UNCLASSIFIED ~~CONFIDENTIAL~~

Copy
RM E53H11

NACA RM E53H11

NACA

RESEARCH MEMORANDUM

PERFORMANCE COMPARISON AT SUPERSONIC SPEEDS OF INLETS SPILLING EXCESS FLOW BY MEANS OF BOW SHOCK, CONICAL SHOCK, OR BYPASS

By J. L. Allen and Andrew Beke

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

CLASSIFICATION CHANGED

UNCLASSIFIED

To

By authority of Nasa PA 4 Date Effective 2-10-59
NB 4-16-59

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
October 23, 1953

~~CONFIDENTIAL~~

UNCLASSIFIED

UNCLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

PERFORMANCE COMPARISON AT SUPERSONIC SPEEDS OF INLETS SPILLING EXCESS FLOW BY MEANS OF BOW SHOCK, CONICAL SHOCK, OR BYPASS

By J. L. Allen and Andrew Beke

SUMMARY

Fixed-geometry, translating-spike, and bypass inlets which were previously investigated on an axially symmetric spike-type model in the Lewis 8- by 6-foot supersonic tunnel at flight Mach numbers of 1.5 to 2.0 are compared on the basis of turbojet- and ram-jet-engine performance. The inlet for the turbojet engine was so sized at a subsonic Mach number that spillage of air was required at supersonic speeds. Fixed-exhaust-nozzle ram-jet engines were designed for maximum impulse at a flight Mach number of 2.0 and evaluated on the basis of excess thrust available with the three types of inlet for mass-flow spillage.

In general, the bypass inlet had the highest turbojet effective thrust ratio and the fixed-geometry inlet had the lowest. The performance of the translating-spike inlet could be made competitive between flight Mach numbers of 1.5 to 1.9 if the pressure-recovery losses due to spike translation were minimized. At a flight Mach number of 2.0, competitive performance could not be realized, since the drag associated with conical shock spillage was about twice that due to bypassing. For constant pressure-altitude and flight Mach number operation at nonstandard atmospheric temperatures, the effective thrust ratio of the bypass inlet was nearly constant whereas the effective thrust ratios for the other inlets varied.

The excess thrust obtainable with the bypass-inlet ram jet was greater than that of the other inlets at flight Mach numbers from 1.6 to 2.0; at the lower Mach numbers, this indicated that a smaller booster unit could be used. At a flight Mach number of 2.0 and angles of attack from 0° to 9°, the bypass inlet had the largest excess-thrust margin; at an angle of attack of 9°, only the bypass-inlet ram jet was capable of thrust greater than that required for cruising at an angle of attack of 0°.

[redacted]

UNCLASSIFIED

INTRODUCTION

When the air-flow capacity of a fixed-geometry inlet exceeds that required by the engine at supersonic speeds, the excess weight flow must be spilled behind an inlet normal shock with attendant high drags. Various methods of reducing these high drags by varying the inlet geometry have been proposed. One method consists in varying the tip projection of the compression surface so that the spillage occurs behind an oblique or conical shock. In another method, a small scoop, or bypass, is located in the diffuser forward of the engine or combustion chamber to discharge excess mass flow. These systems have been investigated in the NACA Lewis laboratory 8- by 6-foot supersonic tunnel on an axially symmetric spike-type model suitable for a nacelle power-plant installation. The fixed-geometry data are reported in reference 1; the bypass data, in references 2 to 4; and the translating-spike data, in reference 5.

The purpose of this report is to evaluate these data in terms of turbojet- and ram-jet-engine performance on the basis of effective thrust ratio for the turbojet, net propulsive thrust for the ram-jet, and specific impulse for both types of engine. Propulsive-unit performance characteristics for a turbojet engine utilizing the three types of inlets are presented for a range of flight Mach numbers from 1.5 to 2.0 and an altitude of 35,000 feet. The ram jet is analyzed with respect to excess thrust available for an engine designed for efficient cruising at a flight Mach number of 2.0.

