EFFECTS OF INLET TECHNOLOGY
ON CRUISE SPEED SELECTION

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SUMMARY

Recent Lockheed studies of supersonic cruise research (SCR) aircraft have studied the impact of cruise speed on technology level for certain aircraft components. In the present study, external-compression inlets were compared with mixed-compression, self-starting inlets at cruise Mach numbers of 2.0 and 2.3. Inlet-engine combinations that provided the greatest aircraft range were identified. Results showed that increased transonic-to-cruise corrected air flow ratio gave decreased range for missions dominated by supersonic cruise. It was also found important that inlets be designed to minimize spillage drag at subsonic cruise, because of the need for efficient performance for overland operations. The external-compression inlet emerged as the probable first choice at Mach 2.0, while the self-starting inlet was the probable first choice at Mach 2.3. Airframe-propulsion system interference effects were significant, and further study is needed to assess the existing design methods and to develop improvements.

INTRODUCTION

Supersonic cruise research (SCR) studies at the Lockheed-California Company have recently been directed toward aircraft designed for different supersonic cruise Mach numbers. The general purpose of this effort was to assess where a change in supersonic cruise speed imposed a change in technology level for certain components of the aircraft. Through 1978, Lockheed studies concentrated on aircraft with a supersonic cruise speed of Mach 2.55. During 1979, these studies were expanded to include Mach 2.0 and Mach 2.3 cruise aircraft.

Mach 2.0 was approximately the lowest speed of interest in the Lockheed studies. At this speed, external-compression inlets were expected to be competitive with mixed-compression types. By contrast, cruise at Mach 2.55 clearly required mixed-compression inlets. Studies at Mach 2.3 were undertaken to define more clearly a crossover Mach number at which the advantage would swing to a higher-technology, mixed-compression inlet.

The main objectives of the present study are:

- Identify inlet-engine combinations that provide maximum range at Mach 2.0 and 2.3

- Evaluate effect of transonic-to-cruise corrected air flow ratio on aircraft range

- Obtain quantitative performance comparisons on the effect of internal contraction at Mach 2.0 and 2.3

Inlet performance cannot be optimized in isolation from engine performance. Thus, it was desired to identify those inlet-engine combinations that provided the greatest aircraft range. This in turn allowed those inlets which were leading candidates for further development to be identified.

An issue that arose from past studies was the desirability of engines with relatively large transonic air flow capacity. Because of the importance of transonic-to-cruise corrected air flow ratio on inlet design, it was desired to evaluate the influence of this parameter on aircraft range.

The completed study configurations are indicated by checks in figure 1. The mixed-compression inlets studied at Mach 2.0 and 2.3 were limited to self-starting types. Such inlets can be restarted without any change in inlet geometry, and so have potentially fewer unstart problems than inlets requiring variable geometry for restart. They also have potentially higher total pressure recovery and lower cowl drag than external-compression inlets. The present paper concentrates on using results for two-dimensional inlets to demonstrate effects of internal contraction and of corrected air-flow ratio on aircraft performance. A parallel effort is underway for the axisymmetric inlet types indicated in figure 1. These axisymmetric inlets have potentially lower drag and lower weight than the two-dimensional inlets in the podded nacelle configuration of the Lockheed SCR aircraft. The results of the axisymmetric inlet studies will be reported at a later date.

At Mach 2.55, both translating centerbody (TCB) and collapsing centerbody (CCB) inlets were analyzed, and the results were reported in reference 1. Both of these inlets were axisymmetric, with mixed compression and variable geometry for restart. Advantages of the CCB inlet were low bleed and low internal contraction, plus greater possible throat area variation. Its disadvantages were higher weight and greater complexity. The CCB inlet was preferred, but with reservations about its complexity.

The two-dimensional, self-starting inlet design at Mach 2.55 is described in reference 2. This design was based on that of the Lockheed supersonic transport of 1966.

Figure 2 summarizes the principal factors that influence the choice of transonic-to-cruise corrected air flow ratio. These factors point toward lower corrected air flow ratios for missions dominated by supersonic cruise.

Takeoff noise requirements may limit reductions in corrected air flow ratio, however. To obtain quantitative results, inlets at Mach 2.0 and 2.55 were combined with engines having different transonic-to-cruise air flow ratios. It was not considered necessary to repeat this study at Mach 2.3. Thus, the Mach 2.3 studies were mainly concerned with comparing inlet types for a given engine.

STUDY CONFIGURATIONS

The Mach 2.0 and Mach 2.3 aircraft used in this study are shown in figures 3 and 4, respectively. These aircraft are derivatives of the Lockheed baseline Mach 2.55 aircraft, which has takeoff gross weight of 268,527 kg (592,000 lb), 290 passengers, wing loading of 4213 N/m^2 (88 psf), leading-edge sweep angles 73/70/58 degrees, and aspect ratio 1.72 (ref. 1). The Mach 2.0 and 2.3 aircraft have the same takeoff gross weight and number of passengers as the Mach 2.55 aircraft. For the Mach 2.0 aircraft, the wing loading is 4357 N/m^2 (91 psf), the leading-edge sweep angles are 68/66/53 degrees, and the aspect ratio is 2.1. The Mach 2.3 aircraft has wing loading 4070 N/m^2 (85 psf), leading-edge sweep angles 71/67/55 degrees, and aspect ratio 1.95. The optimum wing loading and takeoff thrust-to-weight ratio for each aircraft were determined from the Lockheed ASSET (Advanced Systems Synthesis and Evaluation Technique) code results.

Figure 5 shows an isometric view of the Mach 2.0, two-dimensional, external-compression inlet (2.0/2D/EX) in the overwing/underwing configuration. (The wing is not shown.) The installation shown in the figure is on the left-hand side of the aircraft. The overwing inlet has part of the cowl cut away. The centerbody is in the cruise (expanded) position. Other features shown are the centerbody bleed slot and the bypass (nearer engine face) and auxiliary inlet doors. The underwing inlet has a toe-in, and the overwing inlet a toe-out, to align the inlets with the wing-induced flow direction. A similar isometric view of the Mach 2.0, two-dimensional, self-starting inlet is shown in figure 6. The shallower ramp and cowl angles are evident, compared with the 2.0/2D/EX inlet.

Each of the Mach 2.0 inlet types was matched with two or more engines, to assess the influence of transonic-to-cruise corrected air flow ratio on aircraft range. Certain modifications to each inlet type were required to match engine air flow requirements, while simultaneously maximizing total pressure recovery and minimizing drag. This is illustrated in figure 7, which shows the 2.0/2D/EX inlet contours when matched to the GE21/J11 B21 and the GE21/J11 B13 engines. The 2.0/2D/EX inlets have external compression provided by an initial wedge shock, followed by isentropic compression to a maximum ramp angle, and terminated by a strong-solution oblique shock from the cowl lip. The cowl-lip shock intersects the forward edge of the bleed slot. The most obvious differences between the inlets were in the length and the engine face diameter. These were both due to the larger front fan diameter of the -B13 engine, which has a larger transonic-to-cruise corrected air flow ratio (table 1 summarizes some of the principal characteristics of the Mach 2.0 and 2.3 study engines). The larger engine diameter generally required greater inlet length, because of limitations on subsonic diffuser divergence angle.

