NASA TECHNICAL MEMORANDUM

NASA TM-78955

(NASA-TM-78955) INLET-ENGINE MATCHING FOR SCAR INCLUDING APPLICATION OF A BICONE VARIABLE GEOMETRY INLET (NASA) 23 p HC A02/MF A01 CSCL 21E

N78-27125

Unclas
G3/07 25193

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TECHNICAL PAPER to be presented at the
Fourteenth Propulsion Conference
cosponsored by the American Institute of Aeronautics and Astronautics and the Society of Automotive Engineers
Las Vegas, Nevada, July 25-27, 1978

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E-9706

ABSTRACT

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined where the second cone of a two cone centerbody collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

INTRODUCTION

A major goal of the NASA Supersonic Cruise Aircraft Research (SCAR) program has been to define viable variable cycle engines, (VCE). The airflow characteristics of these engines have shown large variations transonically. For example, engines designed for a cruise Mach number of 2.32 can have transonic airflow requirements of 1.3 to 1.6 times the cruise Mach number airflow. Not having to derate the airflow requirements transonically could significantly improve the climb acceleration and subsonic cruise performance for a supersonic cruise aircraft. It then becomes important to design inlet systems that provide the transonic airflow capability while maintaining high internal performance with minimum weight and drag.

Two-dimensional inlet concepts with collapsing ramps easily meet all VCE airflow requirements while maintaining high internal performance. However, the weight and drag characeristics are somewhat higher for the two-dimensional inlet than for axisymmetric inlets. An axisymmetric inlet with a translating centerbody for off design operation, can provide only the bare minimum transonic airflow for design Mach numbers of 2.5 and below. However, if the centerbody is collapsed rather than translated at Mach numbers below the cruise value, about 20 percent more transonic airflow can be delivered by the inlet. An axisymmetric inlet concept with a collapsing centerbody variable geometry feature is examined herein in relation to previously considered axisymmetric translating centerbody inlets.

SINGLE CONE INLETS

Some single cone inlet concepts are characterized in figure 1. Inlet A is a translating centerbody inlet whose maximum transonic throat area is limited to the area at the cowl lip station when the centerbody is translated upstream. For maximum transonic flow, this area must be only slightly less than the minimum internal area between the cowl and the centerbody support tube with the centerbody translated upstream. For constant speed engines, type A inlets, designed for cruise Mach numbers below 2.7, cannot provide sufficient transonic airflow, reference 1. However, this inlet does match the transonic airflow requirements for some VCE types that employ an inverse throttle schedule (ITS) operation. With ITS, mechanical rotor speed is varied such that maximum rotor speed occurs at supersonic cruise. For engines of equal size, ITS engine operation increases the supersonic cruise airflow significantly over that for constant-speed throttle schedule operation which results in larger inlet capture area and increased transonic airflow.

An alternative to inlet A is inlet B, which is a translating centerbody inlet with a centerbody auxiliary airflow system. The increase in maximum inlet throat area of this inlet over inlet A is approximately 8 percent. An additional degree of mechanical complexity is added to the translation mechanism and the design of the centerbody bleed system becomes a complex cross-passageway system which ducts the bleed airflow through struts transversing the auxiliary airflow passage to the centerbody bleed airflow vent, reference 2. This inlet also requires a control to match the diffusion in the two airflow paths to avoid excessive distortion.

Inlet C is typical of inlet systems with a single cone collapsing centerbody that permits high transonic airflow and matches or exceeds airflow demands of most turbine engines. However, for this inlet system, the centerbody is mechanically complex. The pressure variations along the centerbody surface forces compartmentalization of the centerbody bleed system. The bleed porosity on the overlapping centerbody segements varies during the collapsing process making boundary layer control difficult. Also, sealing the overlapping and hinged segements becomes difficult. Therefore, the practicality of this inlet appears limited.

Airflow schedules of all three single cone inlets are compared with the envelope of airflow capabilities (shaded area) predicted for variable cycle engines, figure 2. The lower curve of this envelope characterizes VCE's with inverse throttle type schedules while the upper curve represents engines with constant speed type schedules. The increased VCE airflow between Mach 0 and .3 represents VCE's that incorporate 10 or 20 percent high flow front fans to help reduce noise during takeoff and approach operations. At takeoff, larger auxiliary inlets would be required to provide the necessary airflow. Also, these airflow increases associated with oversized fans could improve thrust and SFC during subsonic cruise and transonic acceleration if the inlet could provide the extra airflow.

Inlet A appears to be well suited for VCE's with the inverse throttle schedule operations. Because of the restrictions on airflow for inlet A, the advantages of high flow engines at subsonic cruise are denied, and reheat may be required during transonic acceleration and climb operation. Also, inlet noise suppression at takeoff becomes more difficult for the high flow engines because of the large auxiliary inlets that would be required.

Inlet B provides about 8 percent more airflow than inlet A. An airflow deficiency does occur just above the inlet starting Mach number of 1.6. This deficit can be overcome by starting the inlet at a higher Mach number as suggested in reference 2. The reason for this deficit is that during the inlet start operation, the inlet maximum throat area, with the auxiliary system closed, is less than that of inlet A for the same condition. This results because of the larger centerbody radius required to provide for the centerbody auxiliary airflow system. Experimental transonic data for inlet B are published in reference 3.

Inlet C exhibits about a 23 percent increase in airflow over inlet A and provides all the engine airflow required including some excess which can be reduced through changes in design. Because of the large airflow capacity, smaller auxiliary inlets would be required which would aid the takeoff inlet noise problem in the terminal area.

