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Conceptual Study of a Turbojet/Ramjet Inlet

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SUMMARY

An inlet concept for separate turbojet and ramjet engines was defined and compared with an equivalent inlet for a wraparound turboramjet engine. The comparison was made for a typical high-altitude hypersonic cruise vehicle where the turbojet inlet capture area was required to be half as large as the ramjet inlet capture area at cruise. Results of the study suggest the use of a shorter nacelle having substantially lower cooling requirements at cruise for the inlet concept for separate turbojet and ramjet engines. In addition, the separate engine concept better isolates the turbojet from the ramjet, requires no special close-off mechanisms within the turbojet, and avoids the circumferential heat load imposed by a wraparound ramjet, but it does require more variable geometry.

INTRODUCTION

The first generation of manned hypersonic cruise vehicles will probably utilize a ramjet propulsion system for high speeds and turbojets for subsonic flight and low-speed acceleration. Studies conducted in the past two decades (refs. 1 and 2) have utilized such systems which typically employ a wraparound turboramjet engine that is installed with a hypersonic inlet in much the same manner as a turbojet engine is installed with a supersonic inlet. The turboramjet engine may be installed on the vehicle in a highly integrated fashion, as in the airbreathing launch-vehicle studies of reference 1 which utilize the vehicle forebody for inlet precompression and the afterbody as part of the nozzle. However, for cruise applications at lower hypersonic speeds where the inlet and nozzle do not become prohibitively large, the propulsion system may be installed outside the forebody precompression region, such as on the wing, and will ingest airflow at essentially free-stream conditions. The inlet design requirements for a turbojet/ramjet propulsion system depend on the propulsion-system concept as well as the usual mission-related factors. The relative location of the turbojet and ramjet on the vehicle and their location to each other are important factors. In the present report, both the wraparound turboramjet and separate turbojet and ramjet concepts are considered.

The wraparound turboramjet is an integrated engine concept that consists of a core turbojet inside an annular duct which forms the ramjet (ref. 3). This results in a ramjet engine that has a large surface area. In addition, the diameter at the engine face of the combined engine requires a large subsonic diffuser ahead of the engine to meet the requirements of both the turbojet and ramjet. Thus, the wraparound turboramjet engine leads to large, wetted, internal duct areas and heat loads at cruise, and because of its integrated nature, may require the simultaneous development of both the turbojet and ramjet portions of the engine. If independent propulsion nacelles were used to separate the turbojet and ramjet engines, the development of the core turbojet and ramjet could be done separately. However, a heavy propulsion system would result, as would problems of locations for multiple nacelles on the vehicle. Past studies have considered the possibility of using a common inlet to operate a separate turbojet and ramjet or scramjet (refs. 1 and 4), and they suggest certain advantages for separating the two engines.

The purpose of this paper is to provide a baseline for studies and research of the integration of vehicles and propulsion systems at low hypersonic speeds, which is a concept similar to that of references 1 and 4 for an inlet and diffuser that would supply the necessary airflow for separate turbojet and ramjet engines in the same nacelle. A comparison is made with a wraparound turboramjet propulsion system installation using the same basic inlet design. The turbojet and ramjet engines are sized for a typical high-altitude hypersonic cruise vehicle operating at Mach 5. Some variation in relative engine-size requirements was also considered to determine the impact on the propulsion nacelle.

It should be noted that there were many factors which were not specifically assessed. These include the nozzle concept; nozzle performance; details of engine cooling; ramjet flameholder effects on duct area; weight penalties; and take-off, transonic, and off-design operational problems of the variable geometry involved. In addition, the requirement for blow-in doors, boundary-layer bleed, and other factors to facilitate inlet starting at supersonic speeds has not been addressed. These factors will undoubtedly alter the performance of a propulsion system. Further refinements of the design would necessarily involve careful consideration of the factors mentioned.

SYMBOLS

A_c inlet cowl area

A_o inlet capture area

A_t inlet throat area

C_T thrust coefficient, $\frac{\text{Thrust}}{qA_o}$

E engine face station

L/D vehicle lift-drag ratio

l axial distance

M local Mach number

M_o free-stream Mach number

NS_1 station ahead of normal shock wave

NS_2 station behind normal shock wave

p_2/p_1 local static-pressure ratio between two stations

P/P_o	ratio of local static pressure to free-stream static pressure
P_{T_2}/P_{T_1}	local total-pressure ratio between two stations
P_T/P_{T_o}	ratio of local total pressure to free-stream total pressure
q	free-stream dynamic pressure
t	inlet throat station
t'	inlet throat flow condition based on one-step calculation
TRJ	wraparound turboramjet engine
TJ/RJ	separate turbojet and ramjet engine
δ	compressive-flow turning angle, deg
ν	Prandtl-Meyer expansion angle, deg

ASSUMPTIONS

In order to define the geometric lines of a propulsion nacelle, values for engine and airframe performance must be known, along with the flight requirements of the vehicle. The purpose of this paper is to present a concept for a turboramjet inlet which may prove attractive for future hypersonic vehicle studies rather than to present the detailed design of a propulsion system to meet a specific mission requirement. In this regard, the performance assumptions used were based on current hypersonic aerodynamic research and on study engines that are typical of what might be expected in future aircraft systems. Turbojet performance is based on an advanced turbojet engine that has been studied for a supersonic transport application and is described in reference 5. Typical ramjet performance is given in reference 3.

It is not the intention of this study to design an engine for a particular mission, but rather to take these values as a typical case in order to develop engine-inlet concepts and design considerations for hypersonic cruise vehicles.

PROPULSION REQUIREMENTS

The propulsion nacelle for a combined turbojet and ramjet engine must provide for the basic inlet requirements of both engines. In a turboramjet engine designed for cruise applications, the turbojet is typically sized either by the thrust required at take-off or by the aircraft drag at transonic speeds. In addition, for a given turbojet size, the turbojet inlet cowl area is a strong function of the maximum turbojet operating speed. Based on the performance levels derived from reference 5 and the computed values of inlet efficiency, operating the turbojet at Mach 3 would require a 60-percent larger inlet cowl area than operating at Mach 2. Thus, the inlet cowl area required for the turbojet is a function of both the thrust requirement of the vehicle and the operating speed of the turbojet. For this study, a baseline turbojet inlet area was chosen to correspond to a maximum operating speed of Mach 3.

In the selection of ramjet inlet area, cruise speed and altitude are of primary importance. Since thrust is equal to drag at cruise, the inlet area can be expressed as

$$A_c = \frac{\text{Weight at cruise}}{q C_T (L/D)}$$

where weight at cruise is adjusted for centrifugal lift. As cruise speed is increased, both C_T and aerodynamic L/D are typically decreased, which tends to increase ramjet inlet area. In addition, inlet area is inversely proportional to flight dynamic pressure q, which causes inlet area to increase with increasing altitude. Thus, a large range of ramjet inlet sizes could be chosen for a given size vehicle, with the dominant variables being speed and altitude. For this study, a baseline ramjet inlet cowl area was chosen to correspond to a cruise speed of Mach 5 at an altitude of 30 500 m.

An additional parameter to be determined in order to define the inlet-engine propulsion nacelle is the ramjet burner size. The ramjet burner face area used for this study was somewhat arbitrarily selected to be 0.4 of the ramjet inlet cowl area. Based on calculated inlet compressive shock patterns, this assumption yields a Mach number of 0.11 at the burner face at cruise conditions.