There are significant differences in inlet local Mach number overwing and underwing. At a freestream Mach number of 2.0, the overwing local Mach number is 2.16, while the underwing value is 1.97. The design procedure followed here was to design the inlet for the overwing local Mach number. The underwing inlet was then operated off-design at cruise, but with only a small critical spillage drag penalty. The inlets were sized to provide the same corrected air flow rate at cruise; thus, the underwing capture area was smaller than the overwing value. For inlet started (self-starting type) or cowl-lip shock attached (external-compression type), ramp position depended only on local Mach number. At lower Mach numbers, the overwing and underwing ramp angles were scheduled separately with local Mach number and required engine air flow, to minimize spillage drag.

Figure 8 shows the contours of the 2.0/2D/SS inlets matched to the GE21/J11 B21 and the GE21/J11 B13 engines. For the 2.0/2D/SS inlets, external compression was provided by an initial wedge shock, followed by isentropic compression and a second ramp oblique shock. Internal compression was achieved by the cowl-lip shock, followed by isentropic cowl compression between the cowl lip and the throat, and terminated by a normal shock. The amount of internal contraction was limited by the requirement for self-starting. The allowable internal contraction was determined from existing experimental data, and was 42 percent for these designs. As in figure 7, the main differences between the two self-starting inlets were in length and in engine face diameter. These led to differences in weight and wave drag, as will be shown later.

Figure 9 illustrates the contours of the 2.3/2D/EX and the 2.3/2D/SS inlets that were matched to the GE21/J11 B19 engine. These inlets were designed according to the same criteria as their Mach 2.0 counterparts. At a freestream Mach number of 2.3, the overwing local Mach number is 2.48, and the underwing local Mach number is 2.26. The characteristic differences between these two inlet types are evident. The external-compression inlet was shorter by 24 cm, and thus had lower weight and lower bleed drag. The self-starting inlet had more gradual compression, hence higher total pressure recovery; and had a smaller cowl angle, giving lower wave drag. Its internal contraction was 35 percent. Each of the designs shown in figures 7 through 9 resulted from trade studies at supersonic cruise speed. Sensitivity factors for the effect of total pressure recovery, drag, and weight on aircraft range were used to select the inlet contours.

RESULTS

Inlet weight is affected by inlet type and by transonic-to-cruise corrected air flow ratio. Figure 10 shows results from some recent Lockheed studies. Here the average inlet weight was nondimensionalized by the ambient pressure at cruise altitude and by the average capture area. These altitudes were about 16 km at Mach 2.0, 17 km at Mach 2.3, and 18 km at Mach 2.55.

The weights of the 2.0/2D/EX and the 2.0/2D/SS inlets are nearly the same for the GE21/J11B21 engine. The 2.0/2D/EX inlet could have been shorter based on aerodynamic criteria, but had to be lengthened to accommodate auxiliary inlet doors. The inlets matched to the GE21/J11B13 are heavier mainly because of their longer subsonic diffusers (figures 7 and 8). At Mach 2.3, the self-starting inlets were heavier by about 360 kg (800 lb) overall because of the difference in length (figure 9).

The details of the Mach 2.55 studies were reported in reference 1. The collapsing centerbody inlets (CCB) for the GE21/J11B11 were about 1100 kg (2400 lb) heavier overall than the translating centerbody inlets, because of the added mechanism required for the CCB inlet. The CCB inlets with the GE21/J11B20 engine were longer than their counterparts for the -B11 engine, because of the increased engine face diameter. This resulted in an overall weight difference of about 800 kg (1800 lb) between these CCB inlets.

Table 2 presents total pressure recovery and bleed drag at supersonic cruise conditions for the Mach 2.0 and Mach 2.3 inlets. The self-starting inlets showed higher total pressure recovery, as expected, because some internal compression allows lower shock losses for a given cowl angle than does all-external compression. The 2.0/2D/SS inlet with the GE21/J11B13 engine showed higher pressure recovery than with the GE21/J11B21 engine for two reasons: (1) a higher cowl angle, required to match the maximum engine air flow rate, allowed more efficient supersonic compression with a weaker cowl lip shock; (2) the longer subsonic diffuser was more efficient. It may be noted that the self-starting inlet with the GE21/J11B21 engine was optimized at lower pressure recovery by a trade with cowl drag.

Figure 11 shows the bleed flow correlation presented by Bowditch in reference 3. Some data points have been added for Mach 2.2, two-dimensional inlets, plus other labeled points. The NASA-Lewis bicone-type inlets (ref. 4; circles, lower line) do not correlate well with the other data. These bicone-type inlets would probably have to be operated with a stability bleed system, however.

In the present studies the performance of a number of inlets was being compared. It was therefore necessary to account for differences in wetted area and local Mach number in a consistent manner. The upper line was used to estimate bleed flow requirements, although it may be conservative.

Bleed drag coefficient, referenced to wing area, is given in table 2. The principal differences were between the external-compression and the self-starting inlets. These resulted from the differences in wetted area in the supersonic diffusers of these inlets.

The differences in spillage drag at off-design conditions for the various inlet-engine combinations emerged as one of the more significant factors affecting aircraft range. These differences are illustrated in figure 12 for the Mach 2.0 study cases. The conditions correspond to the local Mach number and engine air flow along the SCR climb profile. Results are shown for the overwing inlets only, which had greater spillage and bypass drag than the underwing inlets. This is because the underwing inlet was able to supply the maximum engine air flow, and had a smaller capture area.

For the external-compression inlets, excess inlet air flow was bypassed if the strong-oblique, cowl-lip shock was attached, and was spilled if this shock was detached. The local Mach number at which detachment occurs is about 1.65. For the mixed-compression inlets, excess inlet air flow was bypassed if the inlet was started, and spilled if it was unstarted. The local Mach number for unstart is also about 1.65.

The study revealed that these external-compression inlets could be operated with no subcritical spillage, and the bypass amounts were very small. Thus, nearly all of the drag was due to critical spillage. As expected, the spillage drag correlated inversely with $(W\sqrt{\theta}/\delta)_{Ml}/(W\sqrt{\theta}/\delta)_{CRUISE}$. The engine with the higher relative transonic air flow, the GE21/J11B13, led to the lower spillage drag.

At local Mach numbers below 1.65, the self-starting inlets had some subcritical spillage because they still had some internal contraction. This caused the high spillage drag relative to the 2.0/2D/EX inlets, as shown in figure 12. Again, the relative spillage drag of the 2.0/2D/SS inlets correlated inversely with $(W\sqrt{\theta}/\delta)_{Ml}/(W\sqrt{\theta}/\delta)_{CRUISE}$.

The remaining internal contraction in the self-starting inlets, when below the unstart Mach number, could be removed by a design modification. For example, another hinge could be provided on the forward ramp, plus suitable actuation. This would involve some weight penalty, but would probably be desirable if the spillage drag could be reduced to the level of the external-compression inlets. This will be further illustrated later by the results of the aircraft mission analyses.

The Mach 2.3 studies showed the same trends of spillage and bypass drag as for Mach 2.0. Again, the self-starting inlet had high subcritical spillage drag because of internal contraction at unstarted conditions.