SYMBOLS

The following symbols are used in this report:

A	area
A_m	external maximum cross-sectional area
$C_{D,e}$	external-drag coefficient, D_e/q_0A_m
$C_{D,s}$	spillage-drag coefficient, external-drag coefficient minus minimum-drag coefficient for fixed-geometry inlet
$C_{F,n}$	net-thrust coefficient of ram jet, F_n/q_0A_m
D_e	force on inlet in stream direction determined by applying momentum theorem to air passing outside engine (plus internal and external effect of bypassing)

3022

CK-1 back

F_n	net thrust, net force in flight direction resulting from change of momentum of engine mass flow between free stream and exit
$\frac{F_n - D_s}{F_{n,i}}$	effective thrust parameter for turbojet
$F_{n,i}$	ideal net thrust at 100 percent pressure recovery
I	specific impulse, $\frac{F_n - D_s}{W_f}$ and $\frac{F_n - D_e}{W_f}$, sec
L	length of subsonic diffuser, 46.9 in.
M	Mach number
m	mass flow
$\frac{m_4}{m_0}$	mass-flow ratio, $\frac{\text{diffuser-exit mass flow}}{\rho_0 V_0 A_c}$
P	total pressure
p	static pressure
q	dynamic pressure, $\gamma p M^2/2$
T	total temperature, °R
t	static or atmospheric temperature, °R
V	velocity
W	weight flow, lb/sec
$\frac{W\sqrt{\theta}}{\delta}$	corrected rate of weight flow, lb/sec
W_f	rate of fuel flow, lb/sec
x	longitudinal station, in.
γ	ratio of specific heats for air
δ	ratio of local total pressure to static pressure of NACA standard atmosphere at sea level, 2116 lb/sq ft abs

ρ	mass density of air
τ	ram-jet-engine total-temperature ratio, T_7/T_0
θ	ratio of total temperature to static temperature of NACA standard atmosphere at sea level, 519° R

Subscripts:

c	capture (area of cowling)
s	spillage
x	longitudinal station
0	free stream
1	inlet at minimum area
4	diffuser exit
7	ram-jet exit

DESCRIPTION OF MODELS

An axially symmetric spike-type inlet was used for the experimental investigations of the fixed-geometry, translating-spike, and bypass models; details of the models are described in references 1 to 5. The fixed-geometry inlet used herein was inlet B of reference 1, which was designed for a mass-flow ratio of unity at a flight Mach number of 2.0. The longitudinal area-ratio variation for this inlet is shown by the solid line in figure 1. The bypass inlet was made from the fixed-geometry inlet by adding one or two fixed-area bypass inserts, each of which was capable of spilling approximately 10 percent of the captured mass flow. Detailed data for the model with two bypasses are presented in reference 2; and data for a single bypass, in reference 3. The change in diffuser area-ratio variation with one and two bypasses installed is shown in figure 1. The importance of maintaining a low bypass-exit angle is shown in reference 4. The translating-spike model, which was also made from inlet B of reference 1, had three progressively greater spike projections which roughly corresponded to mass-flow spillages of 10, 20, and 30 percent of the maximum capture mass flow. Diffuser area-ratio changes associated with these spike translations are also shown in figure 1. The common point of the various spikes, which would correspond to a telescoping junction on an actual installation, was at a mechanically feasible location where the slope of the centerbody was nearly zero. A slight external difference in the cowl leading-edge radius existed between the models of references 1 and 5.