BICONE COLLAPSING CENTERBODY

From the survey of single cone inlets, it appears that the large airflow capabilities of the collapsing centerbody are desirable but not its complexities. If the complexities of a collapsing centerbody can somehow be resolved, the advantages are many. At takeoff and approach, the large throat area reduces the size of the auxiliary inlets. Problems of inlet noise suppression at takeoff are reduced because of smaller auxiliary inlets. For subsonic cruise, the large throat area provides the means to high flow the engine at this condition. High flowing the engine at subsonic cruise reduces exit nozzle boatail angle thus reducing boatail drag. Also, higher airflow capability permits larger bypass ratio engines and improved SFC. During acceleration and climb operation, high inlet airflow capability, resulting from the large inlet throat area, permits some VCE's to operate at their full potential and may even eliminate the need for afterburning. Since inlet airflow restrictions on engine operation are minimized with this type of inlet, engine cycle design could be enhanced because of the larger inlet airflow capability.

The inlet system, featured in this paper, uses a collapsing centerbody concept that could provide solutions to the problems plaguing this inlet concept and is shown in figure 3. The inlet has a two cone centerbody in which the second cone collapsed with the subsonic diffuser centerbody surface to the initial cone angle or beyond when mechanically feasiable. The problems of collapsing porous bleed surfaces and a compartmented centerbody are solved by having a single throat slot. The higher pressure on the second cone permits higher bleed pressures without getting recirculation through the seals onto the cone surface. As the centerbody is collapsed, the inlet throat remains fixed with proper design of the subsonic diffuser. Any bleed required on the cowl is always opposite the centerbody bleed when the centerbody is collapsed. Only longitudinal seals for the collapsing centerbody panels would be required. The cowl length from the lip to the throat is short, less than an inlet radius, reducing wetted area in the supersonic diffuser with a concomitant bleed reduction.

Reference 4 presents results from a bicone inlet that was designed and tested at Lewis Research Center. At cruise operation, the inlet demonstrated low bleed requirements (no cowl bleed necessary) with high pressure recovery. The angle of attack tolerance is higher than that of similar single cone inlets and the unstart transients are milder than those of a single cone inlet, reference 5.

Design of the two cone axisymmetric mixed compression inlet is based on a method of characteristics solution described in reference 6. Independent parameters used to describe a particular design are shown in figure 3. Cowl lip position is determined with the requirement that the initial cone shock intercept the cowl lip or spill a small amount (about one-half percent of capture mass flow) around the cowl lip for improved angle of attack capability. Selection of the second cone angle then determines the intersection of the first and second cones, such that the second cone shock intercepts the cowl lip. Choice of the internal cowl angle fixes the postiton of cowl shock impingement of the centerbody surface. The length and contour of the compression surface on the cowl beyond the cowl lip is determined by the selection of the centerbody surface length, Lt, surface flow angle, α2, and Mach number Mt. The centerbody surface of length Lt is contoured such that the cowl lip shock and cowl compression fan are canceled over this length of centerbody surface. Surface flow angle, α2, and Mach number, Mt, describe the exit flow conditions on the centerbody surface of length Lt. The final Mach number, Mt, is in most cases the throat Mach number. The short length of contoured surface over this compression region is generally used as the location of the centerbody bleed slot for boundary layer control ahead of the inlet throat.

In general, a distorted throat Mach number profile exists due to over-expansion or over-compression on the cowl surface ahead of the throat. The program only satisfies the specified conditions of Lt, α2, and Mt on the centerbody surface. However, a uniform profile at the throat can easily be obtained by recontouring the aft portion of the second cone surface and the cowl surface ahead of the throat.

Because of the several independent variables that are used to design a bicone inlet, its airflow capabilities can be varied to match engine requirements. Results of a parametric study in the variation of these parameters is shown in figures 4, 5, and 6. In this study, only three parameters were varied, first cone angle δ1, second cone angle δ2, and internal cowl lip angle α1. The remaining parameters were assigned fixed values: length of compression surface to throat, Lt, is 0.1 of the cowl lip radius; centerbody surface throat angle, α2, is -3 degrees; centerbody surface throat Mach number, Mt, is 1.30; and local free stream Mach number, Mo, is 2.32. For figures 5 and 6, the internal cowl lip angle, α1, was fixed at 2 degrees. A study on the effect of internal cowl angle for a bicone inlet is presented in reference 7.

Variations of the first cone angle, second cone angle, and internal cowl lip angle on the theoretical inviscid terminal shock pressure recovery is shown in figure 4. Results show that the smaller the amount of shock flow turning required, the better the pressure recovery. However, compromises must be considered before the final parameter selections are made. For example, the necessary increase in throat area that is needed to satisfy engine requirements must be considered. Also, considerations of low cowl wave drag would tend to favor the lower cowl angles.

Increases in available throat area for bicone collapsing centerbody inlets is shown in figure 5. If the second cone is limited to collapsing to only the first cone angle, then large throat variation would favor the lower initial cone angles and higher second angles. However, if the second cone could collapse to .6 of the centerbody throat radius as a possible practical limit, independent of the first cone value, then the previous restriction could be ignored. All parametric curves then collapse to the single line-dash-line curve shown and thus throat area increase is limited to selection of second cone angle. As the second cone angle is increased, providing more external compression, less internal compression from cowl turning is required. This results in a larger cowl radius at the throat and provides a larger throat area with the centerbody collapsed.