Wave drag comparisons for the Mach 2.0 study cases are shown in figure 13. The figure shows wave drag coefficient for all four nacelles, referenced to wing area. For a given engine, the external-compression inlets have higher wave drag, as expected, because of their larger external flow turning. For a given inlet type, the wave drag increases as $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$ increases. This follows from the general need for higher cowl angles to match the larger engine diameter.

The results in figure 13 are for the isolated nacelles, as computed by the near-field wave drag method of reference 5. The far-field wave drag method of reference 5 was used to obtain complete aircraft wave drag for the 2.0/2D/EX - GE21/J11B13 installation. The near-field method was used to compute wave and interference drag for each nacelle configuration. The increments in these near-field values from the 2.0/2D/EX - GE21/J11B13 case were used to arrive at complete aircraft wave drag for the remaining cases. Friction drag was also computed by the methods of reference 5.

The same procedure was followed to establish wave drag for the Mach 2.3 study cases. The isolated nacelle results, comparing the 2.3/2D/EX and 2.3/2D/SS inlets with the GE21/J11B19 engine were similar to those shown in figure 13.

There is some uncertainty about the accuracy of the wave drag results, because the design methods are based on modifications to linearized theory and on superposition of solutions. The greater the shock strengths and turning angles for a nacelle installation, the greater the expected error. A related example was reported in reference 6, in which the cowl drag of an external-compression inlet was underestimated by using linearized theories. By contrast, the same linearized theories agreed with the method of characteristics in predicting the wave drag of a mixed-compression inlet, which had a smaller external cowl angle. This example suggests that the wave drag of the external-compression inlets studied here may also have been underestimated, relative to the self-starting inlets.

Aircraft performance was evaluated for each of the study cases. The mission profile is illustrated in figure 14. Subsonic cruise segments considered were zero (all-supersonic cruise), 1111 km (600 n. mi.), and 2778 km (1500 n. mi.). These subsonic cruise segments were divided into two equal parts, occurring before and after the supersonic cruise segment.

In figure 15, results of mission analyses are used to illustrate the effect of transonic-to-cruise corrected air flow ratio on aircraft range. The 2.0/2D/EX inlets had nearly the same installed SFC at supersonic cruise (table 3). The case with the GE21/J11B21 engine had lower wave drag and lower weight, however, leading to greater range. The same circumstances applied for the 2.0/2D/SS inlets, and the bicone-type, CCB inlets at Mach 2.55. Thus, for engines of the same family, increased $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$ yields reduced range. The responsible factors seem to be the higher wave drag, and higher weight that accompany higher transonic-to-cruise corrected air flow ratios.

Further reductions in corrected air flow ratio are now being explored. This will indicate whether range goes through a maximum with respect to corrected air flow ratio, and the nature of the controlling factors. Takeoff noise requirements may also limit reductions in corrected air flow ratio.

The effects of subsonic cruise distance on aircraft range were also explored. It is desirable for a supersonic transport aircraft to have efficient subsonic cruise capability, to enhance its usefulness for both overwater and overland operations. Any effects of inlet type on aircraft range for mixed supersonic and subsonic cruise are then potentially important.

Figure 16 shows total range as a function of subsonic cruise distance for the Mach 2.0 aircraft study cases. The aircraft with 2.0/2D/EX inlets showed small increases in range as subsonic cruise distance increased. This trend was a result of the relative values of $(M_0/SFC)(L/D)$ for supersonic and subsonic cruise. Average values of SFC and L/D are given in table 3. In contrast, the aircraft with the 2.0/2D/SS inlets showed a small decrease in range as subsonic cruise distance increased. From table 3 it is apparent that $(M_0/SFC)(L/D)$ for the 2.0/2D/SS inlets is slightly higher at supersonic cruise, and substantially lower at subsonic cruise, compared with the 2.0/2D/EX inlet cases. The subcritical spillage of the 2.0/2D/SS inlets, which was responsible for the higher subsonic SFCs, explains this behavior. As suggested earlier, this subcritical spillage could be eliminated by modifying the self-starting inlet to have no internal contraction at subsonic cruise. This would add weight, but would produce a more favorable variation of total range with subsonic cruise distance.

Mission results for the Mach 2.3 aircraft cases are shown in figure 17. Again, the behavior is due to the relative values of M_0/SFC at supersonic and subsonic cruise. For the aircraft with the 2.3/2D/EX inlet, the large relative improvement in M_0/SFC at subsonic cruise produced increases in range as subsonic cruise distance increased. For the aircraft with the 2.3/2D/SS inlets, the subcritical spillage greatly increased subsonic cruise SFC. The resulting unfavorable effect on subsonic M_0/SFC yielded a significant decrease in range as subsonic cruise distance increased. As for the Mach 2.0 cases, modification of the 2.3/2D/SS inlet to eliminate subcritical spillage at Mach 0.9 would greatly improve this situation.

These considerations of subsonic cruise distance indicate the importance of inlet performance at subsonic cruise conditions. In particular, it is important that inlets be designed to minimize spillage drag at subsonic cruise. In this connection, figure 16 also reveals that differences due to $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$ became smaller as subsonic cruise distance increased. This resulted from the lower spillage drag associated with higher $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$. Again, the importance of accurate estimation of spillage effects on nacelle-airframe interference should be noted.

The factors influencing the choice of 2.0/2D/EX inlets or 2.0/2D/SS inlets can now be summarized. The external-compression and self-starting inlets had nearly the same supersonic cruise SFC. The self-starting inlets were heavier because of their greater length. The small range advantage of the self-starting inlets at supersonic cruise was then a result of their lower wave drag. As noted before, however, the wave drag difference between the 2.0/2D/EX and the 2.0/2D/SS inlets may have been too low, thus possibly narrowing the range increment for all-supersonic cruise.

The external-compression inlets showed an advantage at subsonic cruise because of their capacity to operate at critical conditions, and so minimize spillage drag. For the 2.0/2D/SS inlets, their subcritical spillage drag could be eliminated at the cost of some added mechanical complexity.

In addition to performance factors, it is necessary to consider relative mechanical complexity and flow stability. Here the advantage goes to the external-compression inlets. More effort could be expected to develop a self-starting design than an external-compression design.

On balance, the external-compression inlets are the probable first choice for the Mach 2.0 aircraft. Their small supersonic cruise range deficit is offset by their simplicity and their relatively high performance at subsonic cruise. Thus, a lower technology approach seems adequate for the Mach 2.0 aircraft. For now, however, this conclusion must be qualified by the uncertainty in installed wave drag and spillage effects. Also, the results of the axisymmetric inlet studies may alter this conclusion.

For the Mach 2.3 aircraft, the 2.3/2D/SS inlet had a more distinct advantage at supersonic cruise. This was partly due to its lower wave drag, but mainly due to its lower SFC. Remaining trade-offs were similar to those of the Mach 2.0 aircraft. Thus, the external-compression inlet had somewhat lower weight, had greater flow stability, and had lower spillage drag at subsonic cruise. The 2.3/2D/SS inlet also had the capacity to eliminate subcritical spillage at subsonic cruise conditions at the cost of extra complexity. Finally, the wave drag difference between the 2.3/2D/EX and the 2.3/2D/SS inlets may have been underestimated.