INLET CONCEPT

In the previous section, propulsive performance requirements were somewhat arbitrarily chosen and included cruise at Mach 5 at an altitude of 30 500 m and a turbojet accelerator engine operating to a maximum speed of Mach 3. The result of those assumptions is estimated to be a hypersonic propulsion system having a turbojet inlet cowl area that is roughly 50 percent of the required ramjet inlet cowl area. In addition, a moderate inlet contraction ratio A_c/A_t of 12 was used for the ramjet inlet at cruise to allow for a relatively high level of inlet efficiency. The optimum selection of inlet contraction and the proper allowances for boundary-layer bleed is a subject that requires detailed tests and analysis, such as is given in reference 6, and is well beyond the scope of this paper. These specific inlet and engine sizes are a strong function of the mission requirements imposed on the vehicle and represent only one of the many combinations that could have been chosen.

Turboramjet Inlet Concepts

The turboramjet inlet and engines chosen for this study were integrated into a two-dimensional nacelle. A schematic of an inlet and subsonic diffuser for a wraparound turboramjet engine is shown in figure 1 and represents a basis of comparison for this study. The inlet is shown capturing free-stream airflow at Mach 5 cruise conditions and has a contraction ratio of about 12. The two-dimensional subsonic diffuser has a total expansion angle of 10° and extends from the throat to a cross-sectional area equal to that of the total engine face area. A constant-area transition section connects the rectangular diffuser to the circular engine and is assumed to have a length equal to 1.5 times the total turboramjet engine face diameter. An annular ramjet and a portion of its diffuser are formed around the core turbojet and are aligned with the aft end of the turbojet for installation to a nozzle. Variable geometry is accomplished by a movable inlet upper wall (identified by the cross-hatching) which extends from the second external compression surface to a point in the diffuser where the cross-sectional area is somewhat greater than the maximum required inlet throat area at transonic speeds.

The geometric lines of the turboramjet inlet and diffuser of figure 1 are considered to be generally representative of a Mach 5 engine system and yield a relatively long nacelle to meet the demands of the wraparound turboramjet engine. An alternate approach is to separate the turbojet and ramjet engines and their respective subsonic diffusers but to remain within the confines of a single nacelle. A schematic of such an engine system is shown in figure 2 and is compared with the same inlet system illustrated in figure 1. The ramjet inlet geometry at cruise is identical for the two cases shown. However, the subsonic diffuser is only required to expand to a cross section equal to the ramjet burner area and is followed by a shorter transition section since the ramjet should be less sensitive to flow distortion than the turbojet. The turbojet is accommodated above the ramjet burners by an inlet system that is formed by opening the second external compression ramp of the ramjet inlet. The lines of the inlet at Mach 3 during and after turbojet operation are shown in the schematics of figure 3. The turbojet portion of the nacelle features an external/internal compression inlet with its throat displaced forward of the ramjet inlet throat and a short diffuser that is only required to expand the airflow to a cross-sectional area equal to that of the turbojet face. The result is a nacelle that is shorter by about 25 percent, than that required of the wraparound turboramjet engine in figure 1. An additional benefit of the separate engine inlet geometry is a reduced amount of external compression when both engines are operating, which results in an increase in mass-flow ratio from 67 percent to 83 percent of the inlet cowl area at Mach 3. This improvement is caused by nearly eliminating the second external compression surface when the turbojet inlet is opened. The nozzle has been omitted from these nacelle schematics since its design, which includes weight, cooling, thrust performance, and boattail drag considerations, is beyond the scope of this paper. However, it might be observed that the separate engine concept would lend itself to a two-dimensional type nozzle although the wraparound turboramjet engine would integrate well with either axisymmetric or two-dimensional nozzles.

Inlet Analysis

The inlet design illustrated in figures 1 to 3 was intended to be a typical design for forming a basis of comparison between the separate and the wraparound ramjet engine approach. In this regard, inlet contours were defined to yield an ideal compressive shock pattern at a design cruise speed of Mach 5. The inlet inviscid flow field is given in figure 4 and features two external shock waves focused on the cowl lip. The internal shock wave originating from the cowl lip is canceled by an expansion corner on the upper surface and is followed by a second shock wave that is partially canceled by an expansion corner on the upper surface. Beyond bay 4, compression is completed through a series of weak shock waves, each having a compressive turning angle of 3°. The result is an inlet having 14° of external compressive turning and 32° of internal compressive turning.

The tabulation of inlet flow-field conditions given in figure 4 was derived from the tables of reference 7 and includes Mach number, compressive turning angle, both local static-pressure rise and total-pressure loss across the shock wave ahead of a given bay, and the accumulated static-pressure rise and total-pressure loss. Bay t' represents a one-step calculation using reference 8 to define the inlet throat flow field based on an overall inlet contraction ratio of 12 and the accumulated total pressure loss through the shock waves. In the calculation of shock-wave loss, the normal shock wave is the major contributor to the inlet total-pressure loss and is assumed to occur at a point beyond the throat where the duct cross-sectional area has expanded 10 percent. Bays NS_1 and NS_2 represent the flow field ahead of and behind the normal shock wave. The diffuser has a half-angle expansion of 5°, and based on reference 9, which assumes a thin boundary layer, would have a total-pressure recovery of about 98 percent. The inlet flow field given in figure 4 represents only one of many compression schedules and inlet contraction ratios which could be employed. A final choice would be the result of trade-offs between performance, weight, cost, and many other factors.

The inlet inviscid flow field at Mach 3, which corresponds to the inlet geometries given in figure 3, is presented in figures 5 and 6. The inlet flow field is given in figure 5 for the case in which the turbojet inlet is closed and the internal variable-geometry wall is opened a maximum amount to reduce the overall inlet contraction ratio. The resulting inlet aerodynamic contraction ratio A_o/A_t is 3.9 and, along with a rapid compression schedule, produces a long constant-area throat section having a low supersonic Mach number. When the turbojet inlet is opened, as illustrated in figure 6, the result is a flow field with a reduced rate of compression within both inlets and weak shocks ahead of the inlet throat. This flow field results from splitting the ingested inlet airflow into two streams, each requiring a smaller throat area than the combined flow field of figure 5.

The flow-field analyses given in figures 4 to 6 represent simplified calculations based on inviscid flow assumptions and illustrate the types of flow fields that could be encountered in these inlets. However, a transient condition will exist at $M = 3$ where the turbojet would be closing, with the total airflow being shifted to the ramjet. This transient condition would have to be analyzed based on the turbojet shutdown characteristics and the feasible rate of change in geometry and fuel flows for the ramjet inlet portion. Experimental results would be needed for the inlet configuration to address inlet performance and unstart characteristics under those conditions. The inlet flow field for the wraparound turboramjet engine at Mach 5 is identical to that given in figure 4 up to the normal shock, with the only difference being a larger subsonic diffuser ahead of the engine. At Mach 3, the inlet flow field for the wraparound turboramjet engine would lie somewhere between that given in figures 5 and 6 for the separate turbojet/ramjet inlet concept.

Comparative Performance

Some of the differences between the separate and wraparound turbojet/ramjet nacelle concepts include inlet mass-flow ratio at lower speeds, internal surface area at cruise, and for the separate concept, a turbojet which is better isolated from the ramjet. A detailed vehicle design and mission analysis would be required to properly assess differences in propulsion-system performance on overall vehicle performance. However, a cursory qualitative comparison of the separate and wraparound turboramjet nacelle performance is given in this section.

Inlet mass-flow ratio at speeds less than cruise can have an effect on spillage drag, ramjet airflow, and the resulting acceleration performance. Both of the inlet systems given in figure 2 are designed for full capture at Mach 5. The mass-flow ratio of the inlet for separate engines is given at several lower Mach numbers in figures 3 and 7. Between Mach 5 and Mach 3, the inlet spills across 14° of external compressive turning. At Mach 3, the turbojet portion of the inlet is opened to provide the required airflow for the turbojet, and consequently reduces the external inlet compression ahead of the ramjet with a resulting increase in mass-flow ratio. At lower speeds (fig. 7), the turbojet inlet closes to follow a required airflow schedule, whereas the inlet throat area is increased for a lower contraction ratio to maintain supersonic flow at the inlet throat. The result is an increase in external compressive turning ahead of the ramjet and an increase in inlet air spilled at lower speeds. A set of inlet schematics illustrating spillage at lower speeds for the wraparound turboramjet inlet is given in figure 8. For this inlet, compressive turning across the second external compression surface is reduced at lower Mach numbers as the inlet throat area is increased to pass the combined ramjet and turbojet airflow at the proper contraction ratio.

