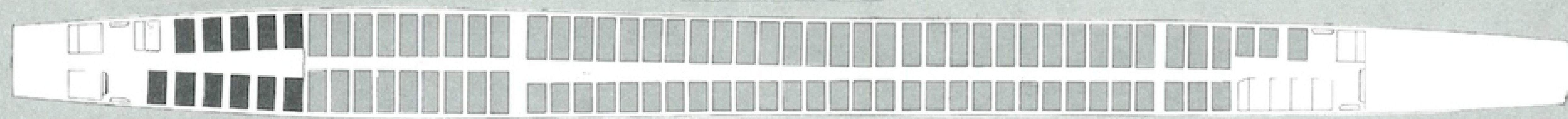
INTERIOR ARRANGEMENT COMPARISON

INTERNATIONAL

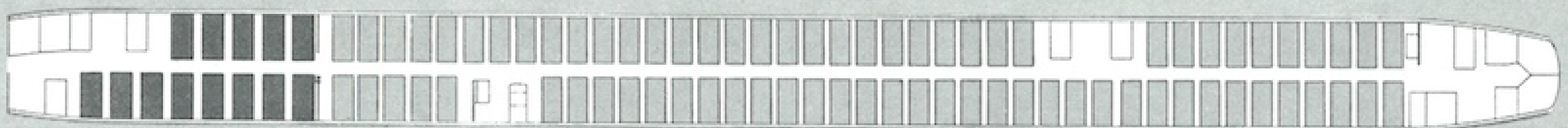
PASSENGER MIX: 10% FIRST CLASS 90% TOURIST
SEAT PITCH : 40" FIRST CLASS 34" TOURIST

733-290



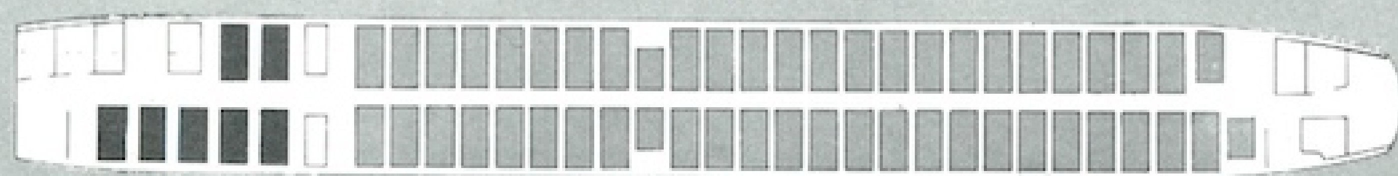
22 FIRST CLASS — 208 TOURIST — 230 TOTAL

707-820



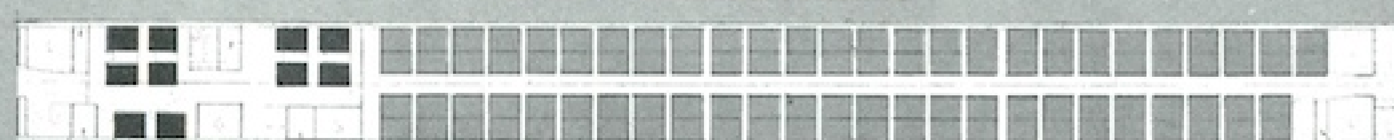
26 FIRST CLASS — 225 TOURIST — 251 TOTAL

707-320B



14 FIRST CLASS — 141 TOURIST — 161 TOTAL

CONCORDE

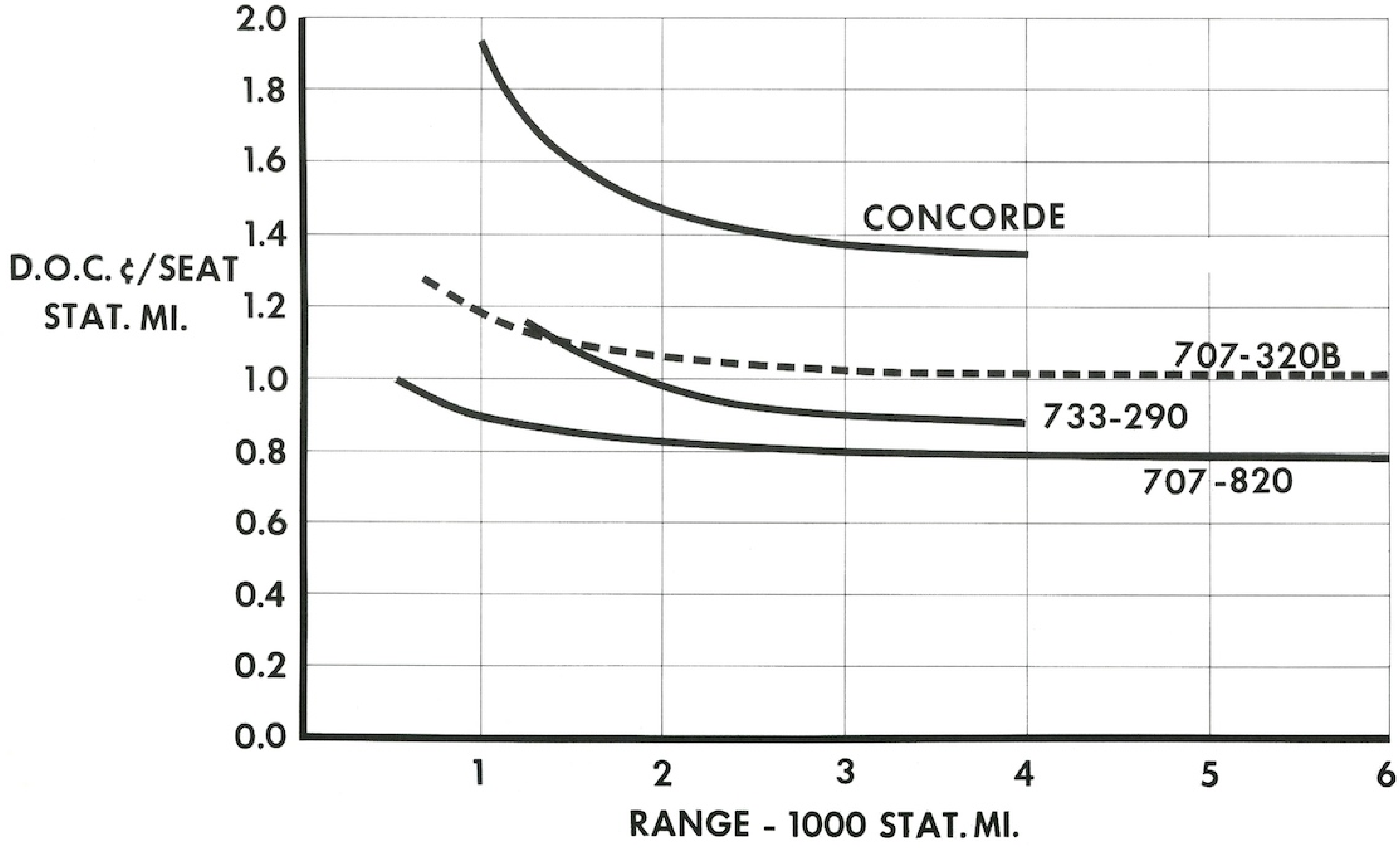


10 FIRST CLASS — 102 TOURIST — 112 TOTAL

The DOC's in cents per seat mile are shown versus range. The larger airplanes have the better unit cost. The supersonics show a greater improvement with range than the subsonics because they are better able to take advantage of their high cruise speeds at the longer ranges.

All costs were computed using the FAA Phase II-A international economic model.

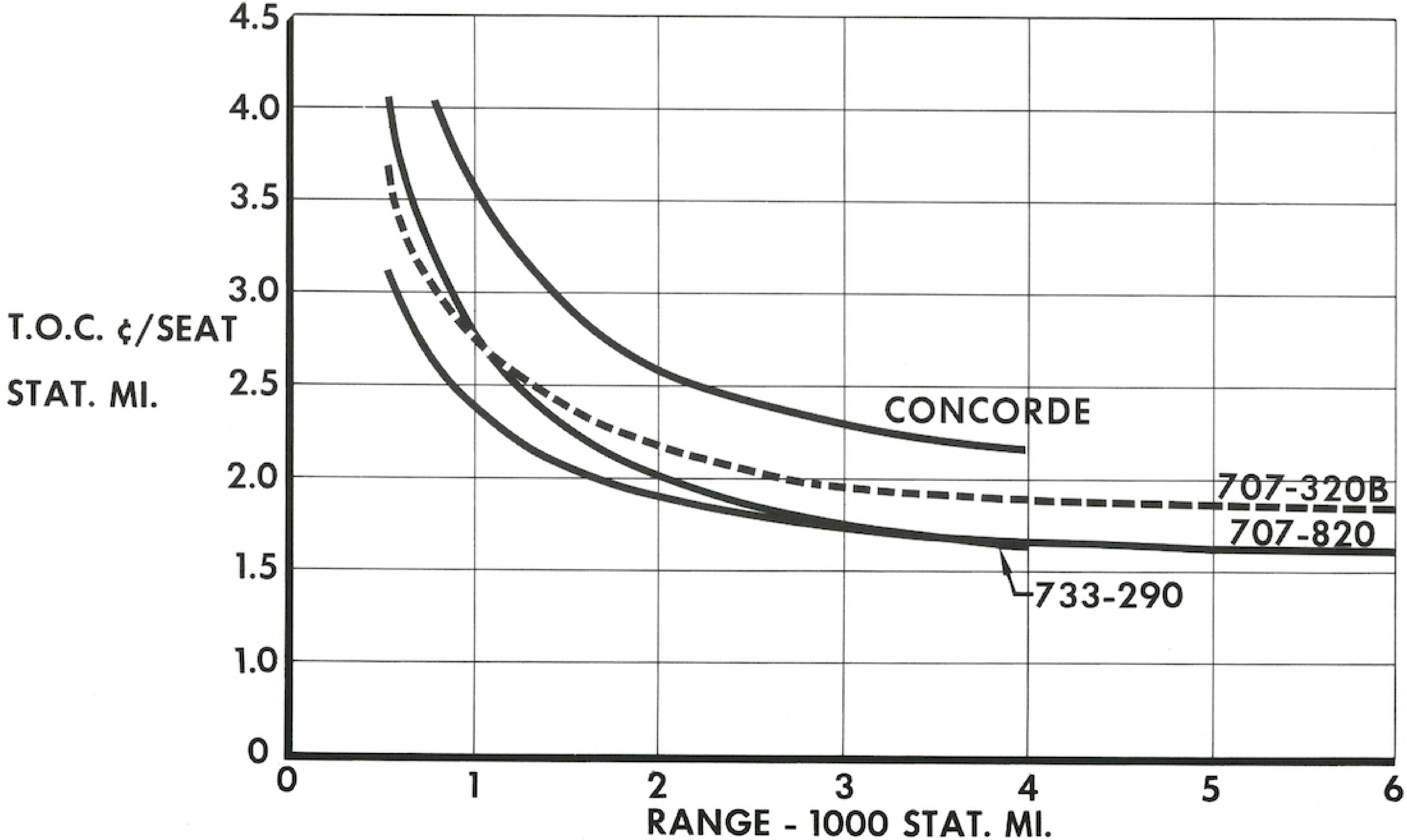
D.O.C. - SEAT MILE COMPARISONS
PHASE IIA INT'L. ECON. MODEL



Adding the indirect costs to the direct costs results in total operating costs. The indirect costs were computed according to the FAA international model mentioned on the previous page. According to these rules a 50 percent load factor is assumed for computing those indirect costs which are sensitive to number of passengers on board, such as meal costs and expense of commissions on ticket sales. The high speed of the supersonics pays off in the indirects by reducing the seat mile cost of meals and stewardesses. For example today one major carrier serves an average of two and one-half meals per person per North Atlantic trip. When the trip time is reduced from 7 hours to 2.5 hours one meal would seem adequate.

T.O.C. - SEAT MILE COMPARISONS

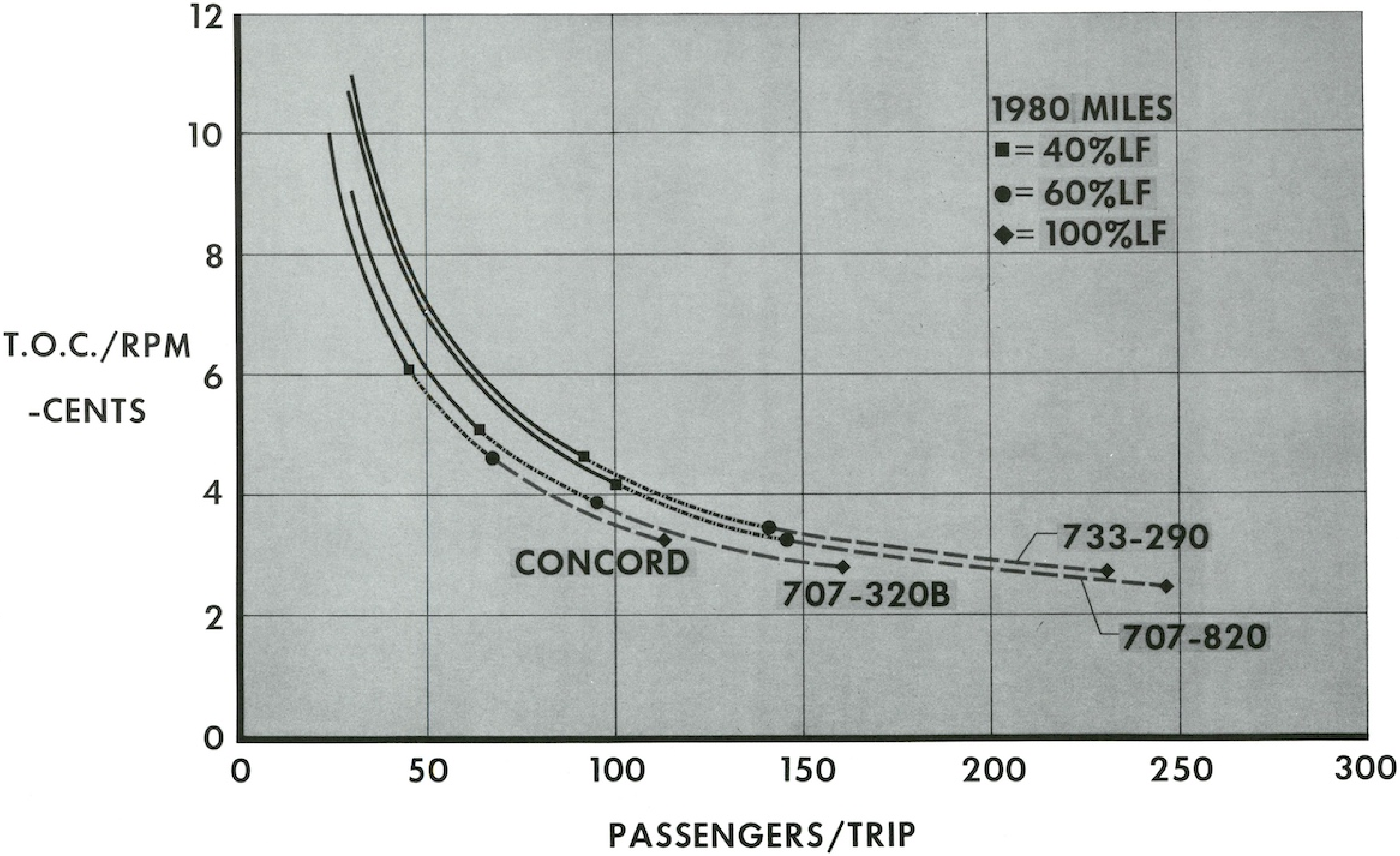
PHASE IIA INT'L. ECON. MODEL



Now looking at a specific range (1980 miles, the average range of the FAA Phase II-A economic model), the total operating cost can be computed as a function of the number of passengers on board for each trip. These costs are now expressed in terms of cents per revenue passenger mile instead of per seat mile as on the previous page. Thus, as an airplane carries more and more passengers per trip, the cost per passenger decreases because the fixed costs are spread over a greater number of passengers. The absolute limit on this is the capacity of the airplane (100 percent load factor). Annual average load factors of over 60 percent are difficult to achieve in service because of fluctuations in demand and because of scheduling problems. However, in early service where a limited supply of a new type exists, load factors of 90 percent can be expected.

With a 90 percent load factor the cost of the Concorde would be approximately 3.5 cents per revenue passenger mile. The 707-320B, operating at 60 percent load factor, would have a 3.9 cent cost and the 707-820 cost would be about 3.4 cents. During this introductory period the Concorde seat mix would heavily favor first class fares as opposed to economy or reduced economy fares. Using 1964 yields, the passenger revenue might be as high as 10 cents per revenue passenger mile as opposed to about 5 cents for the subsonics. (See the Appendix for fare comparisons.) The earnings of the supersonics would be very high.

TOTAL OPERATING COSTS
U.S. INTERNATIONAL

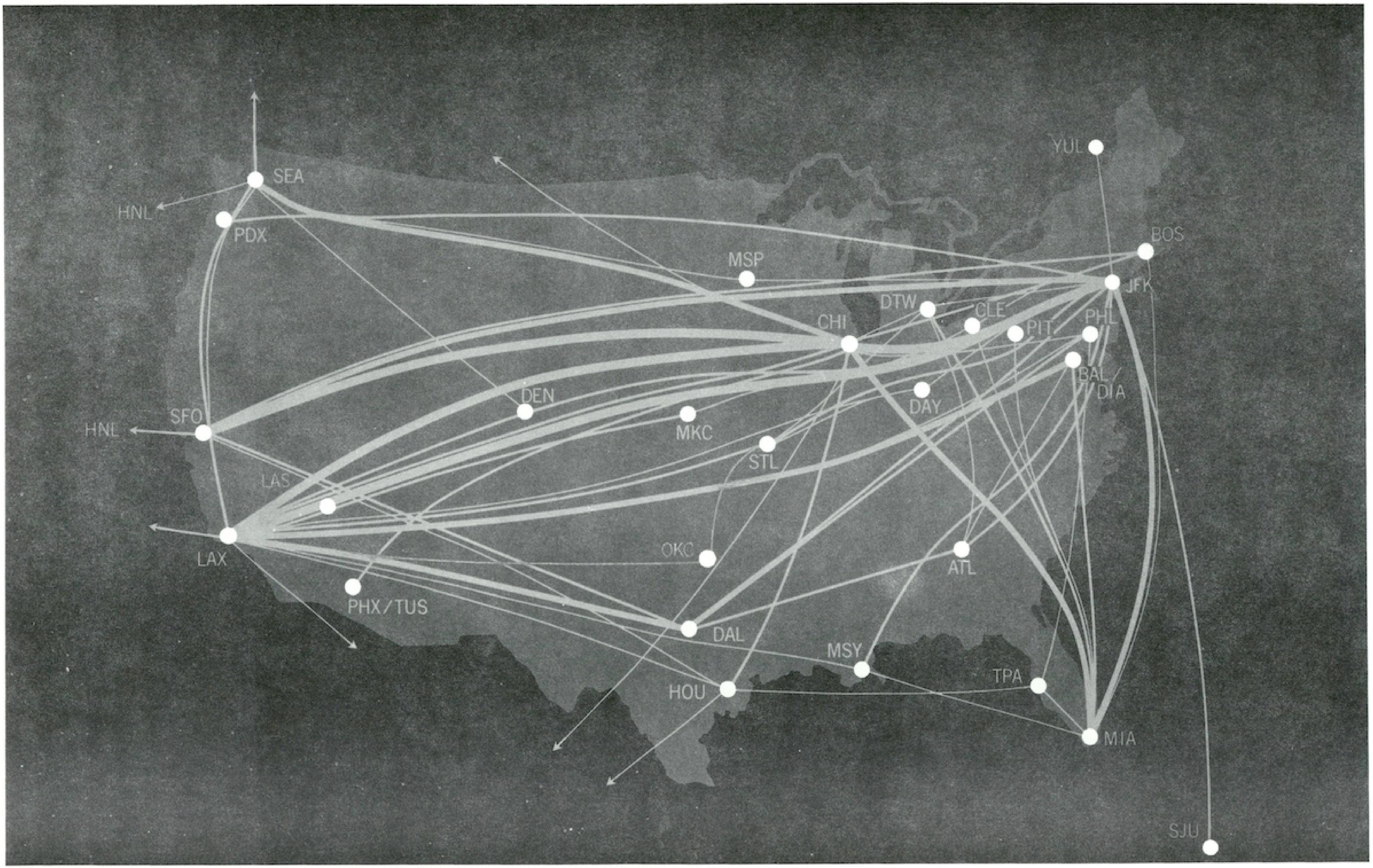


Boeing has done route by route, carrier by carrier, analyses to determine potential routes for the SST. These routes are shown on the next two pages. Two factors are apparent from this study. First, the majority of the routes are over water or unpopulated areas. Even if severe sonic boom restrictions were imposed, there would be about two-thirds of the full market available.

Second, it is apparent that the first market area to be penetrated by supersonics will be the North Atlantic. The second will be the U.S. transcontinental. In these highly profitable markets competition between airlines is intense and a loss in share would have a major impact on a carrier's over-all profit because these lucrative routes help support those in market areas that are not as well developed.

WORLD SST ROUTES

U.S. SST ROUTES

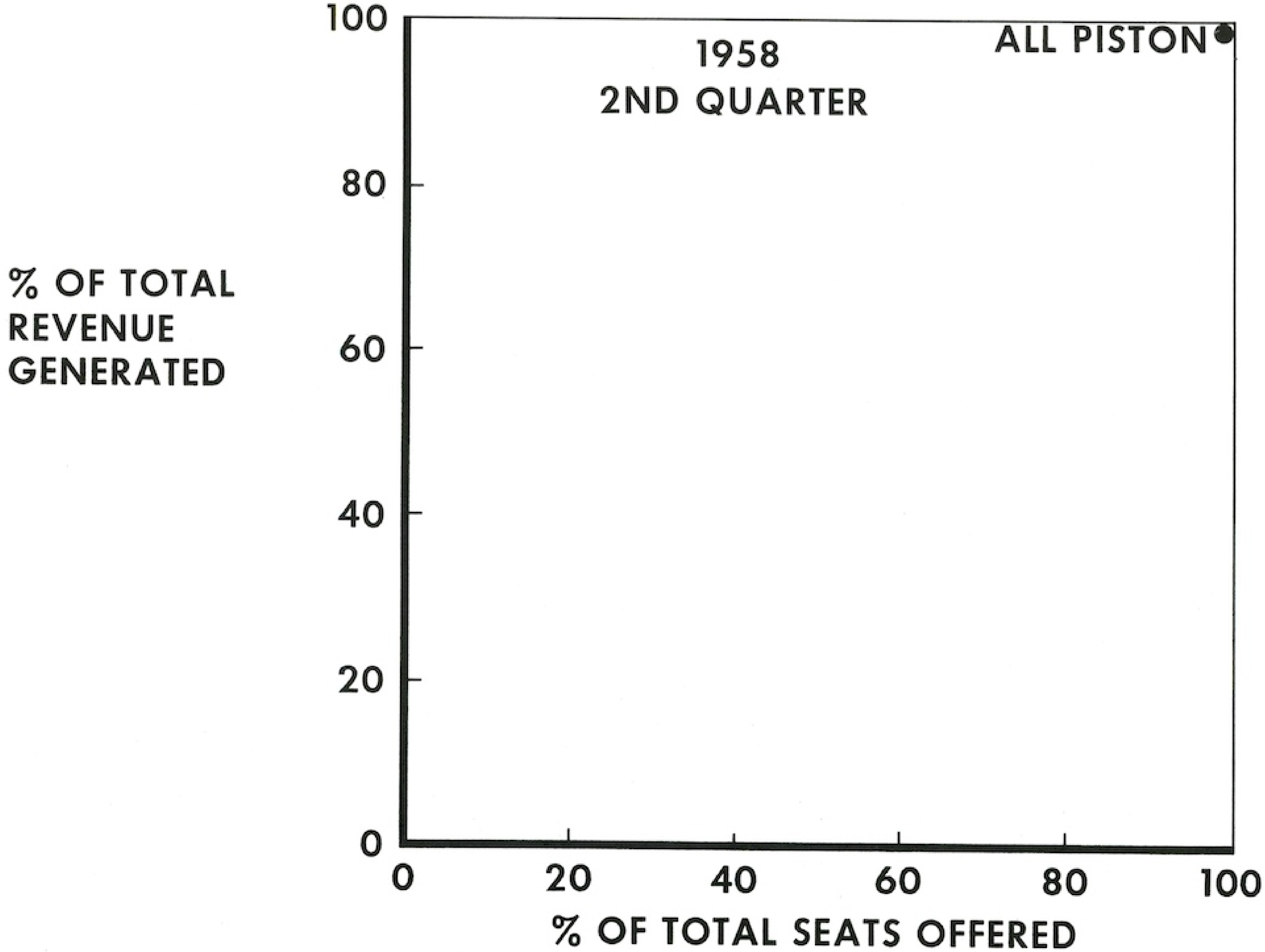


By way of example, it is interesting to examine the way in which the jets took over the market in the years 1959 to 1962. A measure of the penetration is the percent of total seats offered which were jets. Public acceptance is reflected in the percentage of total passenger revenues generated by jets relative to the percent of seats offered.

In the second quarter of 1958 there were no jets in airline operation. One hundred percent of the seats offered were on piston engine aircraft and they generated 100 percent of the passenger revenue. In October 1958, about one month after Boeing had been issued a type certificate, Pan American World Airways placed their first 707 into service on the North Atlantic. The graphs that follow show the jet penetration of the U.S. international market.

THE JET TAKE-OVER
1959-1962

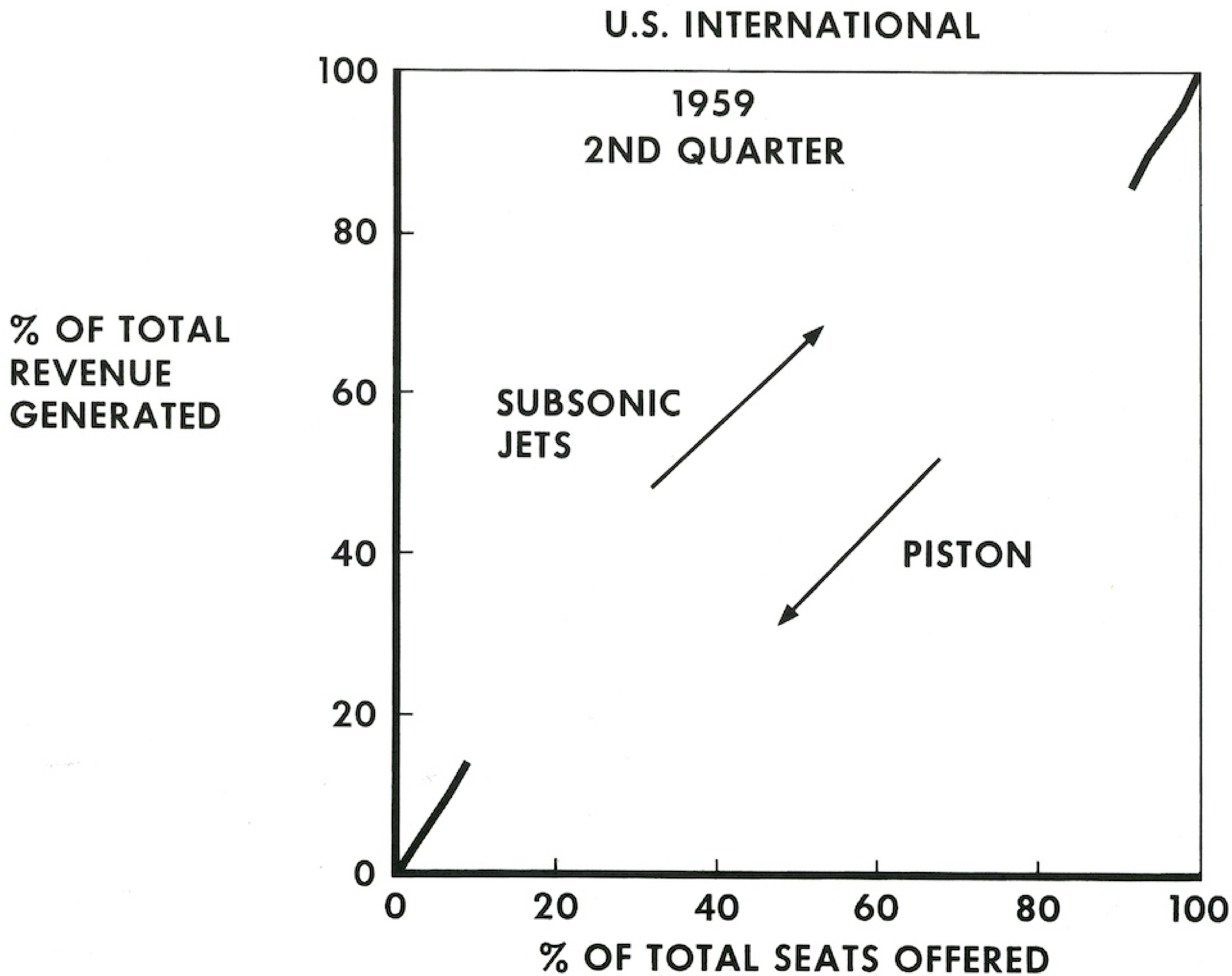
U.S. INTERNATIONAL



By the second quarter of 1959 less than 10 percent of the seats offered were jets, but they were generating more than 15 percent of the revenues.

The revenue advantage of the jets was due to the facts that percentage of its seats occupied was greater than that of the piston airplanes and that fare differentials, which the public was willing to pay, favored the jets.

THE JET TAKE-OVER
1959-1962



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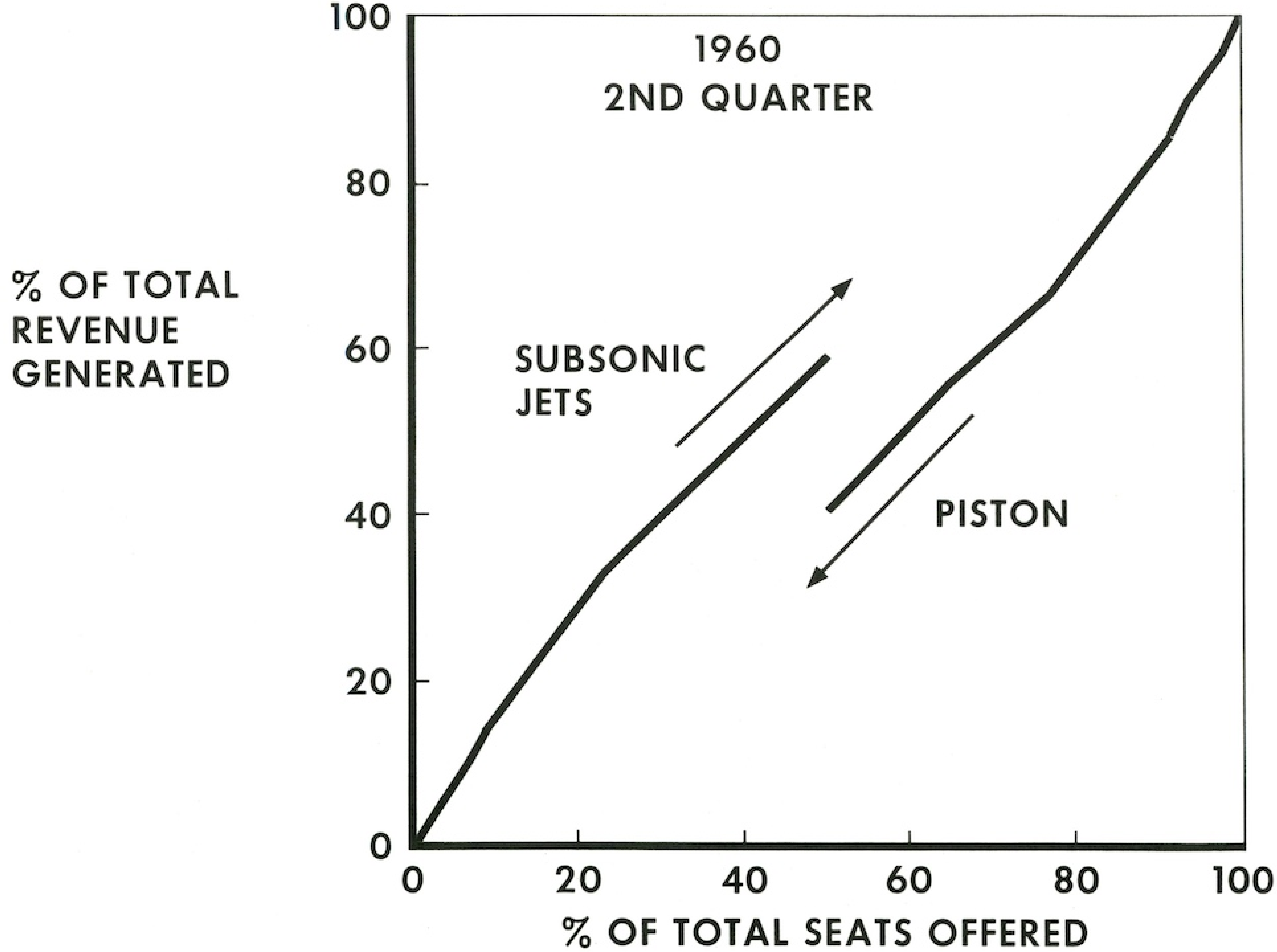
By the second quarter of 1960 the jets were generating 50 percent more revenue than the pistons with about the same number of seats offered.