METHODS OF ANALYSIS

Propulsive units consisting of a turbojet engine having fixed-geometry, translating-spike, or bypass inlets are compared on the basis of an effective thrust parameter $(F_n - D_s)/F_{n,i}$ and specific impulse I. The thrust of the installed engine with afterburning F_n was corrected for inlet total-pressure losses but not for total-pressure-loss changes in the exhaust nozzle; ideal thrust $F_{n,i}$ is for 100 percent pressure recovery. Spillage drag D_s is the drag at the operating point minus the minimum drag for the fixed-geometry inlet at critical inlet flow for the same flight Mach number. The spillage drag corresponds to additive drag plus the change in pressure and friction drag due to spillage. Spillage drag is due to bow-shock spillage for the fixed-geometry inlet and to conical-shock spillage for the translating spike. For the bypass inlet, the shock structure is not changed by bypassing, and the spillage drag is the net internal and external effect due to bypassing. Specific impulse I is another parameter for evaluating inlet performance. Specific impulse, which is the reciprocal of thrust specific fuel consumption expressed in seconds, was computed by correcting the fuel flow at 100 percent recovery for constant fuel-air-ratio operation at other recoveries. In addition, specific impulse is proportional to the net efficiency of the propulsive unit for a given flight speed and fuel and, hence, is proportional to aircraft range for a Breguet flight plan in the isothermal atmospheric region.

The performance of the ram-jet engine was computed by adding the effects of a flame-holder pressure loss, of heat addition without mass addition, and of exhaust-nozzle force to the cold-flow inlet data. The flame-holder pressure loss $\Delta P/q$ was assumed to be 2.0. One-dimensional flow relations were used to compute the effects of heat addition for ratios of specific heats of air of 1.4 before and 1.3 after combustion and through the nozzle. A combustion efficiency of 100 percent was assumed; and the convergent-divergent exhaust nozzle, which re-expanded to maximum engine diameter (equal to cold-flow diffuser-exit diameter), was assumed to be 100 percent efficient. The nozzle size was selected for maximum impulse at a Mach number of 2.0 and an altitude of 35,000 feet. The drag D_e is the total external drag of the ram jet which was considered as an isolated nacelle unit; consequently, impulse parameters for the turbojet and ram-jet engines are not comparable.

RESULTS AND DISCUSSION

Comparison of experimental data. - Comparisons of drag due to spillage, diffuser total-pressure recovery, and diffuser-exit mass-flow ratio for the fixed-geometry, translating-spike, and bypass inlets at an angle of attack of 0° and flight Mach numbers from 1.5 to 2.0 are shown in figure 2 as functions of corrected weight flow per unit of diffuser-exit area. Variable-spike-projection or bypass sonic-discharge area are represented by the curves faired through the data points for the translating-spike and bypass configurations, respectively. Inlet operation along these lines corresponds to critical inlet flow (normal shock at the inlet entrance) and spilling excess mass flow either through the bypass or by means of the conical shock for the translating spike. Except for the mandatory spillage behind the conical shock at below-design flight Mach numbers, fixed-geometry spillage occurs behind a bow or normal shock.

The increase in drag due to spilling air flow by means of the bypass or the translating spike was only a fraction (10 to 50 percent) of that for equivalent bow-shock spillage over the range of flight Mach numbers. For a flight Mach number of 2.0, the bypass drag was about one-fifth and the translating-spike drag about one-half of the drag for equivalent bow-shock spillage. At a flight Mach number of 1.8 (fig. 2(b)), drags for both the translating spike and the bypass were only a small fraction of those for the fixed geometry although the bypass drags were about twice those of the translating spike. This drag cross-over is presumably related to an under-pressure condition in the fixed re-expansion - ratio bypass nozzle at the lower Mach numbers. Over the range of flight Mach numbers, the diffuser pressure recovery was not significantly changed when the bypass inlet was used. However, at flight Mach numbers of 2.0 and 1.8 (figs. 2(a) and (b)), pressure recoveries for the translating spike inlet decreased rapidly as the cone was translated outward and spillage occurred behind the conical shock. This pressure-recovery reduction may be associated with expansion of the flow over the knob or shoulder of the cone ahead of the cowl lip (junction of the conical and the centerbody contours). Some possibilities for improving the pressure recovery of the translating spike are discussed in reference 5; however, the drag characteristics at a flight Mach number of 2.0, which are shown to be in agreement with theory in reference 5, would not be subject to large improvement. At a flight Mach number of 1.5 (fig. 2(d)), the pressure recovery for the translating spike remained practically constant as weight flow was reduced.