In a similar manner, consideration of the inherent collapsed centerbody inlet contraction ratio, for bicone inlets, must be made as shown in figure 6 which presents the contraction ratio of a two cone inlet without centerbody translation. The contraction ratio is defined here as the inlet throat area, At, divided by the cowl lip flow area, Ac. For SCAR applications, starting inlet Mach numbers of 1.6 have been the norm. Again, when the second cone collapses only to the first cone value, low first cone angles and high second cone angles favor the lower starting ch numbers. Collapsing the second cone beyond the first cone angle, curve characterized by line-dash-line curve, permits selection of higher first cone angles. Even in this case, the choice of second cone angles must be high (approximately 18 degrees) to satisfy the starting Mach number of 1.6.

However, some relief in required area ratio for starting Mach number is identified in reference 8 and shown in figure 7. A sketch in figure 7 shows the flow mechanism by which inlet starting is effected. A favorable flow separation on the cone, caused by the strong shock boundary layer interaction, changes the flow area ratios to one acceptable for inlet starting. The centerbody bleed slot aids in reattaching the separated flow to the centerbody. The shaded area on the curve represents experimentally determined inlet starting area ratios. If inlet starts at Mach 1.6 are desired an area ratio of .87 rather than .89 would be required. This permits selection of second cone angles down to 16.5 degrees when collapsing beyond the initial cone angle, figure 6.

BICONE-INLET VCE MATCHING

A bicone inlet designed for cruise at Mach 2.32 is presented and compared with representative VCE airflow requirements. Values of the parameters selected for the design are shown in figure 8. The design bicone combination is 10 degrees and 18.5 degrees with an internal cowl angle of 2 degrees and a centerbody surface angle at the throat exit of -3 degrees. To obtain a uniform throat Mach number the aft portion of the second cone surface ahead of the cowl shock impingement was recontoured to accelerate the flow near the cowl. The compression fan from the cowl extended across the centerbody bleed slot whose length was selected as .1 of the cowl lip radius. The resulting supersonic diffuser length from cowl lip to the throat is .39 cowl lip diameters. Centerbody support struts were not included in the subsonic diffuser design. For this example, the second cone collapses only to the first cone angle. With the second cone collapsed, a well defined internal flow passage is maintained. Inlet starting Mach number for this bicone inlet design is Mach 1.6 (Ath/Ac= .87) because of the favorable flow separation defined earlier.

An estimate of the bicone inlet's pressure recovery schedule is presented in figure 9. The total shock losses were obtained by adding the terminal normal shock loss to the oblique shock losses from the method of characteristics computer program. Subsonic diffuser losses are based on a computer program and experimental data of references 9 and 10. Losses due to throat flow and shock position are based on past experience. Diffuser losses for unstarted inlet operation at speeds below Mach 1.6 were adjusted from the normal shock loss to meet the pressure recovery schedule used by one contractor in the SCAR program based upon the experimental results presented in references 11 and 12.

Based on the pressure recovery schedule of figure 9 and assuming a throat Mach number of .8 for unstarted inlet transonic operation, airflow and mass flow schedules were calculated for the bicone inlet and presented in figure 10. Three VCE airflow schedules are also shown and compared with the air supply of the bicone inlet. The GE21/J11-B9 and the P&W VSCE 502B are the most recently defined Mach number 2.4 SCAR engines. They were designed to match typical translating centerbody inlets. The GE21/J9-B1, which is an earlier defined double bypass engine, did not incorporate the improved technology features of the GE21/J11-B9 such as, higher cruise airflow, reduced levels of turbine cooling air, improved fan and compressor efficiencies, etc. Airflow requirements of the GE21/J9-B1 engine, which incorporates a 20 percent high flow front fan, are satisfied by the bicone inlet. Excess airflow supplied by the bicone inlet over the requirements of the GE21/J9-B1 engine represents additional spillage drag. This spillage drag can be reduced with a modest amount of centerbody translation. For the other two engines, a bicone inlet could be designed which would satisfy these engine requirements by selecting combinations of first and second cone angles to obtain the proper throat area variation. In general, the bicone collapsing centerbody inlet offers the opportunity to design VCE's with high off design airflow with efficient inlet-engine matching.

Some various operating modes of the bicone inlet are shown in figure 11. During cruise, inlet operation is well defined, figure 11(a). Off design operation can incorporate a variety of centerbody variations. If a modest amount of translation is permited, approximately .4 of a cowl lip diameter to eliminate any internal contraction, inlet throat area and spillage drag can be controlled over a wide range for inlet matching and improve propulsion system performance.

Without centerbody translation and for started inlet off design operation between Mach 1.6 and 2.32, the centerbody collapses on a schedule that maintains the cowl shock at the forward edge of the centerbody bleed slot, figure 11(b). Unstarted inlet operation, with the second cone collapsed to the first cone value or beyond, is shown in figure 11(c). Because of the inherent internal contraction, the terminal shock stands ahead of the cowl lip and the excess airflow is spilled behind the normal shock resulting in higher spillage drag.

With the additional feature of translation, the following operational modes are possible. Additional airflow spillage through the second cone oblique shock is possible with translation for off design started inlet operation, figure 11(d). A different second cone collapsing schedule would be used so that the cowl shock remains at the forward edge of the centerbody bleed slot. For unstarted inlet operation, with the centerbody translated, the throat area could be varied with the second cone to provied the desired engine airflow requirements while maintaining the normal shock on the cowl lip for minimum spillage drag values, figure 11(e).

Theoretical transonic spillage drag coefficient is calculated for the collapsed centerbody (collapsed to the first cone value) with and without translation for unstarted inlet operation and with an assummed throat Mach number of .8. For off design started operation, calculations were made only for the scheduled collapsing centerbody. Spillage drag coefficient was calculated for the inlet design described in figure 8 using the methods of reference 13. The results are presented in figure 12.