A summary of the mass-flow ratio of the two inlets derived from figures 3, 7, and 8 is compared in figure 9 in terms of mass-flow ratio plotted against flight Mach number. The wraparound engine is given by the dashed curve and shows some advantage in mass-flow ratio at speeds above Mach 3 and a reduced mass-flow ratio below Mach 3. Additive drag resulting from the spillage airflow is also given in figure 9 and shows the same trend, with a large percentage increase in drag for the separate turbojet/ramjet inlet when the turbojet inlet is closed. A large normal force also exists which would produce lift for an inlet located on the bottom portion of an airframe and would be added to the airframe lift as was illustrated in reference 10.

Important aspects of engine performance are weight and heat load at cruise, both of which are a function of the internal surface area. A comparison of the inlet, diffuser, and ramjet burner wetted areas for the wraparound and separate engine concepts is given in table I. There is a small advantage for the separate engine concept in terms of total wetted area, with the reduced wetted area occurring in the inlet diffusers and ramjet burner. However, a much larger difference in surface area exposed to the engine airflow exists at higher speeds when the turbojet is closed off, as shown in column 3 of table I. At this condition, the inlet surface area up to the throat is the same, whereas the ramjet diffuser and burner of the separate engine concept has only 45 percent of the wetted surface area of the wraparound engine concept. The total surface area that is exposed to the flow at cruise is thus reduced by 38 percent. The highest pressures occur in the ramjet diffuser and burner so that a significant reduction in engine heat load would be expected for the separate engine concept. For the separate engine concept, two circular ramjet burners were chosen in response to the possibility of high pressure loads and the need for structural efficiency. A single rectangular or elliptical combustor would further reduce internal surface area by reducing or eliminating the ramjet diffuser transition section and by reducing the surface area of the ramjet burner. The optimum design requires a careful trade between structural efficiency and surface area based on a particular mission. For this study, it was felt that circular ramjet combustors would represent a conservative comparison between the length and wetted area of the two nacelle concepts. The weight of both the variable-geometry wall sections and the required actuators for both concepts needs further study to allow the proper trade-offs to be made.

In addition to the inlet mass-flow ratio, nacelle-size, and internal surface-area differences between the engine concepts discussed so far, there are additional aspects of the nacelle design which would influence performance. One advantage of the separate engine concept is better isolation of the turbojet from the ramjet. The turbojet is aerodynamically isolated from the ramjet through the supersonic inlet, may not require special close-off doors, is not circumferentially exposed to the ramjet heat load at cruise (as is the case with the wraparound engine), and thus should allow more opportunity to utilize existing turbojet engines. Potential disadvantages of the separate engine concept might include the requirement for a more complicated nozzle and more extensive use of variable geometry in the inlet.

Effect of Turbojet Engine Size and Transition Mach Number on the Inlet Size

Thus far, the wraparound and separate turboramjet engine nacelles were compared for the baseline turboramjet engine. The effect of changing the relative size of the turbojet and ramjet engines is parametrically illustrated in figure 10 in terms of three different size turbojets installed with the baseline inlet and ramjet, which represent turbojets that are 43-percent larger and 34-percent smaller than the baseline turbojet size. As would be expected, a change in turbojet size causes a corresponding change in the size of the turbojet inlet and diffuser although the ramjet inlet and diffuser is unchanged above Mach 3. As a result of larger turbojet installations, the forward movable splitter becomes very thin, the structural depth above the ramjet variable-geometry wall is limited, and expansion waves are formed ahead of the ramjet inlet cowl, thus reducing its compressive performance. A similar effect can be seen in figure 11, in which the engine nacelles are shown with the baseline turbojet engine size but operating to different maximum speeds. In order to properly match the turbojet demand airflow, the turbojet inlet size increases significantly at higher speeds and can dominate the overall inlet geometry. The result at Mach 4 is a long turbojet inlet dominating the nacelle with little airflow through the ramjet. Some of these inlet matching problems could probably be reduced by changing design features of the inlet. However, figures 10 and 11 do illustrate that there is a practical limit to the size of turbojet inlet that can be accommodated within this separate turboramjet engine nacelle concept.

CONCLUDING REMARKS

A study of an inlet concept for separate turbojet/ramjet engines for hypersonic cruise vehicles has been conducted and has been compared with an inlet concept for a wraparound turboramjet engine. Results of this study indicate that

1. A nacelle for separate turbojet and ramjet engines can be defined, with the turbojet portion of the inlet formed by opening the second external compression surface of a basic two-dimensional ramjet inlet. The result was a turbojet which did not require special close-off provisions and which was better isolated from the ramjet heat load at hypersonic speeds.

2. Including the ramjet burner, the independent inlets and diffusers of the separate engine concept resulted in a 25-percent shorter nacelle having about 40 percent less surface area for cooling at cruise, as compared with a wraparound turboramjet engine.

3. The concept of forming separate inlets with diffusers from an external compression surface of a basic two-dimensional inlet becomes impractical for separate turbojet and ramjet engines when the turbojet inlet size approaches the size of the ramjet cruise inlet.

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TABLE I.- ENGINE INTERNAL WETTED AREA EXCLUDING

THE TURBOJET AND NOZZLE

Area	Total wetted area/A_c		Exposed wetted area/A_c at cruise	
	Wraparound TRJ	Separate TJ/RJ	Wraparound TRJ	Separate TJ/RJ
Inlet ahead of throat	10.0	13.9	10.0	10.0
Inlet/diffuser aft of throat	16.3	11.8	16.3	6.5
Ramjet burner	5.0	3.2	5.0	3.2
Total wetted area	31.3	28.9	31.3	19.7