THE JET TAKE-OVER
1959-1962

U.S. INTERNATIONAL



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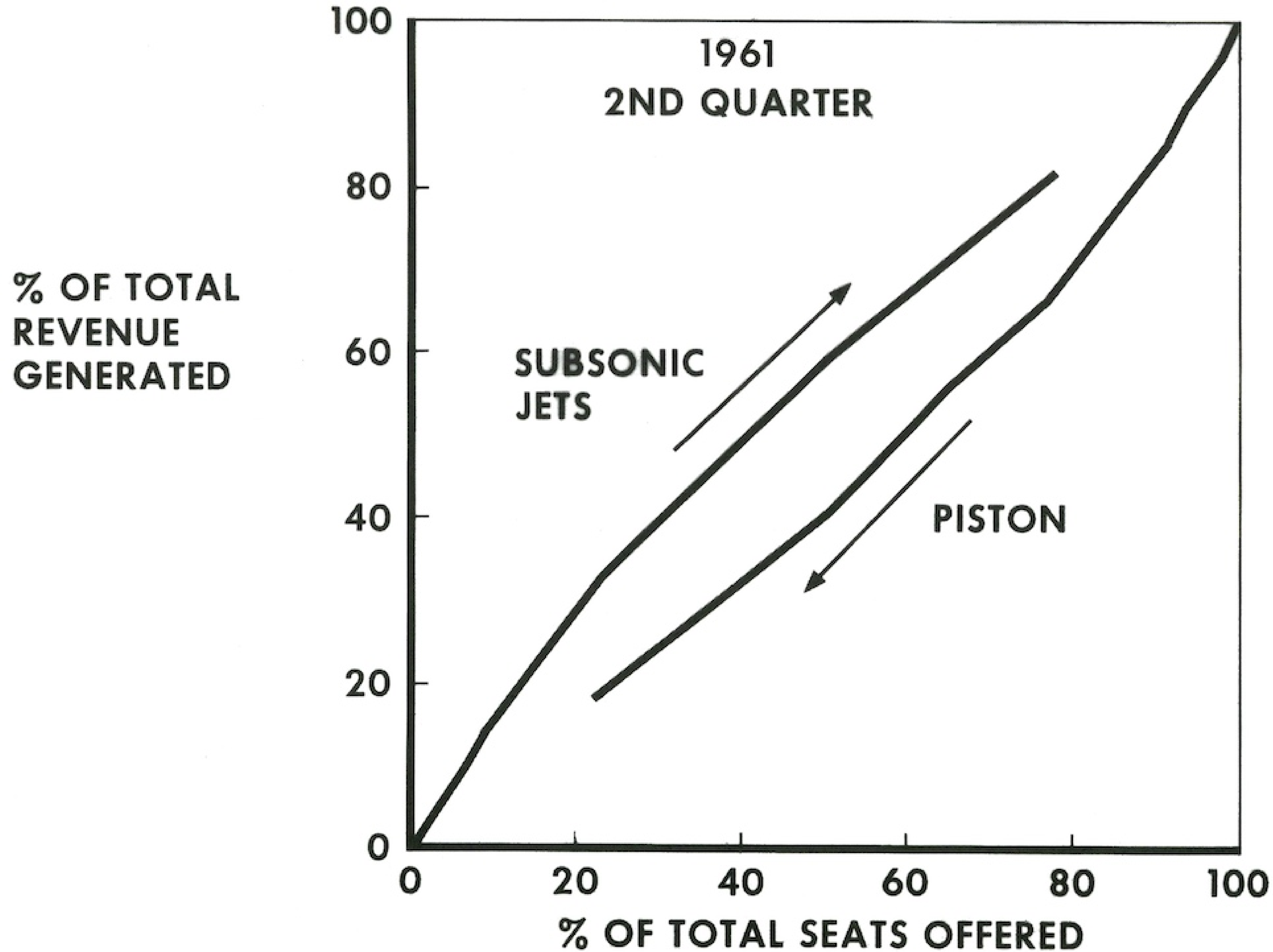
As the jet penetration continued pistons were phased out, because it was only by reducing the size and utilization of the piston fleet that reasonable load factors could be maintained on piston aircraft.

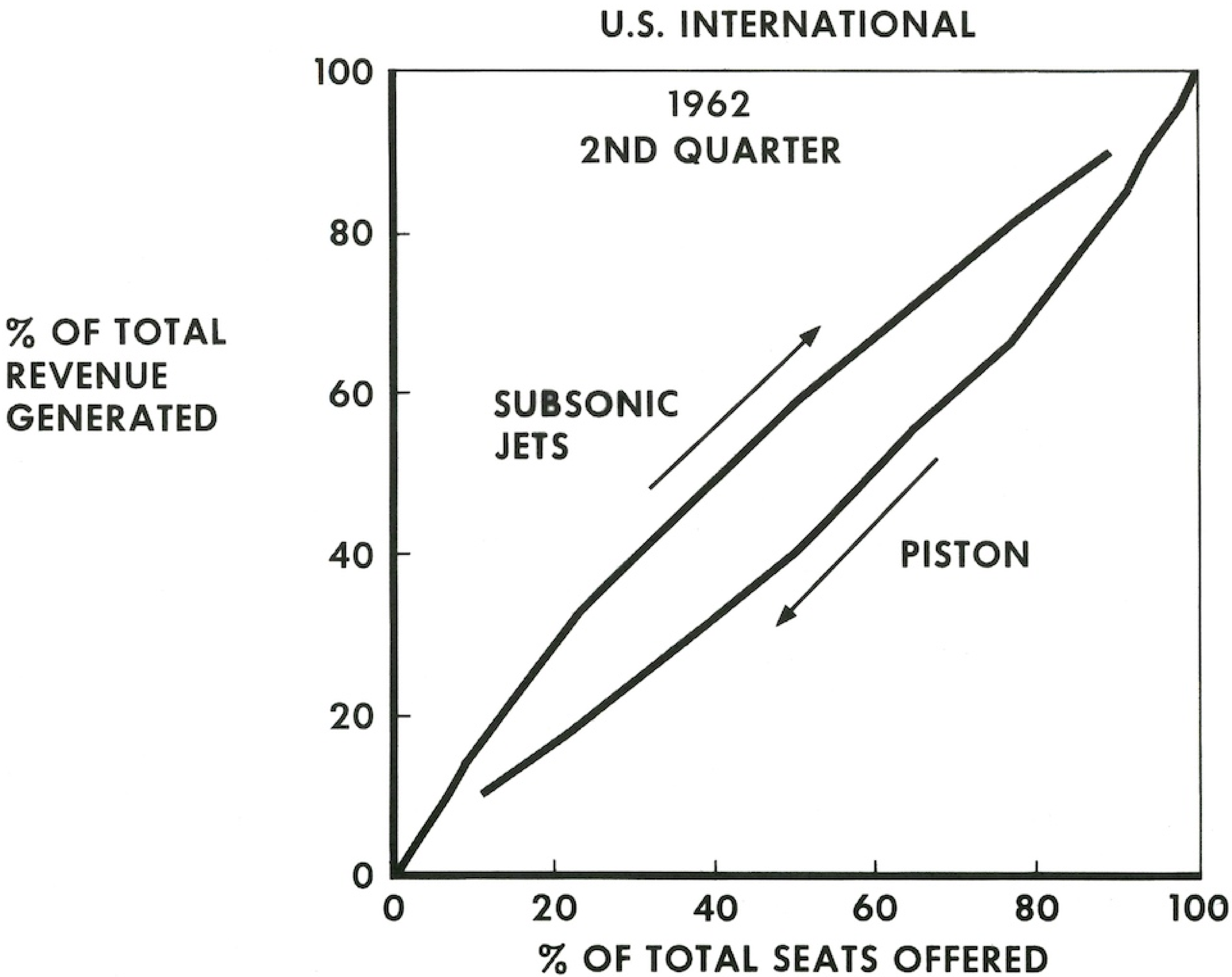
THE JET TAKE-OVER
1959-1962

U.S. INTERNATIONAL



The jet takeover was nearly complete by the second quarter of 1962. Both passenger revenues and total number of passengers had increased greatly during this period, largely as a result of the passenger appeal of the faster jets.

THE JET TAKE-OVER
1959-1962



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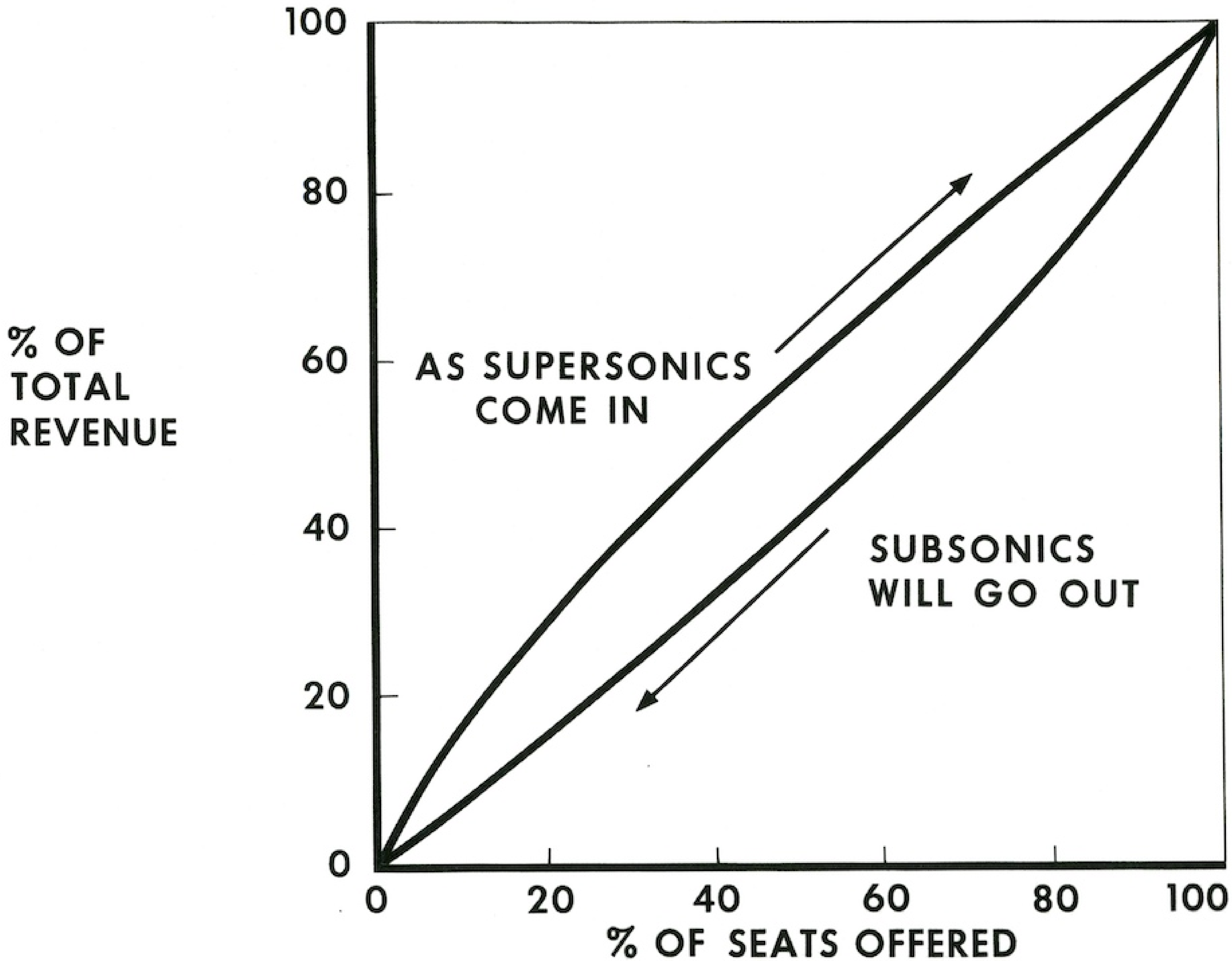
The greatly improved speed of the supersonics insures that they will take over the market from the subsonic jets.

THE SUPERSONIC TAKE-OVER



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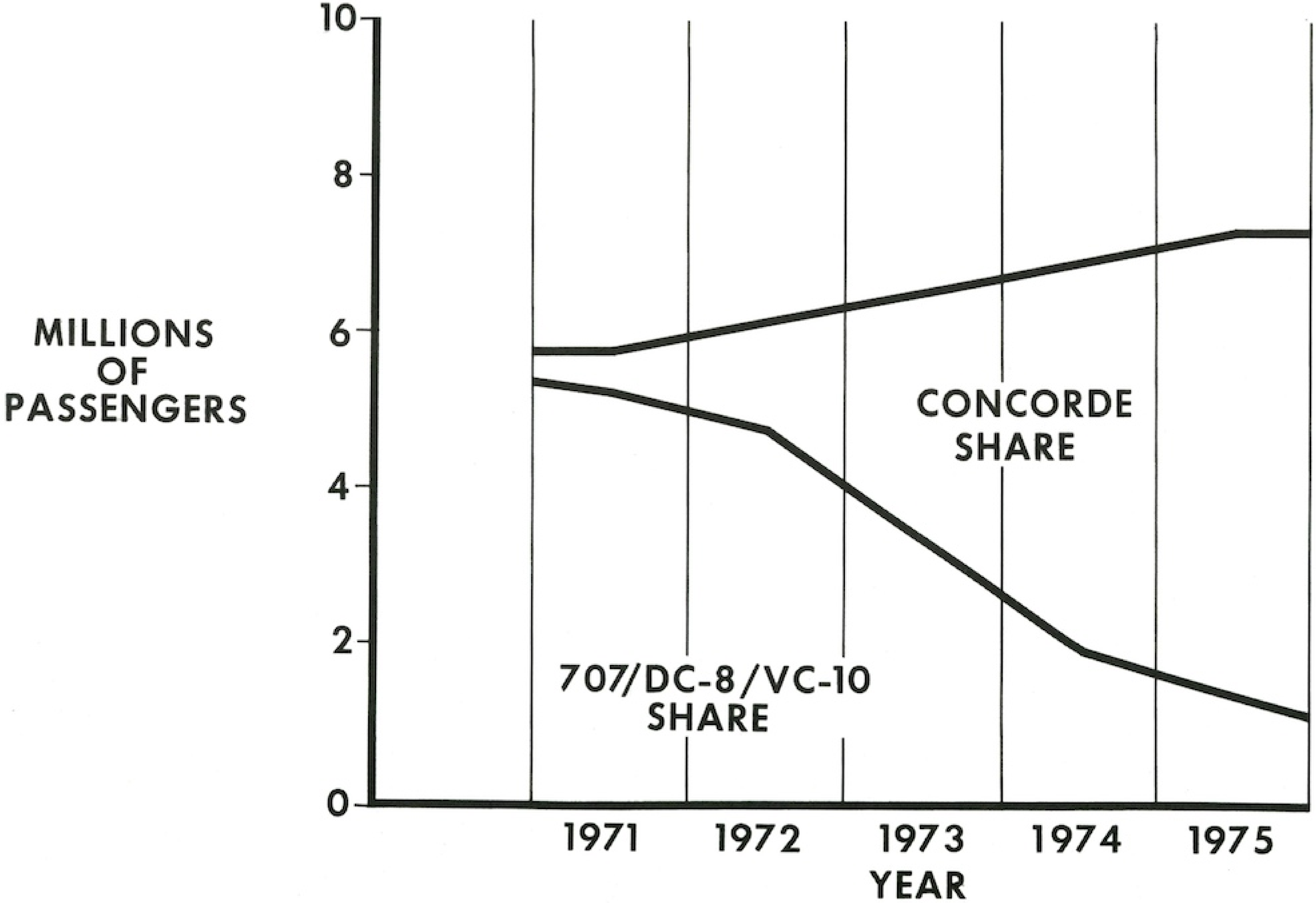
As mentioned previously, the first area of supersonic airplane penetration and competition will be the North Atlantic. Analysis of the growth in the number of one way passengers from 1971 to 1975 shows a growth from about 5.9 million to 7.4 million. If there were no U.S. SST available, and assuming the Concorde was available beginning in 1971 a Concorde takeover could occur in five years. The assumptions used here were that the numbers of Concordes and the load factors were as follows:

Year	Total Number Operating on North Atlantic	Load Factor
June 1971	6	90%
June 1972	18	90%
June 1973	45	70%
June 1974	72	67%
June 1975	100	65%

If the Concorde were not available until 1972 the penetration might be delayed by as much as one year.

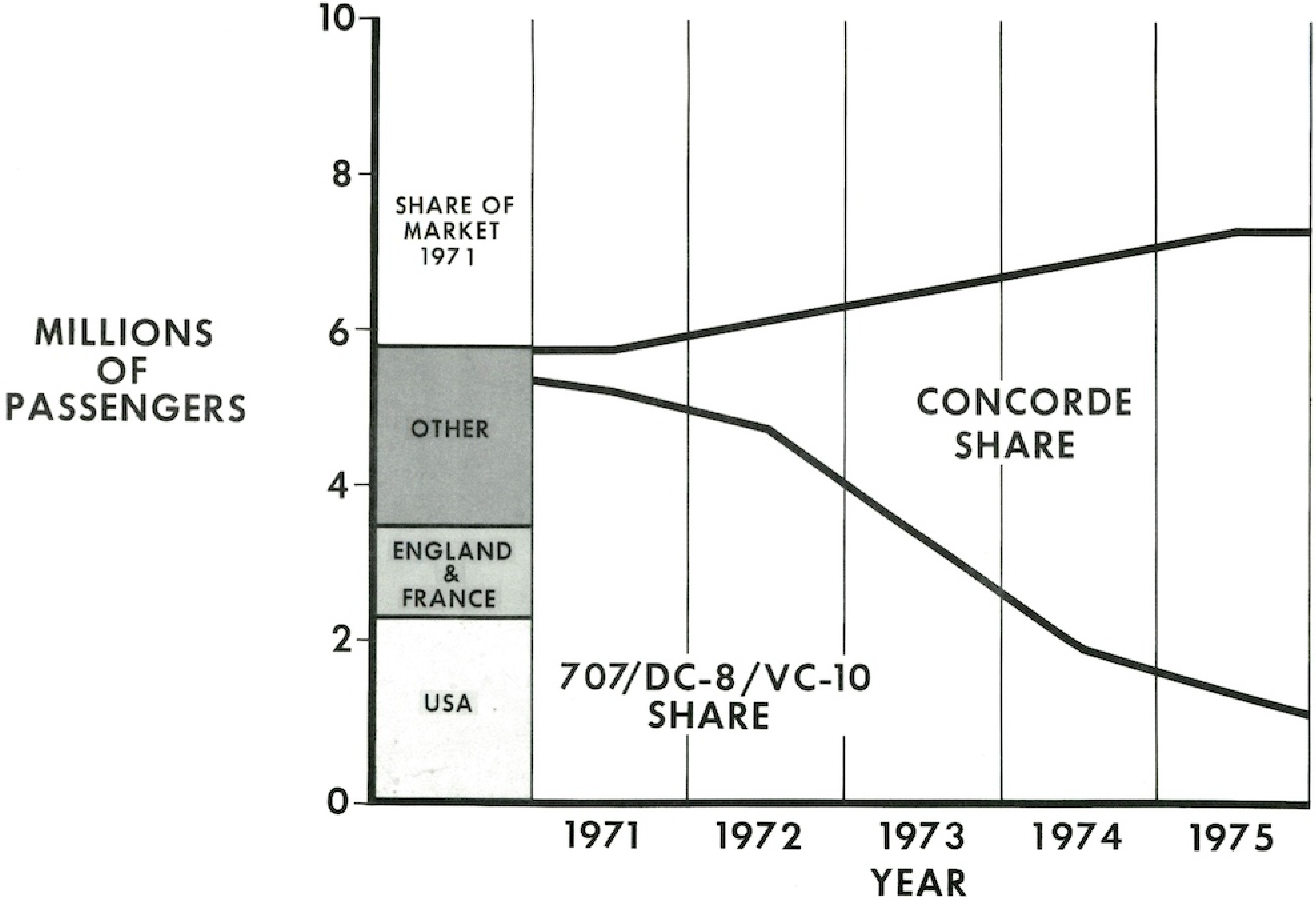
None the less, without a U.S. SST having competitive timing we are exposed to a marketing risk from the Concorde which could have a substantial impact on the sales potential of U.S. aircraft.

NORTH ATLANTIC MARKET
CONCORDE POTENTIAL



An analysis of Concorde orders and order positions indicates that the U.S. is vulnerable to an Anglo/French strategy to increase the BOAC/Air France share of the North Atlantic market at the expense of PAA/TWA (see the Appendix for delivery position information). In 1964 the U.S. carriers enjoyed 40 percent of the North Atlantic market. England and France had about 21 percent of the market between them. Assuming no change in market share until 1971, the bar at the left shows the passengers that would be carried by various carrier groups in 1971. As the Concorde comes into the market the Anglo/French share could be substantially increased.

NORTH ATLANTIC MARKET
CONCORDE POTENTIAL



By splitting the Concorde deliveries evenly between PAA, BOAC, and Air France, and by limiting TWA's deliveries to those required to maintain its share of the U.S. transcontinental market against competition from American Airlines and United Air Lines, England and France could capture 40 percent of the market and reduce the U.S. share to about 25 percent. The loss in share could result in <u>an additional .4 billion</u> dollars outflow in 1974 alone from U.S. citizens travelling on foreign airlines.

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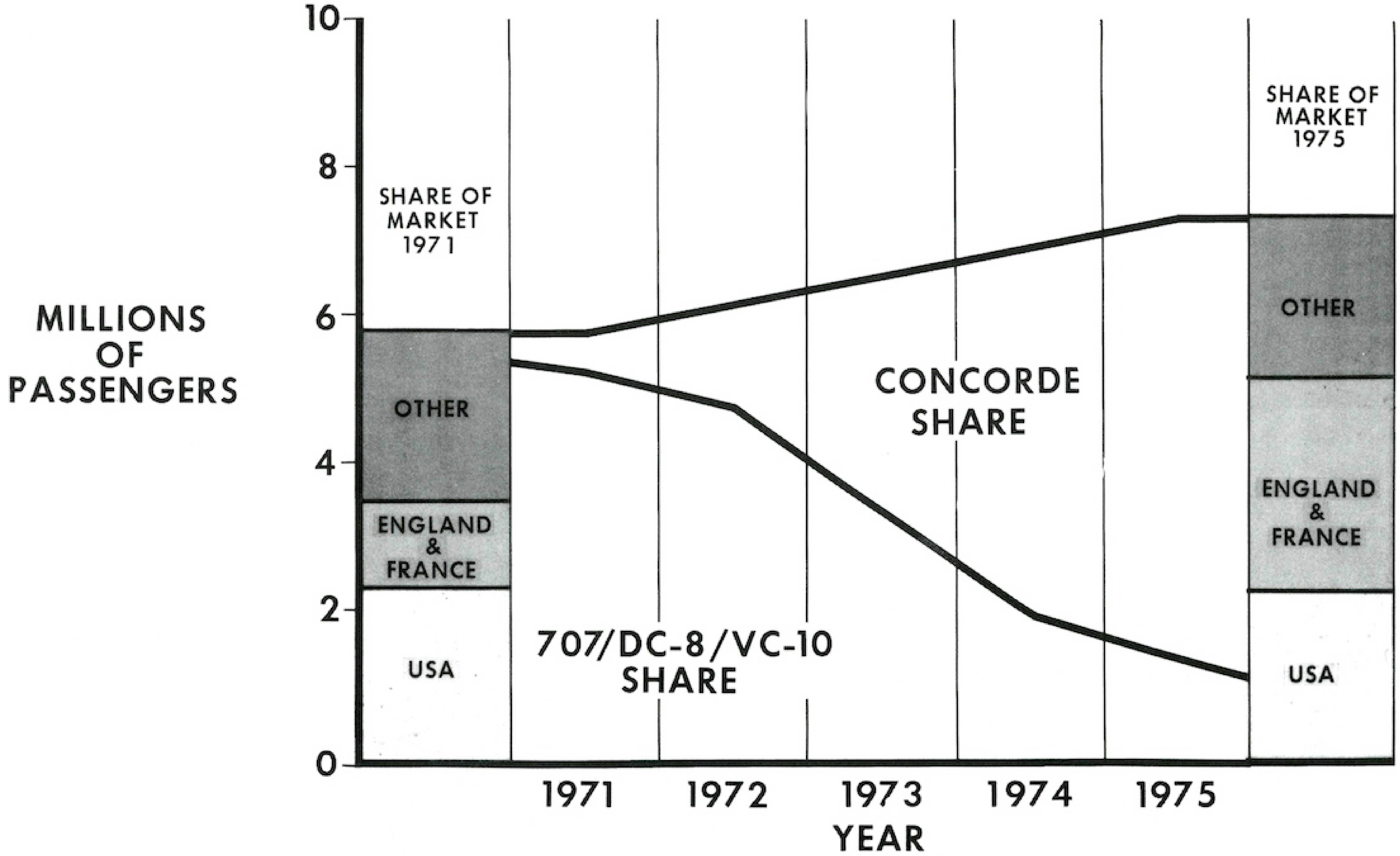
NORTH ATLANTIC MARKET
CONCORDE POTENTIAL

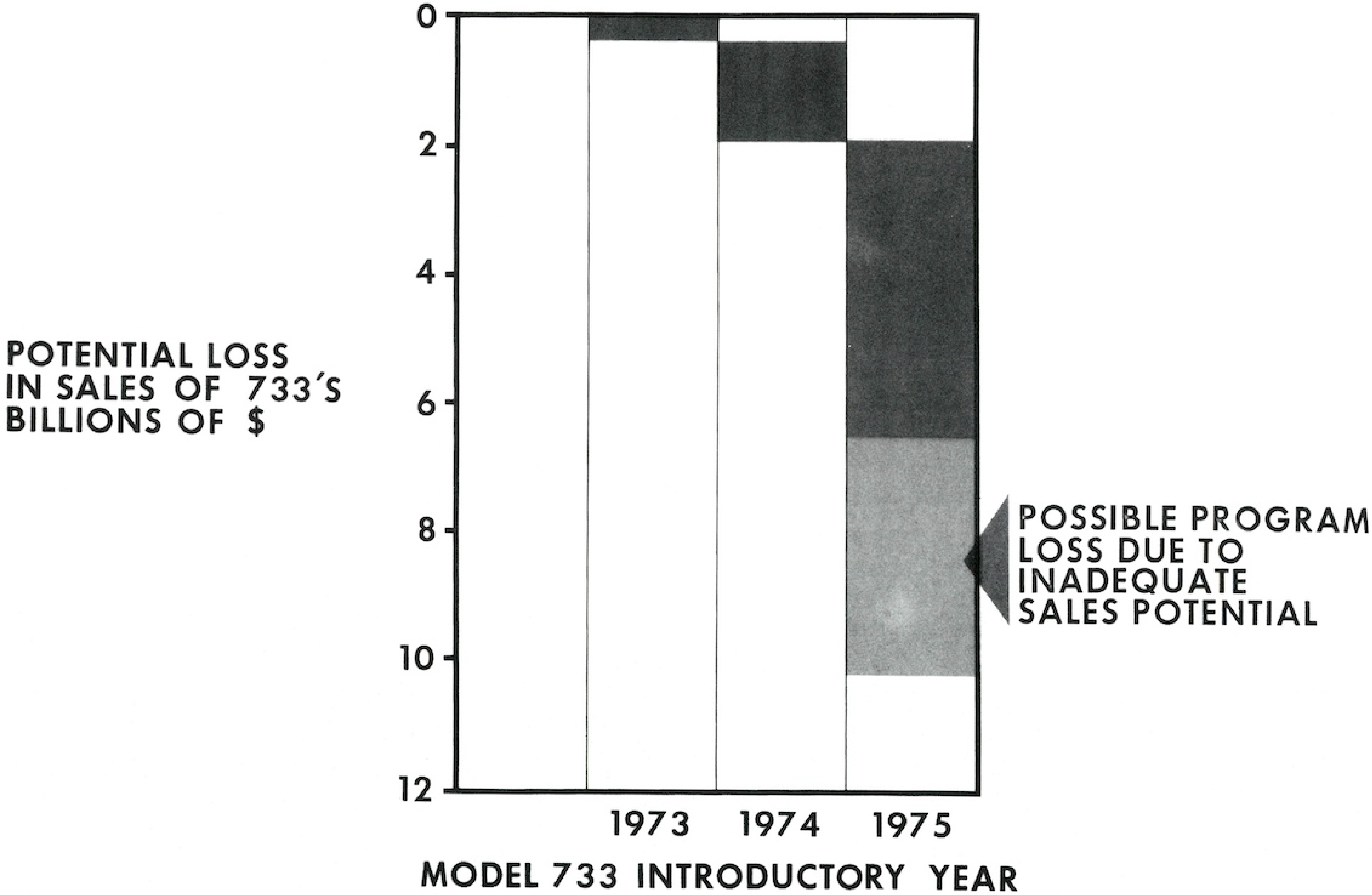


A serious loss in U.S. SST sales is possible as the availability of the U.S. airplane slides. As airlines become aware of the program delay they will become more and more susceptible to the competitive pressures to protect their market share. As larger and larger commitments are made to the Concorde less and less will be available with which to buy U.S. airplanes, even though they have superior economics. Heavy Concorde commitments by the airlines could so severely limit the early sales potential of the U.S. airplane that a production program of the 733 would not be feasible without government subsidy.

Although difficult, an attempt has been made to quantify the potential loss in sales of the Boeing SST model 733-290 as a function of the introductory period. This estimate was made by analyzing the needs of major markets where competition could force penetration of the Concorde. It is estimated that if the 733-290 had been available in the same year as the Concorde, the total ten-year sales potential, including spares, would have been about 10.5 billion dollars. The chart shows the estimated exposure to sales loss as a function of projected introductory year of the 733-290. Under the plan where introduction would occur in 1973, only a 280 million dollar loss is estimated. If introduction is delayed until 1974 the loss exposure is estimated to jump rapidly to 1.7 billion. And, if the 733-290 airplane is not available until 1975, it is estimated that full market penetration of the Concorde could be achieved, with a resulting loss in sales potential of between 6.6 and 10.5 billions, depending on whether or not sufficient early market for the U.S. airplane existed.

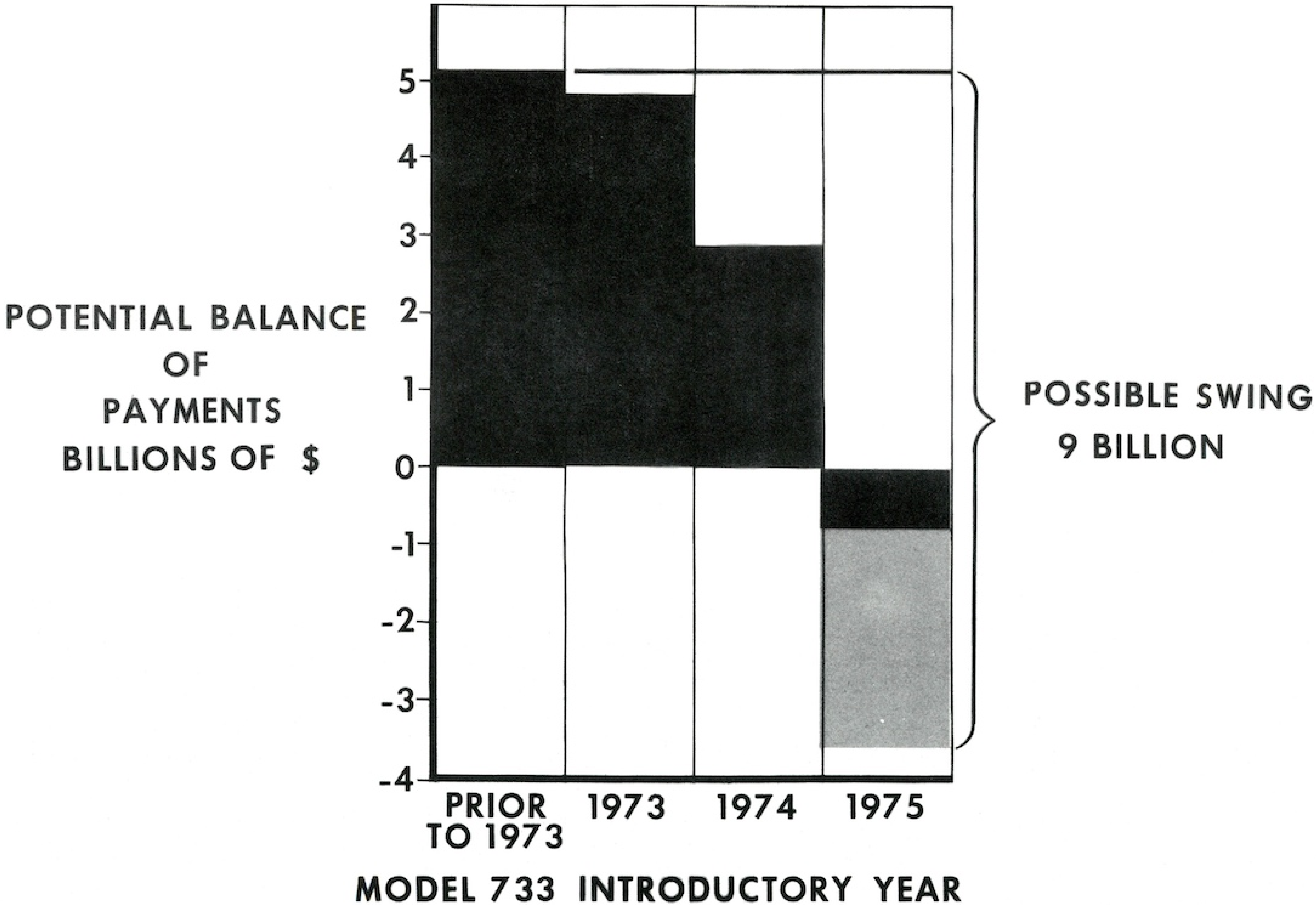
These estimates were made under the assumption that the Concorde was introduced in 1971. If it were introduced in 1972, the loss in sales potential for a 1973 introduction of the U.S. airplane would be unchanged. The 1974 U.S. SST introduction potential sales loss would be reduced to about 1 billion dollars; that for a 1975 introduction would be about 5 billion; and for a 1976 introduction, it would be between 6.6 and 10.5 billions.

INFLUENCE OF INTRODUCTION DELAY ON POTENTIAL SALES



The influence of introductory delays of the U.S. SST on the balance of payments is shown here based upon estimates corresponding to those used to compute the potential sales loss, shown on the previous chart. Only the impact of airplane sales is shown. The Boeing SST Model 733-290 would have produced an estimated favorable impact on the balance of payments of 5.2 billion dollars if its introductory year had been the same as that of the Concorde. Only a modest decrease was projected for a 1973 introductory period with a rapidly deteriorating position for later introductory timing.

EFFECT OF INTRODUCTION DELAY ON BALANCE OF PAYMENTS



In summary, the Model 733-290 has economics superior to the best current subsonic, the 707-320B, and as good as the improved subsonic, the 707-820. Although the Concorde seat mile operating costs are substantially above those of the these three airplanes, it will be a profitable airplane if there is no U.S. SST as an alternative.

A delayed U.S. SST program makes the U.S. vulnerable to a passenger revenue loss of .4 billions of dollars in 1974, an outflow of funds in the export/import balance sheet. The U.S. is exposed to a disproportionate loss in sales and a disproportionate loss in balance of payments position as the U.S. SST introductory date slides and as initiation of the U.S. prototype program is delayed.