On balance, the higher technology self-starting inlets are the probable first choice for the Mach 2.3 aircraft, if they are modified to minimize subcritical spillage. This is based on their superiority at supersonic cruise, and their potential for relatively high performance at subsonic cruise. The requirement for low spillage drag at subsonic cruise does impose additional complexity on the self-starting inlets, however.

Airframe-propulsion system interference effects are significant for aircraft performance and for design of components such as the inlet. This is apparent from the importance of wave drag and inlet spillage in the present results, and from many other studies. Further study is needed to assess and improve existing design methods for airframe-propulsion system interference, as these methods are largely based on linearized theory and modifications thereof. Examples of possible areas of improvement are in location of interference shocks and description of wave reflections, inlet spillage streamline shapes, and effects of inlet bypass and bleed flows.

CONCLUSIONS

- For the configurations studied, increased $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$ gave decreased range for missions dominated by supersonic cruise. Reductions in corrected air flow ratio may be limited by takeoff noise requirements and by the need to minimize spillage at subsonic cruise, however.

- It is important that inlets be designed to minimize spillage drag at subsonic cruise, because of the need for relatively efficient subsonic cruise performance for overland operations. External-compression inlets seem to have an advantage in this respect.

- The external-compression inlet emerged as the probable first choice for the Mach 2.0 aircraft, while the self-starting inlet was the probable first choice at Mach 2.3. This indicated a change in inlet technology level between these Mach numbers.

- Airframe propulsion system interference effects (e.g., installed wave drag and inlet spillage flow) are significant for aircraft performance and for design of components such as the inlet. Further study is needed to assess existing design methods and to develop improvements.

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TABLE 1. - ENGINE CYCLE CHARACTERISTICS

Engine	GE 21/J11B13	GE 21/J11B21	GE 21/J11B19
Cruise Mach No.	2.0	2.0	2.3
Oversize front fan (percent)	20	10	10
Augmentor	Afterburner	Afterburner	Afterburner
$(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$	1.32	1.23	1.45
$(W\sqrt{\theta}/\delta)_{CRUISE}$ (KG/SEC)	224	225	186
$(T/W)_{T/O}$	0.265	0.265	0.265
Bypass ratio	0.35	0.35	0.25
Overall cycle pressure ratio	18.8	18.1	16.0
Fan pressure ratio	3.7	3.5	3.7
Front fan diameter (M)	1.56	1.45	1.50

TABLE 2. - INLET PRESSURE RECOVERY AND BLEED DRAG AT SUPERSONIC CRUISE CONDITIONS

Configuration	1614 – 10A	1614 – 10C	1614 – 11A	1614 – 11C	1631 – 1A	1631 – 1C
Inlet	2.0/2D/EX	2.0/2D/SS	2.0/2D/EX	2.0/2D/SS	2.3/2D/EX	2.3/2D/SS
Engine	GE 21/J11B21	GE 21/J11B21	GE 21/J11B13	GE 21/J11B13	GE 21/J11B19	GE 21/J11B19
P_{T2}/P_{TO} (OW/UW)	0.916/0.940	0.932/0.943	0.916/0.940	0.946/0.953	0.867/0.894	0.913/0.933
C_{D}, bleed (4 inlets)	0.000292	0.000402	0.000291	0.000419	0.000306	0.000452
Internal compression, percent	0	42	0	42	0	35

TABLE 3. - INSTALLED SPECIFIC FUEL CONSUMPTION AND LIFT-DRAG RATIO

Configuration	1614 – 10A	1614 – 10C	1614 – 11A	1614 – 11C	1631 – 1A	1631 – 1C
Inlet	2.0/2D/EX	2.0/2D/SS	2.0/2D/EX	2.0/2D/SS	2.3/2D/EX	2.3/2D/SS
Engine	GE 21/J11B21	GE 21/J11B21	GE 21/J11B13	GE 21/J11B13	GE 21/J11B19	GE 21/J11B19
Supersonic cruise:						
Avg. SFC						
~KG/HR/daN (LBM/HR/LB)	1.273 (1.248)	1.266 (1.241)	1.276 (1.251)	1.265 (1.240)	1.450 (1.422)	1.373 (1.346)
Avg. L/D	8.2	8.3	8.0	8.1	7.8	7.8
Subsonic cruise:						
Avg. SFC						
~KG/HR/daN (LBM/HR/LB)	1.048 (1.027)	1.122 (1.100)	1.054 (1.033)	1.115 (1.093)	1.087 (1.066)	1.177 (1.154)
Avg. L/D	14.1	14.1	14.1	14.1	13.9	13.9

INTERNAL CONTRACTION	M2.0		M2.3		M2.55	
	2D	AXI	2D	AXI	2D	AXI
NONE	✓	*	✓			
SMALL (SELF-STARTING)	✓	*	✓	*	✓	
LARGE (VARIABLE GEOMETRY FOR RESTART)						✓

✓ STUDY COMPLETED

* STUDY IN PROGRESS

Figure 1.- Study configurations.

• HIGHER $(W\sqrt{\theta}/\delta)_{M1}/(W\sqrt{\theta}/\delta)_{CRUISE}$ IMPLIES:

(+)	(-)
LOWER JET NOISE	HIGHER ENGINE WEIGHT
HIGHER TRANSONIC THRUST	HIGHER INLET WEIGHT
LOWER SPILLAGE/BYPASS DRAG	HIGHER WAVE DRAG

• POSITIVE FACTORS APPLY MAINLY AT OFF-DESIGN MACH NUMBERS

• NEGATIVE FACTORS APPLY AT ALL MACH NUMBERS

Figure 2.- Effects of transonic-to-cruise corrected air flow ratio.

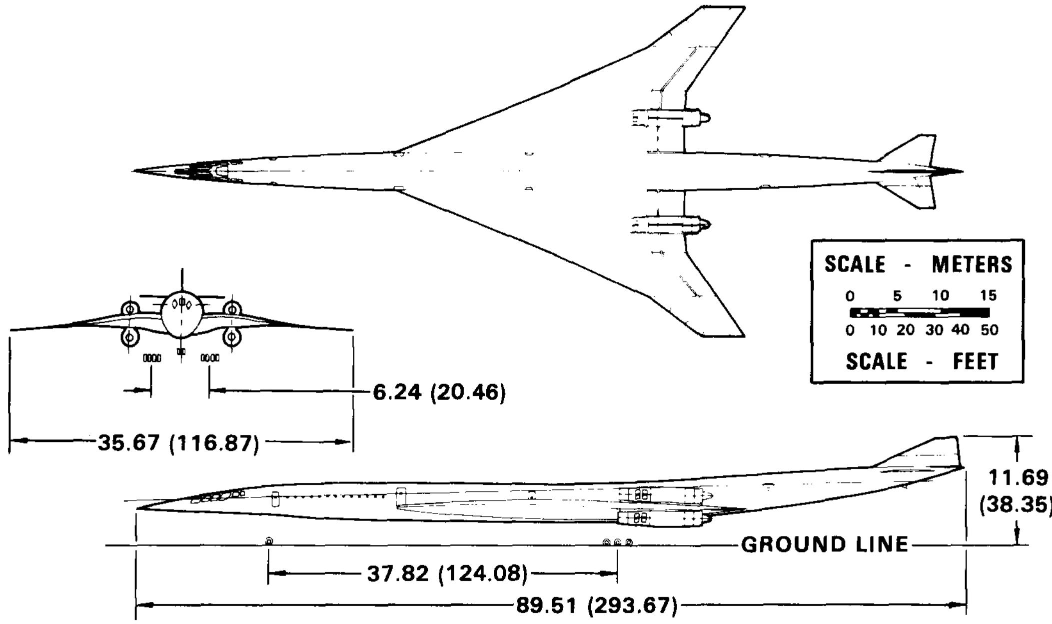

Figure 3.- General arrangement Mach 2.0 SCR vehicle.