Theoretical drag coefficients are based on inlet airflow schedule. Cowl wave drag, nacelle friction drag, and the drag associated with the additional bypass or spillage required to match an engine are not included in the calculations. The total drag for started inlet operation is made up of the oblique shock spillage and bleed flow. Two percent of the capture airflow was used as bleed flow for the off design started inlet operation. Bleed drag was not included for unstarted inlet operation. Because of the very low bleed flow required the cruise bleed drag is very low. During off design started inlet operation, both bleed and spillage drag remain low. With no centerbody translation the unstarted inlet spillage drag values increase due to spillage behind a normal shock caused by internal contraction. However, with a modest amount of centerbody translation, transonic spillage drag is reduced significantly (more than one-half) for the unstarted inlet operation by spilling the extra flow with the cone supersonic flow field. Experimental transonic spillage drag data, for a non-translated and translated centerbody reported in references 14 and 15, are for a bicone inlet with a 10 degree first cone angle and simulating the second cone collapsed to the first cone value. Comparison of the theoretical calculations with the experimental data shows good agreement for both translated and non-translated centerbodies during unstarted inlet operation.

An example of experimental bicone inlet performance at cruise and off design supersonic started inlet operation was reported in reference 4. The inlet of reference 4 was designed for a cruise Mach number of 2.5 and employed a 12.5 degree and 18.5 degree bicone centerbody configuration, figure 13. The initial internal cowl angle was 2 degrees and the centerbody boundary layer was controled by a centerbody bleed slot positioned ahead of the inlet throat. It was determined that cowl bleed was not required for this inlet configuration.

Experimental performance of this inlet is shown for operation at Mach 2.5 and 2.0, figure 14. The inlet's pressure recovery is presented as a function of bleed mass flow ratio. At the design free stream Mach number of 2.5, the peak pressure recovery was .905 at a bleed mass flow ratio of about .02, figure 14(a). The centerbody exit area was maintained constant for all data with open symbols. Inlet bleed mass flow was varied by remotely changing the strut butterfly valves which controlled the bleed exit area. With the maximum bleed exit area available, 5 percent of the inlet capture mass flow ratio was removed providing the potential for an operating margin before an inlet unstart. The peak pressure recovery during this operation was .915.

Inlet performance for a collapsed version of the centerbody at Mach 2.0 operation is shown in figure 14(b). Peak inlet performance for the fixed minimum bleed exit area was .940 with only .014 bleed mass flow ratio. Variation of the bleed exit area increased bleed mass flow ratio to .045 and provided a measure of inlet stability at this Mach number. The pressure recovery increases to about .95 with the increased centerbody bleed.

Inlet performance over an angle-of-attack range is shown in figure 14(c). The angle-of-attack operation is presented for both minimum and maximum centerbody bleed exit areas. At a constant centerbody bleed, mass flow ratio of .021, the maximum angle-of-attack was 2.55 degrees for supercritical operation. For critical inlet operation, that is, inlet operation with the terminal shock in the throat at zero degree angle of attack, the angle-of-attack before an inlet unstart was 1.74 degrees. This was increased to 4.17 degrees, for critical inlet operation, by increasing centerbody bleed which relieves overcompression in the throat region due to angle-of-attack operation. The maximum unstart angle-of-attack that was attained during supercritical operation was 6.85 degrees for full open bleed exit area. All the above angle of attack data were obtained at the design centerbody position.

Steady state distortion (based on 48 tube compressor array) at an angle-of-attack of 6.85 degree was .305. Although the inlet demonstrated a relatively large angle-of-attack range when using increased centerbody bleed, distortion may be a limiting factor. Consideration of the useful angle-of-attack range of any inlet must include the distortion sensitivity of the particular engine to which it is coupled.

CONCLUDING REMARKS

Variable geometry features on axisymmetric inlets designed for supersonic cruise operation are required to meet the airflow demands of conventional and variable-cycle jet engines. Unless the jet engine operates with ITS (inverse throttle schedule) inlets with a translating centerbody or a translating centerbody with centerbody auxiliary inlets have difficulty meeting the airflow demands during portions of transonic operation. A single cone collapsing centerbody could easily meet all the demands of most turbine engines. However, the practicality of this concept has proved to be doubtful.

This paper has presented a variation of the collapsing centerbody concept that appears to be feasible and could provide higher airflow at off design flight speeds. Very low bleed requirements associated with low overall wetted area were demonstrated for cruise and off design operation. By collapsing the inlet second cone to the 10 degree initial cone angle, the inlet should start at a Mach number of 1.6. With additional centerbody collapsing and /or translation, even lower starting Mach numbers should be reached. Theoretical predictions for transonic spillage drag appear to be reasonable for the collapsed centerbody. When a modest amount of translation is provided, transonic spillage drag is reduced by more than one half and is about the same as the translating single cone inlet. Comparisons of the theoretical predictions with limited experimental data shows good agreement. The bicone collapsing centerbody inlet concept offers the opportunity to design VCE's with high off design operation airflow and provide for better, more efficient inlet-engine matching. Further examination of this inlet concept is desirable to document its potentially desirable features over the entire Mach range.