The pressure recovery for the fixed-geometry inlet at critical inlet flow decreased slightly as the flight Mach number decreased from 1.6 to 1.5. This effect is not entirely understood; however, higher friction losses at a flight Mach number of 1.5 in the nearly constant-area portion of the diffuser may have been the cause.

The data for the translating spike and the bypass shown in figure 2 should be interpreted not as a general comparison of optimum inlet configurations but rather as a comparison of the particular inlets investigated, since both could be improved somewhat.

Application to turbojet engines. - The variation of corrected weight flow with flight Mach number at an altitude of 35,000 feet for a selected turbojet engine operating at constant rotational speed is shown in figure 3. Also shown in figure 3 is the weight-flow attainable with a fixed-geometry inlet operating at the pressure recovery at critical inlet flow. The size of the inlet was selected to satisfy engine air-flow requirements at an altitude of 35,000 feet and a flight Mach number of 0.85 (a subsonic-inlet sizing would be considered for efficient subsonic cruising) for choking at the minimum inlet area at an assumed pressure recovery of 0.95. The difference between the inlet and the engine weight-flow curves is the required weight-flow spillage (the actual spillage depends on the pressure recovery at the diffuser match point). The required weight-flow spillage is 32 percent at Mach number 2.0. The alternate choice of sizing the inlet at the high-speed point and using a variable-geometry inlet in the below-design speed range is not considered herein. More complete discussions of the matching problem can be found in references 6, 7, and 8.

The translating-spike and bypass inlets can be utilized to reduce the drag penalties associated with bow-shock spillage that would occur if a fixed-geometry inlet were used. The performance characteristics of the fixed-geometry, translating-spike, and bypass inlets are presented in figure 4 for Mach numbers from 1.5 to 2.0 at an altitude of 35,000 feet. Also included in figure 4 for comparison are curves for the effective thrust parameter and specific impulse for a reference inlet operating at critical inlet pressure recoveries without drag; these reference curves represent the best performance attainable with this particular fixed-angle compression surface and diffuser. Drag due to spillage and thrust loss due to pressure recovery in terms of percent of the ideal thrust are also presented. As shown in figure 4, the thrust parameter for the bypass inlet was consistently higher than that of the translating-spike or the fixed-geometry inlet. The inferior performance of the translating-spike inlet compared with that of the bypass was primarily associated with pressure-recovery losses, since the thrust loss due to drag was smallest for the translating spike except at Mach numbers greater than 1.9. As previously pointed out, the pressure recovery could possibly be increased by redesigning the inlet; hence, competitive performance between the bypass and translating spike at flight Mach numbers from 1.5 to 1.9 could be anticipated. For performance at a flight Mach number of 2.0, the thrust parameter of the bypass inlet was 31 percent greater than that of the fixed-geometry inlet and 95 percent of that attainable with critical inlet pressure recoveries and zero drag.

The bypass inlet had the highest specific impulse except for minor differences between Mach numbers 1.5 and 1.8. In this region, the translating-spike inlet had impulses slightly higher than those of the bypass, because operation at pressure recoveries and drags lower than those for the bypass results in a disproportional effect on the net-thrust and fuel-flow terms of specific impulse.

The specific impulse is proportional to over-all propulsive-unit efficiency and, hence, is of primary importance at the highest flight Mach number (for maximum supersonic-flight endurance at this speed). 3022 At below-design speeds, the specific impulse does influence the time or fuel required to accelerate to the high-speed condition although the time or fuel required to reach the maximum speed is usually small compared with the time available for flight at maximum speed.

Analysis of the thrust available at lower altitudes at supersonic speeds showed similar results, indicating that the variable-geometry-inlet systems, and the bypass system in particular of those analyzed herein, offer increased flexibility in the selection of a flight plan compared with a fixed-geometry inlet.

Another type of comparison is the adaptibility of the inlet under nonstandard atmospheric conditions, such as nonstandard temperatures. This calculation is shown in figure 5 for a flight Mach number of 1.8, a constant pressure-altitude, and the most probable maximum and minimum temperature limits of reference 9. Inasmuch as airplane drag is constant for these assumed flight conditions, the effect of atmospheric temperature variation on engine air-flow characteristics would not seriously affect the performance of an airplane having a bypass system, as indicated by the flat effective-thrust-ratio curve. However, steady flight under these conditions with the translating-spike or fixed-geometry inlets would require a variation in engine power output, as indicated by the variation of effective thrust ratio with temperature.