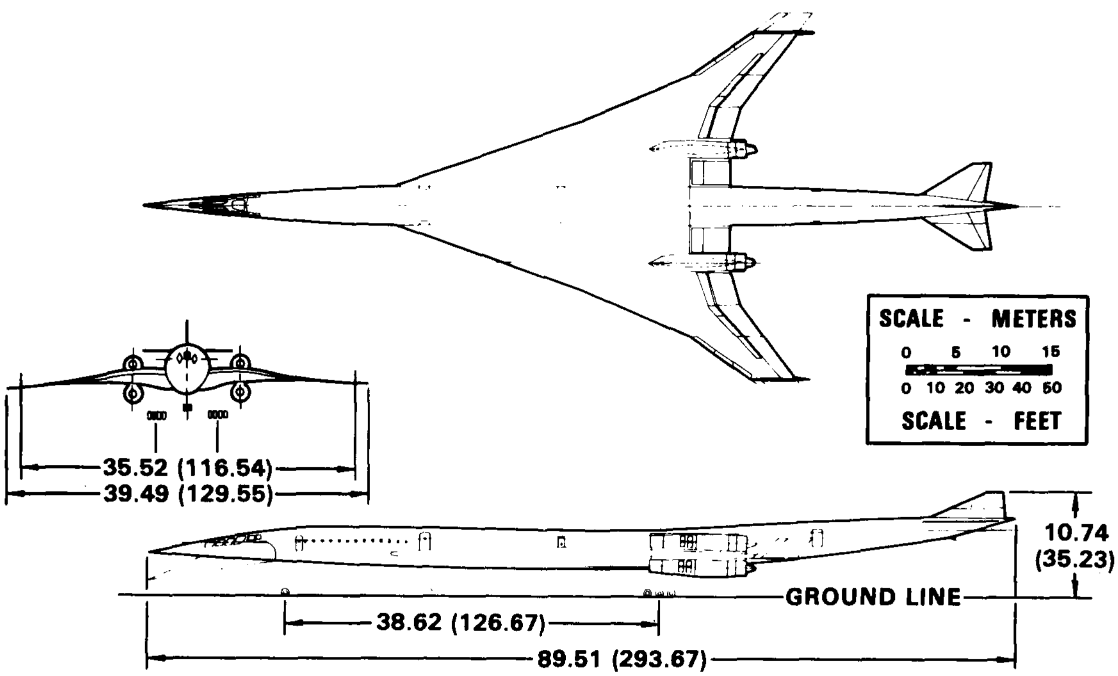

Figure 4.- General arrangement Mach 2.3 SCR vehicle.

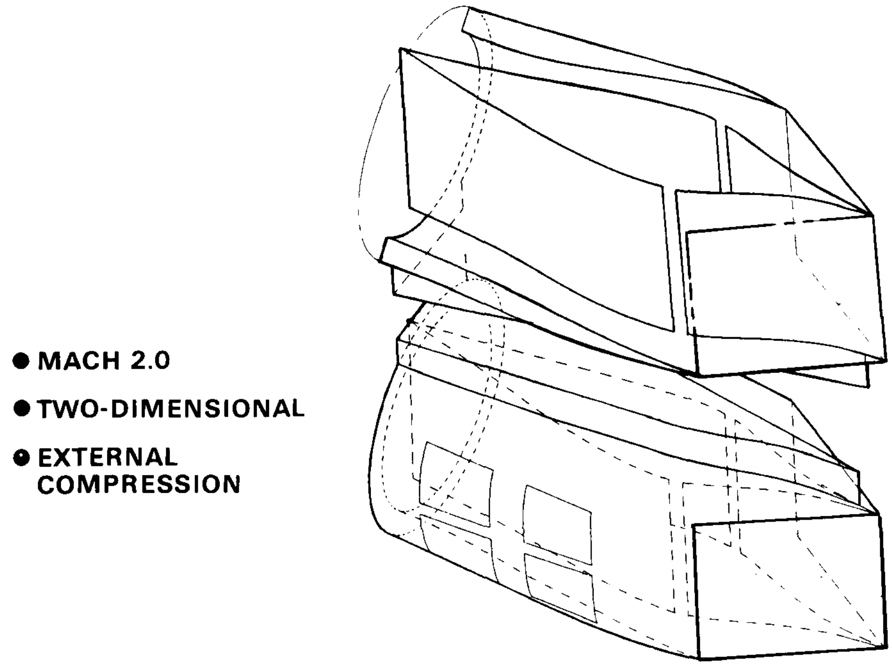

Figure 5.- 2.0/2D/EX inlet.

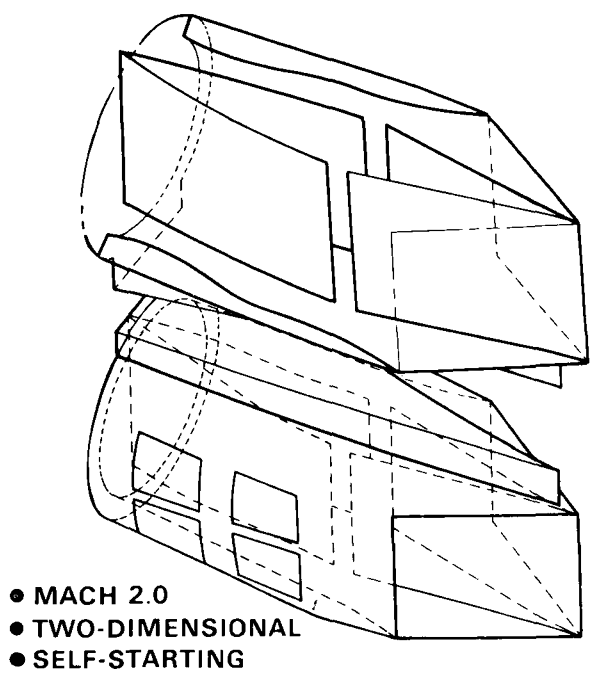

Figure 6.- 2.0/2D/SS inlet.