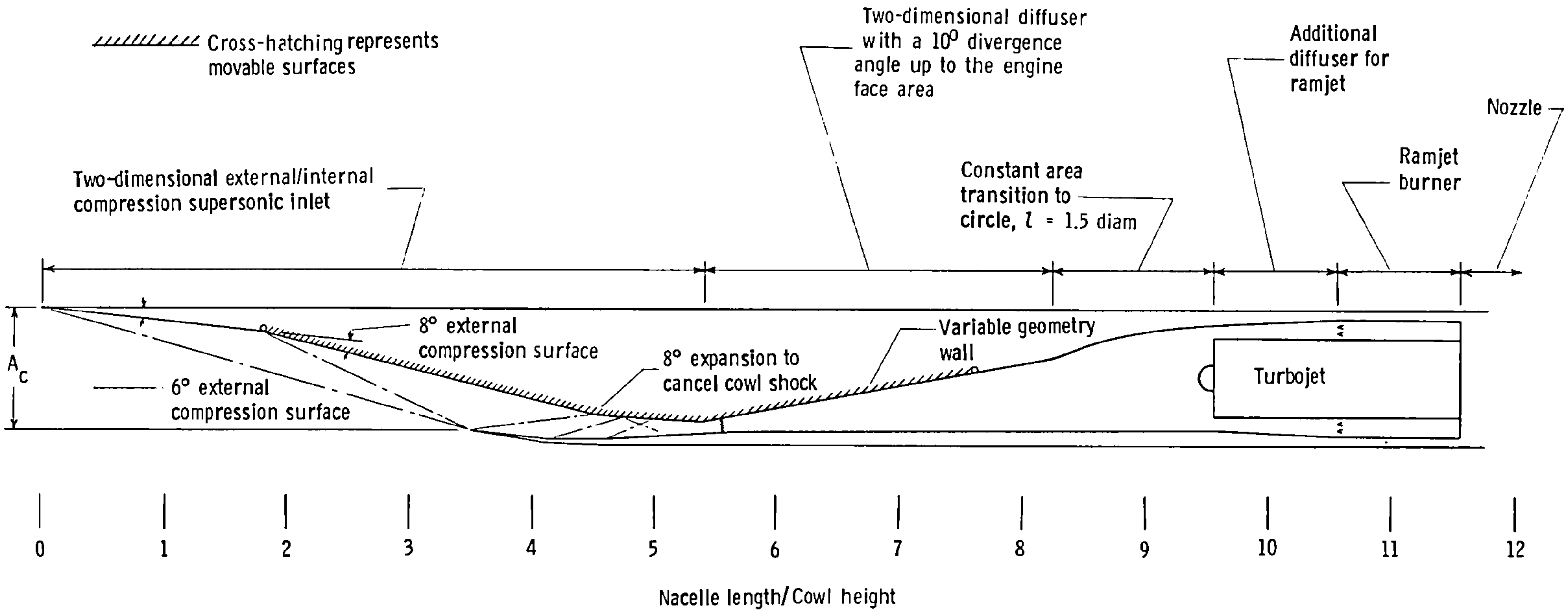


Figure 1.- Two-dimensional inlet concept for turboramjet engine.

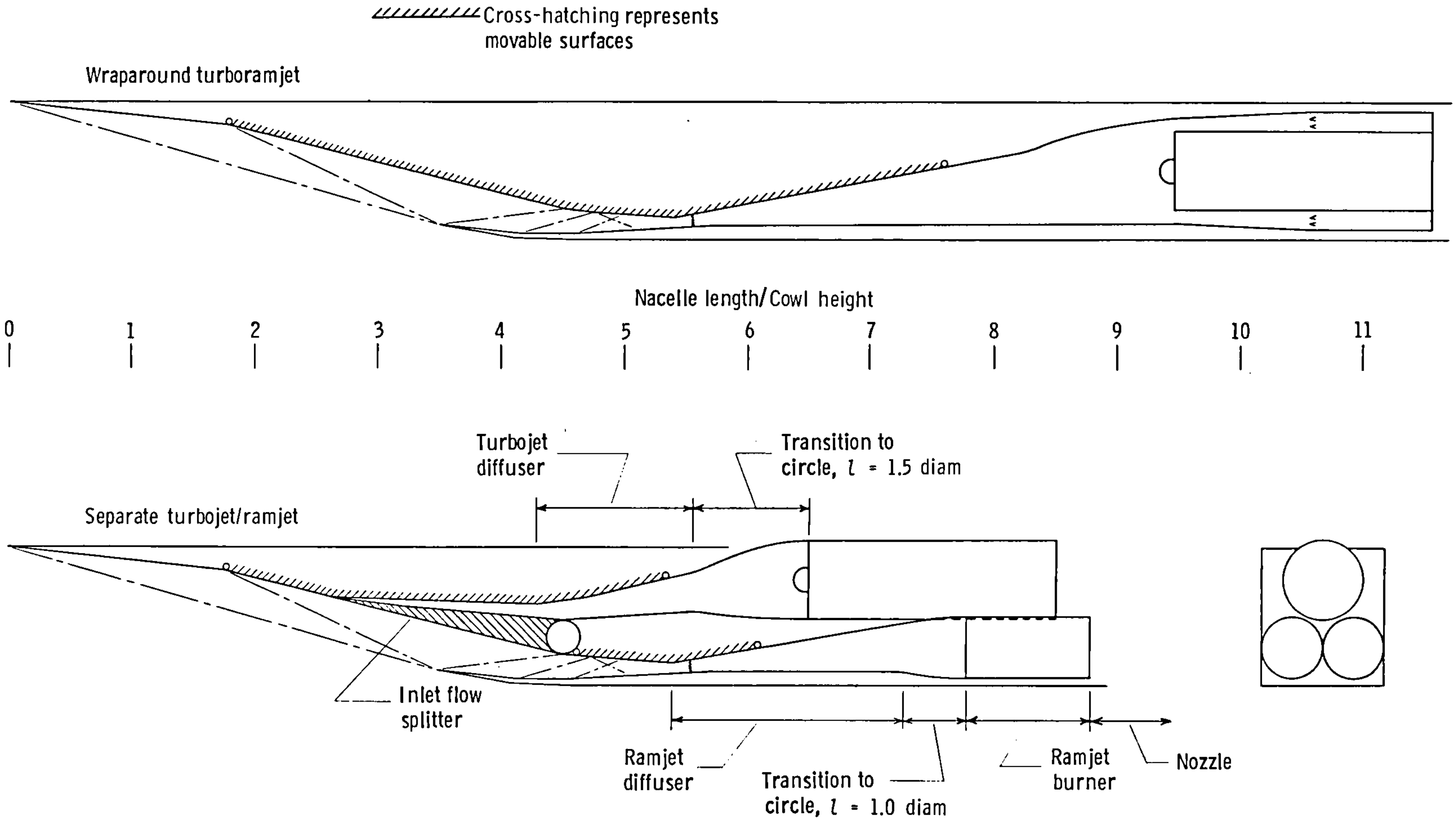


Figure 2.- A comparison of two-dimensional inlet concepts for wraparound and separate turboramjet engine at Mach 5 cruise.