APPENDIX

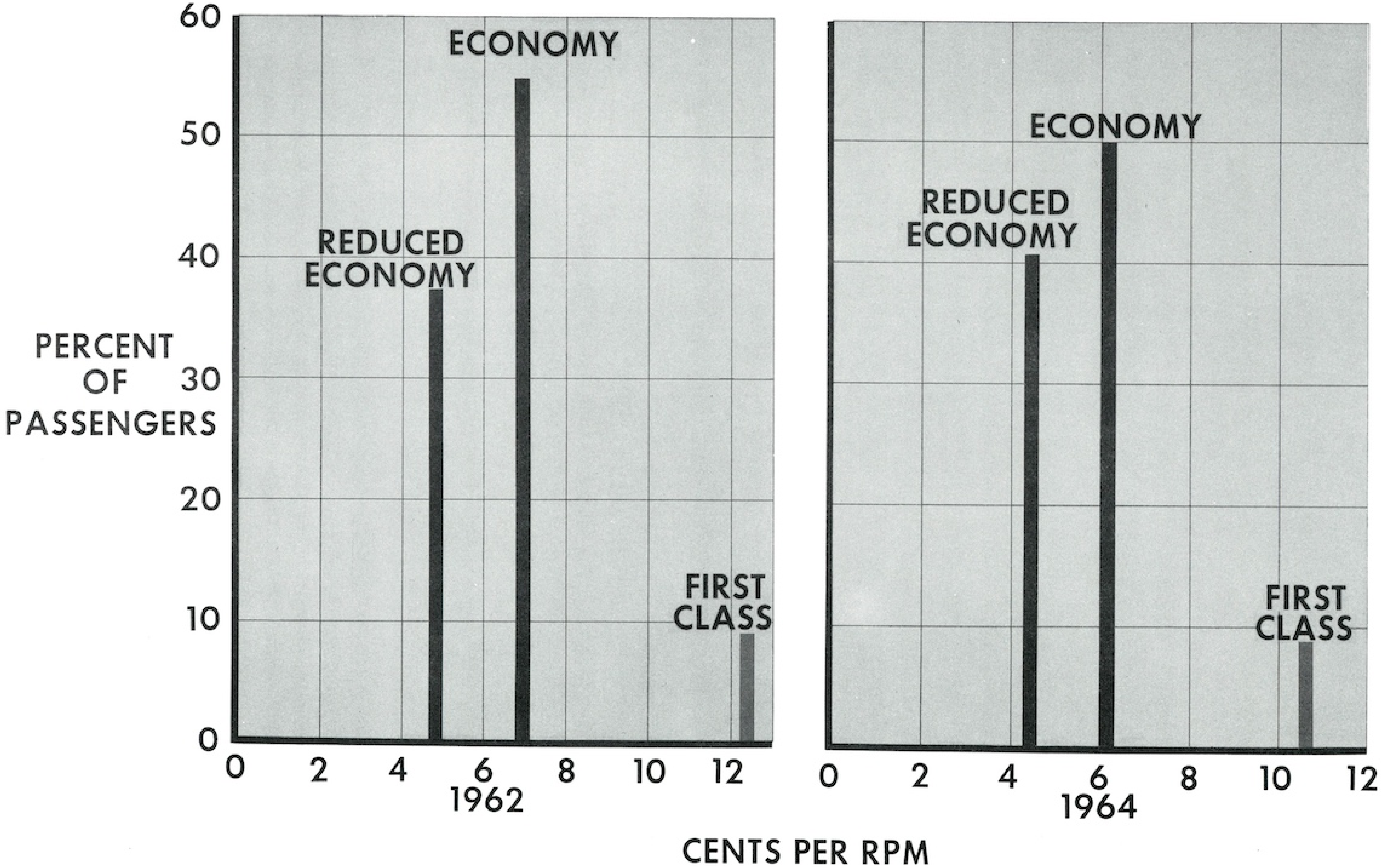
CONCORDE DELIVERY POSITIONS AND ORDERS

CARRIER	NUMBER OF ANNOUNCED ORDERS AS OF APRIL 30, 1965	DELIVERY POSITIONS
Air France	8	1, 4, 7, 10, 13, 16
BOAC	8	2, 5, 8, 11, 14, 17
Pan American	6	3, 6, 9, 12, 15, 18
Continental	3	20, 23, 26
American	6	21, 25, 27, 33
TWA	6	22, 32, 34, 38
Middle East/Air Liban	2	35 49
Qantas	4	30, 36, 40, 42
Air India	2	46, 54

OPEN POSITIONS: 19, 24, 28, 29, 31, 37, 39, 41, 43, 44, 45, 47, 48, 50, 51, 52, 53, 55, and on.

Note that Air France, BOAC, American and TWA each have two orders for which positions are unassigned.

FARE DISTRIBUTION
NORTH ATLANTIC 1962 VS 1964



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- DESIGN DEVELOPMENT
- PERFORMANCE
- SONIC BOOM

The status of Boeing supersonic transport design in 1961 is compared to piston and subsonic jet transports from an operating cost comparison. The effects of improved efficiencies in structural weight, aerodynamics, and specific fuel consumption are noted as reasonably attainable design goals as the technology progresses through further research and development effort.

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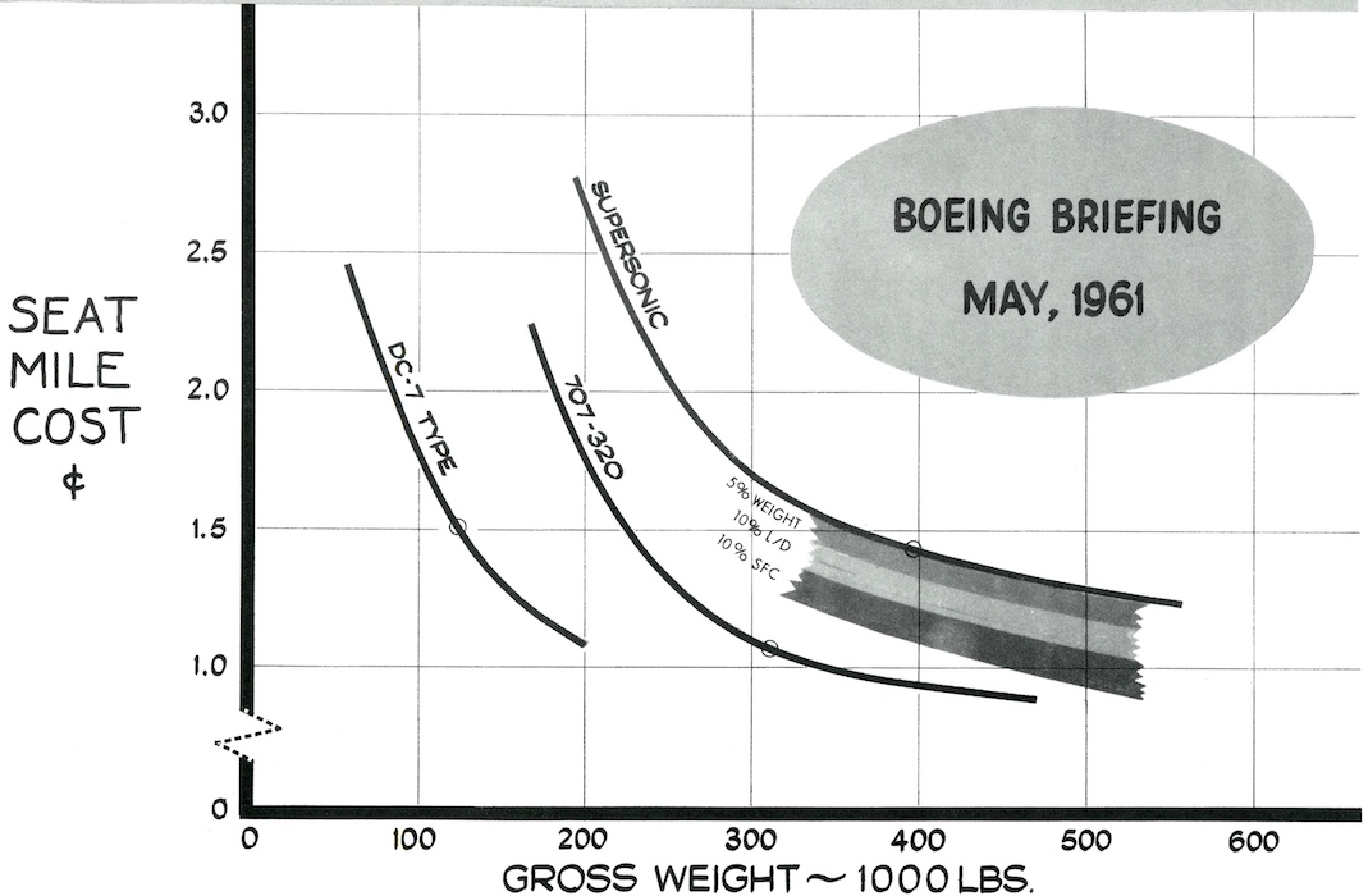
OPERATING COST COMPARISON

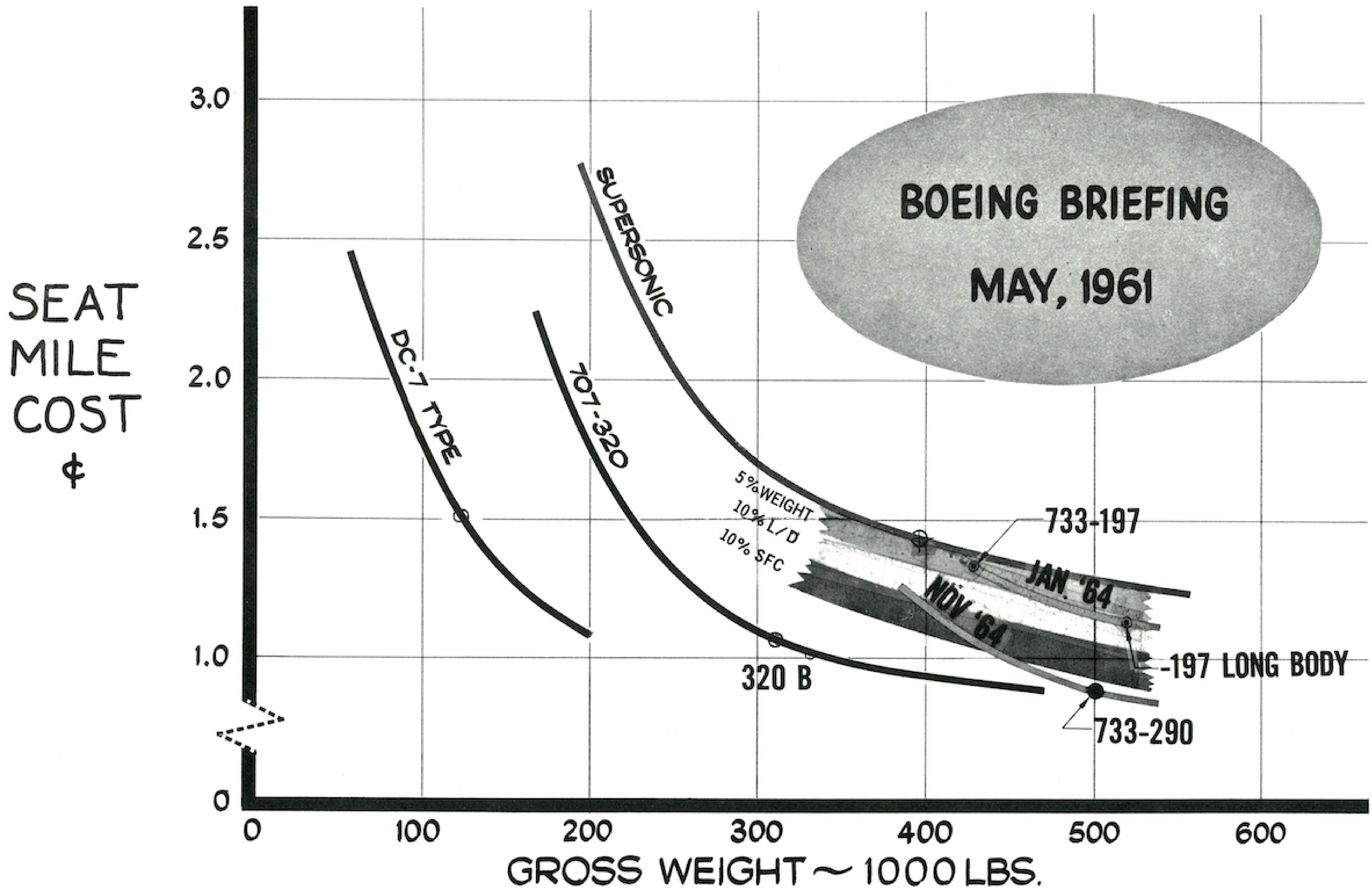


CE 6592B 3-65

The results of the continued Boeing R&D work in supersonic design is apparent by overlaying the seat mile costs of the Phase I Model 733-197 (January 1964) and the Phase II-A Model 733-290 (November 1964) airplanes on the earlier graph. The target goals have been met including the improtant economic achievement of providing lower seat mile costs than current subsonic jet transports.

CE 6595R

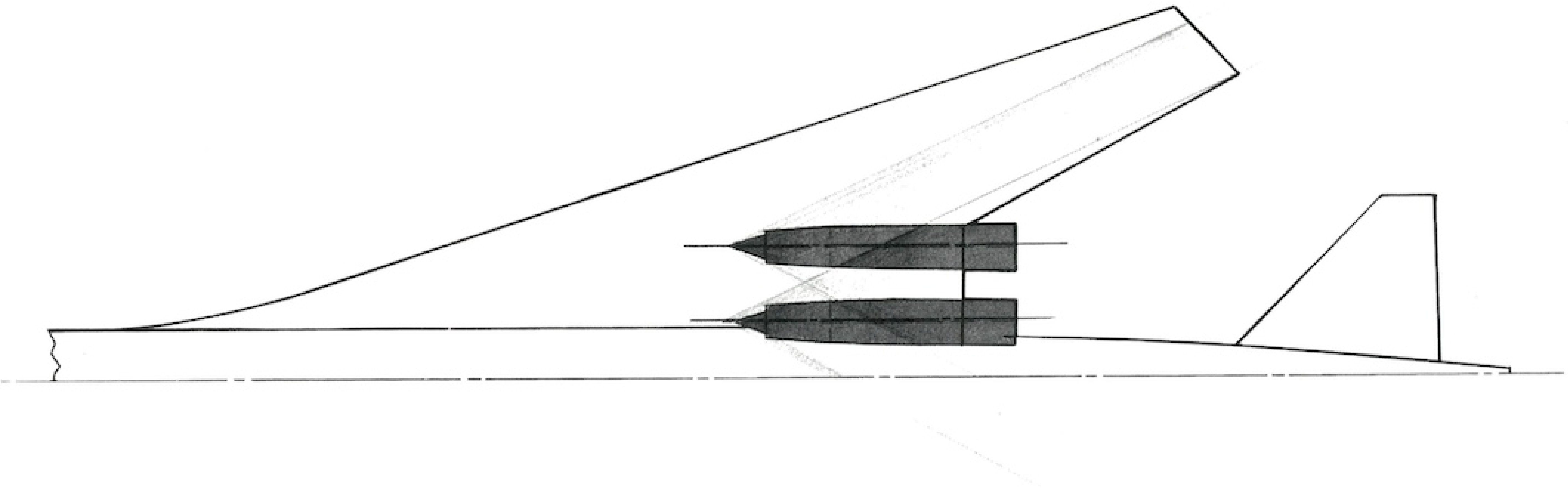
OPERATING COST COMPARISON

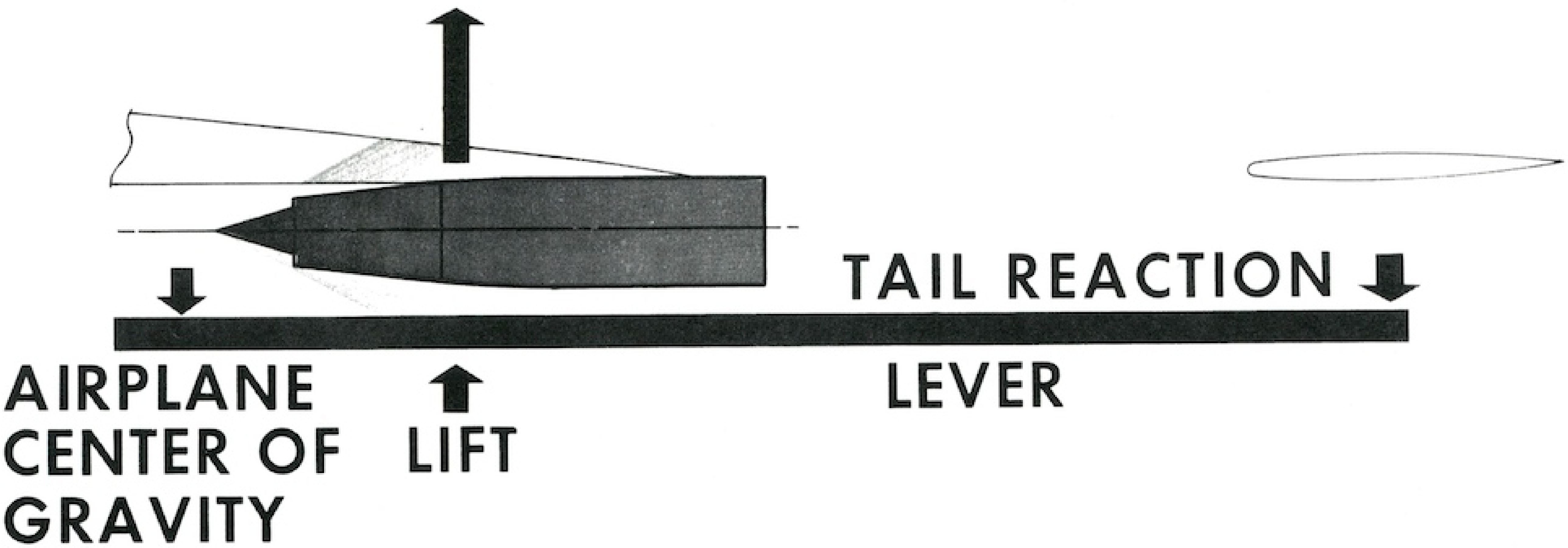


CE 6595R 3-65

Extensive wind tunnel testing has shown that nacelles placed at the rear of the twisted and cambered arrow wing produces a favorable lift interference on the wing. If this wing is properly shaped, this lift interference will also produce an overall reduction in the wave drag of the wing nacelle combination. Boeing has developed extensive analytical and experimental methods to optimize location of the engine nacelles on the wing-body combination.

NACELLE INTEGRATION

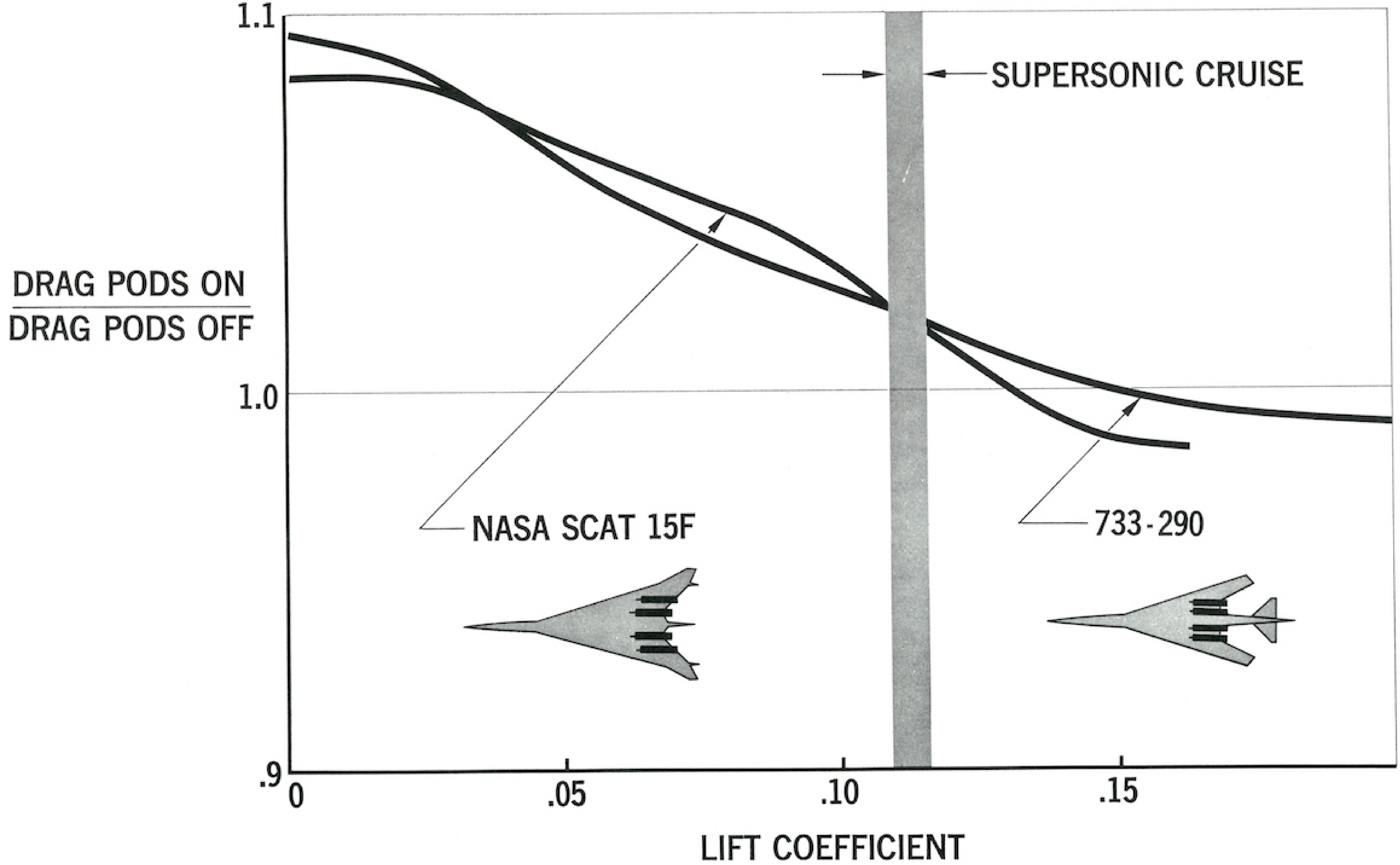




This chart shows a comparison of the drag of the total wing body combination with pods on and pods off. A comparison between the Boeing supersonic transport model and the NASA SCAT 15 aerodynamic configuration shows that the four engine pods have been added to both configurations for practically no drag.

CE 6506

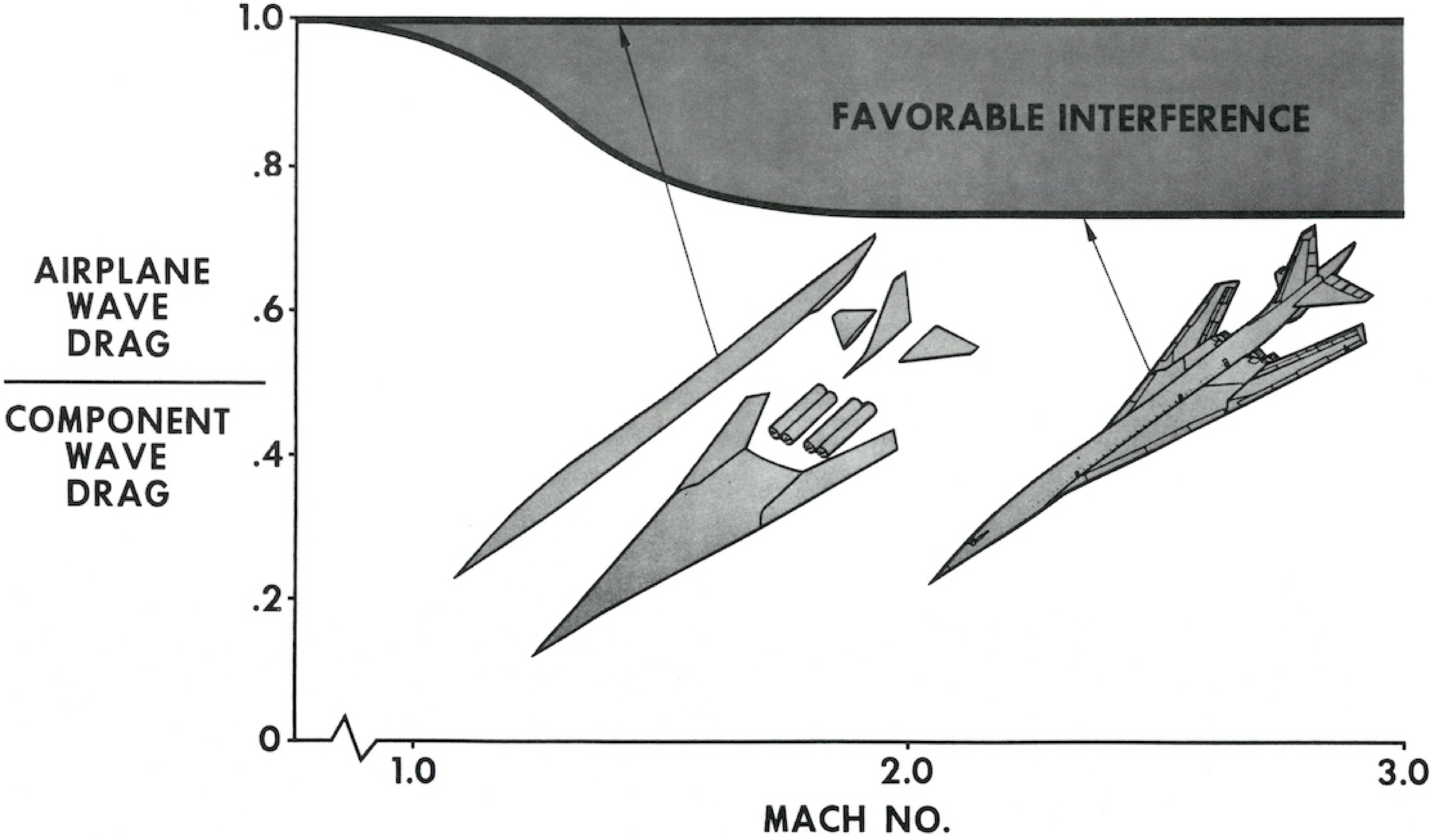
NACELLE FAVORABLE INTERFERENCE



CE6506 11-64

This chart shows the total airplane wave drag divided by the wave drag of the individual components as a function of Mach number. The data indicate that the Boeing configuration has been integrated to such a degree that the airplane wave drag is only 75% of the wave drag of the individual pieces. This represents a significant area of favorable interference for the arrow wing configuration.

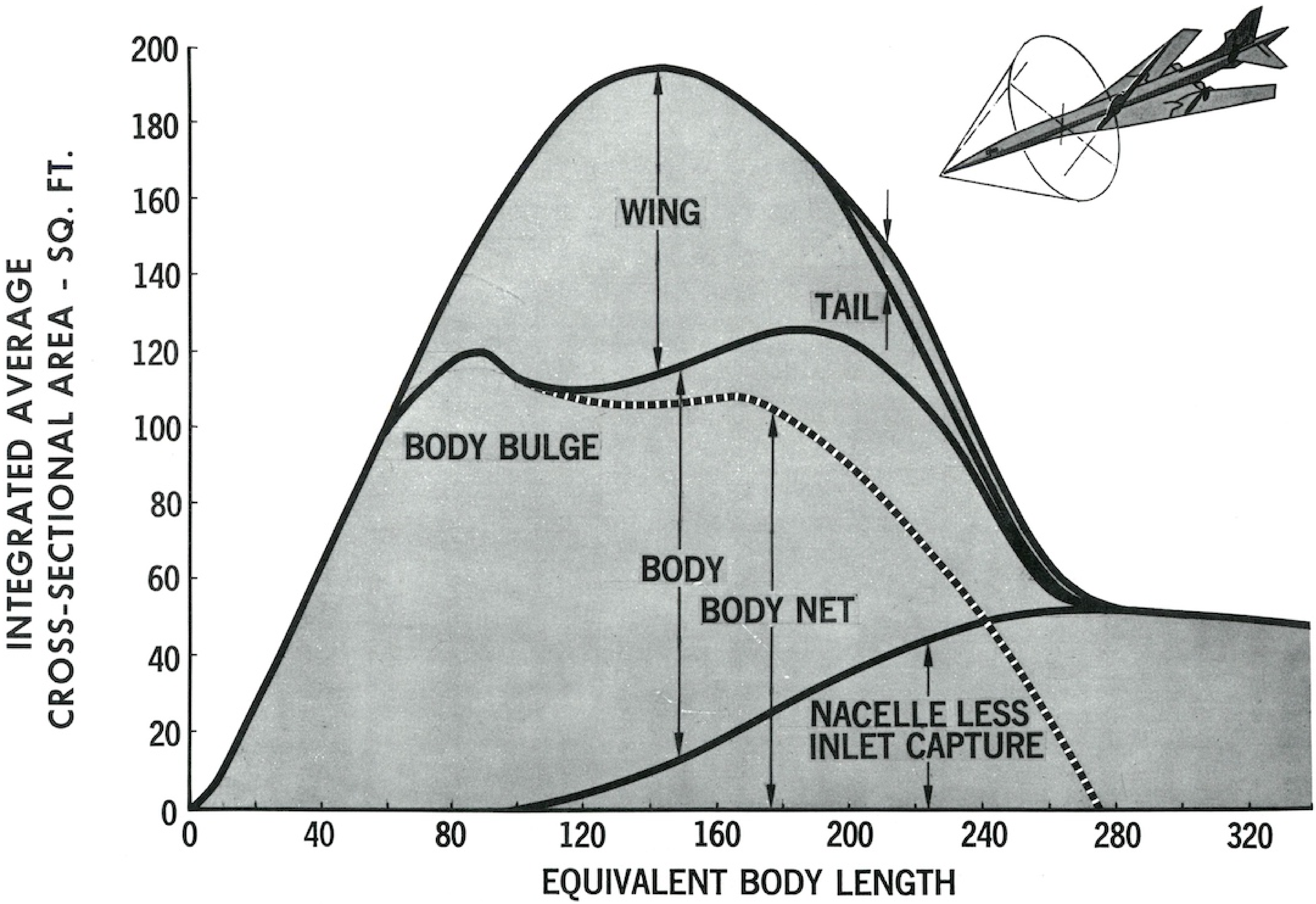
COMPONENT INTEGRATION



CE6515 11-64

Total cross sectional area of the configuration is shown as a function of body length. The important point of this plot is that the wing and nacelles have been added to the body in such a manner that the distribution of area with length is very smooth. The slope of the forebody and the aft body are low and the total cross sectional area is low. Wave drag is a function of the slopes times the maximum cross sectional area and is quite low for the configuration. This chart also explains why the Boeing supersonic transport configuration is bulged ahead of the wing. The bulge smoothes the area plot and it has a beneficial effect on the sonic boom signature of the configuration.

CROSS-SECTION DISTRIBUTION AT MACH 2.7

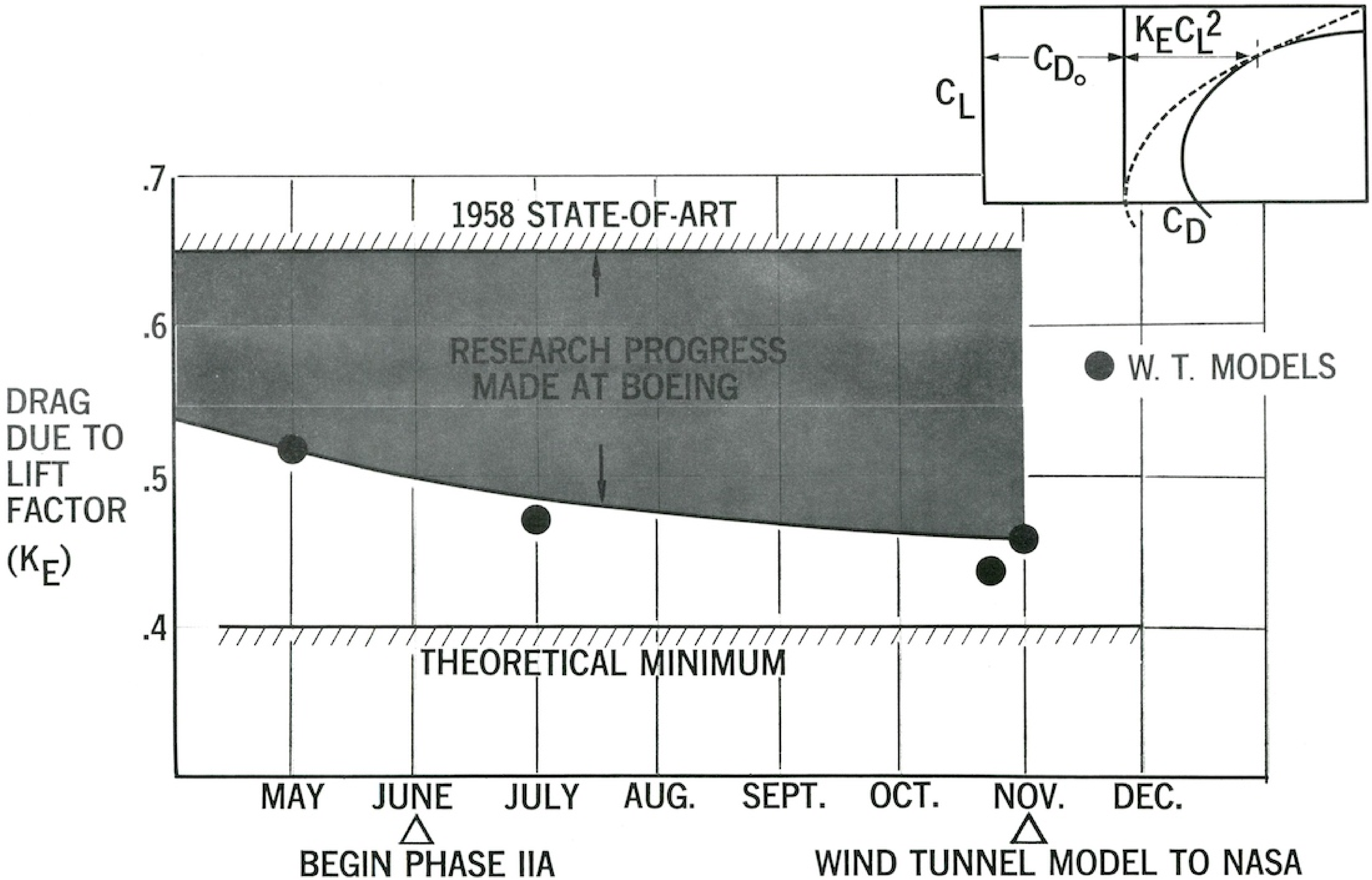


CE6551 11-64

Boeing recognized in 1958 that the twisted and cambered arrow wing had a great deal of potential for an efficient supersonic transport. The drag due to lift factor K_e is shown here as a function of time. Drag due to lift is shown on the plot of drag coefficient vs. lift coefficient in the upper right hand corner and is merely the drag that is associated with the airplane flying at an angle of attack. The theory for the arrow wing indicated a very low value of K_e was possible.