Results similar to those of figures 4 and 5 but of smaller magnitude were obtained using an engine characteristic that required a weight-flow spillage of about 15 percent at a flight Mach number of 2.0 for sizing considerations identical with those in figure 3. This fact suggested the possibility of increasing the size of the inlet (resulting in a lower Mach number sizing) so that the required spillage at a flight Mach number of 2.0 would be about 33 percent of that captured and using the bypass to discharge this excess flow. Thus, at subsonic speeds, the pressure-recovery losses associated with the sharp cowl lip would be reduced, since the larger inlet would operate at lower inlet-velocity ratios. Calculations indicated only a slight reduction in effective thrust ratio and specific impulse at supersonic speeds for the larger inlet and superior performance at subsonic Mach numbers at an altitude of 35,000 feet. While the performance of the larger inlet was also better at take-off and sea-level conditions, an auxiliary scoop or blow-in door would probably be necessary to provide thrust ratios between 0.9 and 1.0 (a smaller auxiliary system could be used for the larger inlet, however). Thus, a bypass system does make the selection of subsonic sizing amenable to compromise, since the supersonic penalty for oversizing is small. Since bypassing about 33 percent of the captured air flow at a flight Mach number of 2.0 and an altitude of 35,000 feet requires a rather large bypass nozzle, these results qualitatively depict a practical limit for oversizing the inlet in an attempt to improve subsonic performance. In considering the frontal area for the two inlets, it was found that, if the diffuser exit were redesigned to match the required engine characteristics, the diameter of a nacelle-type installation would be governed by the maximum engine diameter for the large as well as the small inlet.

Application to ram-jet engines. - Under conditions requiring thrust in excess of that needed for cruising flight, such as accelerating or maneuvering, ram-jet engines can likewise benefit from the use of variable-geometry systems. For an engine with a fixed-area-ratio exhaust nozzle, thrust increases are obtained by increasing the engine total-temperature ratio; this requires the spillage of excess weight flow, which causes the drag losses previously discussed. The exhaust-nozzle area ratio for the calculations herein was selected for maximum impulse at a flight Mach number of 2.0 and critical inlet flow which resulted in a net propulsive thrust coefficient 0.40 and a specific impulse of 1580 seconds at the cruise conditions. Ram-jet-engine excess thrust and specific-impulse characteristics obtainable by using fixed-geometry, translating-spike, and bypass inlets are presented in figure 6 in the form of percentage increase over the cruise value for angles of attack of 0°, 3°, 6°, and 9°. A fixed-geometry inlet with a variable-area exhaust nozzle is included for comparison at zero angle of attack.

Of the fixed-exhaust-nozzle ram jets, the bypass had the highest margin of excess thrust and the smallest reduction in specific impulse over the range of engine total-temperature ratios from cruise to stoichiometric at zero angle of attack. The translating-spike inlet was comparable with the bypass at moderate temperature-ratio increases but suffered a reduction in excess thrust at higher temperature ratios because of inlet pressure-recovery losses. At an engine total-temperature ratio of 5.0, the excess thrust available with the bypass inlet was 65 percent of that attainable with a variable-nozzle fixed-inlet-geometry ram jet.

In general, the thrust for a given engine total-temperature ratio decreased as angle of attack increased. At angles of attack other than zero, the initial thrust increases for the translating spike were greater than for the other ram jets; however, the thrust decreased appreciably at higher temperature ratios. Inasmuch as the range of stable subcritical flow decreased at angles of attack of 6° and 9° for the fixed-geometry inlet, the maximum total-temperature ratios were limited to 4.05 and 3.10, respectively, and consequently the thrust increases were small. At an angle of attack of 9°, thrust greater than that required for cruise was available with the bypass ram jet; depending on airplane induced-drag characteristics, the excess thrust may be sufficient for moderate maneuvers.