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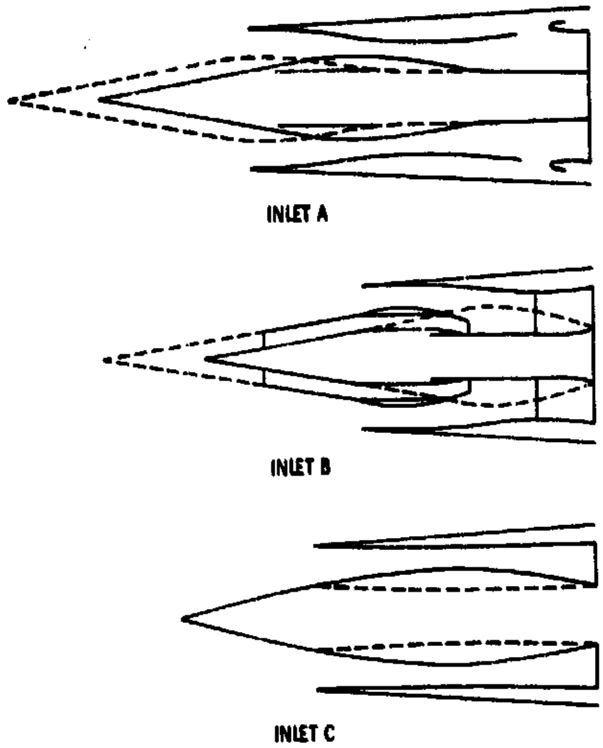

Figure 1. - Variable geometry for single cone axisymmetric inlets.

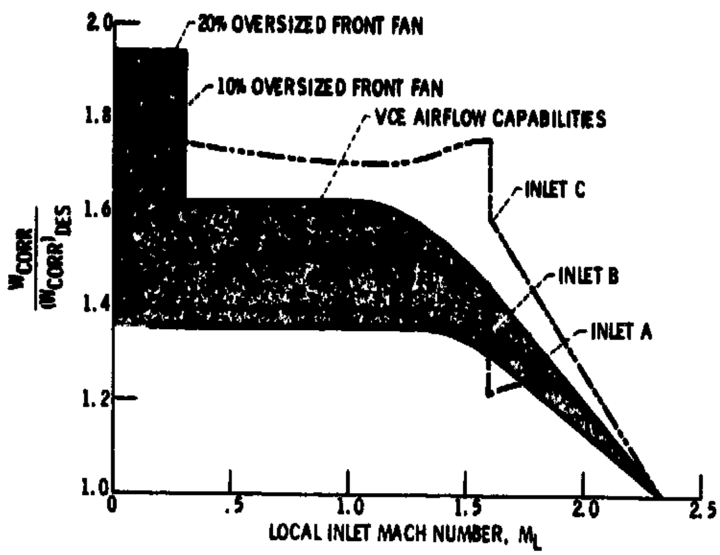

Figure 2. - Airflow characteristics for variable-geometry axisymmetric single cone inlets. Design Mach number of 2.32.

M_0 = DESIGN FREESTREAM MACH NUMBER
M_T = FINAL THROAT MACH NUMBER BEFORE TERMINAL SHOCK
α_1 = INTERNAL COWL ANGLE
α_2 = CENTERBODY THROAT ANGLE
δ_1 = INITIAL CONE ANGLE
δ_2 = SECOND CONE ANGLE
L_T = LENGTH OF COMPRESSION SURFACE TO THROAT

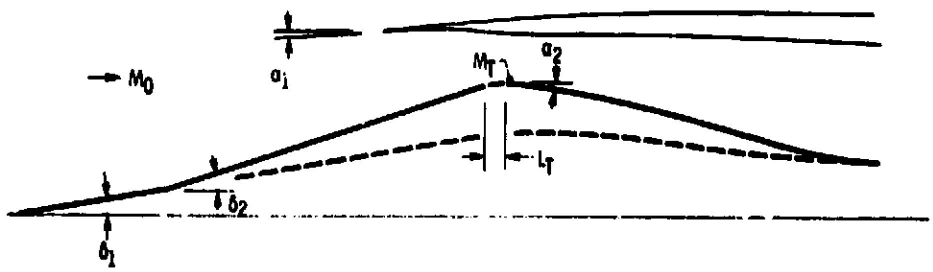

Figure 3. - Design variables for a bicone axisymmetric inlet with collapsing centerbody.

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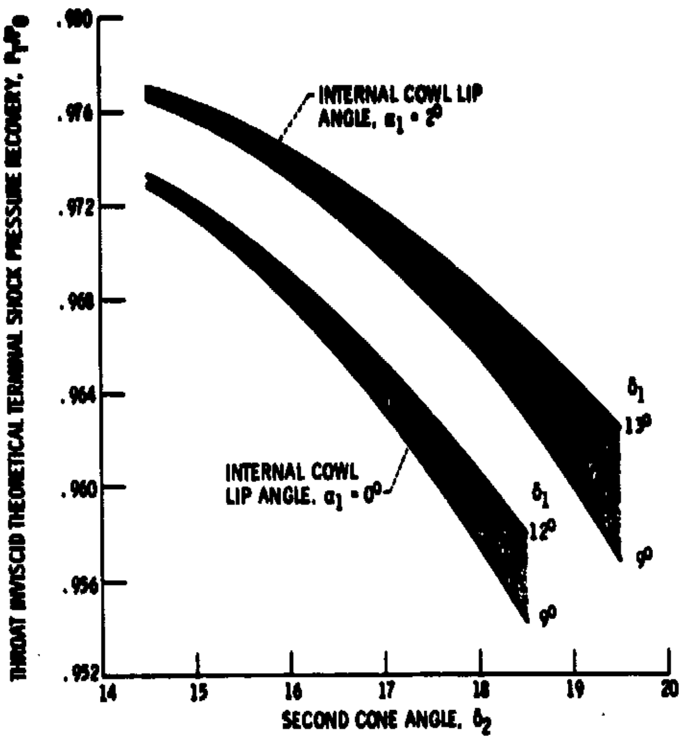


Figure 4. - Theoretical supersonic diffuser performance at M_0 = 2.32. Uniform throat Mach number, M_T = 1.30.