Early test data as represented by the 1958 state-of-the-art line were only slightly better than a flat wing. Through analytical techniques and the wind tunnel testing of sixty individual wings and many modifications on each of these, Boeing has reduced the drag due to lift for the twisted and cambered arrow wing nearly to the theoretical minimum available.

DRAG DUE TO LIFT PROGRESS



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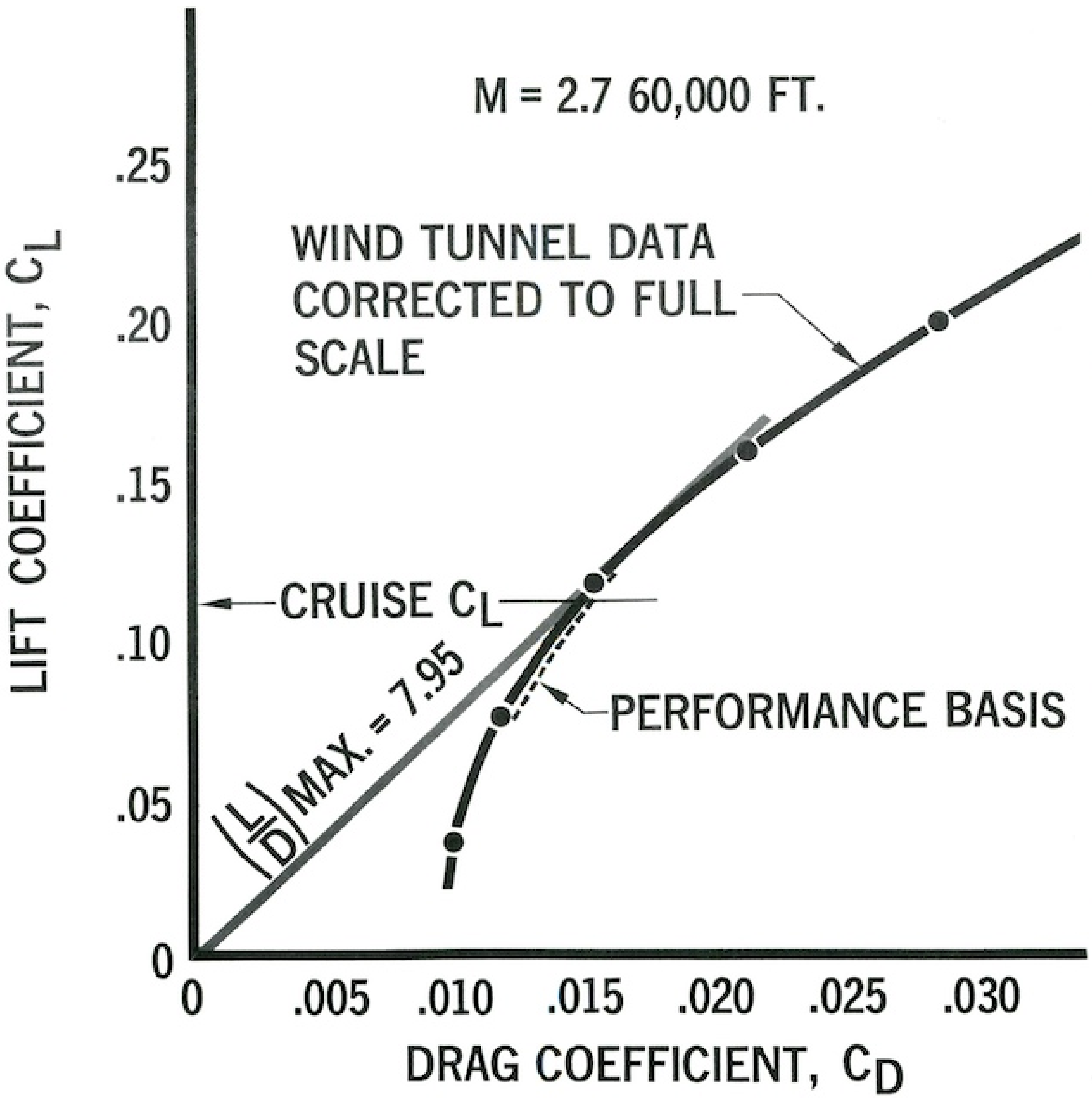
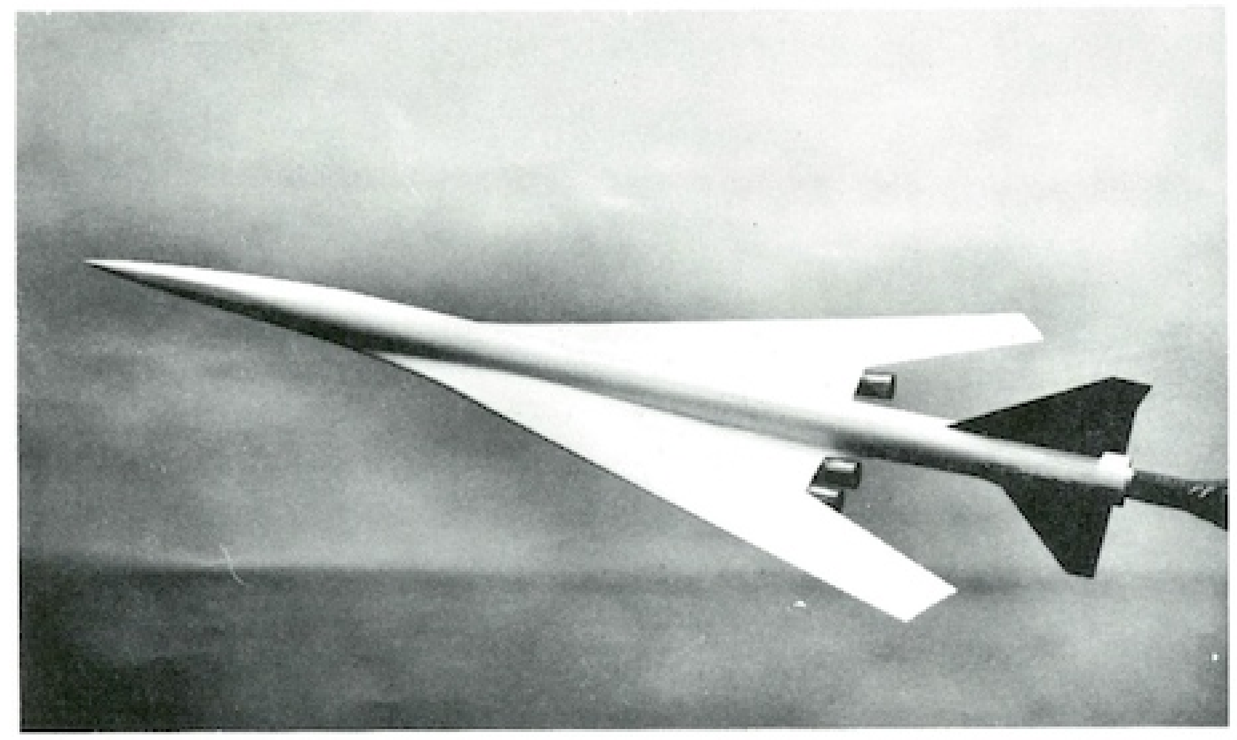
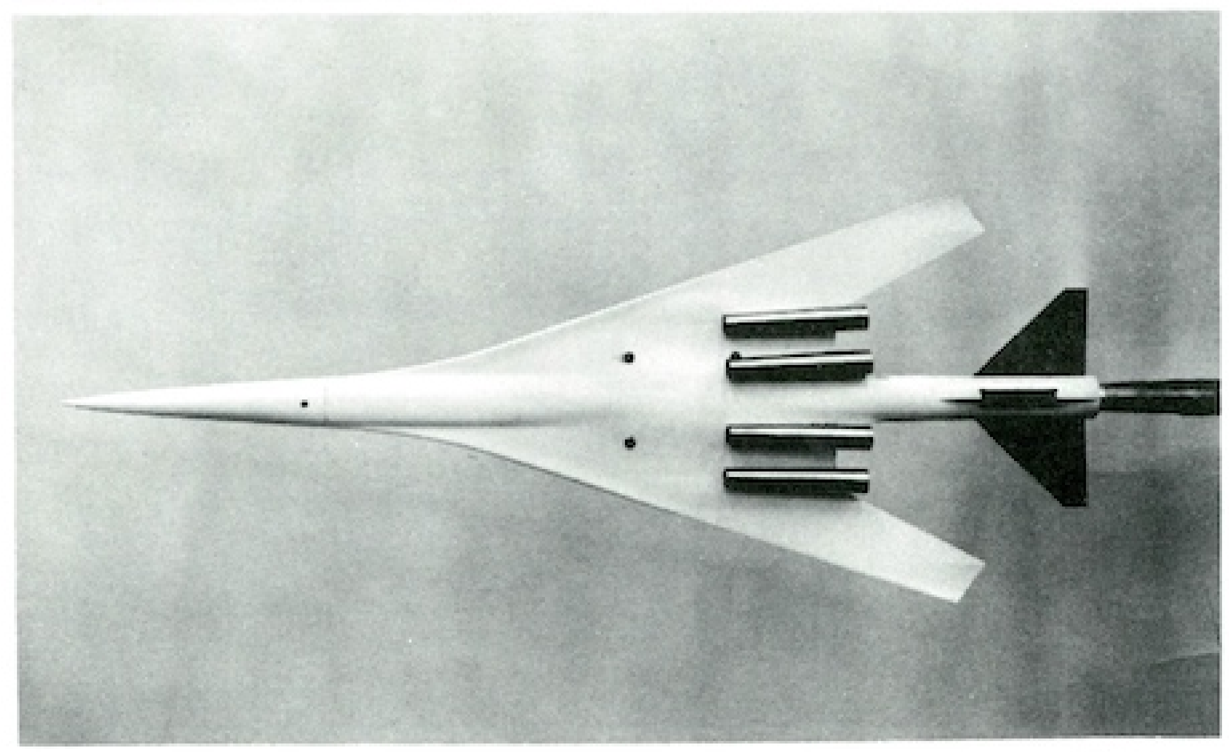
Lift coefficient is plotted against drag coefficient for Boeing's supersonic transport wind tunnel model. The data indicate that we have achieved a maximum lift to drag ratio of 7.95. It is important to note that the performance which has been quoted today is based on the dashed line or a lift to drag ratio of 7.82. The NASA wind tunnel tests in November, 1964 of this configuration validated a maximum L/D of 8.2.

In summary we have shown that the wave drag of a cambered and twisted arrow wing can be very low, that the drag due to lift is nearly the minimum available, and since the friction drag of an arrow wing transport and any delta wing transport would be nearly the same, the arrow wing approach will yield the highest supersonic efficiency. The addition of variable sweep to the arrow wing allows the supersonic transport to achieve this high level of supersonic efficiency and yet take off and land with less noise, lower speeds, and shorter field lengths than the present subsonic jets.

L/D SUBSTANTIATION





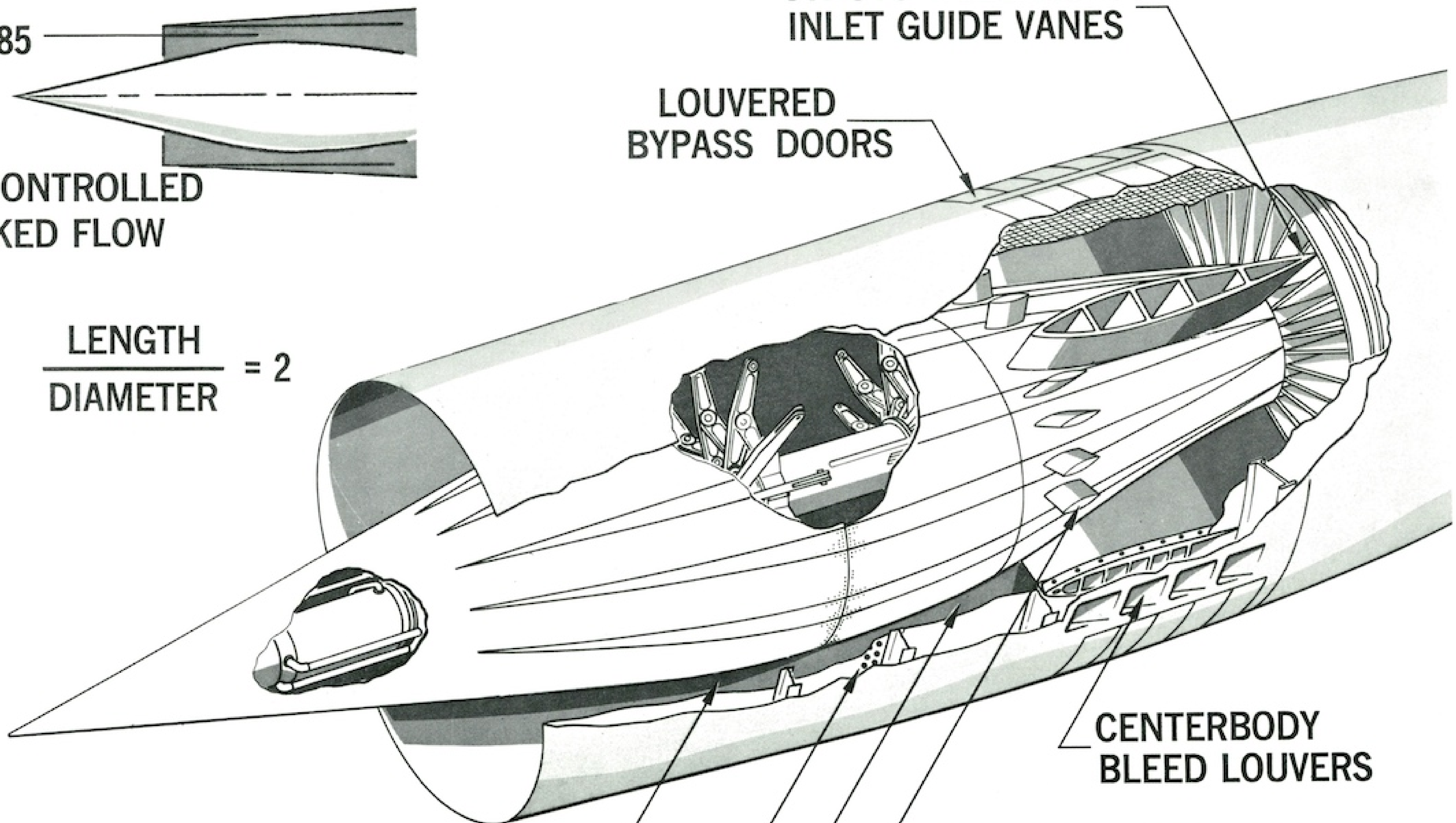


CE6526 11-64

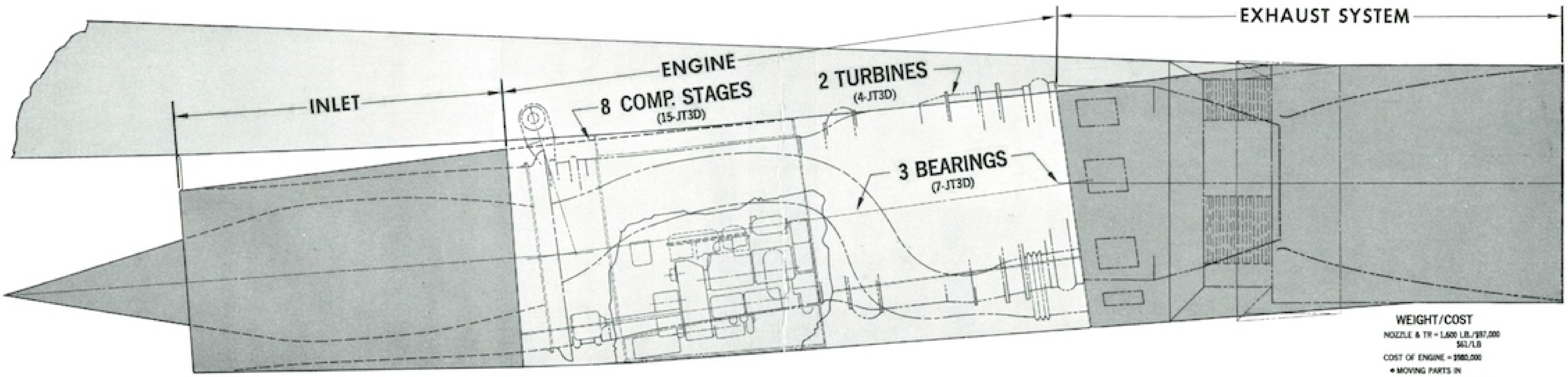
The supersonic inlet does most of the compression work at Mach 2.7. To make it efficient at lower supersonic speeds, the throat area must vary.

We vary the throat by changing the diameter of the centerbody. At subsonic speeds during approach to the airport, the diameter can be expanded and allow the inlet air to be accelerated to nearly the speed of sound at the throat section and then slowed down to enter the compressor at the proper speed. Compressor noise tries to get out the inlet but since air is coming in at the speed of sound, the noise is trapped in the inlet.

BOEING SST INLET DESIGN



PROPULSION POD



		% WORK OF COMPRESSION		THERMAL EFF.	PROPULSIVE EFF.	OVERALL EFF.
SUPERSONIC	(M = 2.7)	47 (INLET)	53 (COMPRESSOR)	53% (T_4 = 2,200°F)	80%	43%
SUBSONIC (JT3D)	(M = .8)	5 (INLET)	95 (COMPRESSOR)	38% (T_4 = 1,500°F)	69%	26%
						(25% DIESEL TRUCK)

WEIGHT/COST

NOZZLE & TR = 1,600 LB./$97,000
$61/LB

COST OF ENGINE = $980,000

- MOVING PARTS IN
  - JT3D REVERSER > 100
  - J93 NOZZLE/REV ≈ 150
- INLET KE EFF. = .97
- NOZZLE VEL. COEFF. = .975

COMPRESSION RATIO JT3

VOLUMETRIC = 23 (8.0)

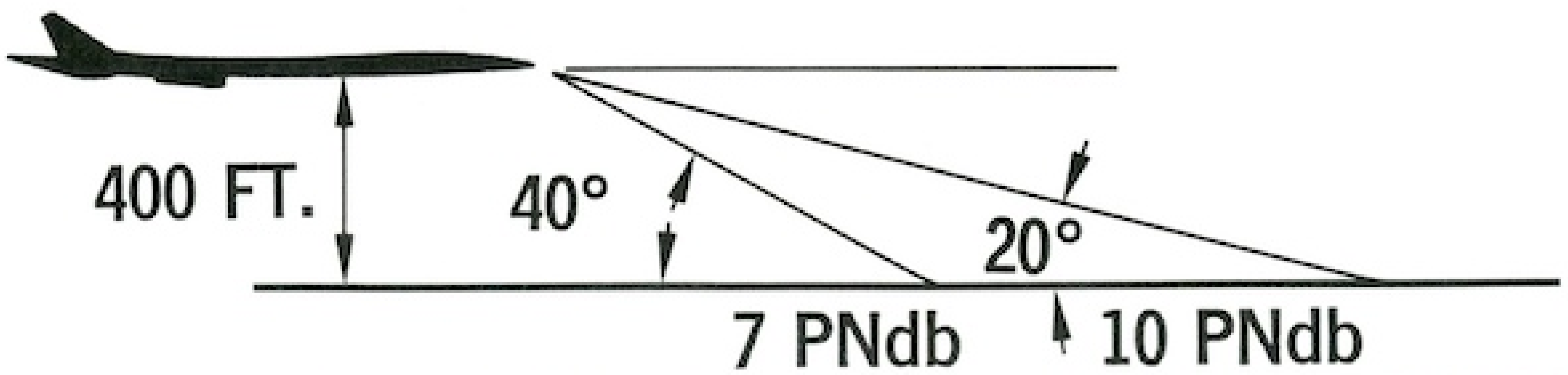
PRESSURE = 88 (19.0)

A test using a J-75 jet engine with a simulated inlet duplicating the approach condition of the SST was set up to test the effect of inlet choking on approach noise. The bellmouth allows simulation of approach speed flow conditions at the lip on the static test rig. No bellmouth will be needed on the actual airplane.

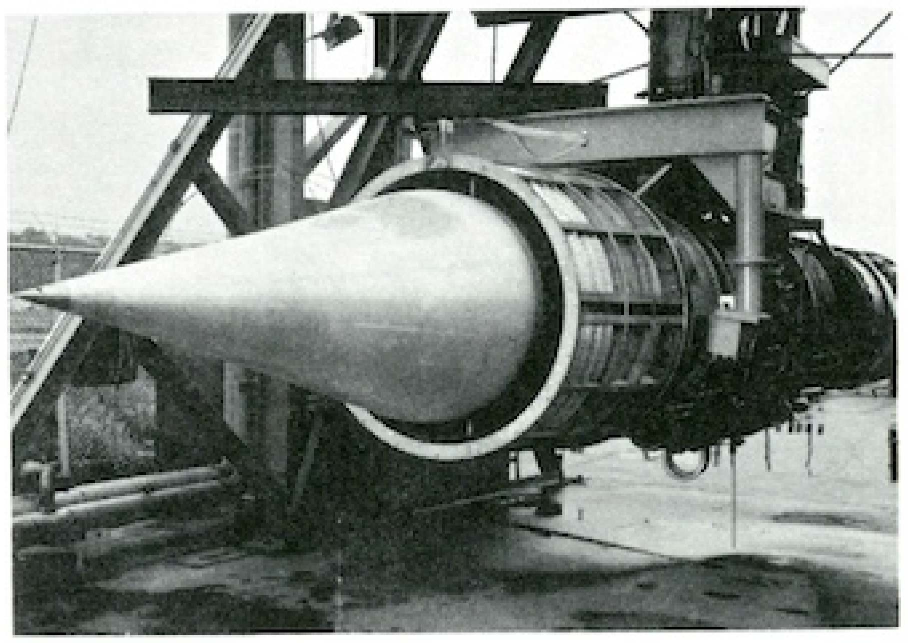
The engine was started and warmed up at idle condition, then the power raised to approximately 25 percent at which time the velocity at the inlet throat is approximately sonic. This is about the power setting required for approach condition on the SST.

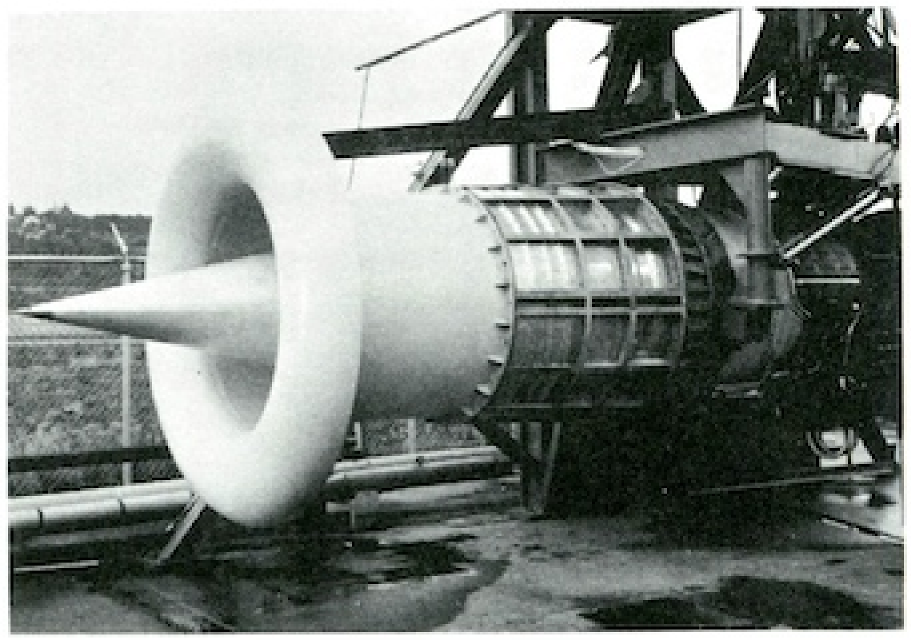
Microphones placed ahead of the inlet have measured sound pressure levels against frequency in cycles per second. At lower than 25 percent power, the air flow is unchoked and the compressor noise is quite apparent. As the power is raised to the choked condition, the compressor noise dropped as shown on the chart. The effective noise suppression from choking the inlet is illustrated by the airplane approach at 400 feet altitude. When the airplane is far away at an angle of about 20 degrees above the ground observer, the suppression would be about 10 PNdb. After the airplane approaches closer, the suppression would be about 7 PNdb.

EFFECT OF INLET CHOKING ON APPROACH NOISE

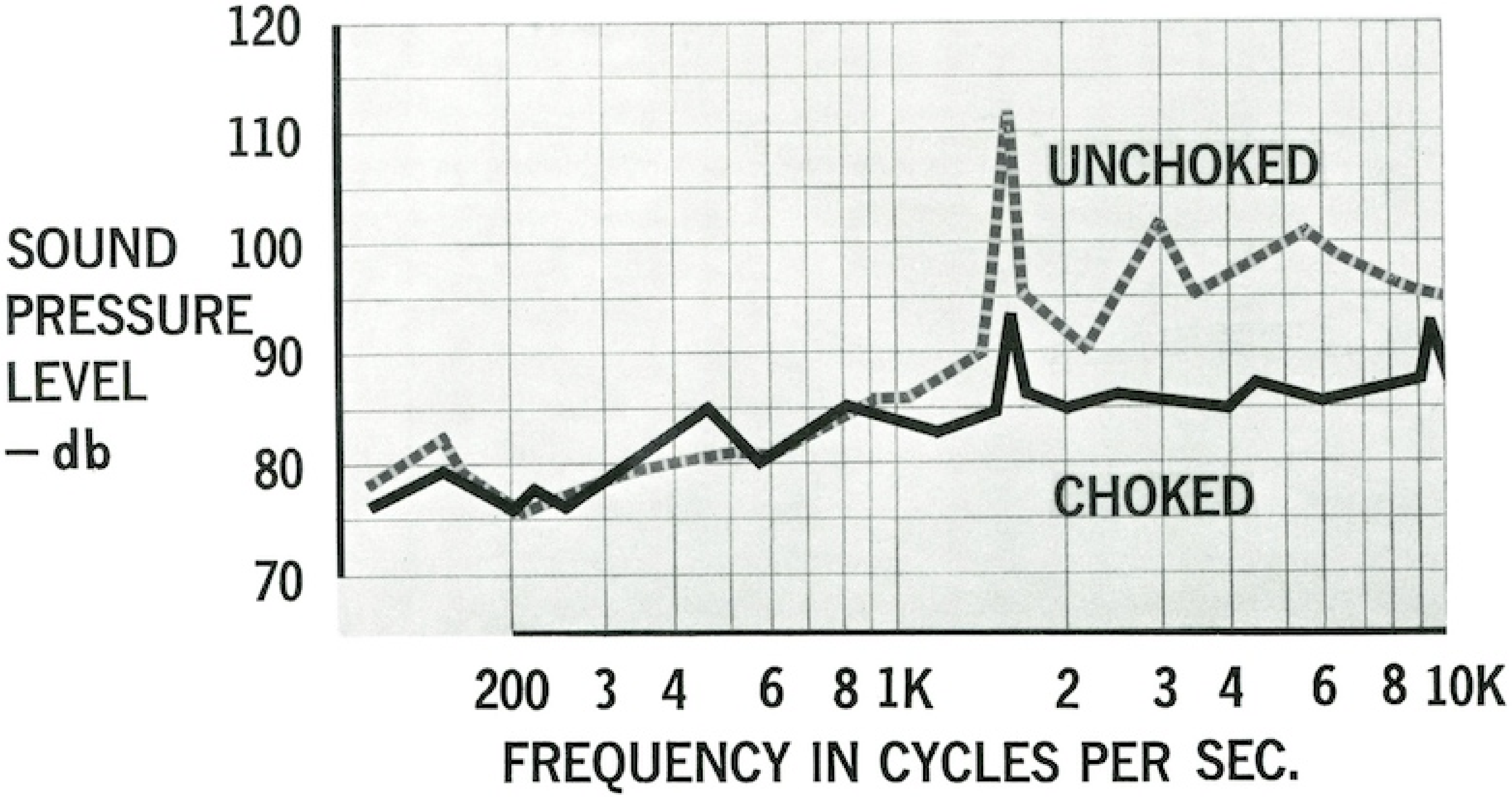


NOISE SUPPRESSION FROM CHOKED INLET





J-75 TEST RIG



Differences between the Phase I (733-197 basic and long body versions) and the 733-290 are highlighted in this figure. The most obvious changes are quickly apparent. The body of the -290 is considerably longer and the cabin is wider. The increased length and width of the body enlarge the payload capability of the -290 airplane.

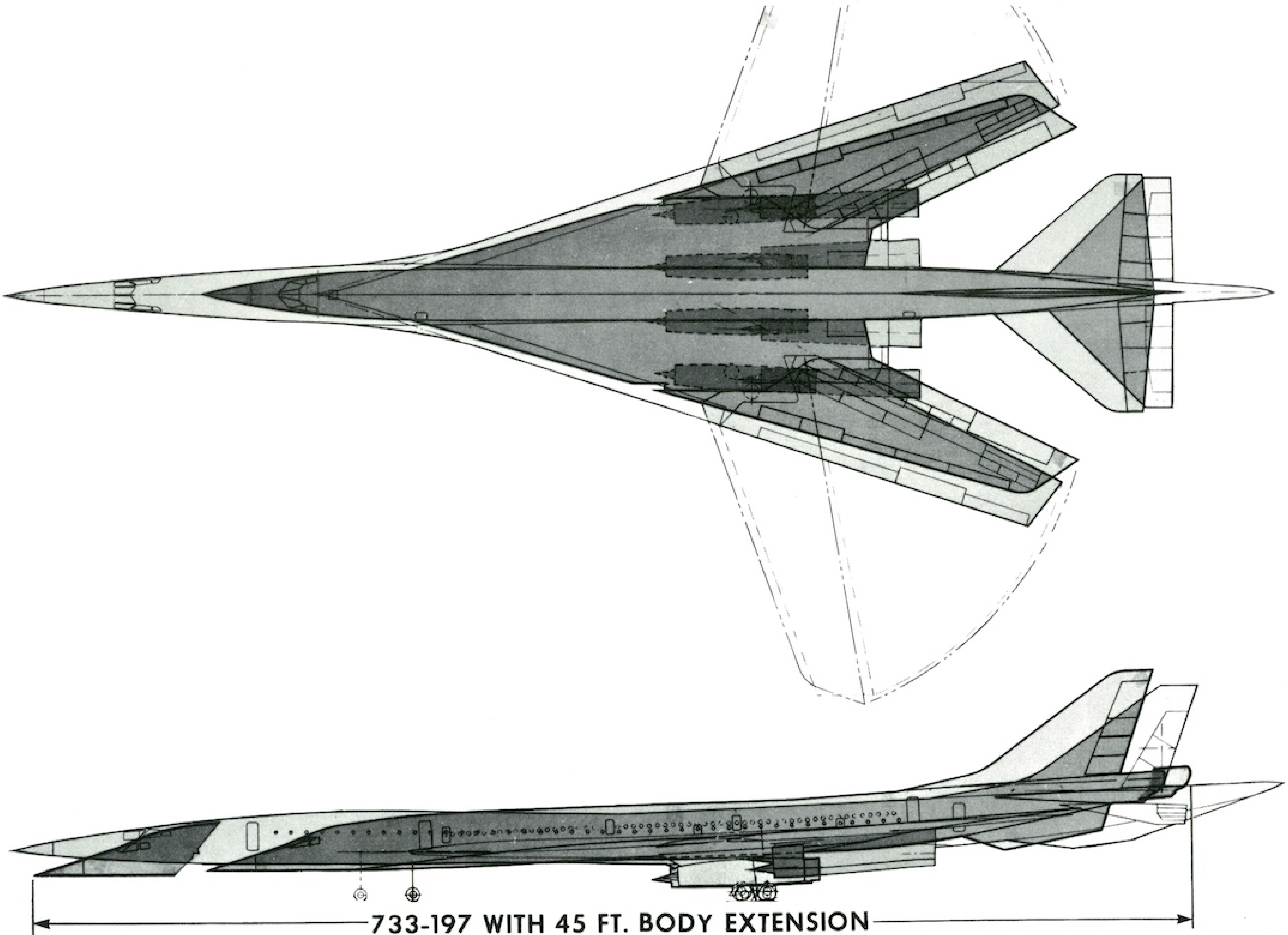
Aerodynamic improvements have changed the airplane at a number of important locations. The wing of the -290 has slightly less sweep when in the full-back position. Less sweep increases the supersonic span slightly and improves the lift/drag ratio. The engine nacelles are located farther aft and their shape has changed from cylindrical to slightly conical to accommodate a more fully expanded nozzle. This relocation and conical shape increases the favorable pressure reaction on the wing which improves the lift/drag ratio at supersonic speeds.

The portion of the body near the wing leading edge intersection has been bulged to create a favorable pressure reaction with the wing which further improves the supersonic lift/drag ratio. The nose shape of the airplane has been slimmed and lengthened for optimum supersonic cruise drag. The tail of the body is also more pointed to improve the over-all lift/drag ratio.

Wing span with the movable sections forward is practically identical with the earlier -197. This span remains constant because the pivot has moved slightly outboard and back for improved weight, balance, and other characteristics.

CE-6577

CONFIGURATION COMPARISONS



733-197 WITH 45 FT. BODY EXTENSION

CE6577 11-64

A further comparison between the 733-197, long body 733-197 and 733-290 Intercontinental airplane and the long body 733-197 and 733-291 Transcontinental airplane is shown on the table on the opposite page.