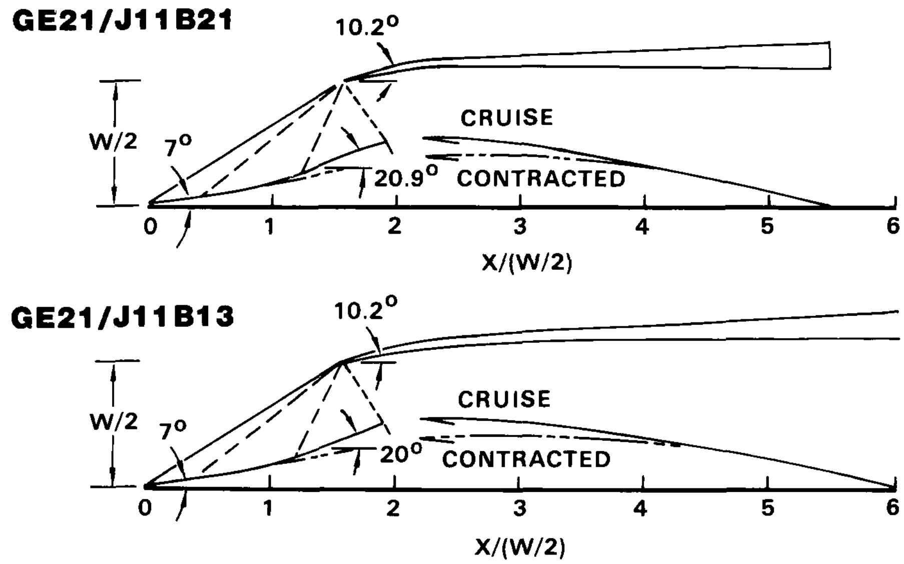

Figure 7.- 2.0/2D/EX inlet contours.

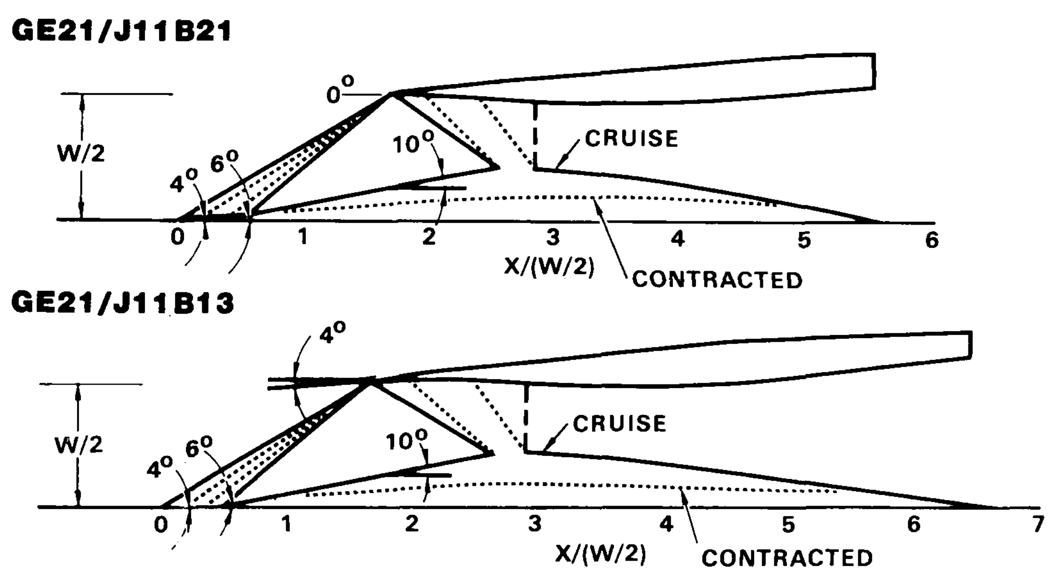

Figure 8.- 2.0/2D/SS inlet contours.

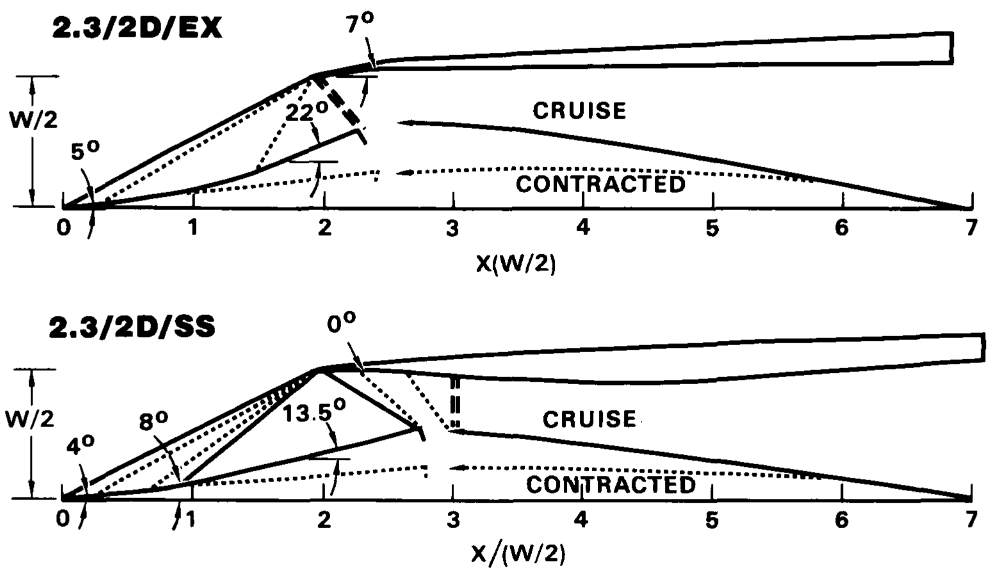

Figure 9.- Mach 2.3 inlet contours.

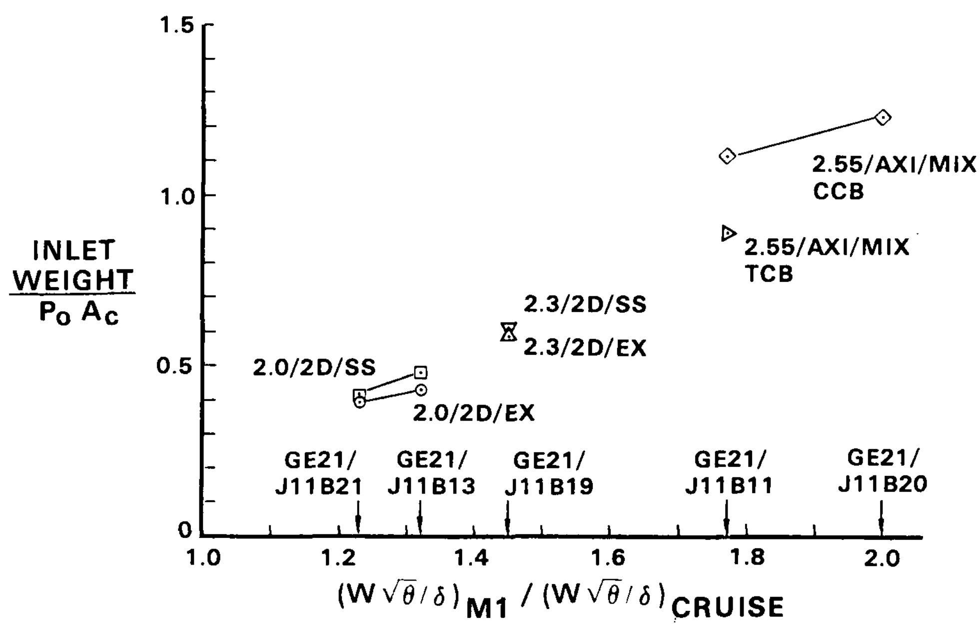

Figure 10.- Inlet weight.