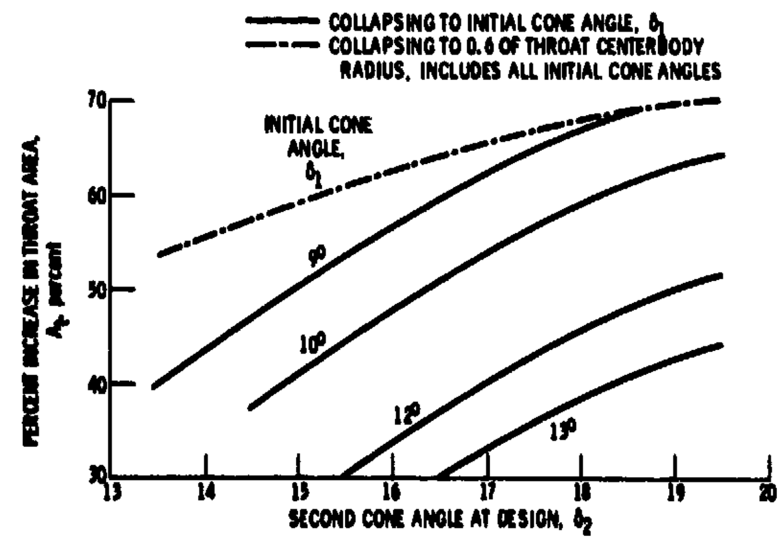


Figure 5. - Percent increase in throat area of a collapsed centerbody for variations of initial cone angles and second cone angles. Mach 2.32 design. Internal cowl lip angle, α_1 = 2°.

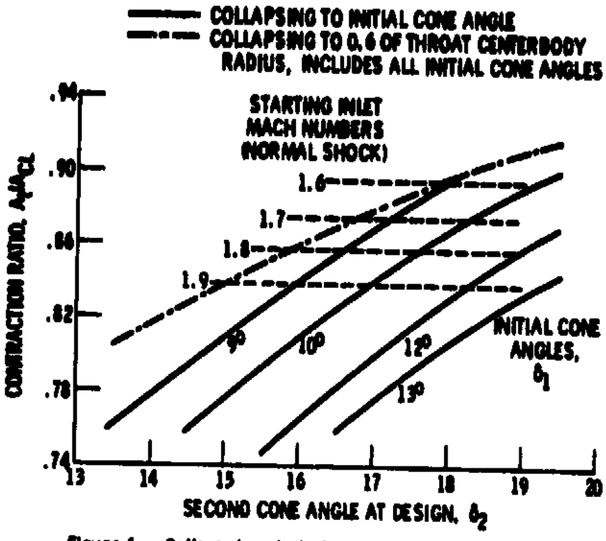


Figure 6. - Collapsed centerbody contraction ratio for variations of initial and second cone angles. Design Mach number 2.32. Internal cowl angle, $\alpha_1 = 2^0$. No centerbody translation.

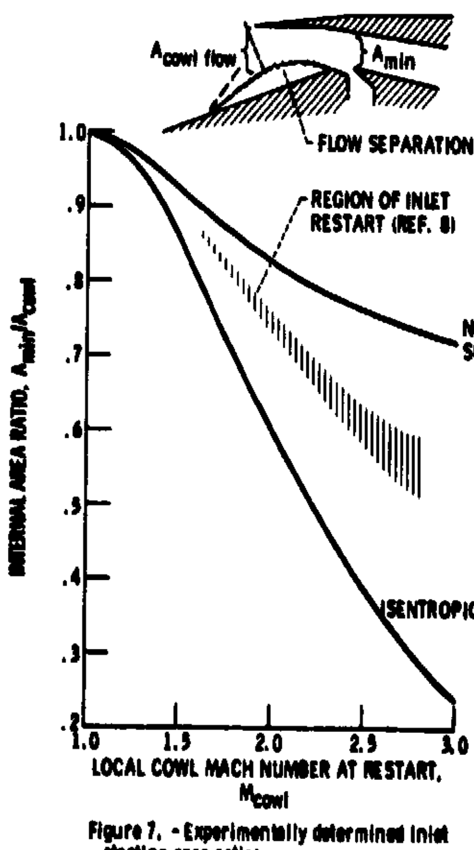


Figure 7. - Experimentally determined inlet starting area ratios.

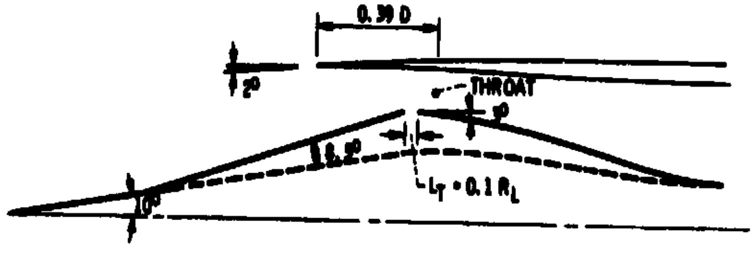


Figure 8. - Bicone inlet designed for M_L = 2.32.