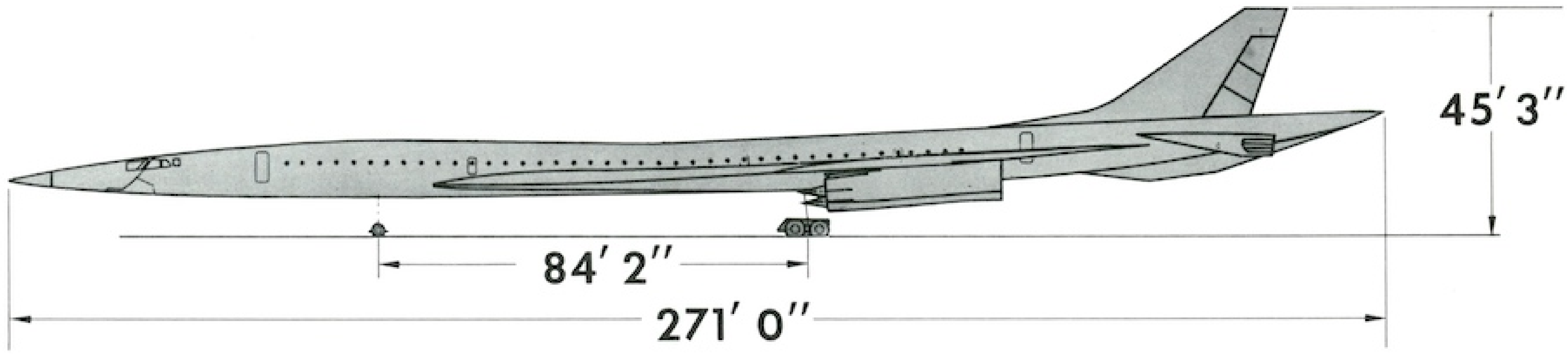
MODEL COMPARISON

	JANUARY		NOVEMBER	JANUARY	NOVEMBER
	FAA	AIRLINES		DOMESTIC AIRLINES	
	733-197	733-197 LONG BODY	733-290	733-197 LONG BODY	733-291
WING AREA-FT^2	4680	4680	5020	4680	5020
GROSS WEIGHT-1000 LB	430	520	500	408	425
NO. PASSENGERS (MIXED CLASS)	145	203	230	194	209
ENGINE G. E. 4- (SIZE-LB/SEC)	J4C 415		J5G 475	J4C 415	J5G 475
MAIN GEAR- TIRES	8-49"		16-40"	8-46"	16-38"

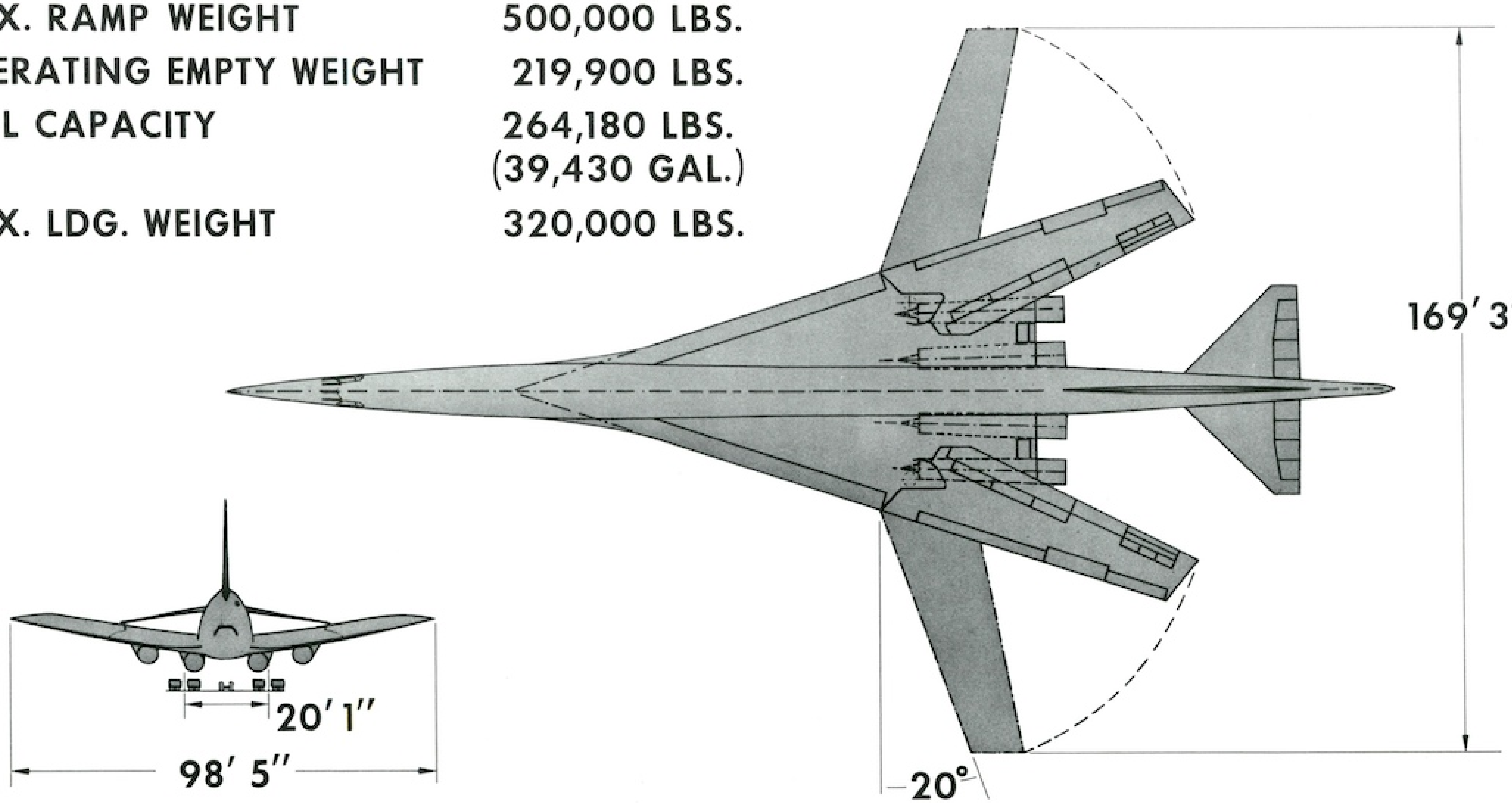
Two versions of the basic airplane are proposed, the 733-290 Intercontinental shown on the opposite page and the 733-291 Transcontinental shown overleaf. Body length and diameter, engines and wing planform for the two versions are identical.

While the configuration has been extensively revised from the Phase I proposal (733-197) it is still relatively close to the ground with the forward entry door only ten feet six inches above the ground line in the parked position. This door sill height is comparable to present subsonic jets.

733-290 GENERAL ARRANGEMENT

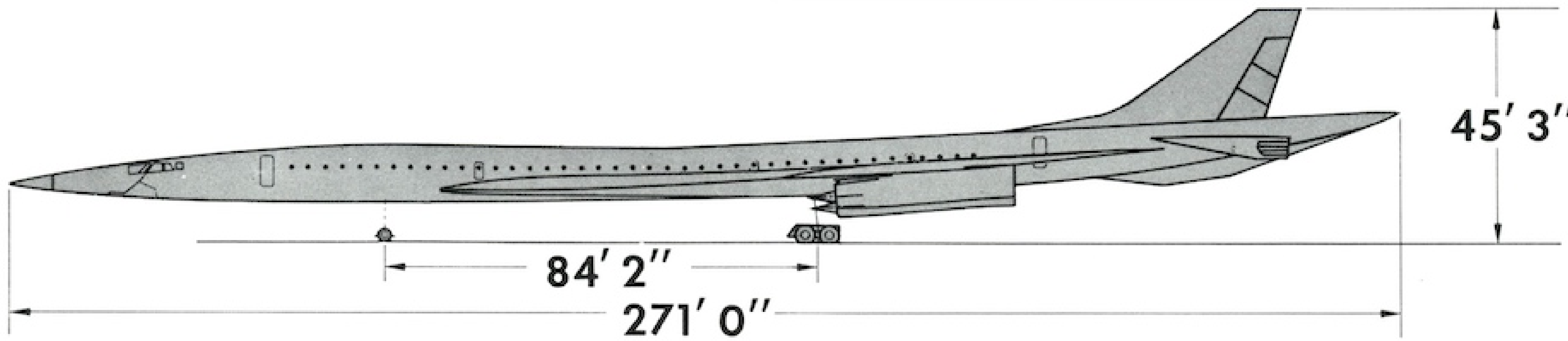


MAX. RAMP WEIGHT	500,000 LBS.
OPERATING EMPTY WEIGHT	219,900 LBS.
FUEL CAPACITY	264,180 LBS. (39,430 GAL.)
MAX. LDG. WEIGHT	320,000 LBS.

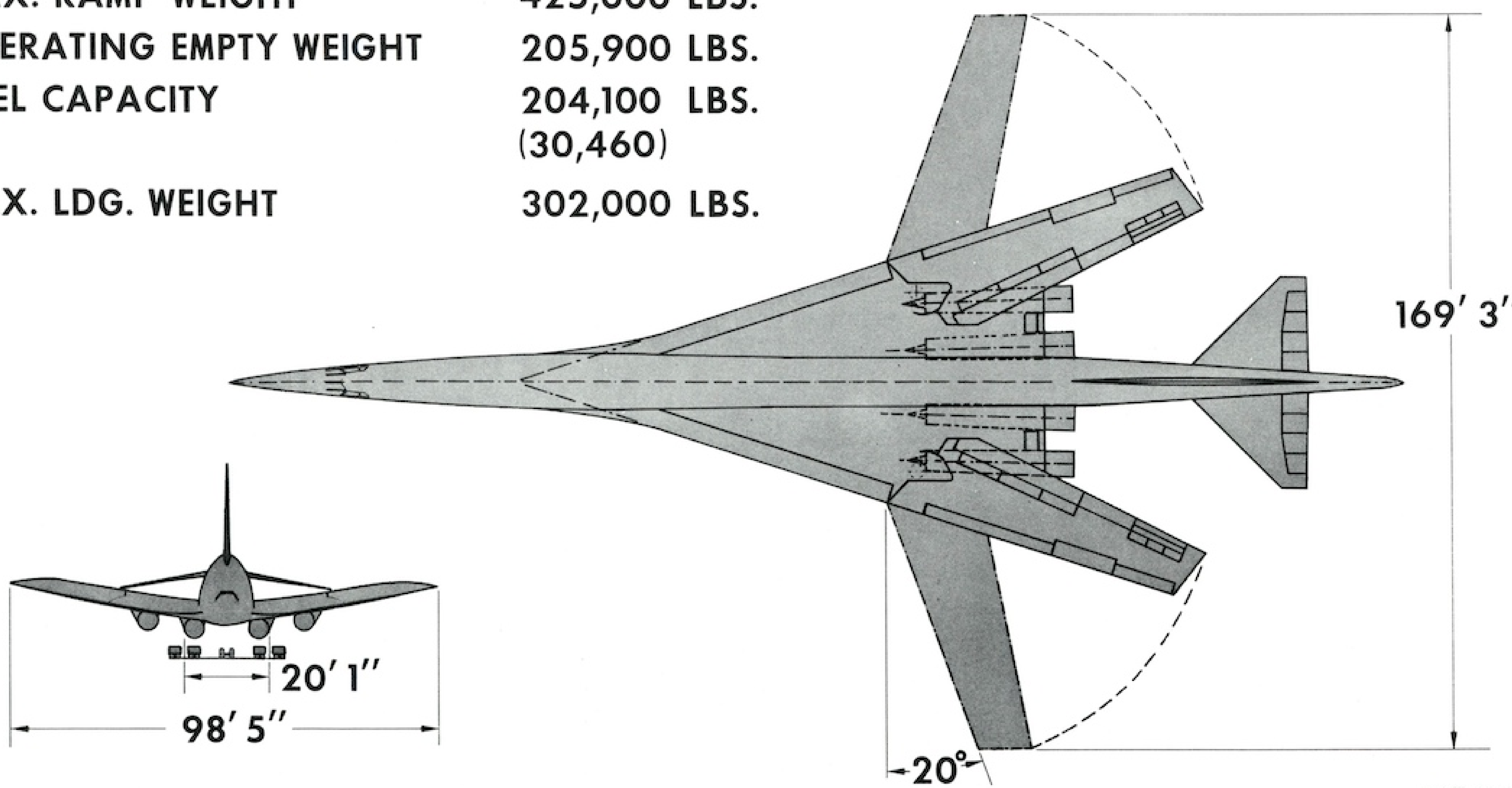


The 733-291 Transcontinental airplane differs mainly from the 733-290 Intercontinental in the amount of fuel carried. Because of this and the resultant reduction in gross weight, we plan to lighten the structure in much the same manner as was done for the Model 720 when it was derived from the original basic 707 design.

733-291 GENERAL ARRANGEMENT



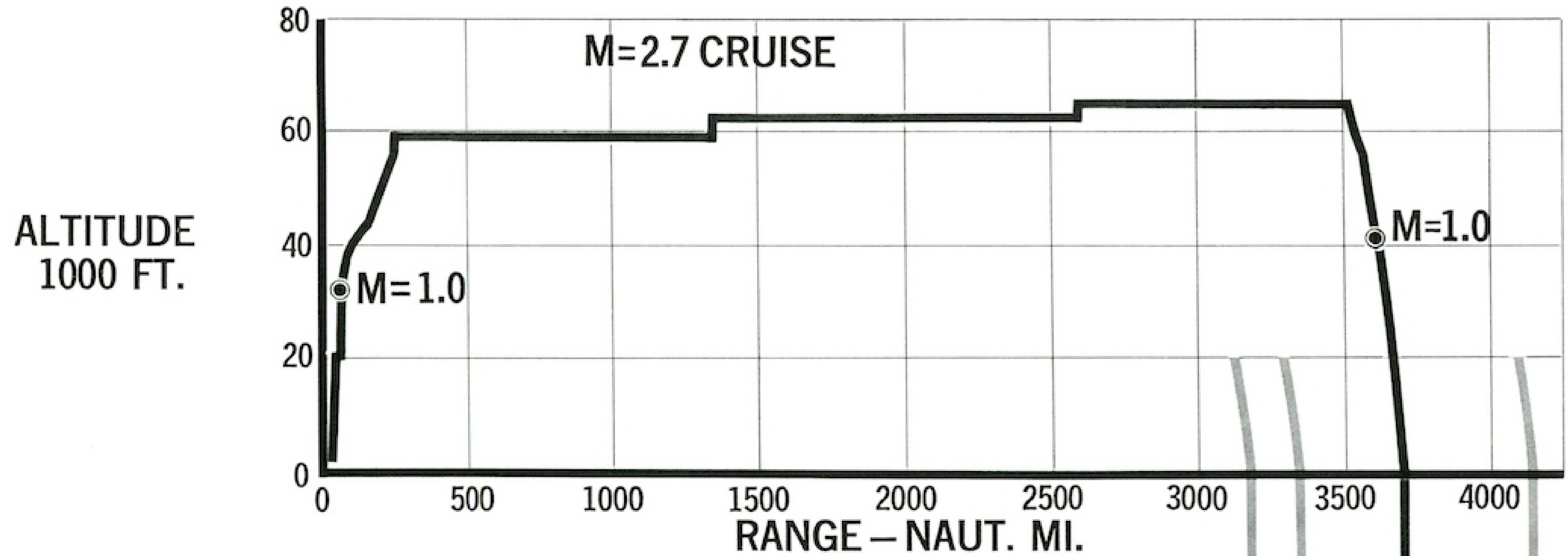
MAX. RAMP WEIGHT	425,000 LBS.
OPERATING EMPTY WEIGHT	205,900 LBS.
FUEL CAPACITY	204,100 LBS. (30,460)
MAX. LDG. WEIGHT	302,000 LBS.



CE6597 11-64

The range-payload capability of the Boeing 733-290 is greatly increased over that of the 733-197. An intensive program of aerodynamic development has produced a remarkable improvement in performance and economy of operation. The 733-290 and -291 can carry up to 65 percent greater payloads than could the -197 over representative intercontinental and transcontinental distances.

CE-6552



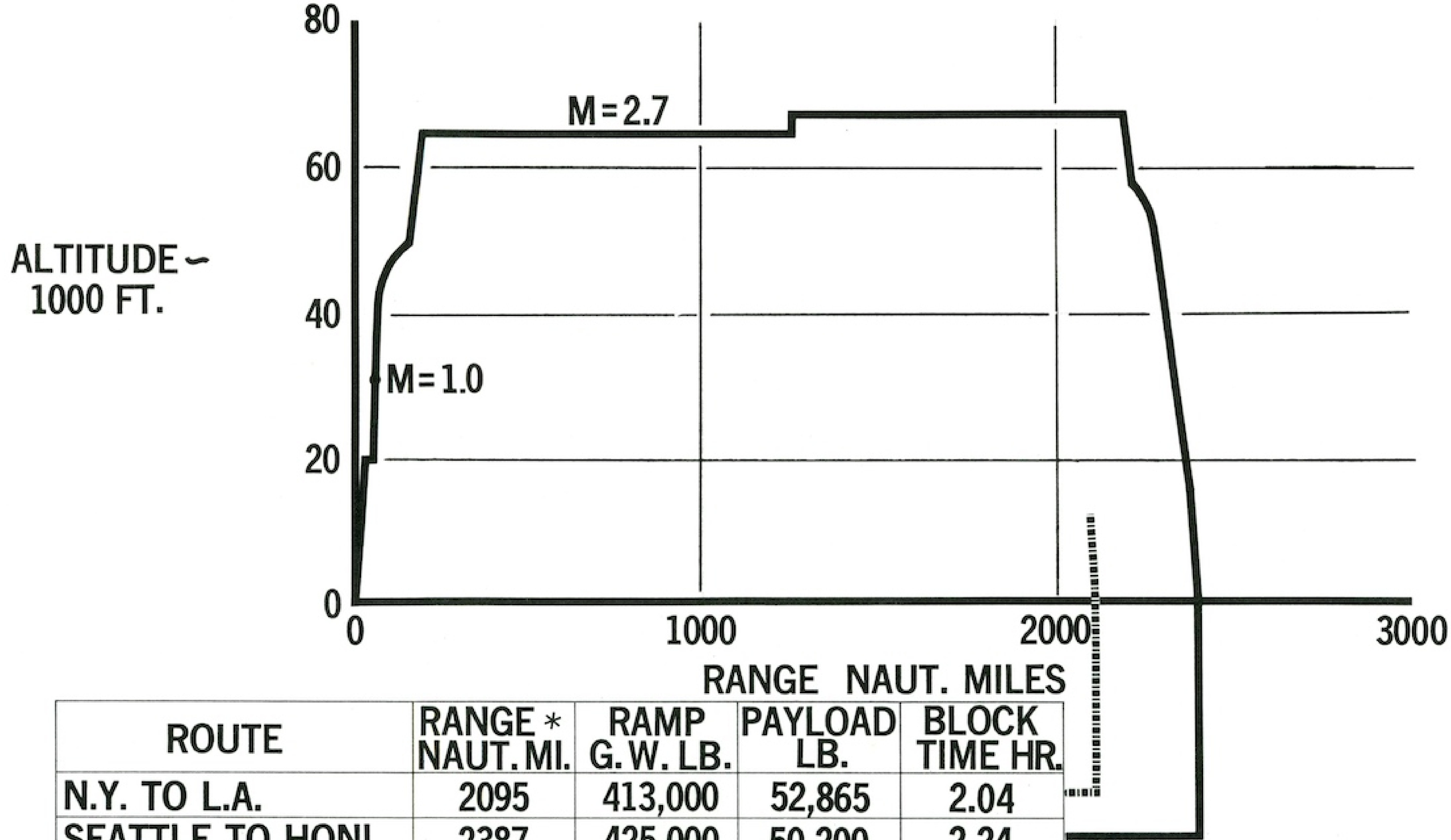
ROUTE	RANGE* NAUT.MI.	RAMP G.W., LB.	PAYLOAD LB.	BLOCK TIME, HR.
N.Y. TO PARIS	3160	494 000	52 865	2.74
N.Y. TO FRANKFURT	3340	500 000	50 500	2.89
N.Y. TO ROME	3680	500 000	37 000	3.07
TOKYO TO SEATTLE	4150	500 000	21 000	3.40

*AIRLINE DISTANCES

Typical mission capabilities of the 733-291 Transcontinental are shown here.

CE-6630

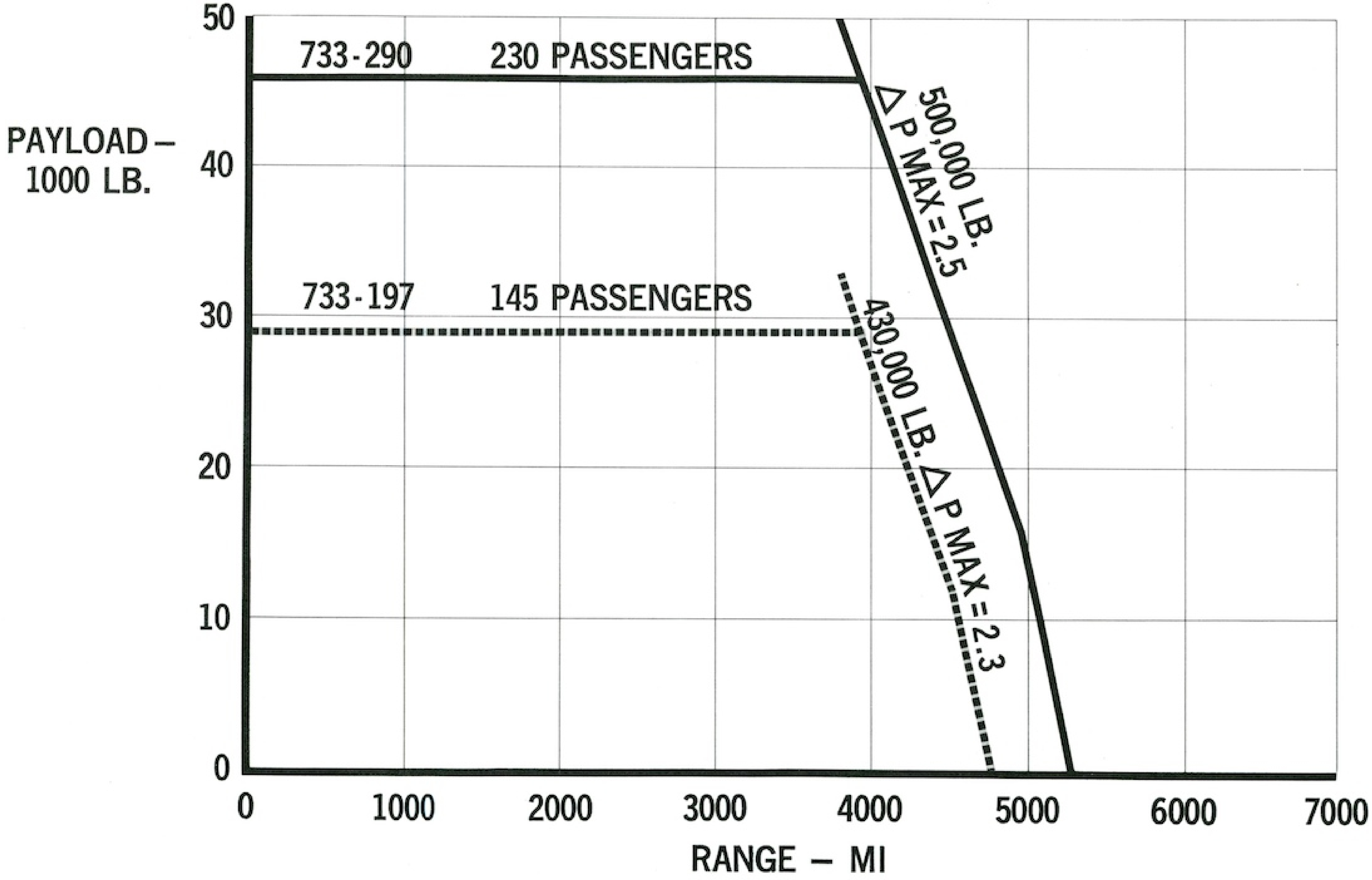
MISSION PERFORMANCE
733—291



ROUTE	RANGE * NAUT. MI.	RAMP G.W. LB.	PAYLOAD LB.	BLOCK TIME HR.
N.Y. TO L.A.	2095	413,000	52,865	2.04
SEATTLE TO HONL.	2387	425,000	50,200	2.24

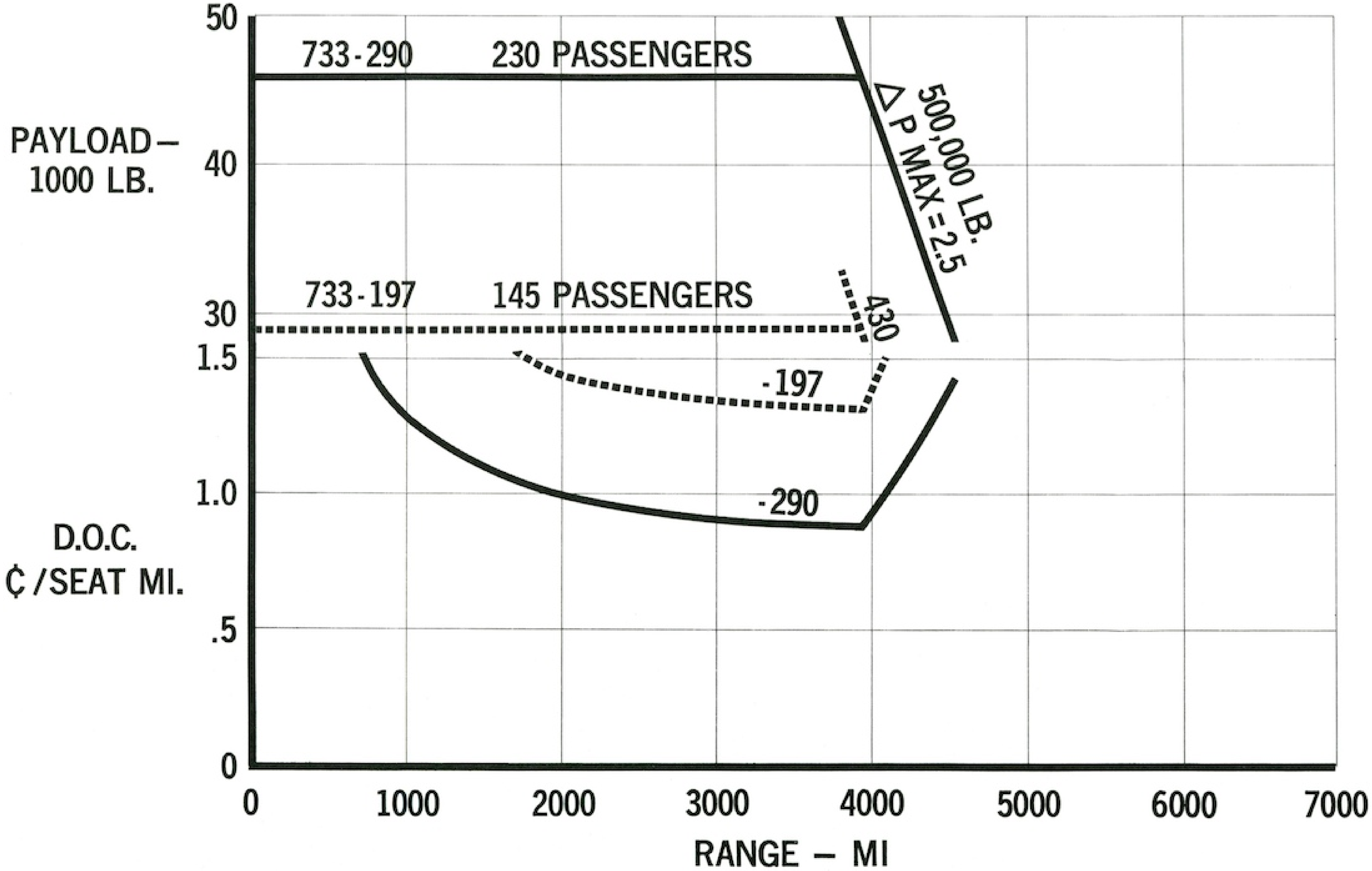
* AIRLINE DISTANCE

COMPARISON OF IMPROVED AIRPLANE 733-290 WITH JANUARY AIRPLANE 733-197



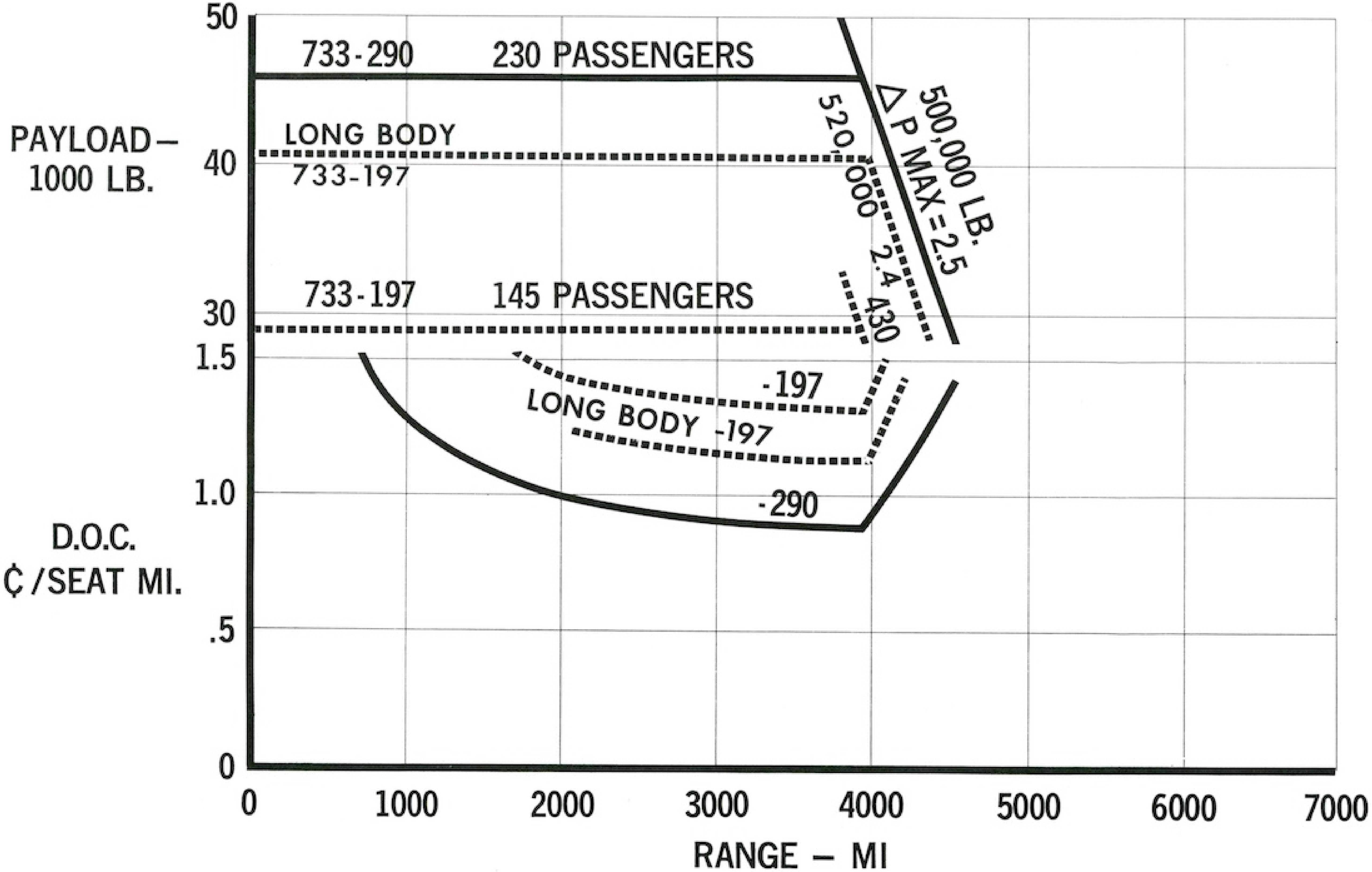
CE6536 11-64

COMPARISON OF IMPROVED AIRPLANE 733-290 WITH JANUARY AIRPLANE 733-197



CE6537 11-64

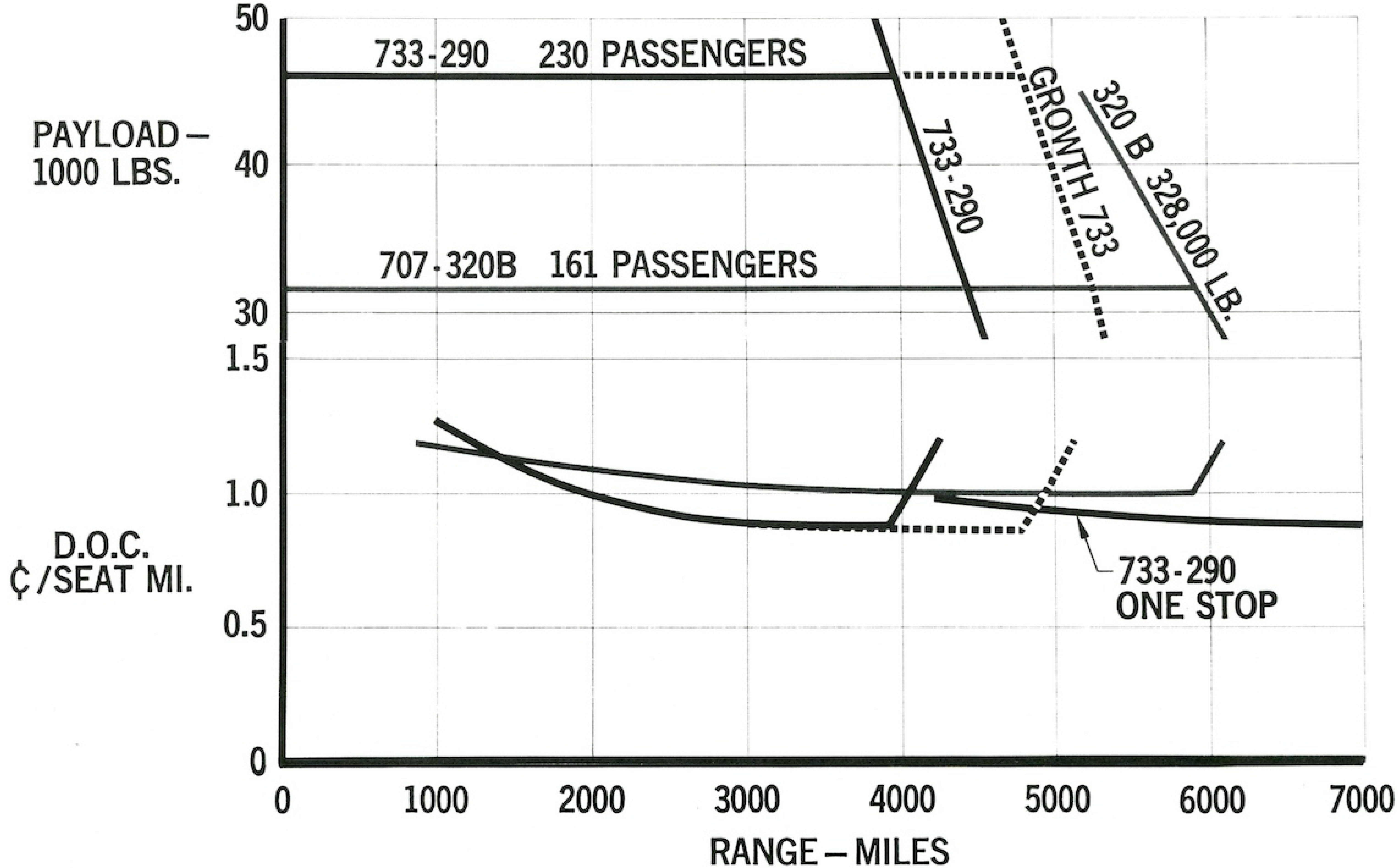
COMPARISON OF IMPROVED AIRPLANE 733-290 WITH JANUARY AIRPLANE 733-197



Payload-range performance of the 733-290 and 707-320B are compared here. The loading mix and seat spacing used on both aircraft are the same: 10 percent of the seats are in a four-abreast first class section at 40 inch pitch, and the remaining 90 percent are in the tourist cabin at 34 inch pitch.