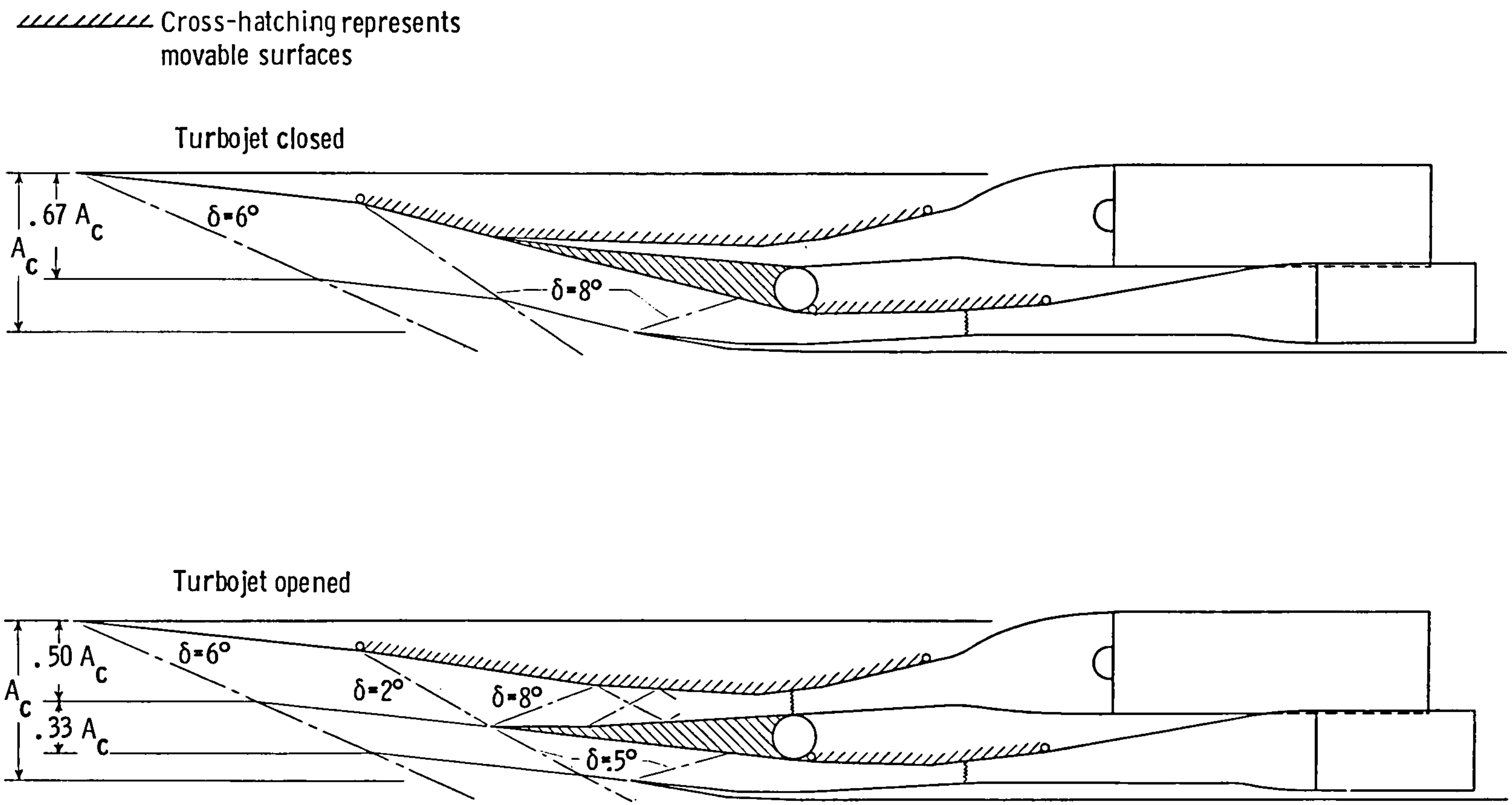
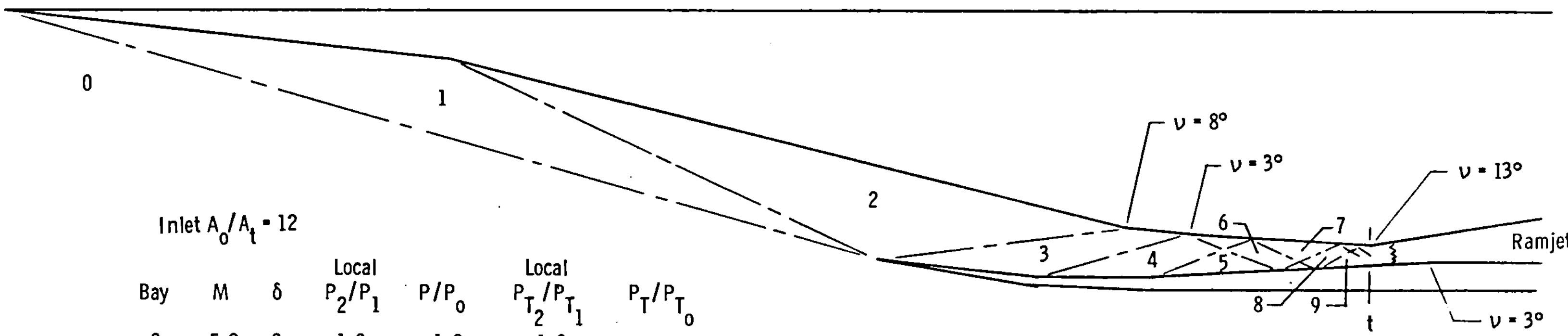


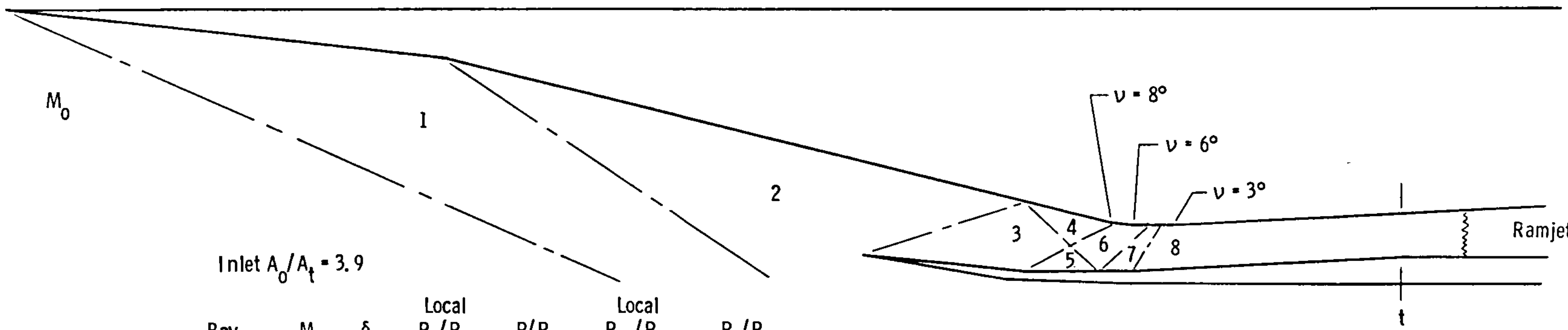
Figure 3.- Separate turboramjet engine concept at Mach 3 with turbojet inlet closed and opened.



Inlet $A_0/A_t = 12$

Bay	M	δ	Local P_2/P_1	P/P_0	Local P_{T_2}/P_{T_1}	P_T/P_{T_0}
0	5.0	0	1.0	1.0	1.0	
1	4.39	6	2.017	2.02	.966	.966
2	3.73	8	2.261	4.56	.947	.915
3	3.21	8	2.025	9.23	.965	.883
4	2.87	6	1.606	14.83	.989	.873
5	2.73	3	1.245	18.46	.999	.872
6	2.58	3	1.234	22.79	.999	.871
7	2.45	3	1.222	27.84	.999	.870
8	2.32	3	1.213	33.77	.999	.870
9	2.20	3	1.203	40.63	.999	.869
t	2.09	3	1.194	48.51	.999	.869
t'	2.08			51.5		.869
NS_1	2.20		.835	43.0	1.00	.869
NS_2	.547		5.480	235.7	.628	.546
E	.11		1.154	272.0	.98	.535

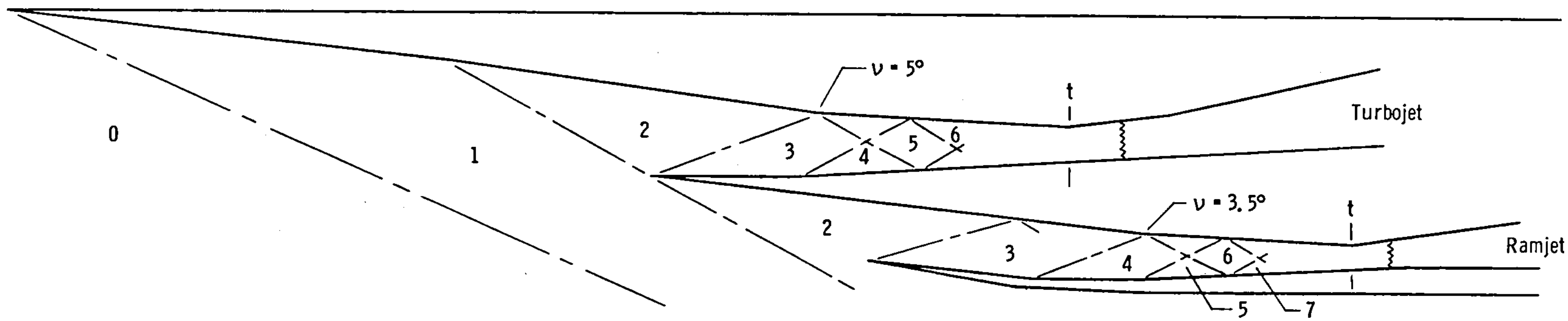
Figure 4.- Inlet inviscid flow field for separate turbojet and ramjet engine at Mach 5 with turbojet inlet closed.