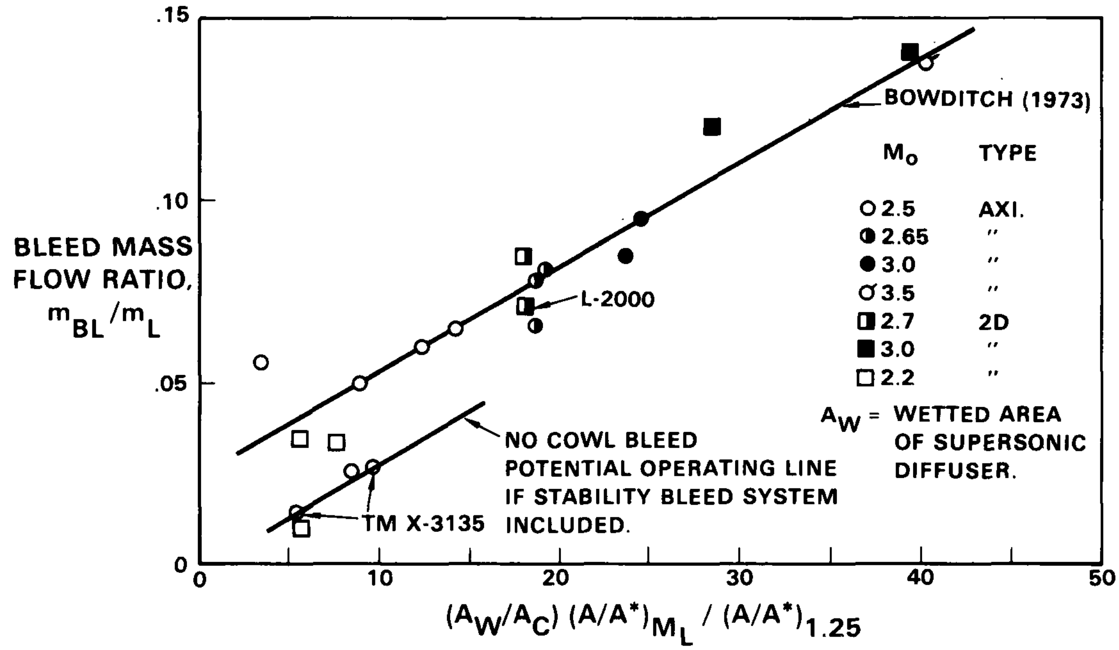

Figure 11.- Inlet bleed flow correlation.

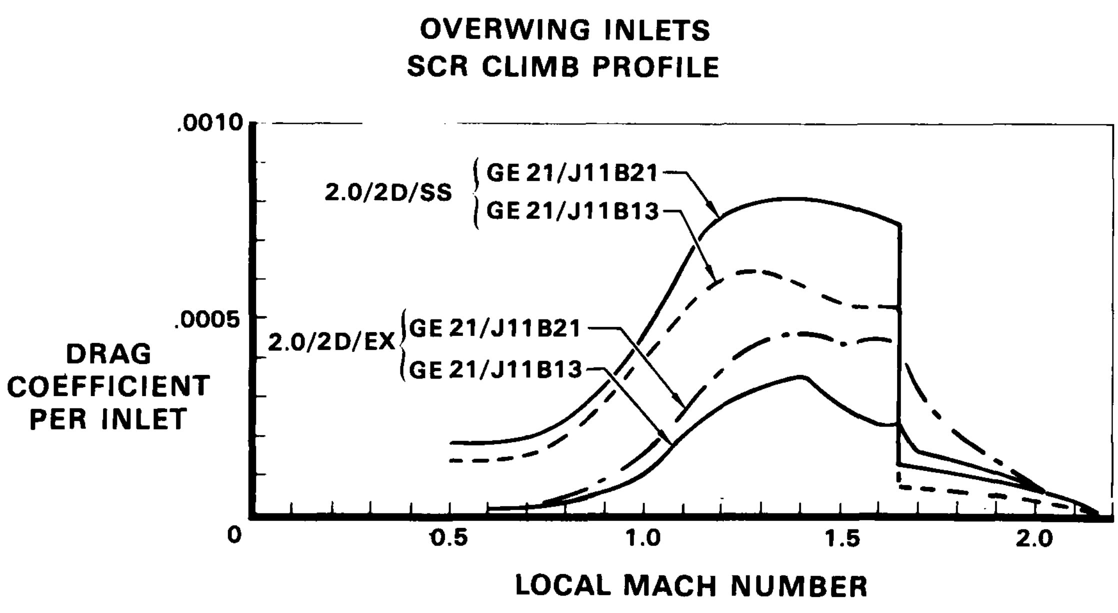

Figure 12.- Inlet spillage and bypass drag.

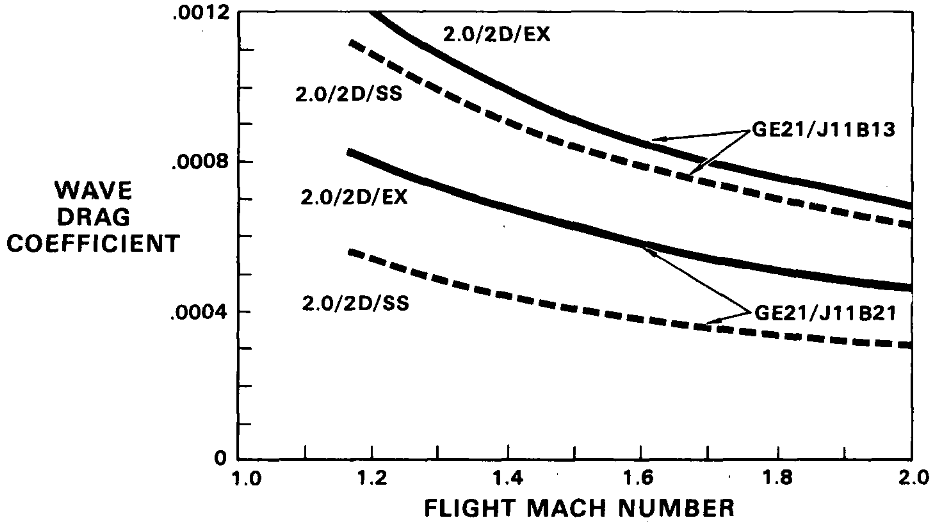

Figure 13.- Nacelle external pressure drag.