The "Growth 733" curve represents a reasonable estimate of the extra range which is potentially available due to anticipated improvements in aerodynamic, propulsion system and structures efficiencies.

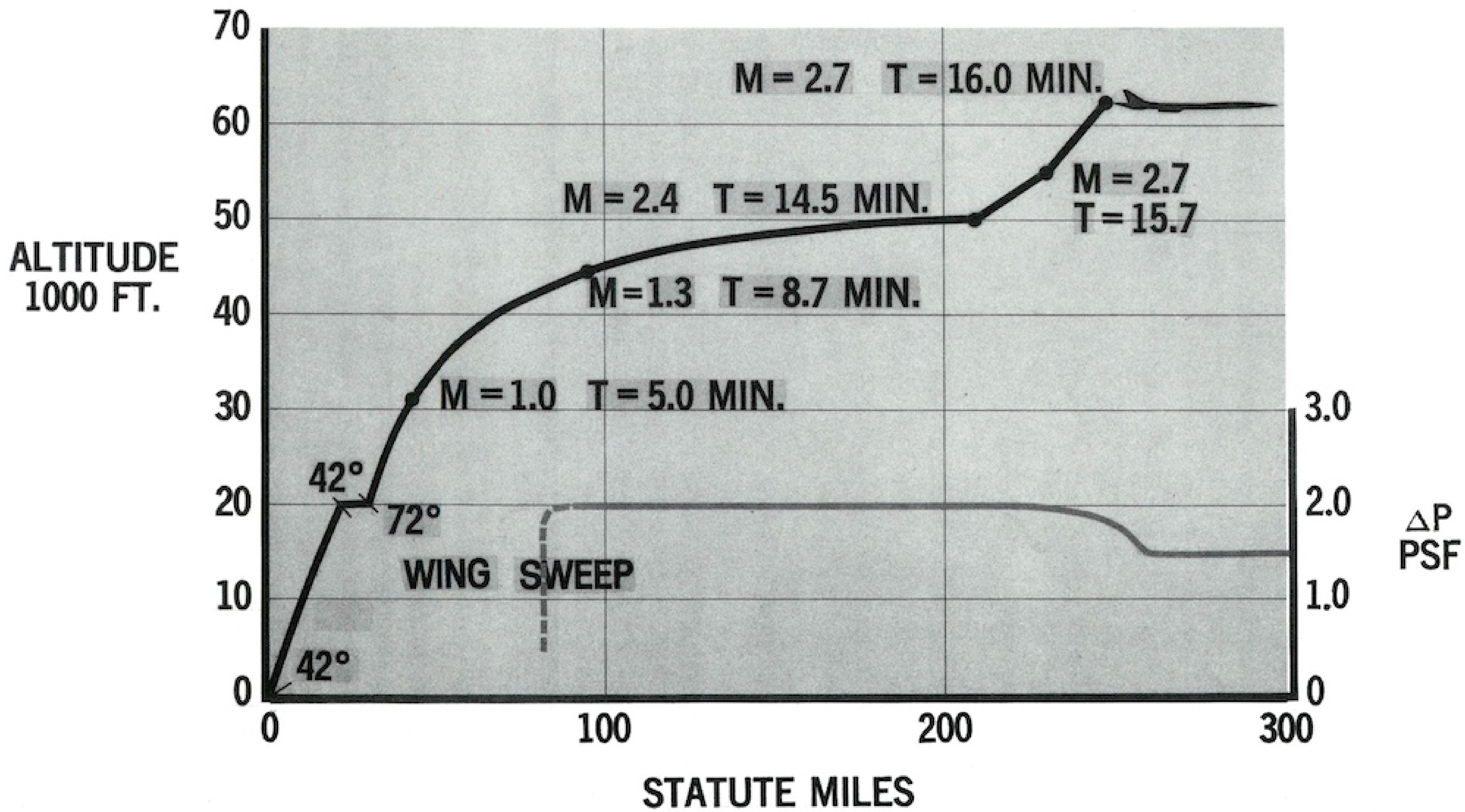
COMPARISON WITH 707-320B



A typical 733-291 climb and acceleration schedule will permit attaining cruise altitude and speed in approximately 16 minutes from brake release at maximum gross weight. This schedule does not exceed a maximum sonic boom overpressure level of 2.0 psf.

At approximately 240 knots IAS or as soon as practical after flaps have been retracted, the thrust is set at maximum dry power and 42° of wing sweep selected. Acceleration to 350 knots IAS and climb to 20,000 feet at this IAS is made, followed by wing sweep to 72° and acceleration to 375 knots IAS. As the airplane approaches Mach 0.9 (20,000 to 25,000 feet), maximum augmented power is applied. The airplane climb angle is reduced slightly at 30,000 feet to accelerate along the selected sonic boom overpressure path. This path is followed out to approximately 630 IAS (50,000 feet) which is then the climb speed until intersecting a final segment at Mach 2.7 (55,000 feet). The Mach 2.7 climb continues until level off at cruise altitude (62,500 feet).

CLIMB AND ACCELERATION
733-291

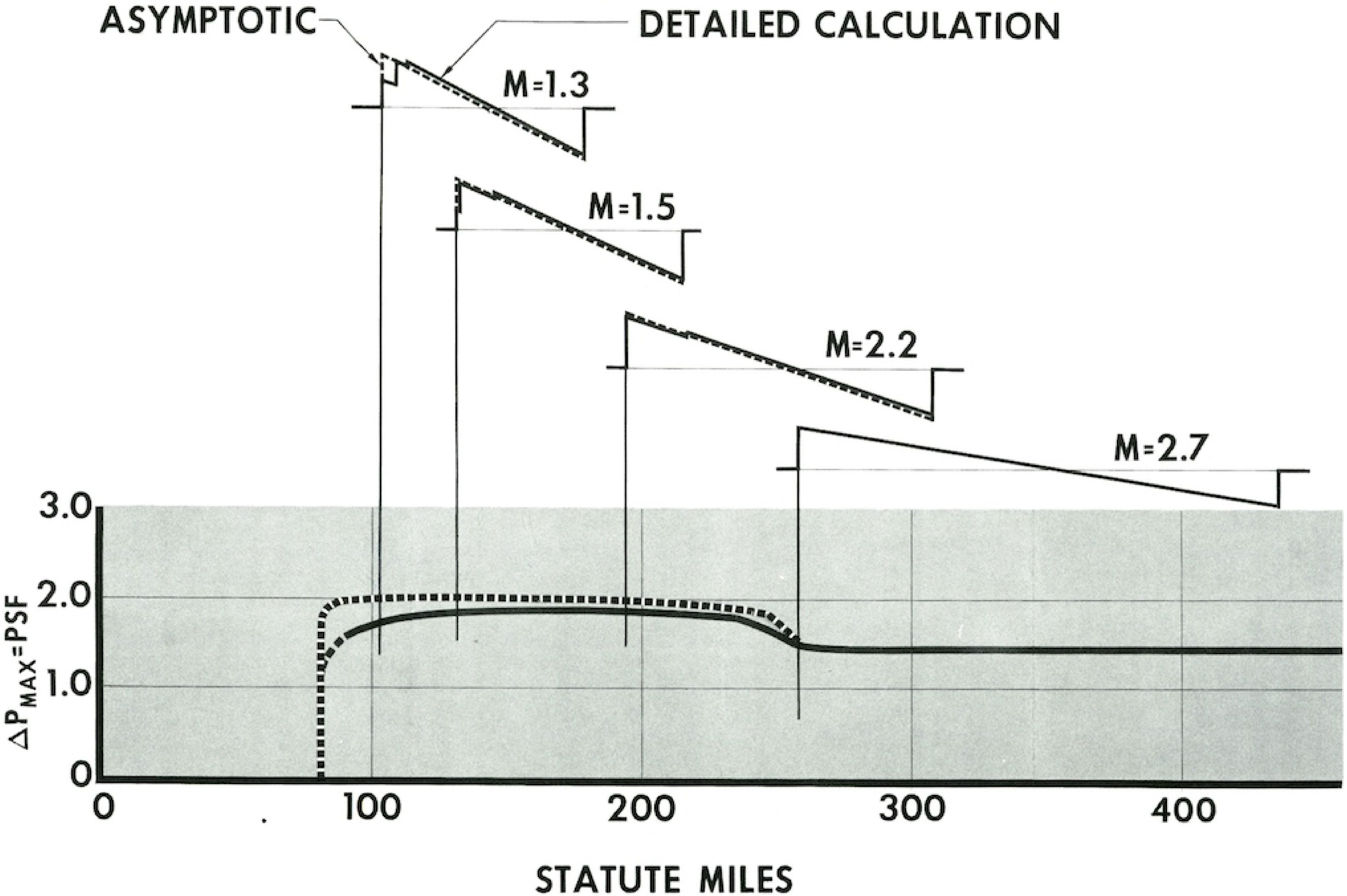


CE6618 R 11-64

SONIC BOOM

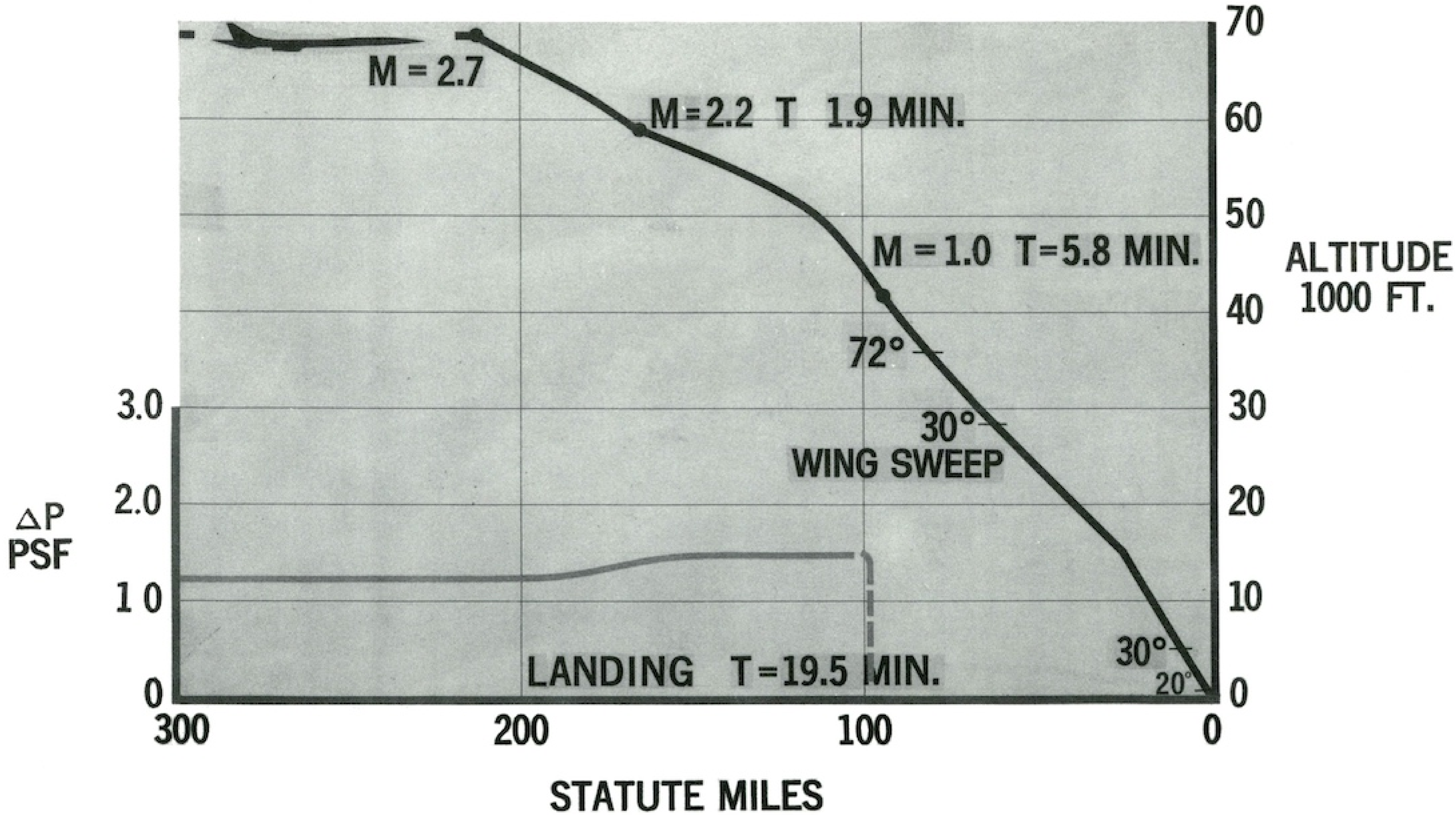
The performance of the 733-290 as submitted in the Phase II-A proposal and as shown on the previous page was based on the asymptotic solution of the sonic boom theory as mutually agreed to by the airframe manufacturers and the FAA. The asymptotic solution assumes that all of the shock waves have coalesced into single leading and trailing shocks which produce the typical N-shaped pressure wave. Since the submittal of the Phase II-A proposals, additional sonic boom evaluations have been accomplished. When the sonic boom characteristics are determined by detailed pressure wave calculations there are combinations of Mach number and altitude in the climb and acceleration phase of the flight where the shock waves from the individual airplane components have not coalesced by the time they reach the ground. The sketches on the opposite page show comparisons of the pressure wave shapes. The resulting sonic boom overpressure is less than would be predicted by the simplifying assumptions of the asymptotic solution as shown on the opposite page. As the Mach number or the altitude increase the two solutions become identical.

SONIC BOOM PRESSURE WAVES
733-291 (CLIMB AND ACCELERATION)



The Model 733 can slow down any time without preparation or c.g. manipulation. "Low idle" is selected and the airplane started down at constant indicated airspeed (essentially the same airspeed held at the end of cruise). This is 500 knots for the normal mission. The 72° wing sweep is held until the airplane decelerates to subsonic speeds. At approximately 58,000 feet the descent path intersects the 1.5 psf sonic boom overpressure limit segment which is then followed. The airplane reaches subsonic speed at 42,000 feet and descends from this point in a manner similar to today's jet transports. The wing sweep is started forward so as to end up at 30° at about Mach 0.8. The normal descent times, sonic boom overpressures and distances are shown on the opposite page.

DECELERATION AND DESCENT
733-291

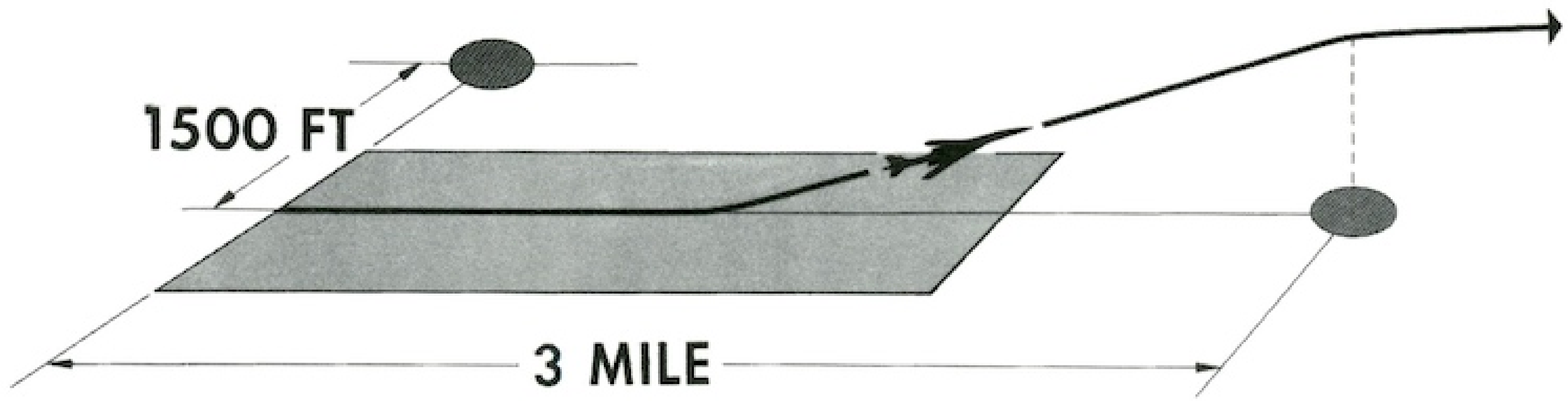


CE6616R 5-65

The excellent low speed performance of the Models 733-290 and -291 helps to maintain low community and airport noise levels. At takeoff, high maximum lift coefficient and high lift/drag ratio permit takeoff in a short distance with moderate airport noise levels, and rapid climbout results in low community noise levels.

The chart opposite compares takeoff performance and noise levels for the 733, 720B, 707-320B, 727 and Concorde under standard day, sea level conditions. Takeoff speeds for the -290 and -291 for these conditions are 159 knots and 146 knots, respectively.

TAKEOFF PERFORMANCE

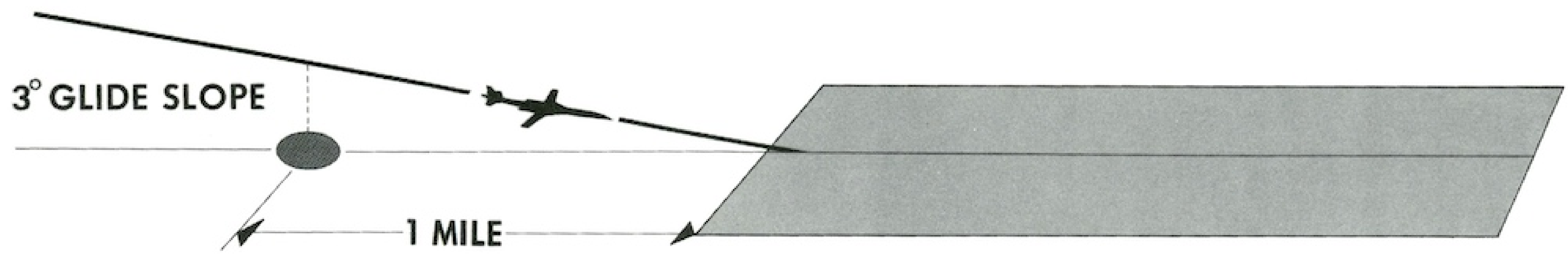


MODEL	GW (1000 LB.)	TAKE-OFF SPEED (KTS)	TAKE-OFF DISTANCE (FEET)	AIRPORT NOISE (PN db)	COMMUNITY NOISE (PNdb)	ALTITUDE (FEET)
733-290	500	159	7060	116	105.5	1570
707-320 B	327	166	10,850	108	120.5	600
733-291	425	146	5115	116	97	2340
720B	234	156	6200	107	110.5	1150
727	152	133	5850	108	100.5	1250
CONCORDE	326	205	9750 (MAX AUG)	118	106(112)	800

Excellent approach and landing performance at low noise levels is another attractive feature of the 733. The airplane's large span with wings swept forward plus an efficient high lift system provide low approach speeds at low attitudes and minimum approach noise because of the low power required. Engine compressor whine is all but eliminated by operating the engine inlet in the choked position.

Approach noise one mile from the end of the runway under the airplane flying an ILS is shown for the maximum landing weights of the -290 (320,000 pounds) and the -291 (302,000 pounds). CAR landing field lengths are also listed. Landing distances are comparable to the 707. Approach noise is substantially less.

LANDING PERFORMANCE



MODEL	LANDING WEIGHT (1000 LB)	APPROACH SPEED (KTS)	BODY APPROACH ATTITUDE (DEGREES)	CAR LDG DISTANCE (FT)	COMMUNITY NOISE (PNdb)
733-290	**320**	**137**	**2.5**	**6440**	**112**
707-320B	207	135	0.9	6420	122.5
733-291	**302**	**133**	**2.5**	**6150**	**111**
720B	175	134	1.6	6400	120
727	135	121	1.4	4600	117.5
CONCORDE	200	165	12	7750	110(119)

Materials Comparison

The Materials Comparison chart shows a comparison of the structural efficiency of stainless steel and titanium 8-1-1 alloy with aluminum. Stainless steel weighs 2.9 times as much as aluminum, and titanium alloy weighs 1.6 times as much as aluminum. At room temperature, steel is 3.2 5imes the strength of aluminum and titanium alloy is 2.2 times the strength of aluminum. If the relative strength is divided by the relative weight, then aluminum will have a structural efficiency of 1, stainless steel will have a structural efficiency of 1.13 and titanium alloy a structural efficiency of 1.1. Thus, a structure of titanium that is the same weight as a structure of aluminum will sustain 40% more load than the aluminum structure. At supersonic speed aluminum cannot be used for speeds much greater than Mach 2, so if the relative strength of aluminum at Mach 2 is 1, then steel at Mach 2.7 would be 3.3 times the strength of aluminum at Mach 2, and titanium at Mach 2.7 would be 2.1 times the strength of aluminum at Mach 2. If the relative strengths are divided by the relative weight, then aluminum at Mach 2 will have a structural efficiency of 1 and stainless steel at 2.7 would have a structural efficiency of 1.18, and titanium would have a structural efficiency at Mach 2.7 of 1.33. Therefore, to obtain a structure of minimum weight we must use titanium alloy.

CE-6682

MATERIALS COMPARISON

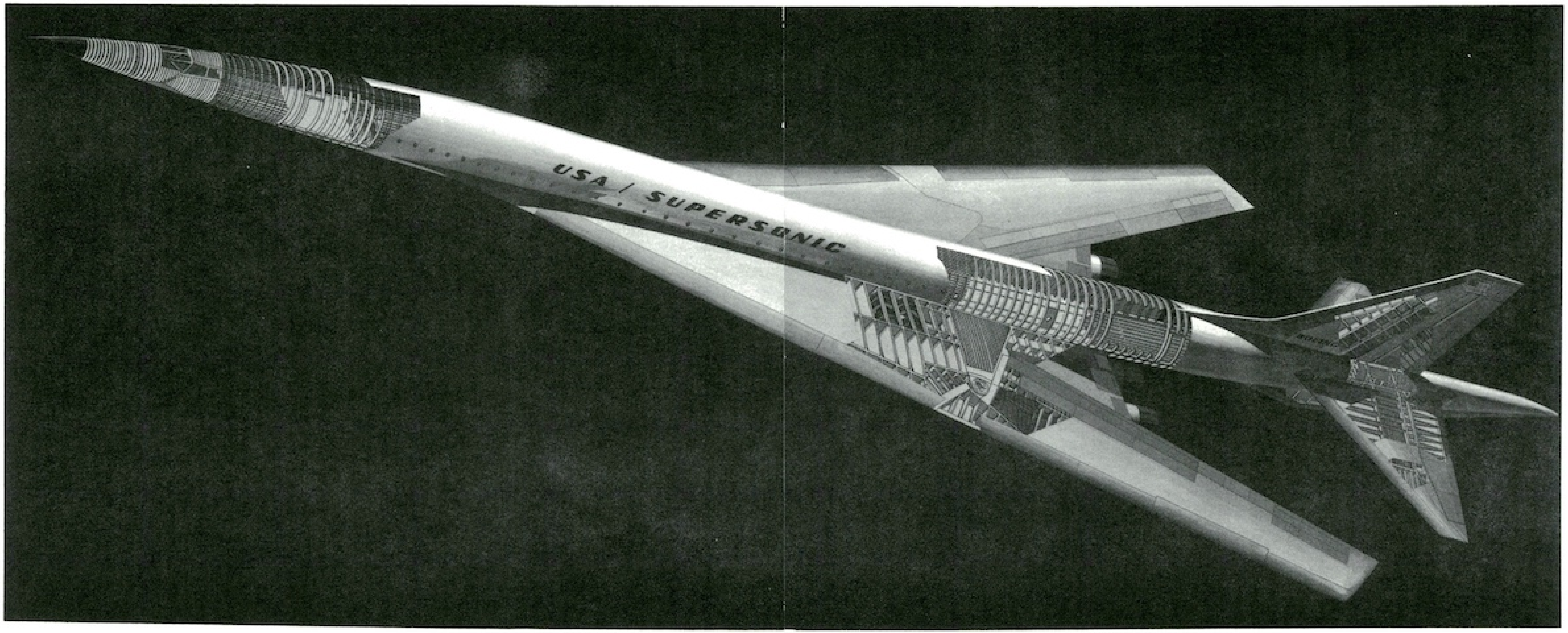
	ALUMINUM	STEEL	TITANIUM
RELATIVE WEIGHT	1	2.9	1.6
ROOM TEMPERATURE PROPERTIES			
RELATIVE STRENGTH	1	3.2	2.2
RELATIVE EFFICIENCY	1	1.13	1.4
HIGH TEMPERATURE PROPERTIES			
AT MACH NO =	2	2.7	2.7
RELATIVE STRENGTH	1	3.3	2.1
RELATIVE EFFICIENCY	1	1.18	1.33

Titanium stiffened skin construction is particularly well suited for use on the primary structure of the Boeing variable sweep wing airplane. This construction is very similar to the aluminum construction used on present day subsonic commercial jets.

Use of high strength titanium alloys allows the structure to be operated at the higher skin temperatures associated with supersonic cruise conditions.

Skin stringer construction features manufacturing simplicity and ease of inspection and repair which has been developed to a high degree on present commercial airplanes.

High temperature adhesive bonded honeycomb panels featuring light weight, low fabrication cost, high aerodynamic smoothness and high sonic resistance will be extensively used in secondary structural applications.

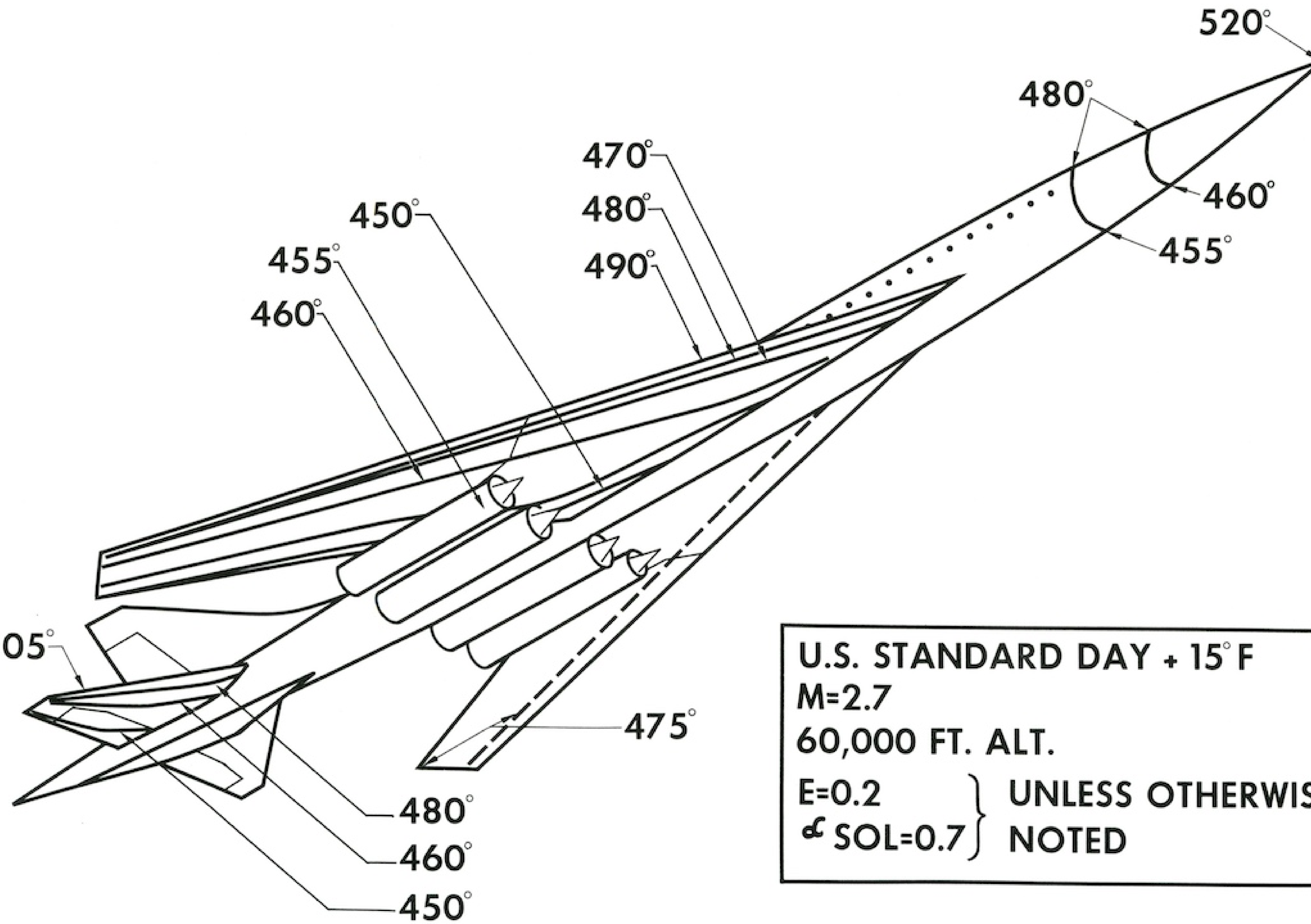

USA / SUPERSONIC

Structural Temperatures

The maximum temperatures that we expect to encounter on the exterior of the SST are shown on the chart. This is for a hot day at Mach 2.7 and at 60,000 feet altitude for an unpainted airplane. The temperatures would be reduced by approximately 50°F if we painted the airplane. The body structure has an exterior temperature of 480°F on top and 455°F on the bottom. The wing primary structure has an exterior temperature of 480°F to 475°F.

The thermal buckling test in the test area was being tested at 500°F, which is higher than the hot day temperatures and is conservative. Also, the large bearing test temperatures were based on calculations from the hot day condition.

STRUCTURAL TEMPERATURES
UNPAINTED AIRPLANE



U.S. STANDARD DAY + 15° F
M=2.7
60,000 FT. ALT.
E=0.2 } UNLESS OTHERWISE
α SOL=0.7 } NOTED

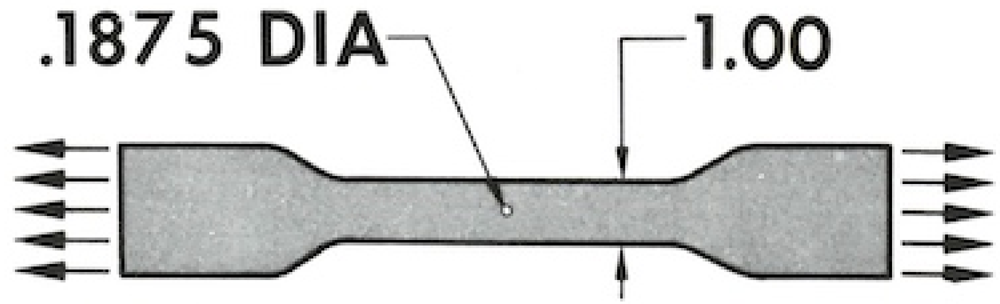
CE6674 3-65

Fatigue Life

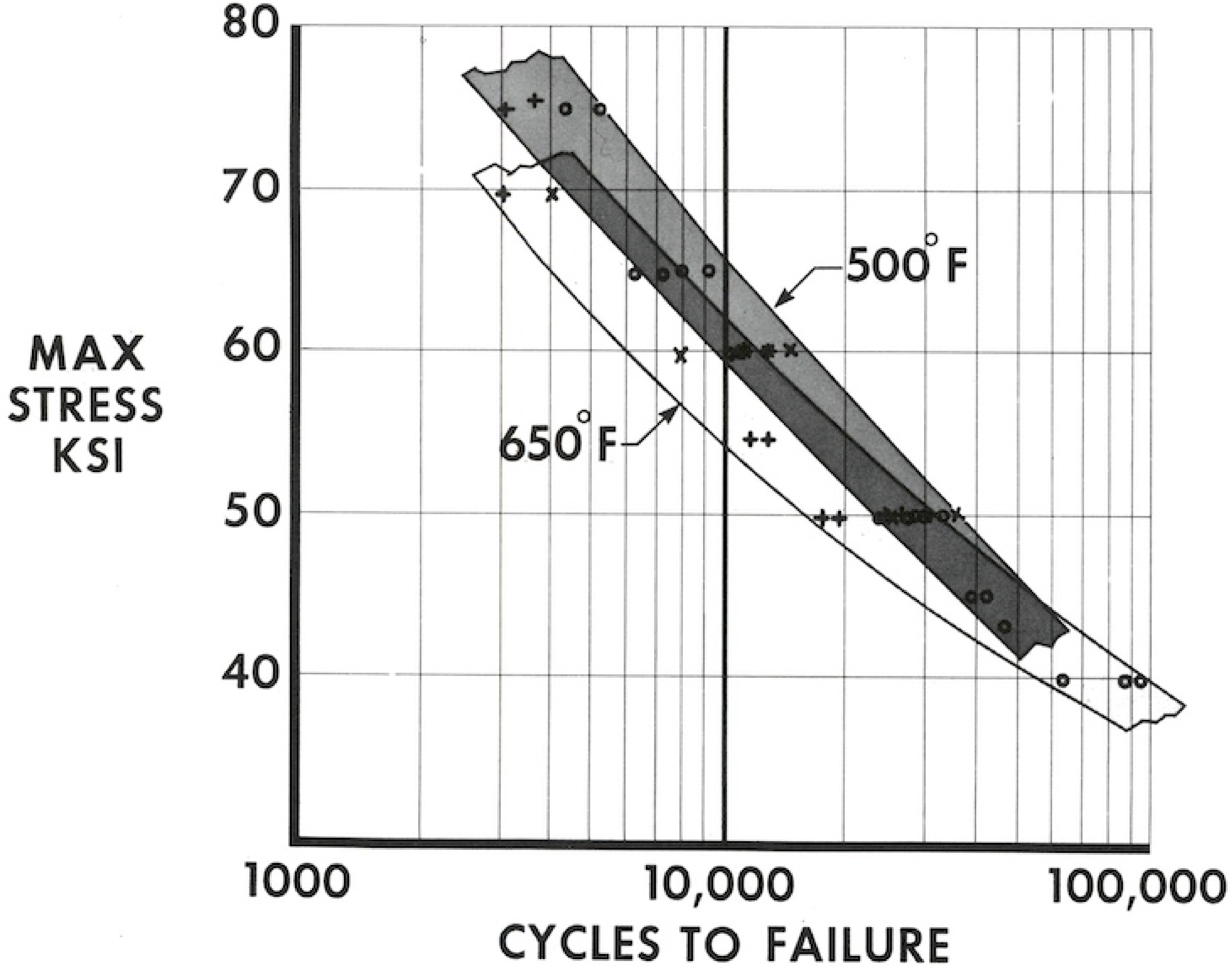
To be certain that the titanium structure will retain its structural integrity for the life of the airplane under the elevated temperature environment, we have conducted extensive fatigue tests on titanium 8-1-1 material. These tests consist of subjecting the specimen to a load of 40,000 pounds per square inch while the specimen is heated to 500°F. (In some tests a temperature of 650°F has been used.) The specimens are loaded and placed in the elevated temperature environment and exposed for an extended period of time. After 2000 hours and 5000 hours exposure test specimens were removed and fatigue tested at various stress levels.