Inlet $A_0/A_t = 3.9$

Bay	M	δ	Local P_2/P_1	P/P_0	Local P_{T_2}/P_{T_1}	P_T/P_{T_0}
0	3.0					
1	2.70	6	1.562	1.56	.991	.991
2	2.35	8	1.710	2.67	.984	.975
3	2.03	8	1.619	4.32	.989	.964
4	1.74	8	1.546	6.69	.992	.957
5	1.81	6	1.391	6.01	.996	.961
6	1.53	6	1.355	9.06	.997	.954
6'	1.53	8	1.505	9.05	.993	.954
7	1.24	8	1.486	13.46	.994	.948
8, t	1.12	3	1.176	15.82	1.000	.948
t'	1.20			14.4		.948
NS_1	1.43		.730	10.52	1.00	.948
NS_2	.727		2.219	23.34	.950	.901
E	.26		1.292	30.16	.98	.883

Figure 5.- Inlet inviscid flow field for separate turbojet and ramjet engine at Mach 3 with turbojet inlet closed.



TURBOJET INLET

Inlet $A_0/A_t = 3.5$

Bay	M	δ	P_2/P_1	P/P_0	P_{T_2}/P_{T_1}	P_T/P_{T_0}
0	3.0					
1	2.70	6	1.562	1.56	.991	.991
2	2.61	2	1.150	1.80	1.000	.991
3	2.26	8	1.685	3.03	.986	.977
4	2.14	3	1.200	3.63	.999	.976
5	2.03	3	1.190	4.32	.999	.975
6	1.92	3	1.183	5.11	1.000	.975
t'	1.50	12		9.74		.973
NS_1	1.65		.802	7.81	1.000	.973
NS_2	.654		3.010	23.51	.876	.852
E	.26		1.210	28.45	.98	.835

RAMJET INLET

Inlet $A_0/A_t = 3.5$

Bay	M	δ	P_2/P_1	P/P_0	P_{T_2}/P_{T_1}	P_T/P_{T_0}
0	3.0					
1	2.70	6	1.562	1.56	.991	.991
2	2.67	.5	1.037	1.62	1.000	.991
3	2.65	.5	1.037	1.68	1.000	.991
4	2.37	6.5	1.544	2.59	.990	.981
5	2.25	3.0	1.206	3.13	.999	.980
6	2.13	3.0	1.198	3.75	.999	.979
7	2.02	3.0	1.190	4.46	.999	.978
t'	1.51	15		9.66		.976
NS_1	1.66		.801	7.74	1.000	.976
NS_2	.651		3.048	23.58	.872	.851
E	.13		1.244	29.33	.98	.834

Figure 6.- Inlet inviscid flow field for separate turbojet and ramjet engine at Mach 3 with turbojet inlet opened.

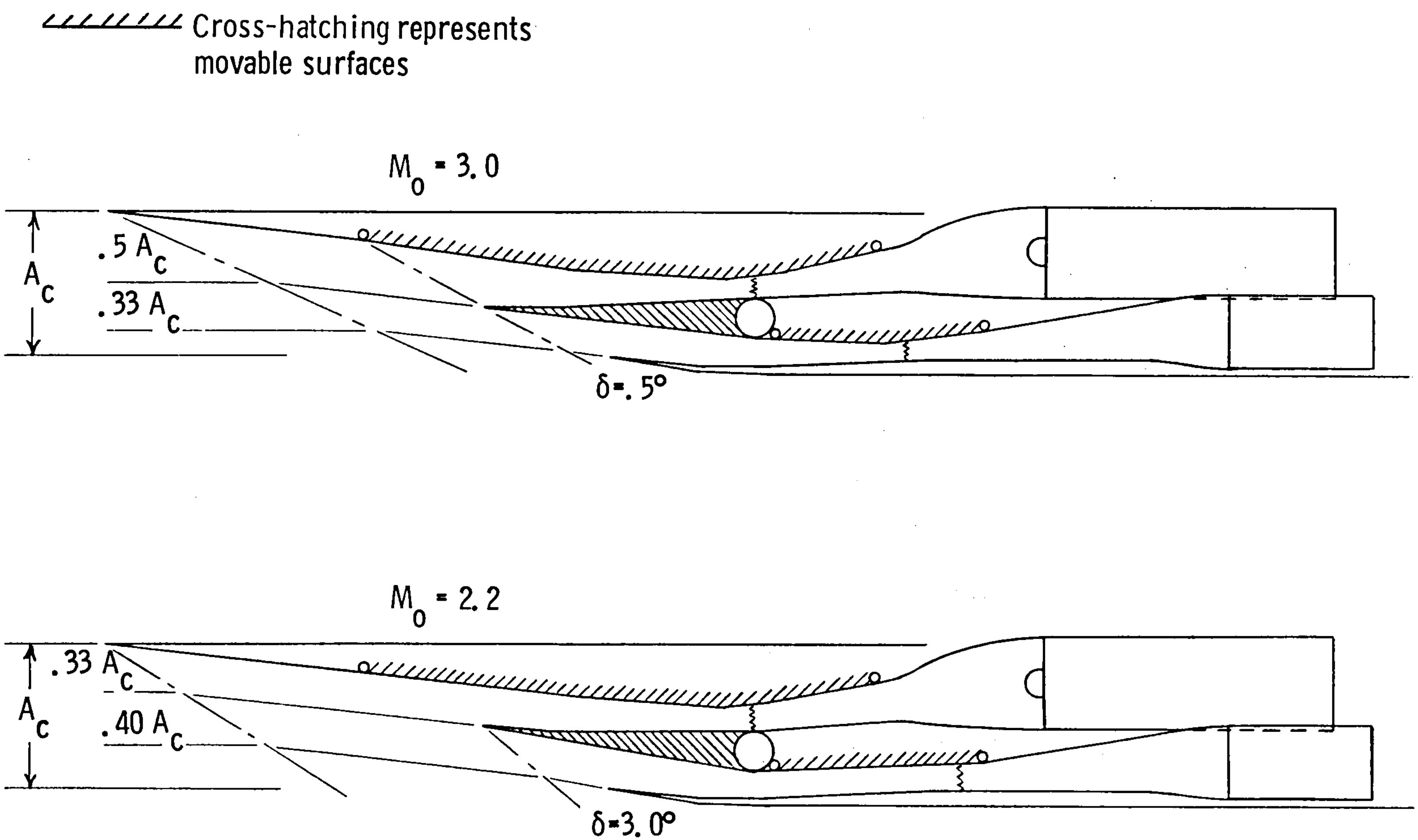


Figure 7.- Inlet external shock pattern at lower speeds for separate turbojet and ramjet engines.