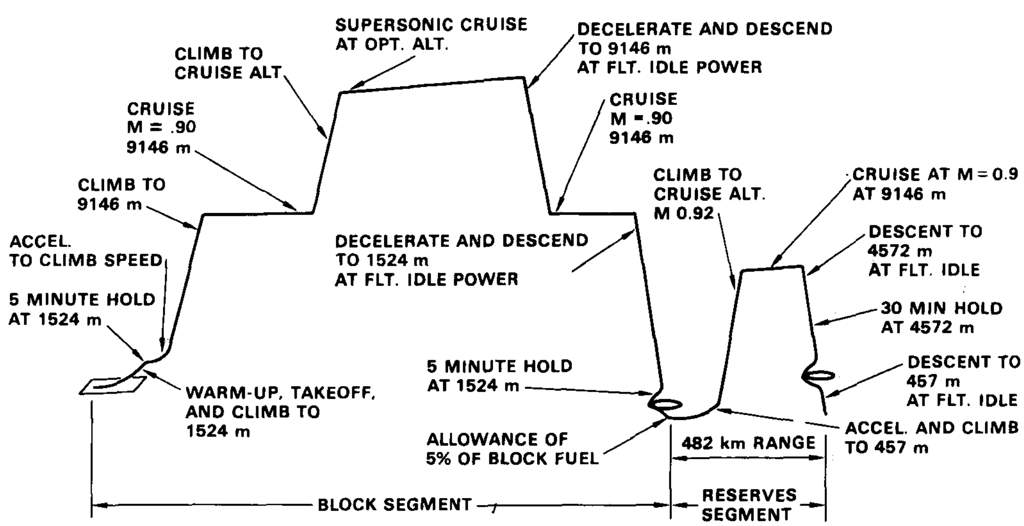

Figure 14.- SCR mission profile.

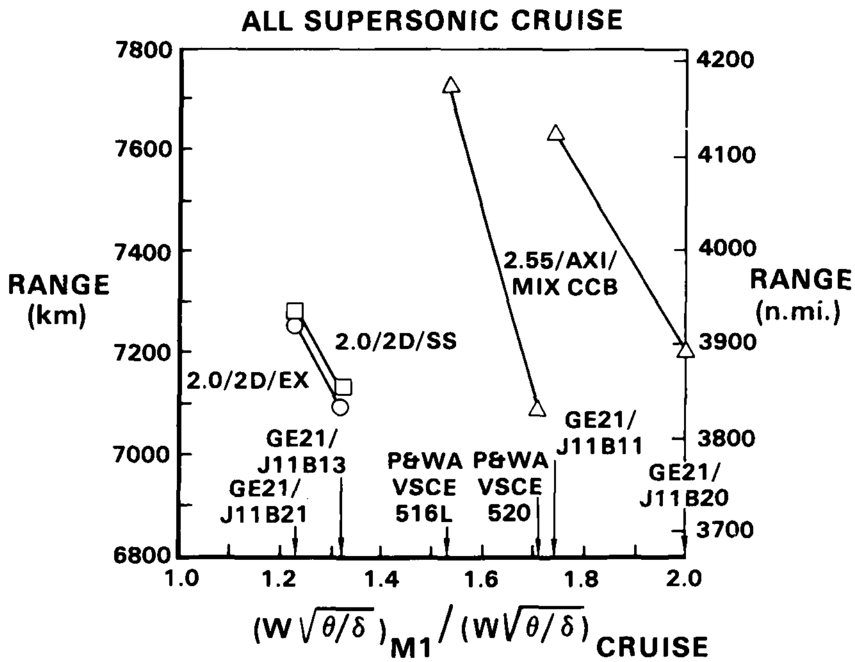

Figure 15.- Effect of corrected air flow ratio on range.

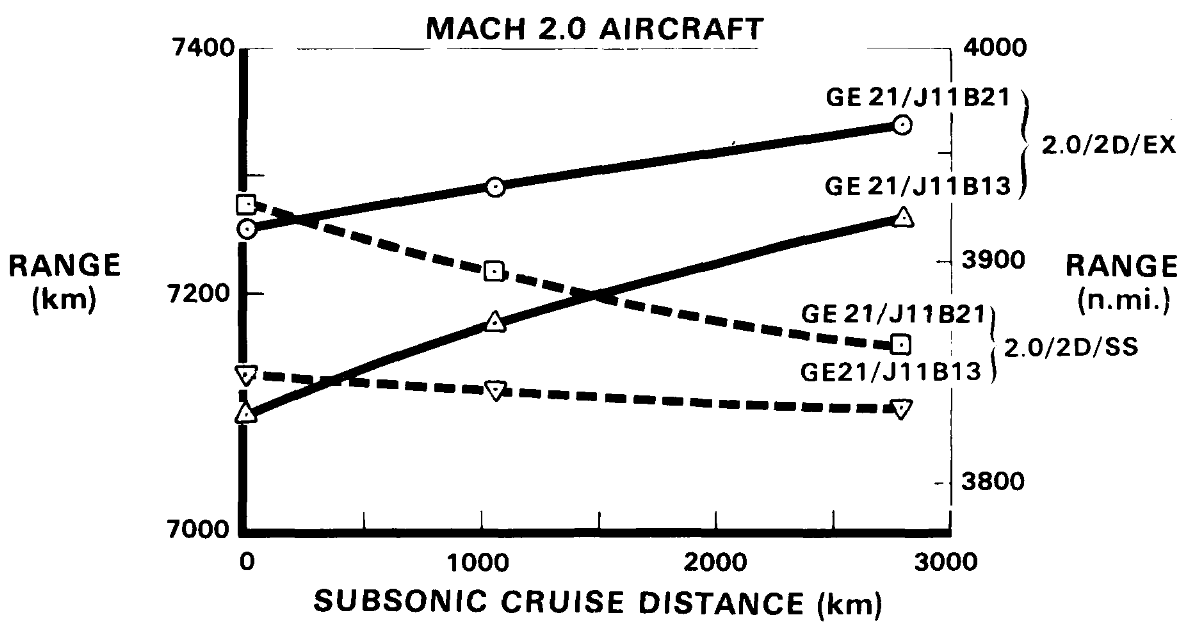

Figure 16.- Effect of subsonic cruise on range for Mach 2.0 aircraft.

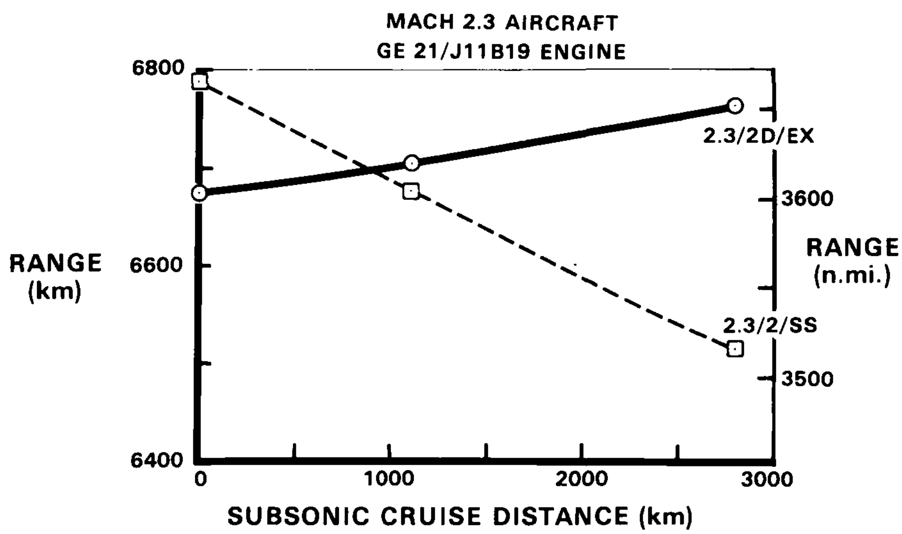

Figure 17.- Effect of subsonic cruise on range for Mach 2.3 aircraft.