The chart compares elevated temperature fatigue results on specimens that have not been exposed with specimens that have been exposed for 2000 hours of temperature and stress, and with specimens exposed at 5000 hours of temperature and stress. The test data shows that there was no deterioration of fatigue properties for the specimens that had been exposed for 2000 hours and 5000 hours at either the 500°F temperature or the 650°F temperature. We have just recently removed specimens which had been exposed to the elevated temperatures and stress for a period of 10,000 hours. NASA test data on materials exposed for 10,000 hours have not shown a decrease in fatigue life over unexposed specimens. We therefore conclude that we have sufficient information to design an airplane that will be satisfactory for the prototype program. As test specimens acquire approximately 9000 hours per year, in three years we will have sufficient information to evaluate this material for the life of the production airplane.

FATIGUE LIFE



TEST SPECIMEN
TITANIUM 8-1-1
DUPLEX ANNEALED
GAGE .040
R .06



EXPOSURE & TEST TEMPERATURE
500° F

650° F

SPECIMEN LEGEND

- ∘ UNEXPOSED
- + 2000 HRS
- × 5000 HRS

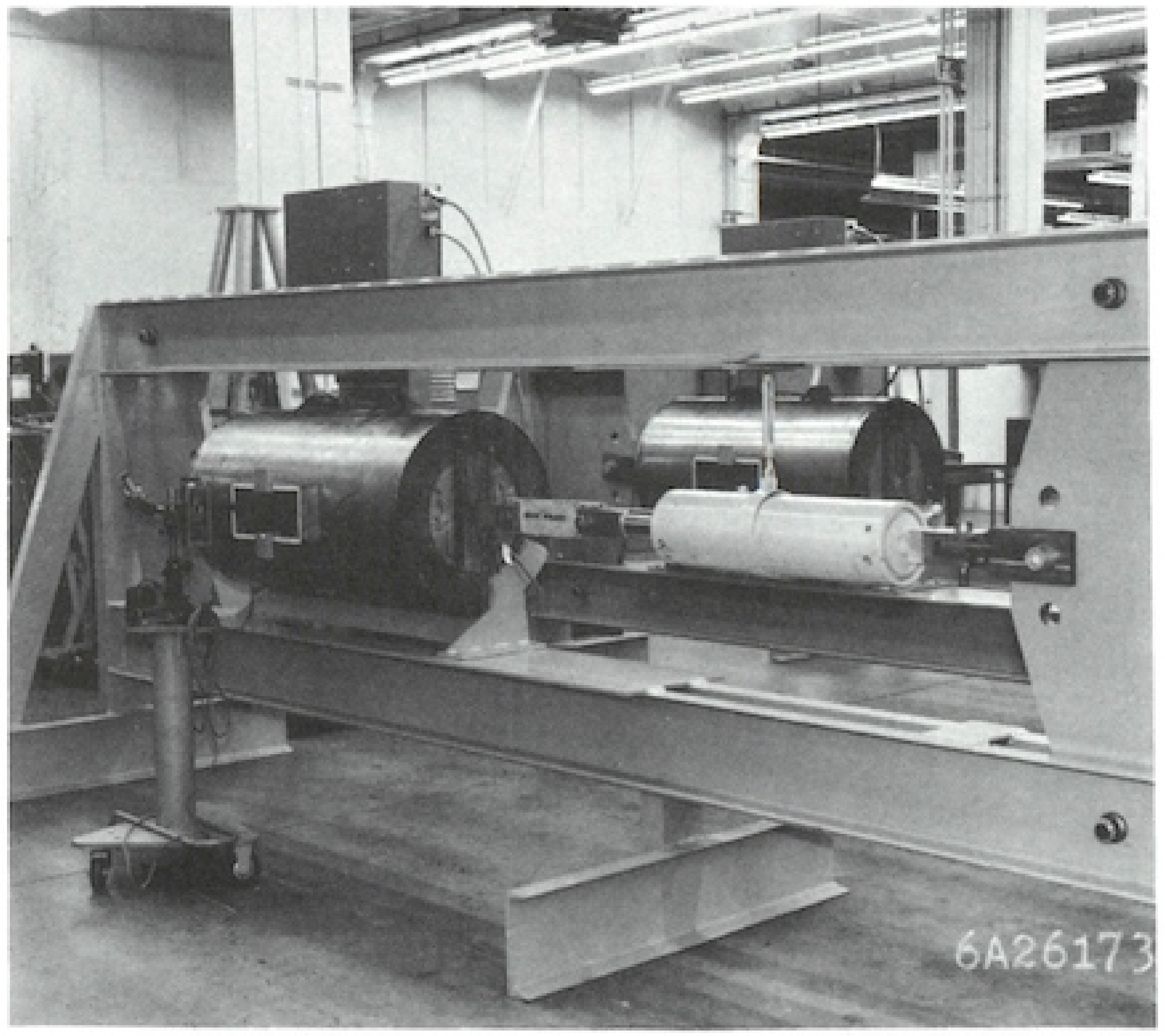
Fatigue and Fail Safe Design

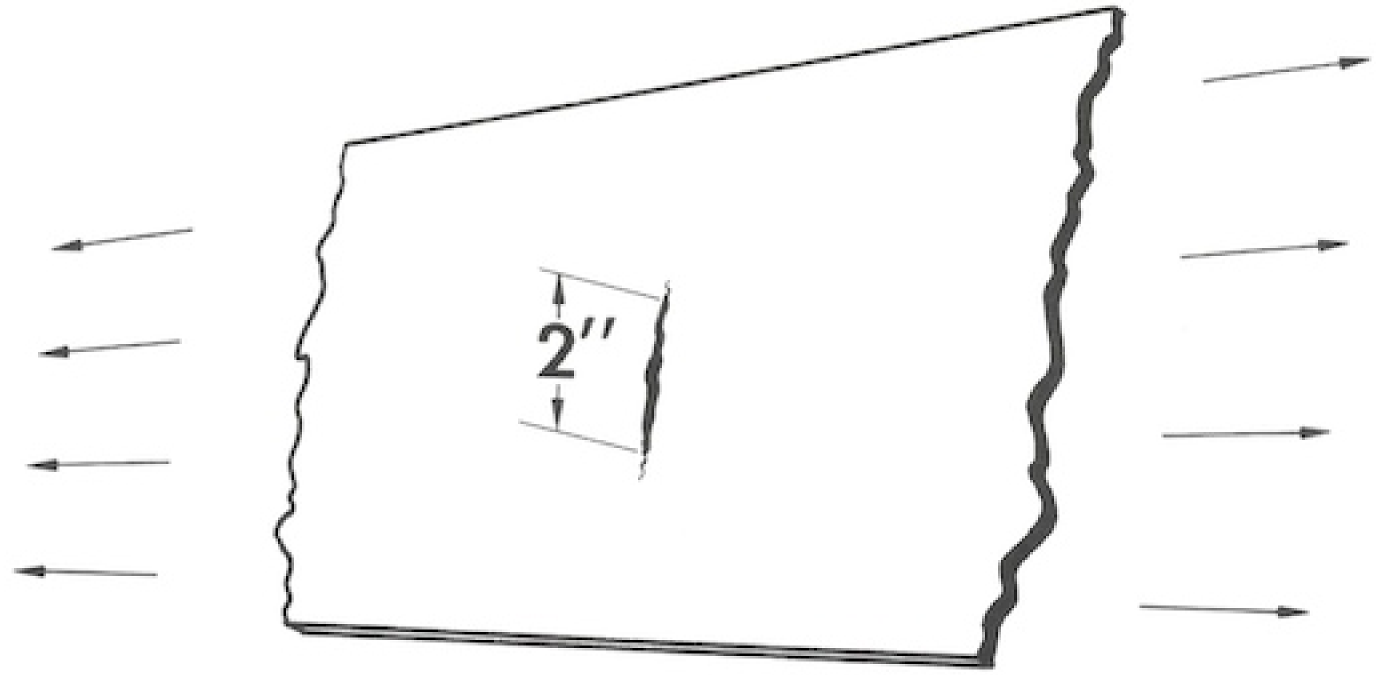
We are very much concerned about the tear resistance of titanium alloy at the SST operating temperatures. The tear resistance chart compares the tear resistance of various structural materials at sub-zero, room, and elevated temperatures. The specimen receives a 2 inch saw cut and is then fatigue tested until a crack starts from each edge of the saw cut. The specimen is then placed in the test temperature environment and subjected to a tension load. In this chart the gross stress at failure is divided by the density of the material so that the materials may be compared on a uniform weight basis. The chart shows that 24ST aluminum alloy, stainless steeel, 2618-T81 aluminum alloy (which the British are using on the Concorde) and titanium 8-1-1 have favorable test values at room temperature, at Mach 2, which is roughly 250°, there is some drop in properties for 2024 aluminum alloy, but titanium 8-1-1 shows no drop in strength characteristics up to 500°F which would indicate that this is a favorable material for the supersonic airplane.

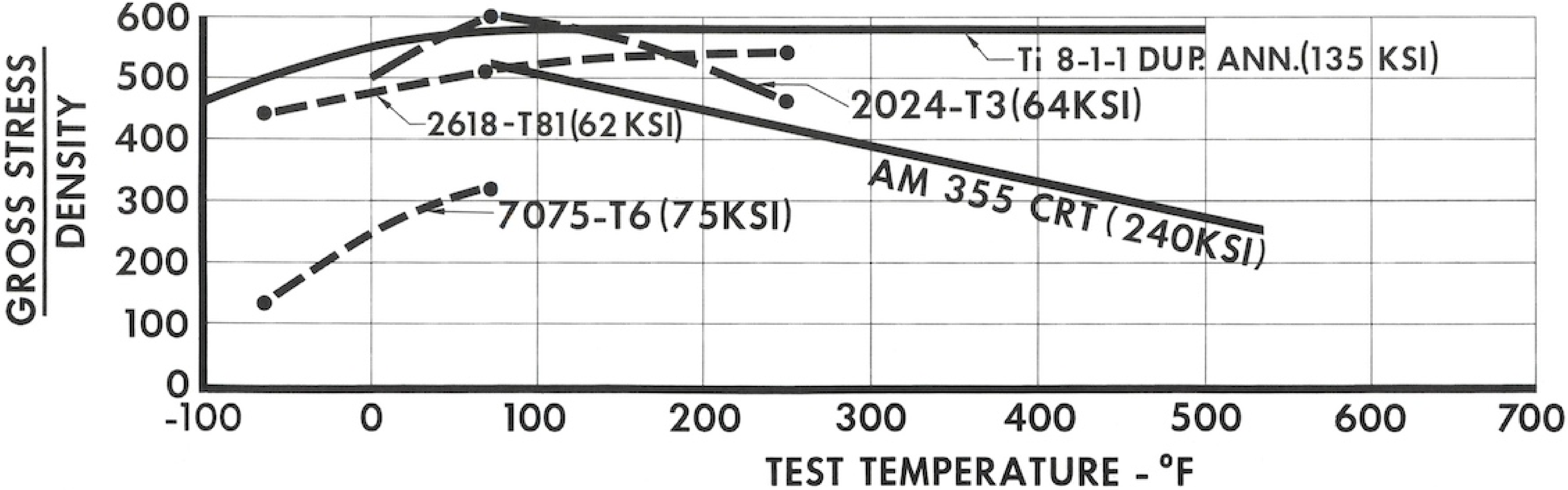
CE-6673

FATIGUE AND FAIL SAFE DESIGN

TEAR RESISTANCE TESTING





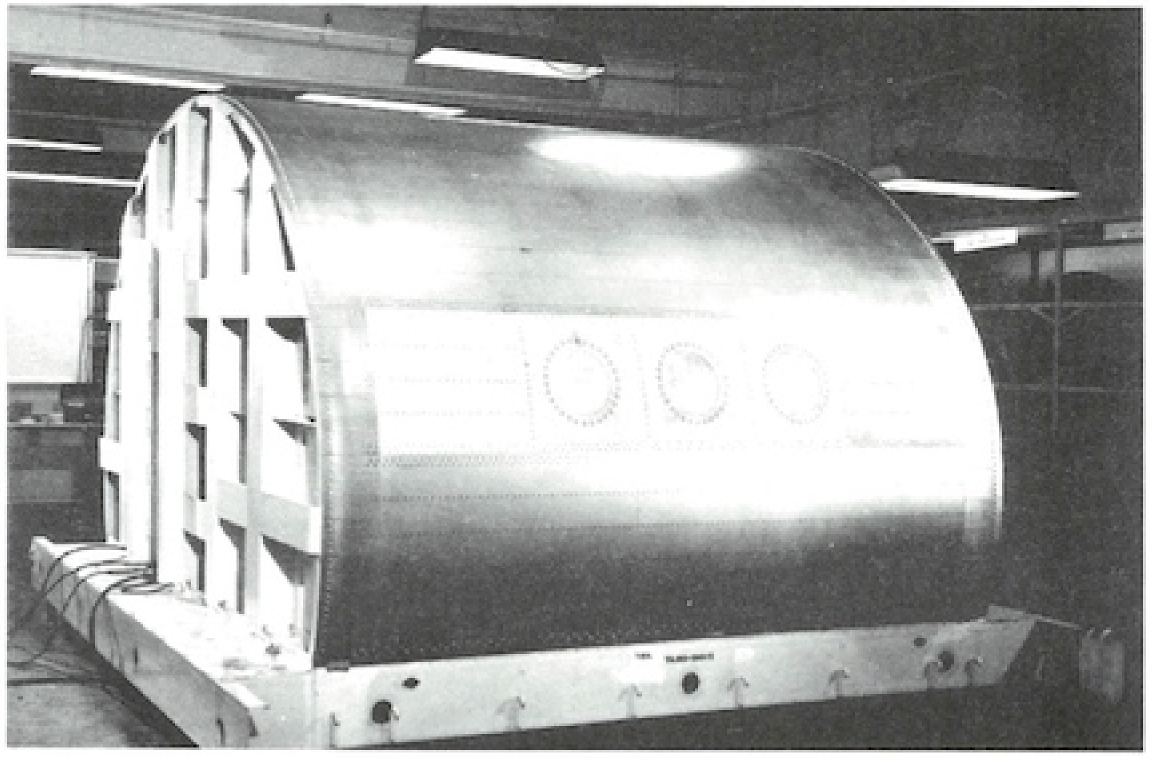


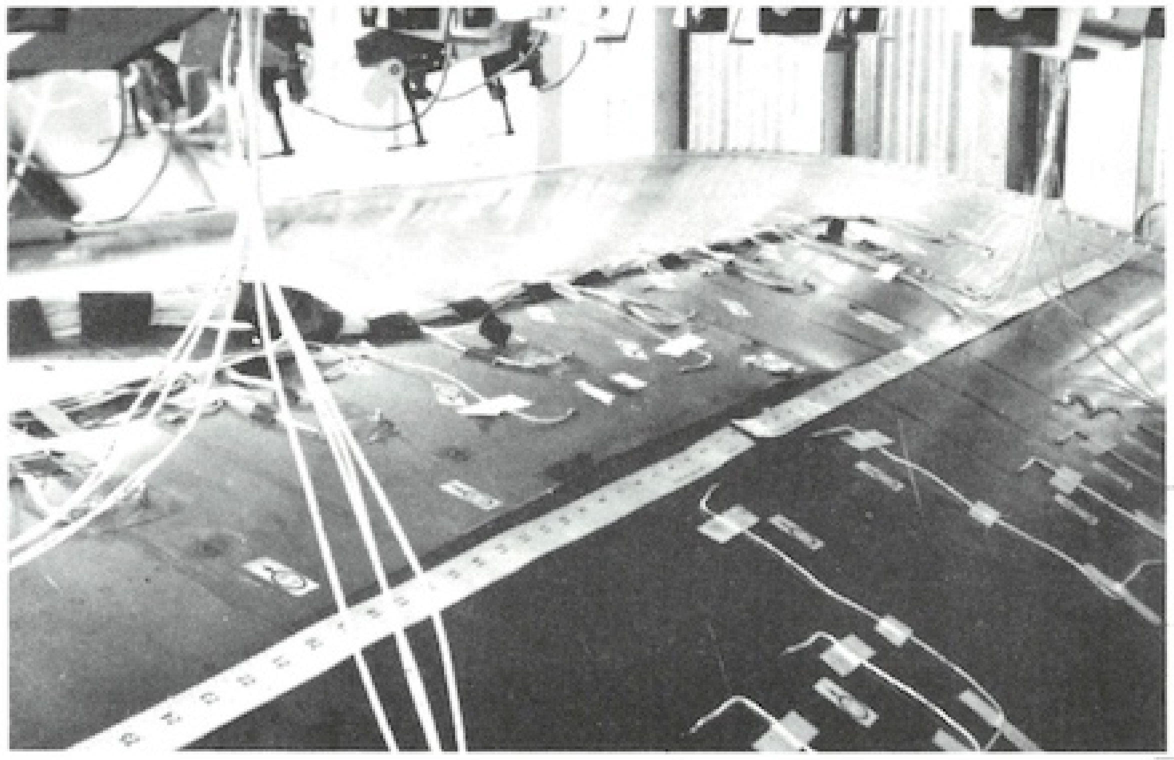
Crack Growth

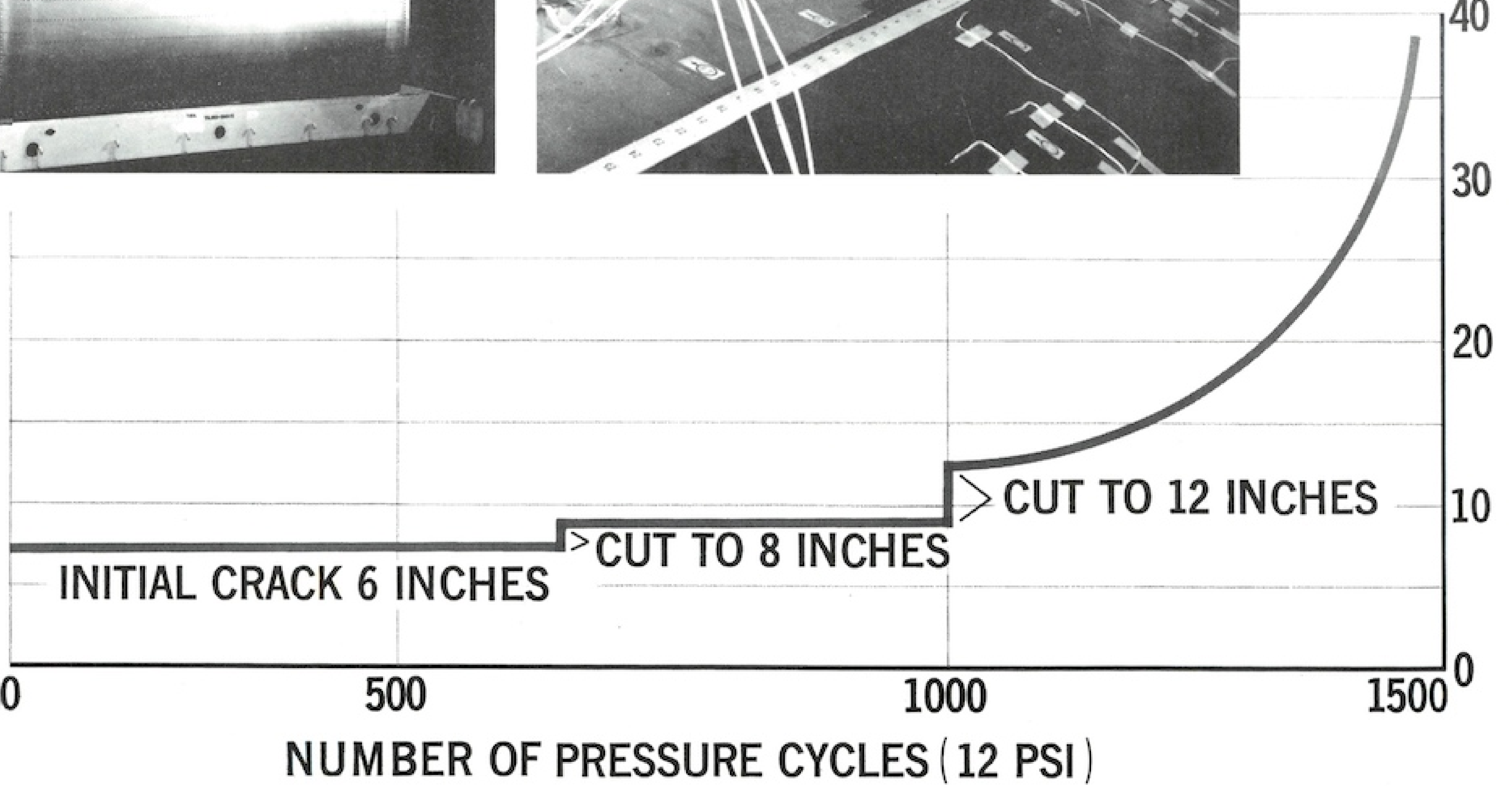
The full size body section is being tested to assure that we have fail safe body design. The chart shows a photograph of the body section before it was tested. The test consisted of cutting a 6-inch long crack in the body skin which is .045 inch thick titanium 8-1-1. We then applied 700 cycles of 12 psi pressure. As very little crack growth was obtained, the saw cut was lengthened to 8 inches and 300 additional pressure cycles were applied to the body. Again there was very little crack growth so the saw cut was lengthened to 12 inches and additional cycles were applied. The curve shows that the crack gradually increased in length to approximately 39 inches when the test was discontinued. It should be noted that even though the total crack length was 30 inches, one pressured cycle increased the crack length only a very small amount. This shows that even though a crack 20 inches in length existed, the crack does not grow catastrophically but can be detected before it extends to any serious length. Thus, we have a high degree of fail safety in our body design.

A similar test has been performed on .032 skin with tear stoppers spotwelded to the skin every 20 inches. In this case with the application of hundreds of cycles, the crack progressed slowly out to the tear stopper and did not progress beyond the tear stopper. This shows a high degree of fail safety in our minimum gage proposed body design.

CRACK GROWTH
TI-8-1-1 BODY SECTION





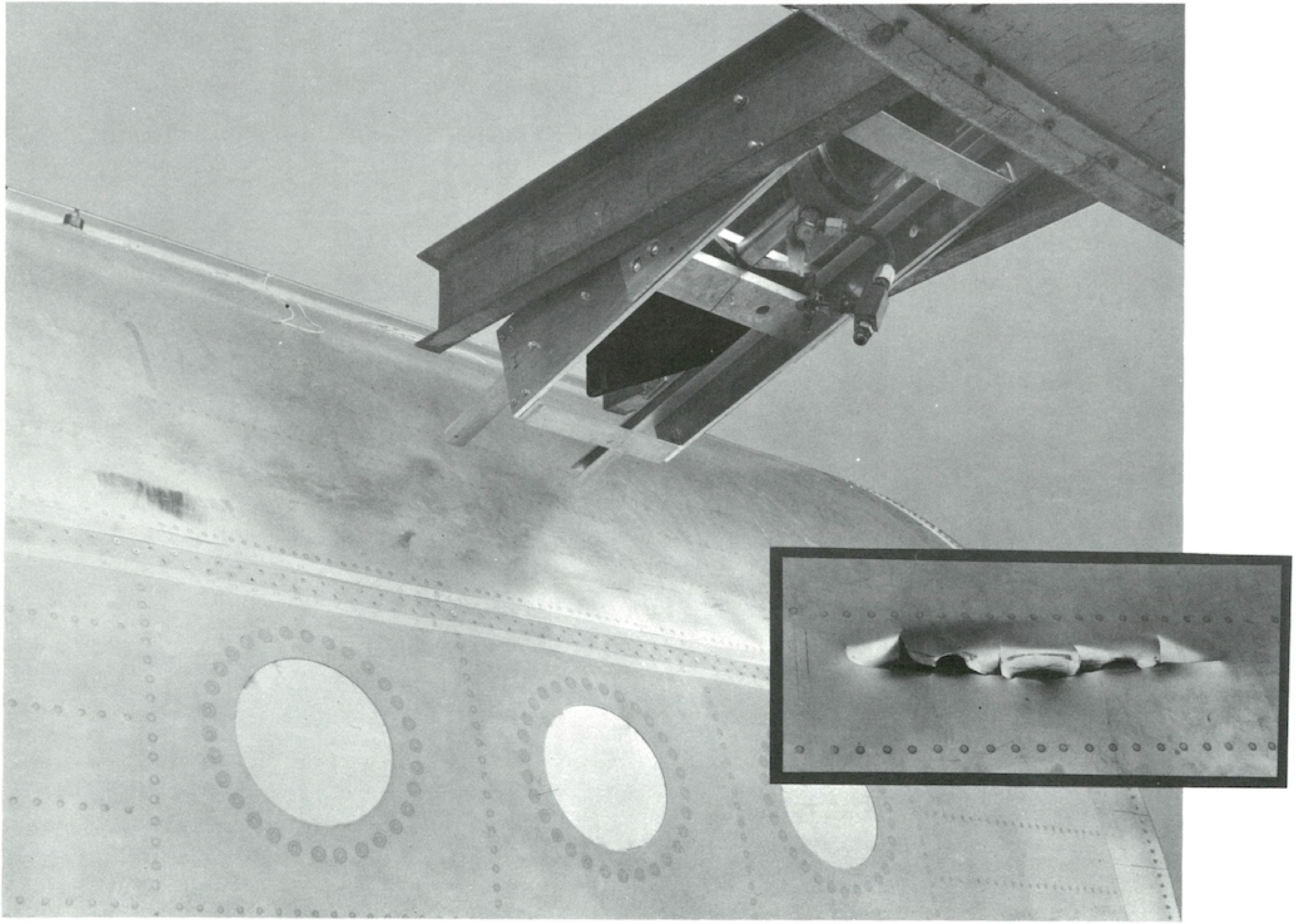


Guillotine Tests

The photograph shows the knife test in which we subjected the body to a pressure of 12 psi and then shot a 12 inch wide knife blade into the pressure body section. Although the body skin was only .032, the cut was limited to a total length which is only slightly greater than the width of the knife blade. A second test was conducted in which the knife blade cut through a body stiffener and the same results were obtained. This shows that if the body were subjected to in-flight impingement of some foreign object that catastrophic failure would not occur.

CE 6678

GUILLOTINE TEST

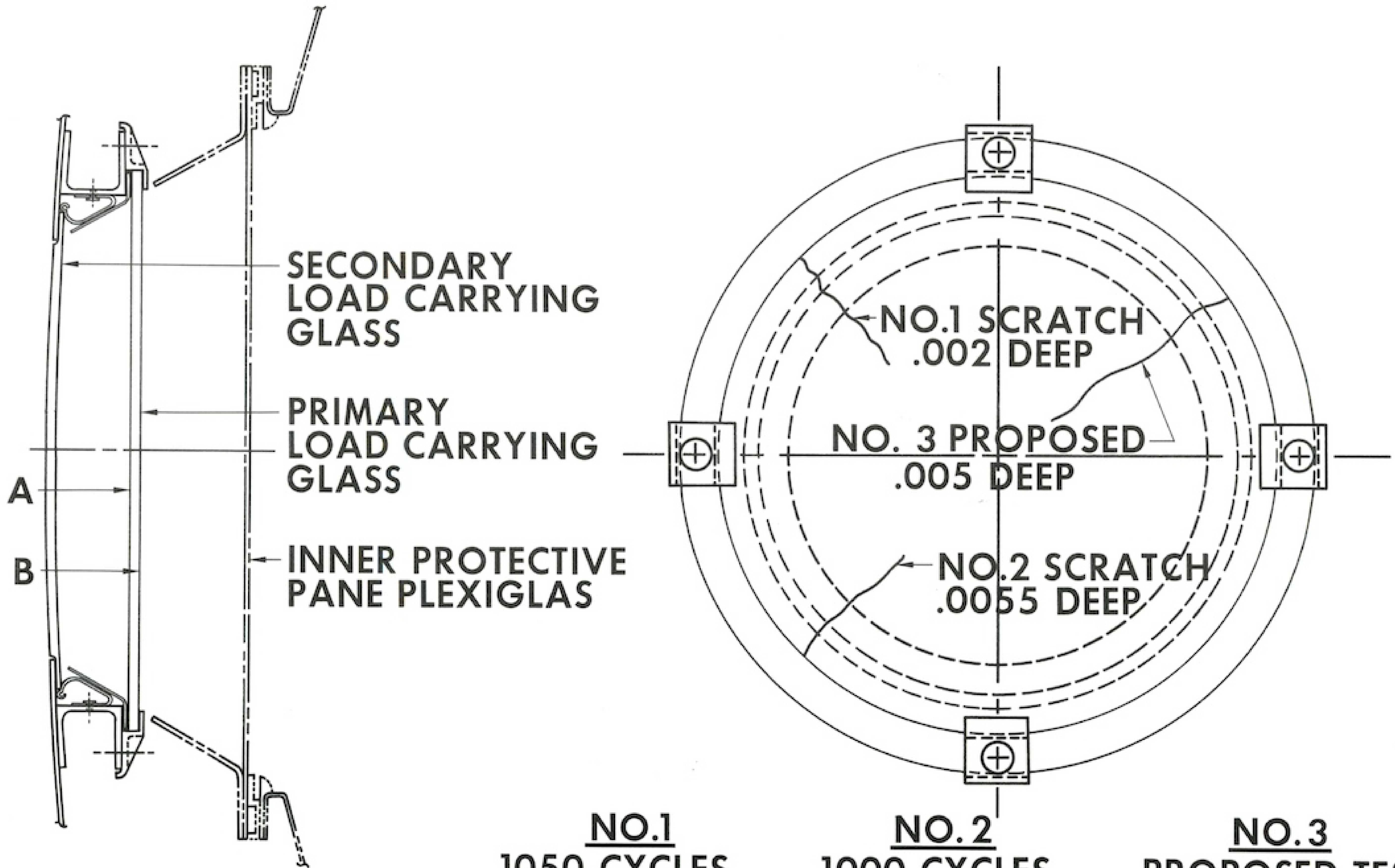


Passenger Window Scratch Test

The window design consists of an inner protective pane of plexiglass, a center pane of load carrying glass, and an outer load carrying pane of glass. A window installation consisting of the outer two load carrying panes was subjected to 36 psi, which is three times the maximum pressure we anticipate, with no failure. The inner primary load carrying pane was struck with a sharp point while the window installation was subjected to 12 psi and the pressure was transmitted to the outer pane and it carried the pressure. A new window was installed on the inner primary load carrying pane and was subjected to a scratch .002 deep and subjected to 1050 cycles with no indication of scratch growth. A second scratch was applied to the window that was .0055 deep and the window was subjected to 1000 cycles of 12 psi pressure with no increase in scratch length. This demonstrates that our window design has excellent damage resistance.

The proposed test No. 3 has been accomplished whereby a third scratch .005 inches deep was applied to the outer face and the window was subjected to 1000 cycles at 12 psi pressure with no failure. The pressure was then increased to three times the cabin pressure (36 psi) at which time window failure occurred.