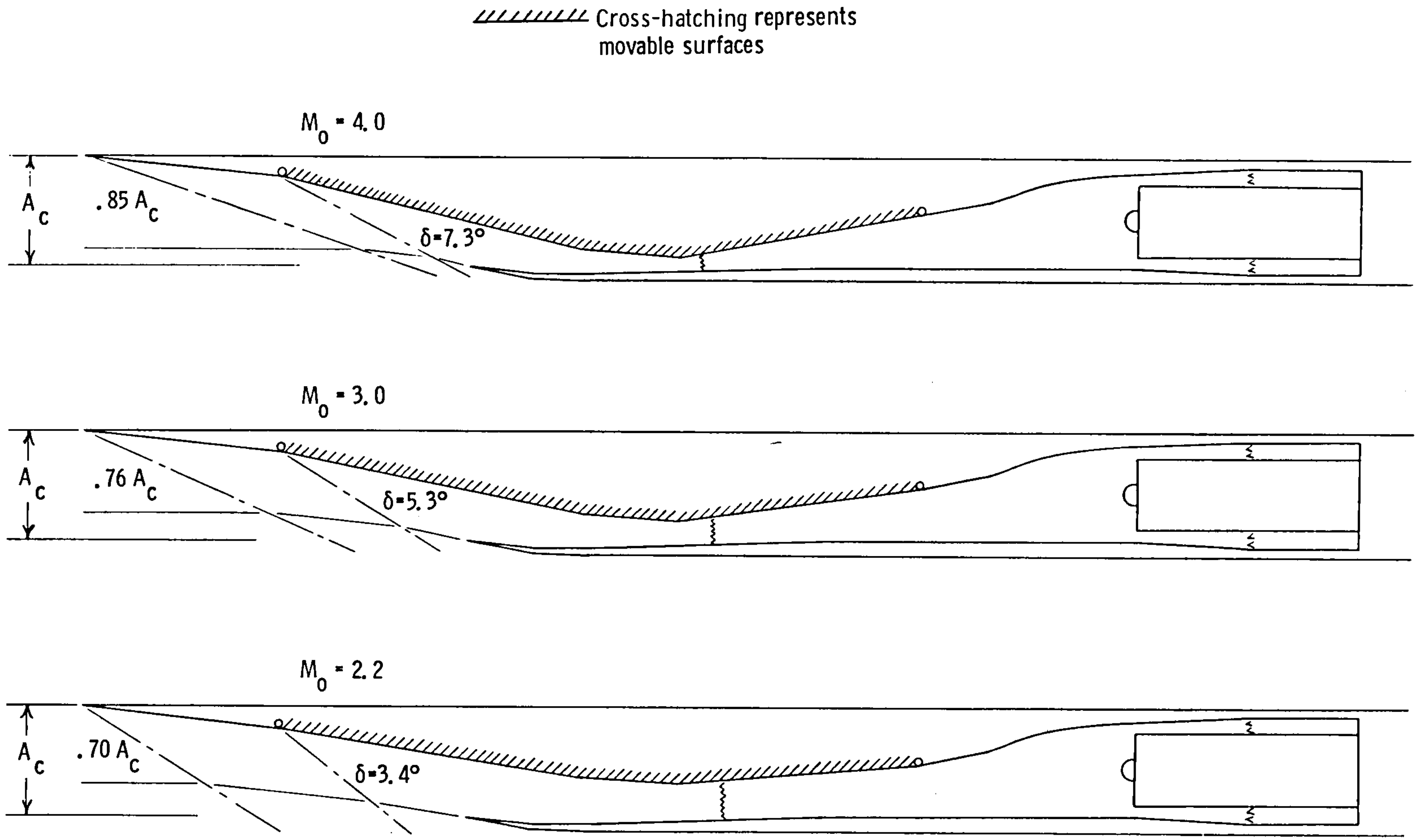


Figure 8.- Inlet external shock pattern at lower speeds for wraparound turboramjet engine.

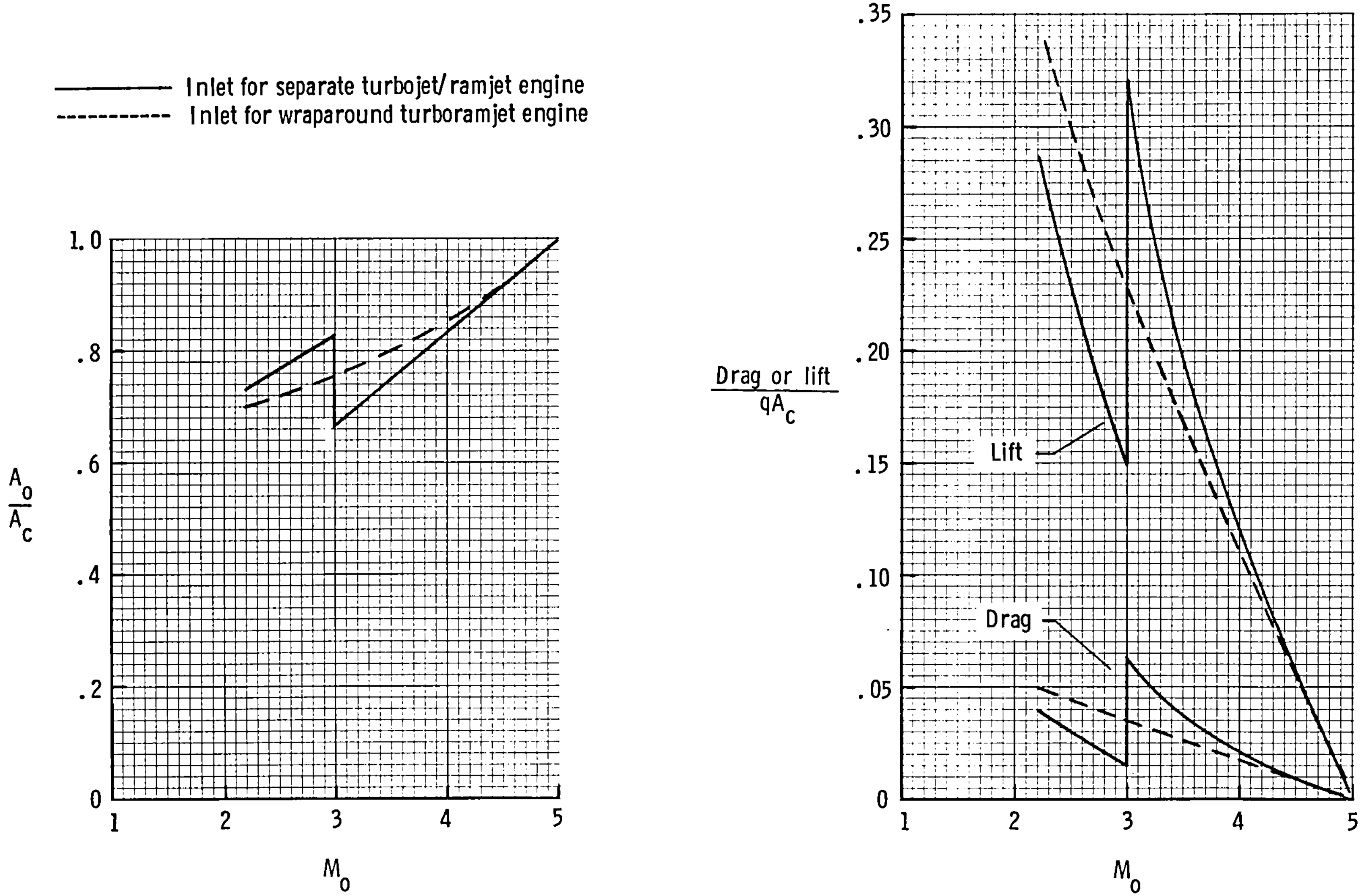


Figure 9.- Inlet mass flow ratio and drag and lift due to spillage.