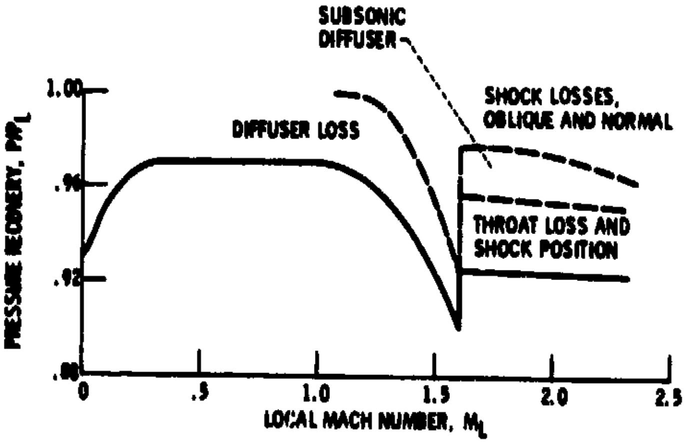


Figure 9. - Estimated bicone inlet pressure recovery.

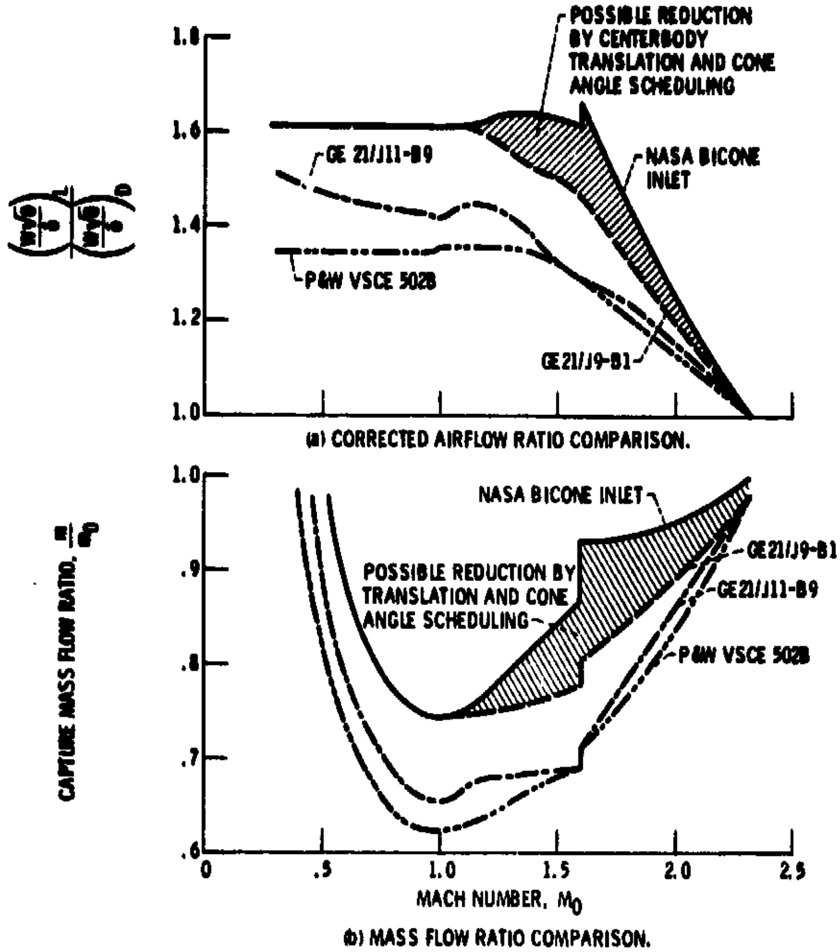
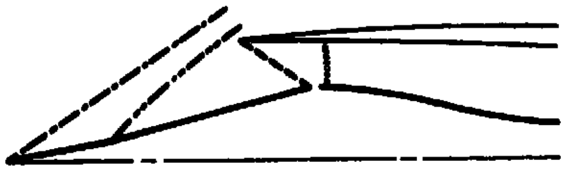


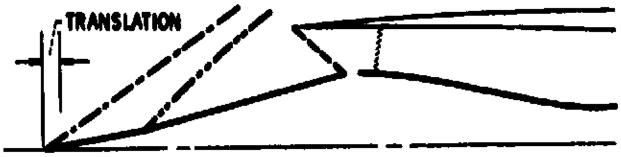
Figure 10. - Bicone inlet airflow matching characteristics. Cruise Mach number of 2.32.

(a) CRUISE CONFIGURATION.

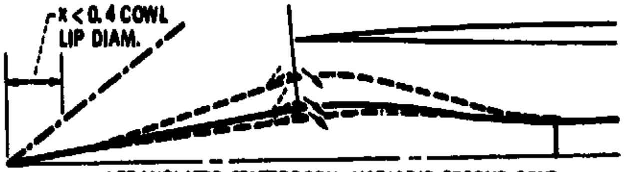


(b) NO TRANSLATION, PARTIAL COLLAPSED CENTERBODY, OFF-DESIGN STARTED INLET OPERATION.

(c) NO TRANSLATION, COLLAPSED CENTERBODY UNSTARTED INLET OPERATION.



(d) TRANSLATED PARTIAL-COLLAPSED CENTERBODY, OFF-DESIGN STARTED INLET OPERATION.



(e) TRANSLATED CENTERBODY, VARIABLE SECOND CONE, UNSTARTED INLET OPERATION.

Figure 11. - Bicone inlet operating modes.