PASSENGER WINDOW SCRATCH TEST



NO.1
1050 CYCLES
+1000 CYCLES
SURFACE (B)

NO. 2
1000 CYCLES
SURFACE (B)

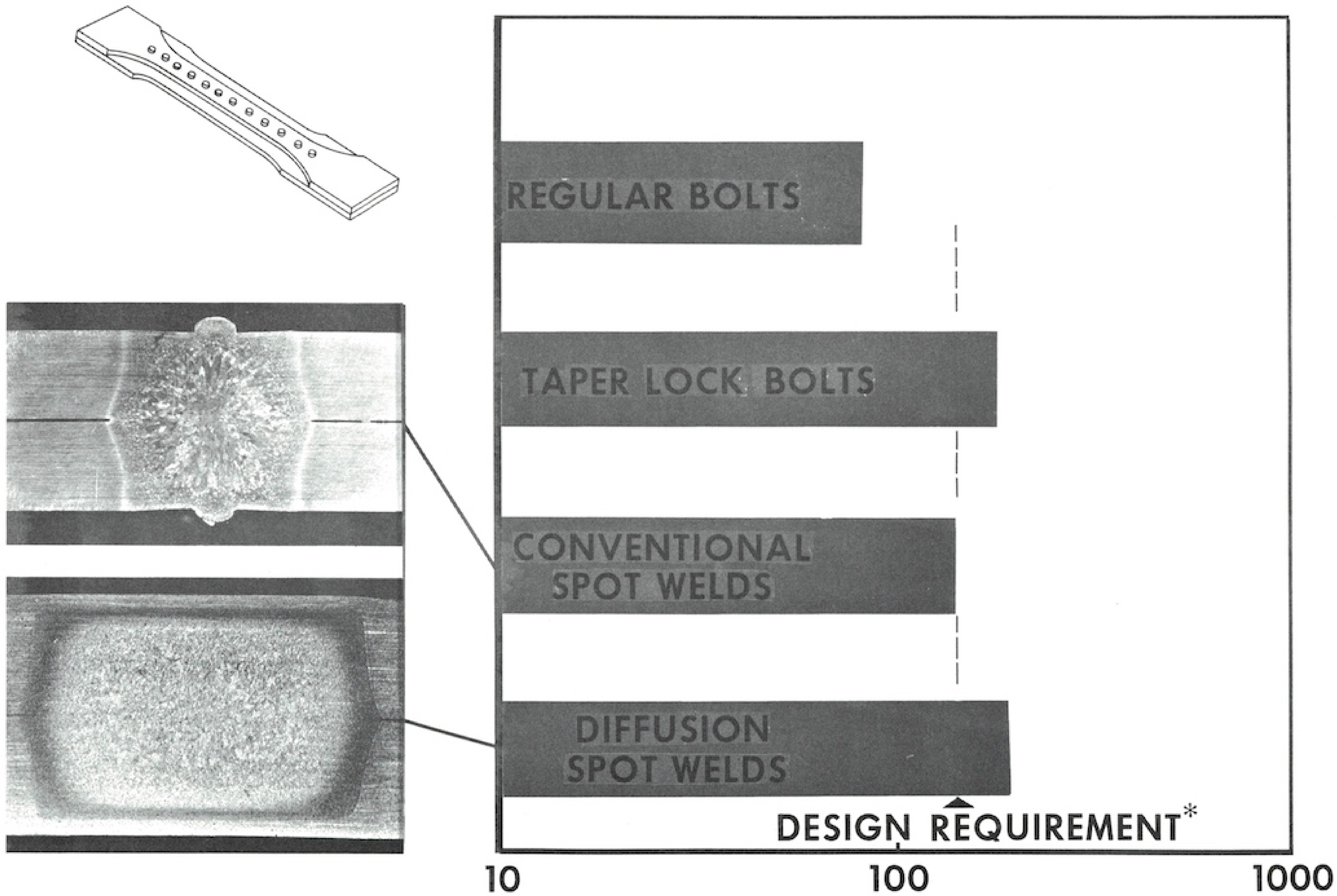
NO. 3
PROPOSED TEST
SURFACE (A)

CE6672 3-65

Fatigue Performance

We are performing an extensive amount of testing on various joining methods to obtain the desired fatigue performance by the most economical method. This chart shows that regular bolts do not meet our design requirements, conventional spotwelds meet our design requirements, and taper lock bolts and diffusion spotwelds exceed our requirements from a fatigue standpoint. We are also performing extensive tests on various methods of riveting. It should be noted that the design requirement is two times the airplane fatigue life. This is done to obtain high structural integrity in design.

FATIGUE PERFORMANCE
JOINING METHODS



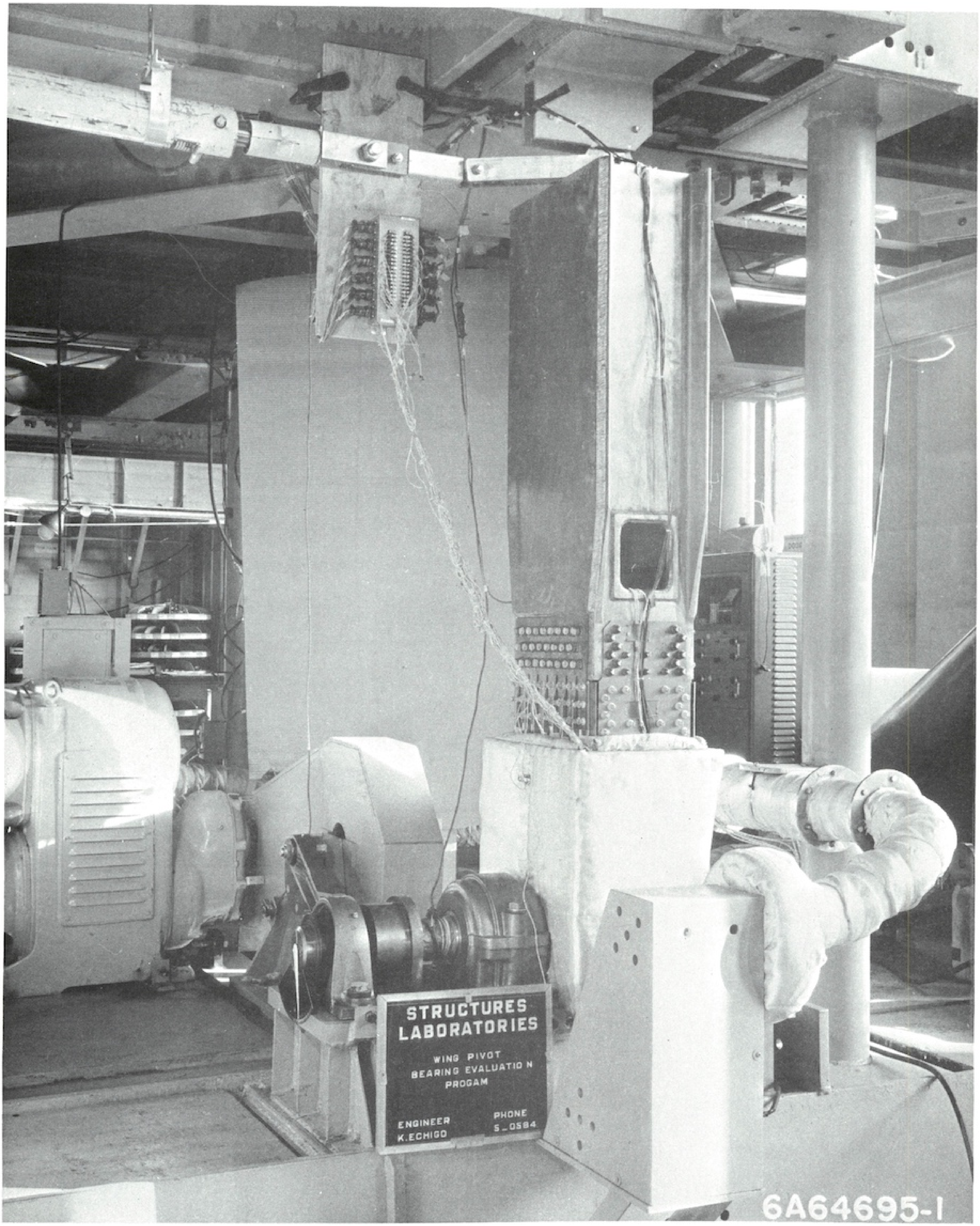
STRUCTURAL LIFE - 1000 CYCLES

* 2 TIMES AIRPLANE FATIGUE LIFE

Quarter Size Bearing Test

In this test we duplicate the typical loading that will occur on the main pivot bearings. The teflon bearing was subjected to 215,000 cycles at 300°F before failure which is more than the life of the airplane.

6A64695-1


STRUCTURES LABORATORIES
WING PIVOT BEARING EVALUATIO N PROGAM
ENGINEER K.ECHIGO
PHONE 5_0584
6A64695-1

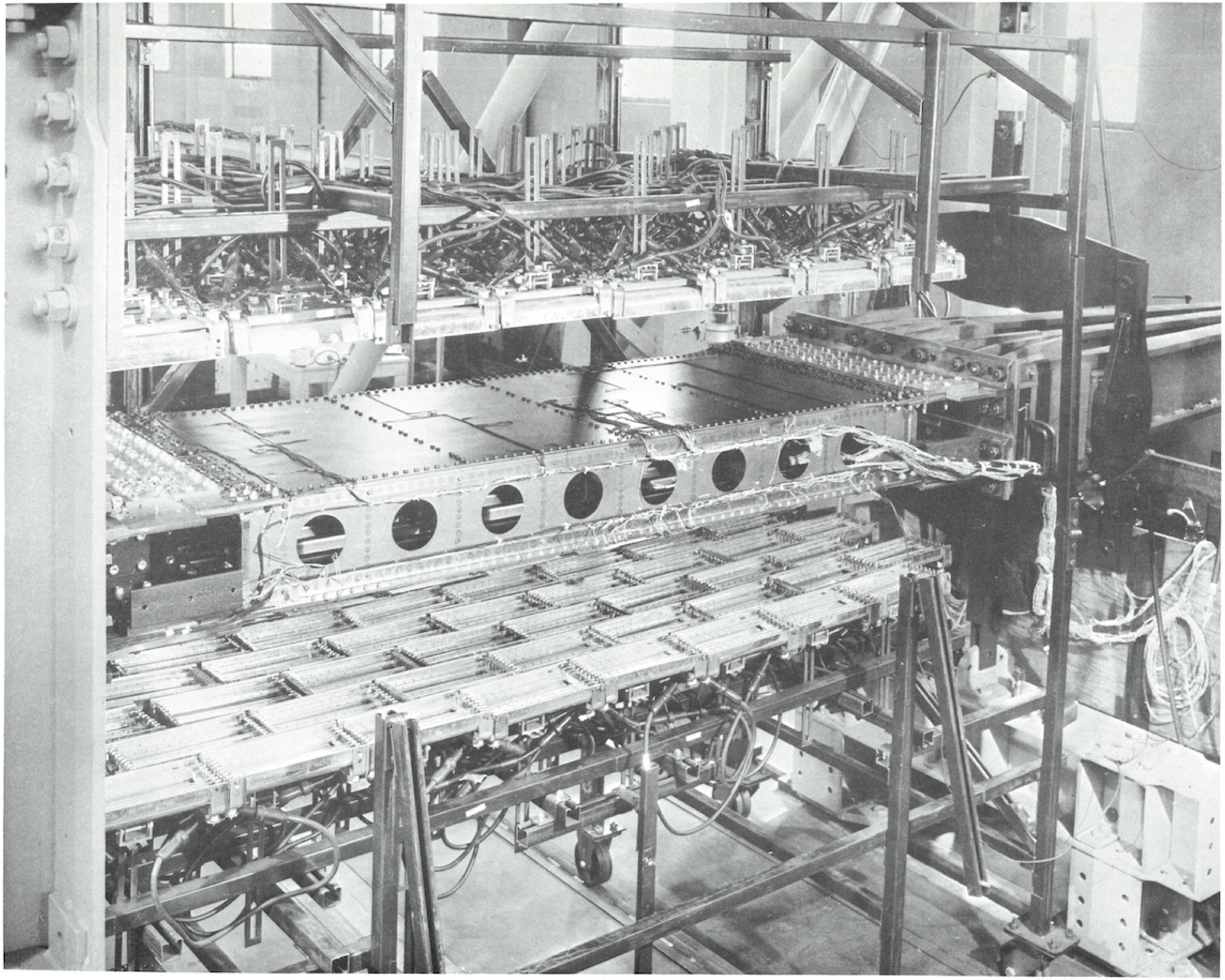
Full Size Wing Pivot Test

The full size wing pivot bearing is being tested at temperatures of -40°F, at room temperature, and 200°F. During actuation, the bearing receives a load that varies from 900,000 pounds to 1,800,000 pounds. Every 10,000 cycles the bearing receives a static load of 3,600,000 pounds. This test should demonstrate that the bearing will be satisfactory for the life of the airplane.

FULL-SIZE WING PIVOT TEST

Thermal Box Test

The structure is typical construction for the empennage area or the outer part of the wing and is subjected to an elevated temperature of 500°F while receiving a bending load. This test will provide information on the distribution of stresses under high temperature and load conditions, also panel deflection under these conditions will be determined.

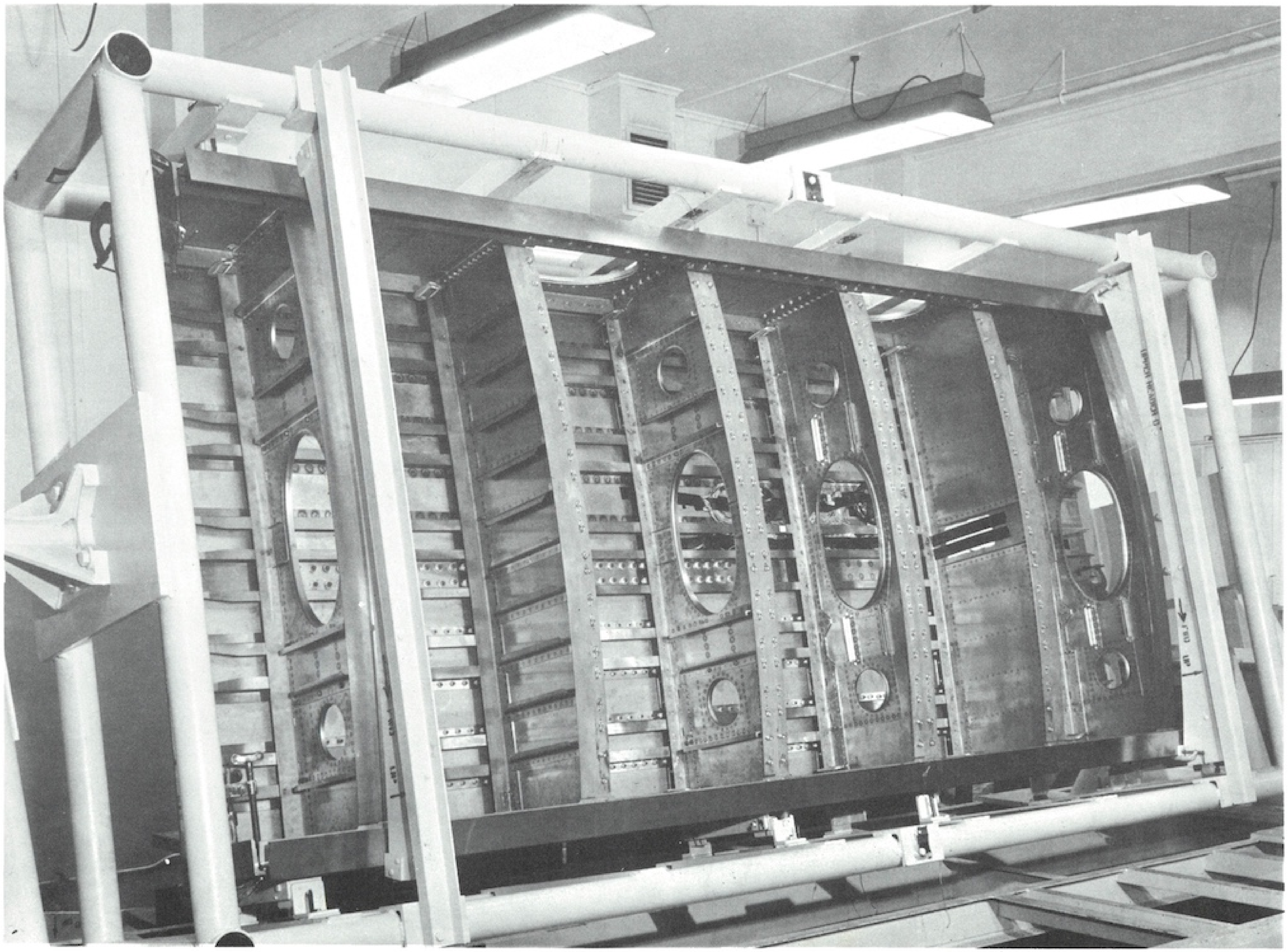


Wing Box Test Structure

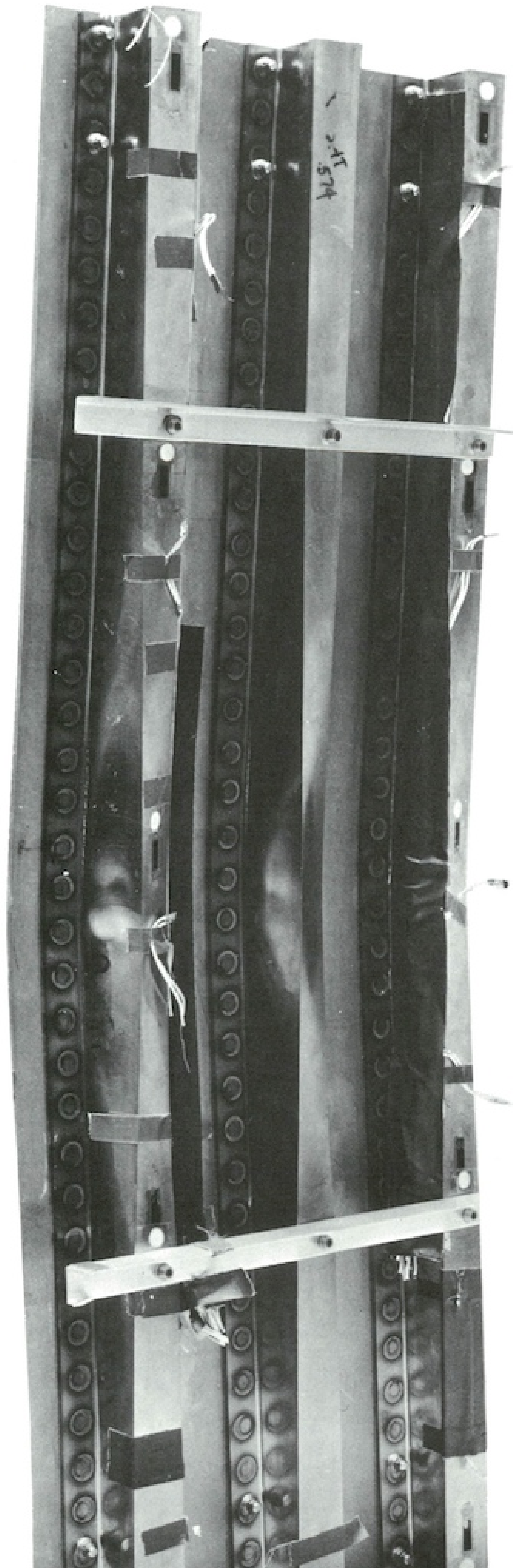
An interior view is shown of our wing box structure. This duplicates the type of structure that would be used in the main wing box and will be tested at room and elevated temperatures duplicating typical wing bending loads.

CE-6447

12 FT. WING BOX SECTION



CE6447 1-65



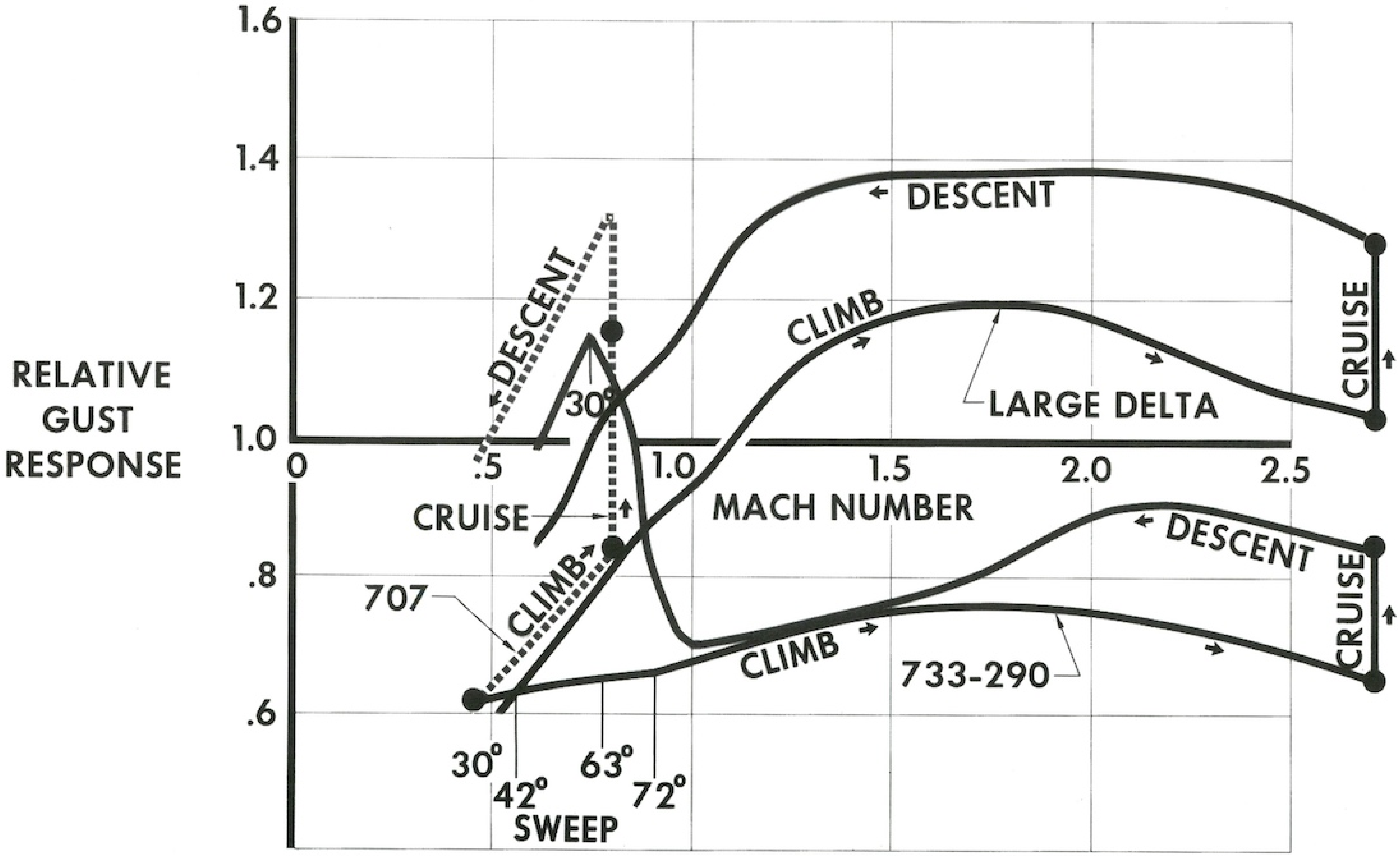
6A65410-1

Gust Load Factor Comparison

This chart provides a comparison of the response of three airplane configurations to a gust of the same magnitude. The response of the 707 is shown as a dotted line and is approximately .6 at takeoff, increases during climb to approximately .85, and then increases during cruise as the airplane becomes lighter. The average during the cruise condition for the 707 will be a relative gust response of 1.0. The 733-290 which is the lower line, starts out with an airplane response of approximately .6. This varies slightly during climb and then increases during cruise condition; however, the average for the cruise condition is a response of .75. In comparison with the 707, the swept wing airplane will have an effective response of 75% of the response of the 707 airplane. Thus, the swept wing airplane will provide a much smoother ride and have less cyclic fatigue damage in the cruise condition than the 707 airplane.

The upper solid line shows a large delta wing airplane response to a given gust. In this case the response is approximately .6 in the takeoff condition and increases during climb with increasing Mach number. During the cruise condition the airplane response is approximately 1.15. A large delta wing would therefore provide a ride that is 15% rougher than the 707 and approximately 50% rougher than the swept wing airplane. These values are for the same gust intensity and do not account for the reduction in equivalent gust velocity that is attained at the higher altitudes of the supersonic airplanes. This reduction in gust intensity is shown on the following chart.

GUST LOAD FACTOR COMPARISON



CE6677 3-65

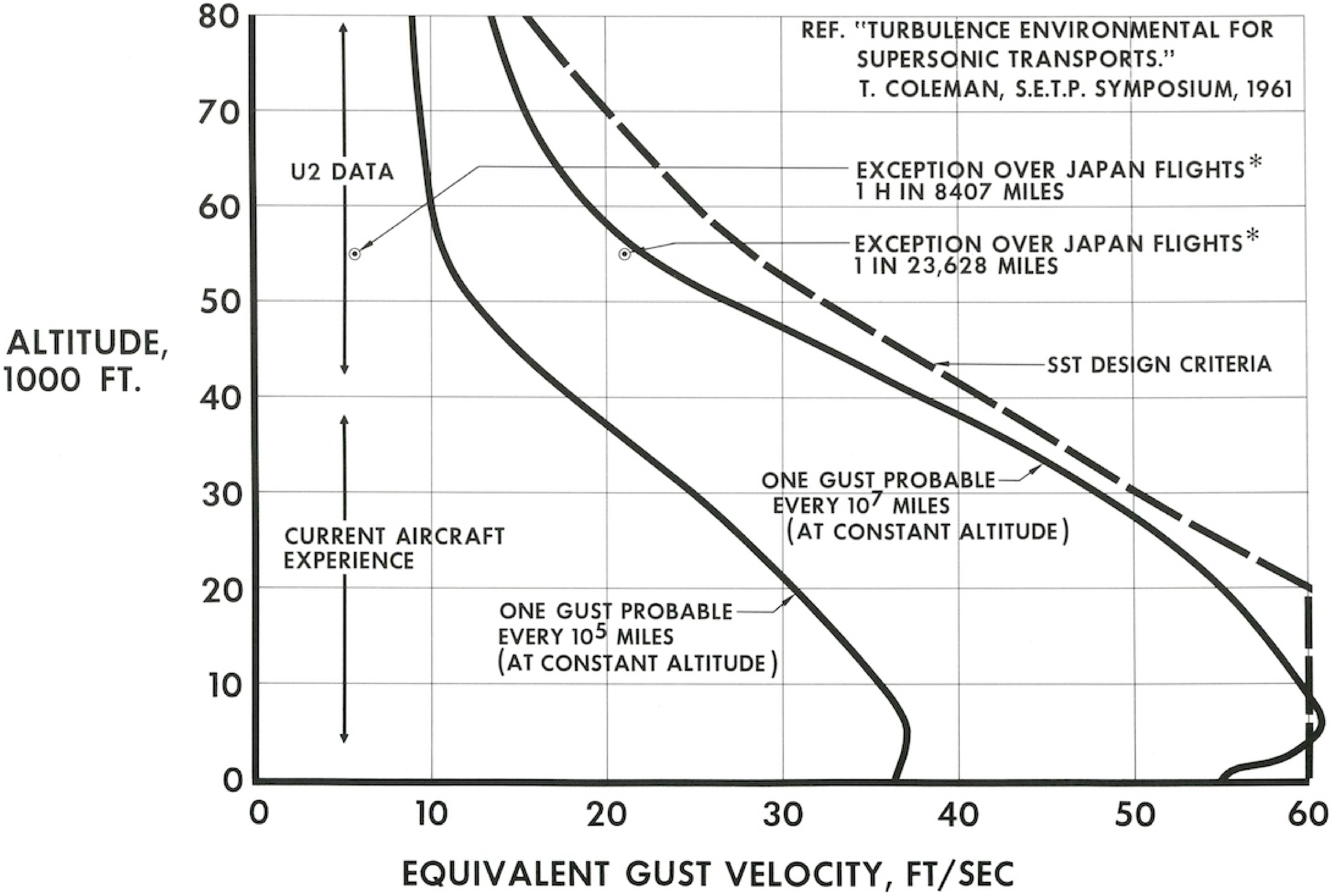
Gust Intensity

The equivalent gust velocity has been plotted for various altitudes. The high altitude information is based on U-2 flight data. This curve shows that the gust velocity is substantially reduced at the higher altitudes which represent the cruise condition for the supersonic airplanes.

Structural Testing Summary

In summary, we are performing an extensive amount of testing to assure that we will have a high degree of fail-safety and that the structure will provide satisfactory performance for the life of the airplane.

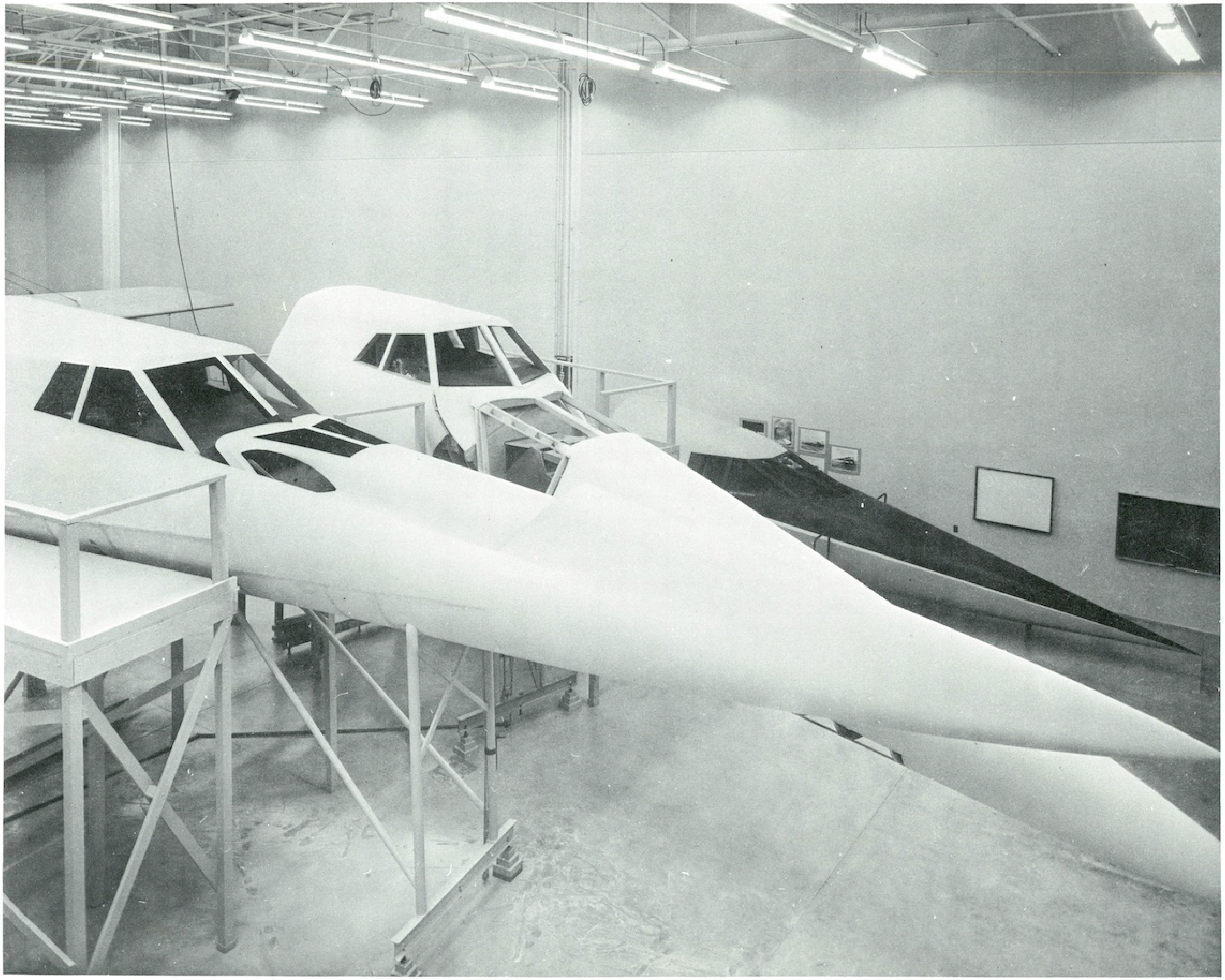
GUST INTENSITY



*(REF NASA TN D 548)

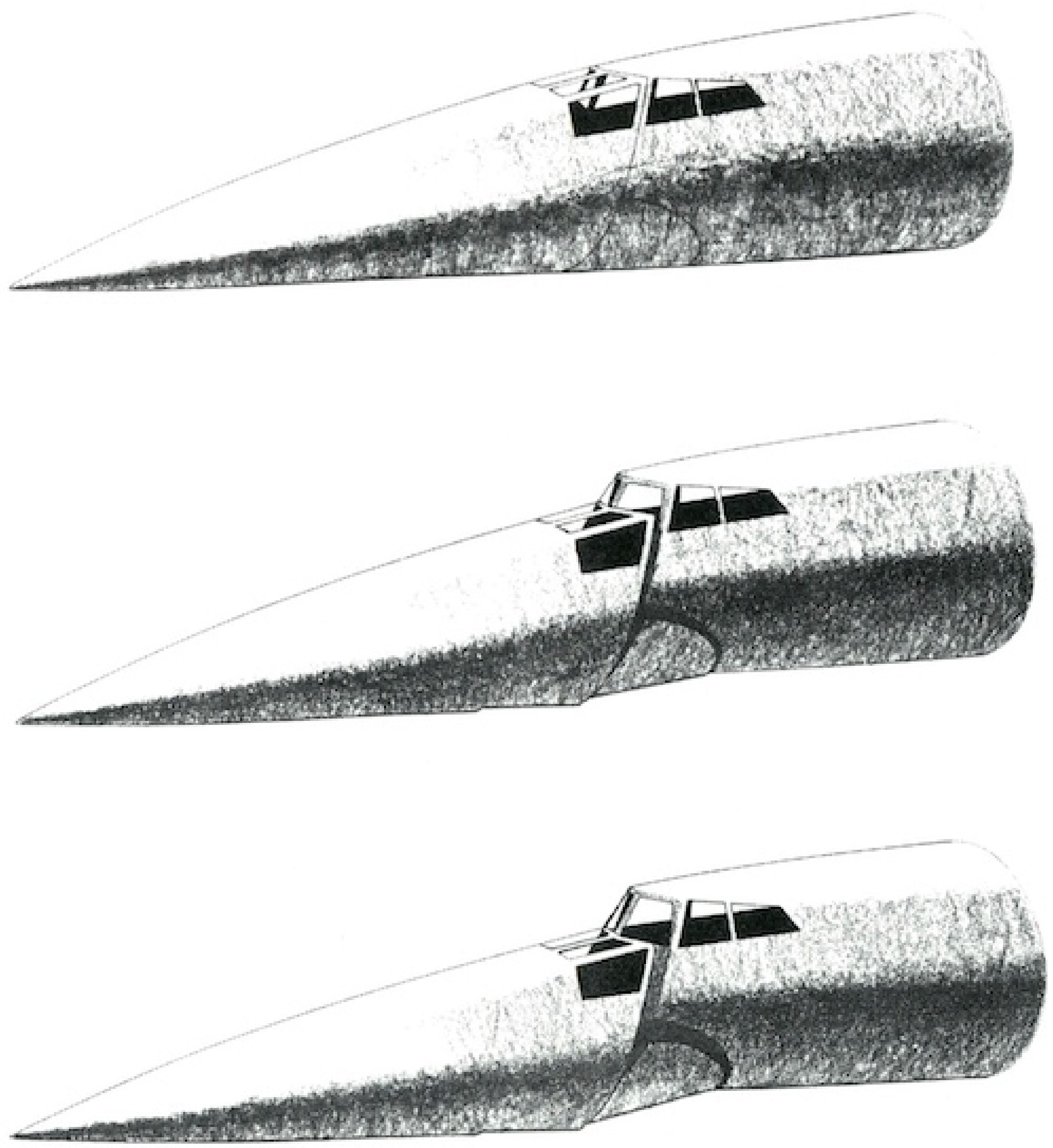
The photo shows the various airplane nose configurations that are being evaluated.

6A65147-5



NOSE CONFIGURATIONS

TRANSLATING (6 TO 1 OGIVE)



WINDSHIELD VISOR (MODIFIED OGIVE)