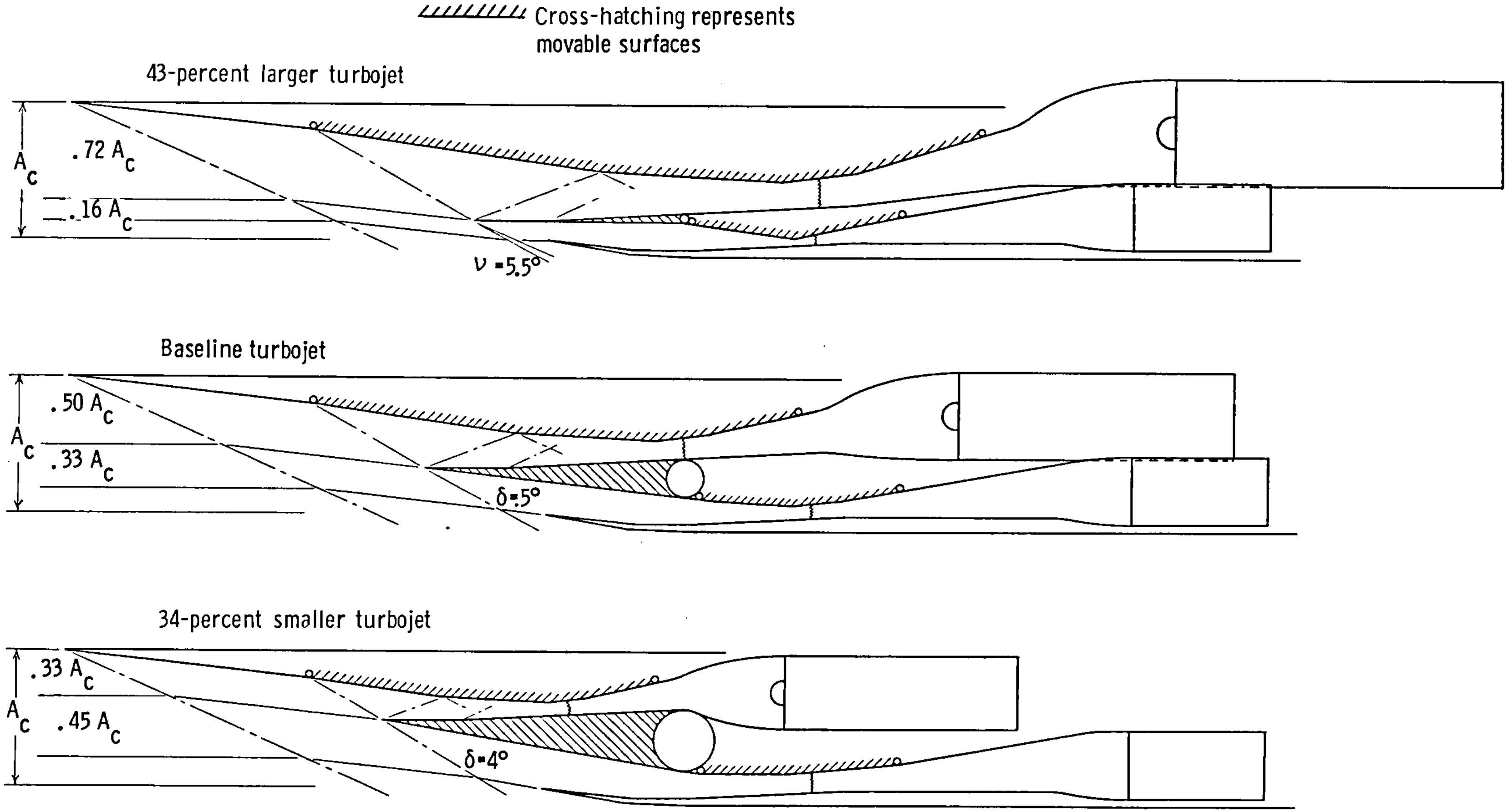


Figure 10.- Effect of relative turbojet size on inlet design at Mach 3.

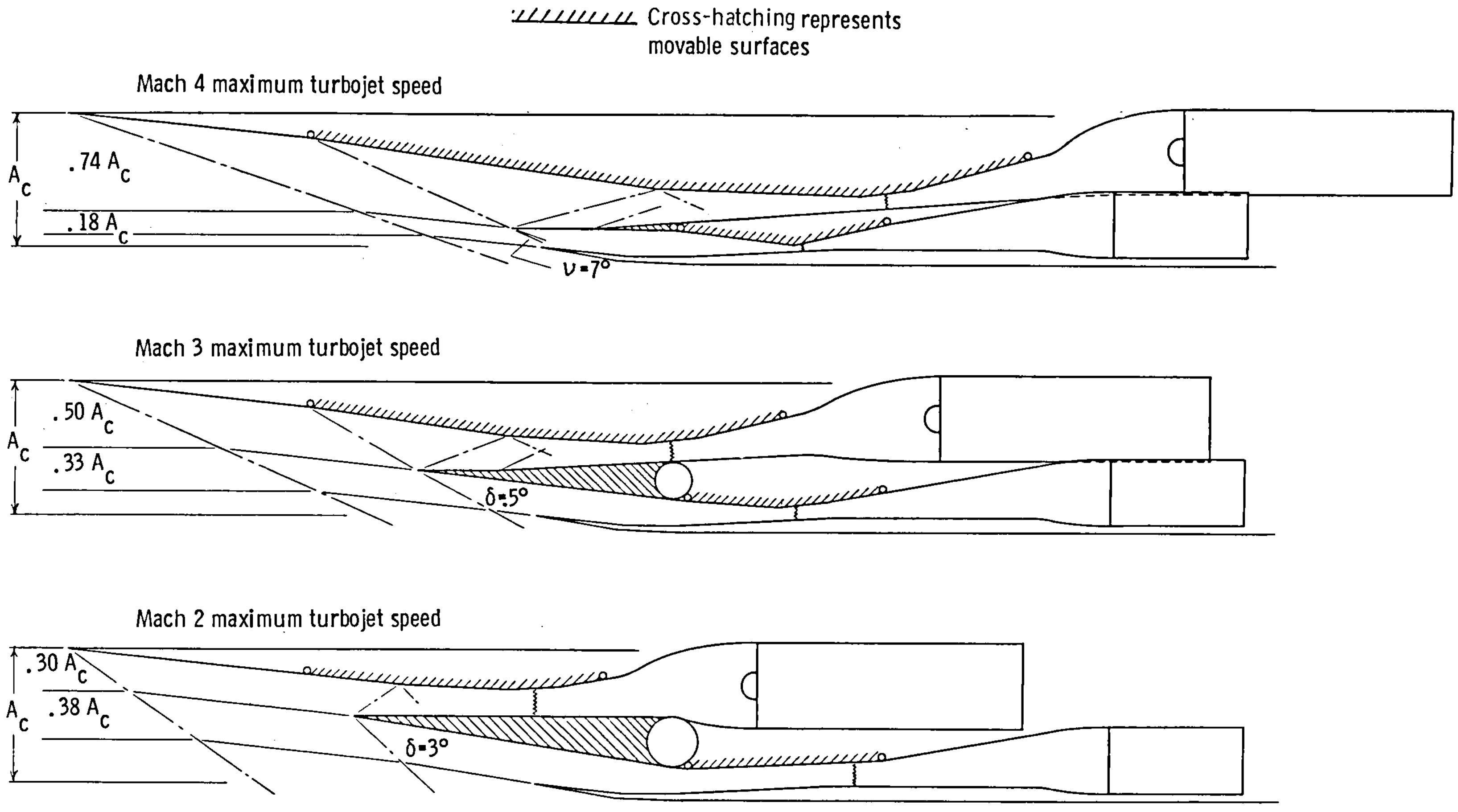


Figure 11.- Effect of maximum turbojet operating speed on inlet design.

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15. Supplementary Notes

16. Abstract

An inlet concept for separate turbojet and ramjet engines was defined and compared with an equivalent inlet for a wraparound turboramjet engine. The comparison was made for a typical high-altitude hypersonic cruise vehicle where the turbojet inlet capture area was required to be half as large as the ramjet inlet capture area at cruise. Results of the study suggest the use of a shorter nacelle having substantially lower cooling requirements at cruise for the inlet concept for separate turbojet and ramjet engines. In addition, the separate engine concept better isolates the turbojet from the ramjet, requires no special close-off mechanisms within the turbojet, and avoids the circumferential heat load imposed by a wraparound ramjet, but it does require more variable geometry.

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