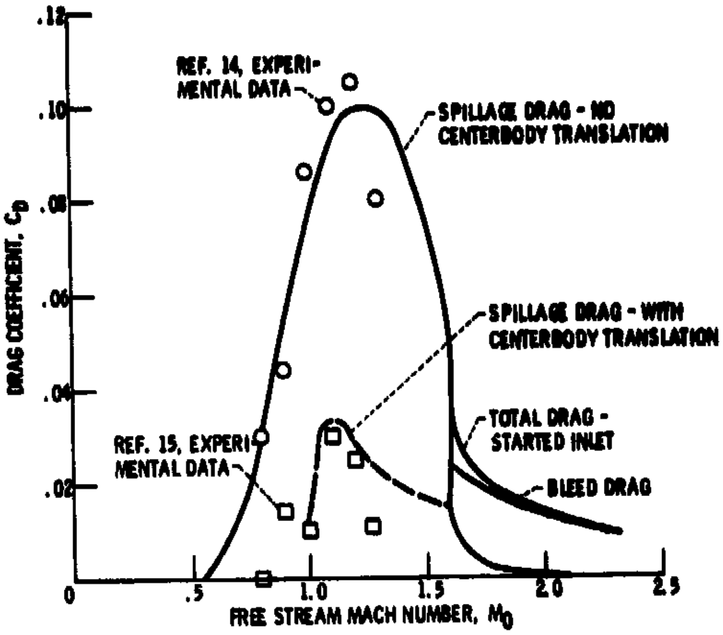


Figure 12. - Bicone inlet theoretical and experimental spillage drag characteristics.

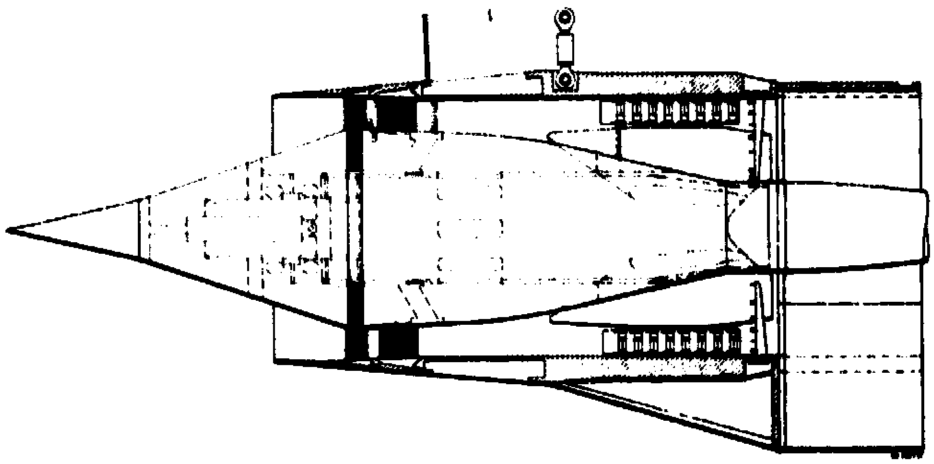
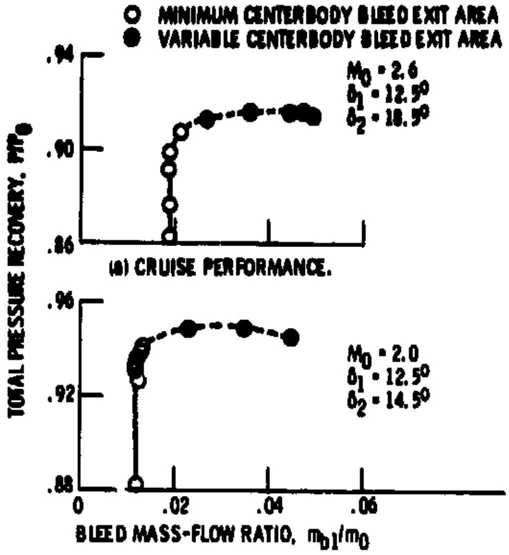
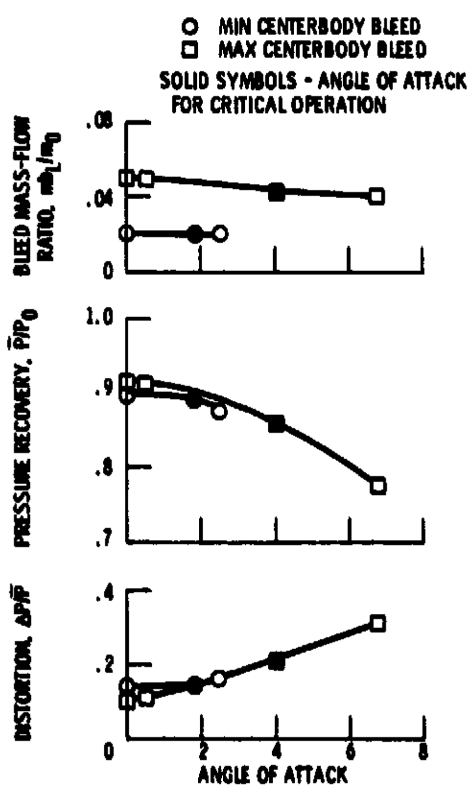


Figure 13. - Bicone inlet designed for Mach number 2.50.



(b) OFF DESIGN PERFORMANCE.

Figure 14. - Experimental inlet performance of a bicone inlet designed for Mach number of 2.50.



(c) CRUISE M_0 = 2.5, ANGLE OF ATTACK OPERATION.

Figure 14. - Concluded.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-78955		
4. Title and Subtitle INLET-ENGINE MATCHING FOR SCAR INCLUDING APPLICATION OF A BICONE VARIABLE GEOMETRY INLET		5. Report Date 6. Performing Organization Code
7. Author(s) Joseph F. Wasserbauer and William H. Gerstenmaier		8. Performing Organization Report No. E-9706
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined, where the second cone of a two cone centerbody collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Supersonic cruise inlets Inlets Propulsion systems		Unclassified - unlimited STAR Category 07	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161