The variation of net-propulsive-thrust coefficients for various ram jets between flight Mach numbers of 1.5 and 2.0 is shown in figure 7. These curves, when used in conjunction with airplane-drag curves, are of interest in defining the potential for acceleration to the cruise point and may be used as aids in determining the point at which the ram jet is capable of sustaining the flight of the airplane, that is,the end of the boost phase or the "take over Mach number." The bypass ram jet had the highest excess-thrust envelope of the fixed-exhaust-nozzle ram jets, although greater net-propulsive-thrust coefficients are indicated for the fixed-inlet variable-nozzle ram jet. Of the fixed-exhaust-nozzle ram jets, the lowest take-over Mach number is indicated for the bypass ram jet and consequently a smaller booster could be used.

CONCLUDING REMARKS

With regard to turbojet effective thrust ratio, the bypass inlet was, in general, superior although the performance of the translating-spike inlet could possibly become competitive between flight Mach numbers of 1.5 and 1.9 if the pressure-recovery losses due to spike translation were minimized by redesigning. At a flight Mach number of 2.0, the drag associated with conical-shock spillage was approximately twice that of the bypass inlet and, consequently, competitive performance would not be expected. For constant pressure-altitude and flight Mach number operation at nonstandard atmospheric temperatures, the effective thrust ratio was maintained nearly constant by means of the bypass whereas the thrust ratios varied for the other types of spillage control.

The fixed-exhaust-nozzle ram jet with a bypass inlet had the highest envelope of excess net propulsive thrust between flight Mach numbers 1.6 and 2.0, indicating a greater potential for accelerating and maneuvering and the possibility of requiring a smaller booster unit than the fixed-geometry or translating-spike ram jets. In general, as the angle of attack increased, all thrust ratios decreased for a given engine total-temperature ratio, and, at an angle of attack of 9° and a flight Mach number of 2.0, only the bypass ram jet indicated net propulsive thrusts greater than those necessary for cruising at an angle of attack of 0°.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 13, 1953

REFERENCES

1. Beke, Andrew, and Allen, J. L.: Force and Pressure-Recovery Characteristics of a Conical-Type Nose Inlet Operating at Mach Numbers of 1.6 to 2.0 and at Angles of Attack to 9°. NACA RM E52I30, 1952.

2. Allen, J. L., and Beke, Andrew: Force and Pressure Recovery Characteristics at Supersonic Speeds of a Conical Spike Inlet with Bypasses Discharging in an Axial Direction. NACA RM E52K14, 1953.

3. Allen, J. L., and Beke, Andrew: Force and Pressure Recovery Characteristics at Supersonic Speeds of a Conical Spike Inlet with a Bypass Discharging from the Top or Bottom of the Diffuser in an Axial Direction. NACA RM E53A29, 1953.

4. Beke, Andrew, and Allen, J. L.: Force and Pressure-Recovery Characteristics at Supersonic Speeds of a Conical Nose Inlet with Bypasses Discharging Outward from the Body Axis. NACA RM E52L18a, 1953.

5. Gorton, Gerald C.: Investigation of Translating-Spike Supersonic Inlet as Means of Mass-Flow Control at Mach Numbers of 1.5, 1.8, and 2.0. NACA RM E53G10, 1953.

6. Schueller, Carl F., and Esenwein, Fred T.: Analytical and Experimental Investigation of Inlet-Engine Matching for Turbojet-Powered Aircraft at Mach Numbers up to 2.0. NACA RM E51K20, 1952.

7. Brajnikoff, George B.: Methods and Graphs for the Evaluation of Air-Induction Systems. NACA TN 2697, 1952.

8. Wyatt, DeMarquis D.: An Analysis of Turbojet-Engine-Inlet Matching. NACA TN

9. Bartlett, P. M.: Recommended Upper Air Standard Temperatures for Aeronautical Use. Power Plant Memo. No. 26, Navy Dept., Bur. Aero.

3022

CK-2 back

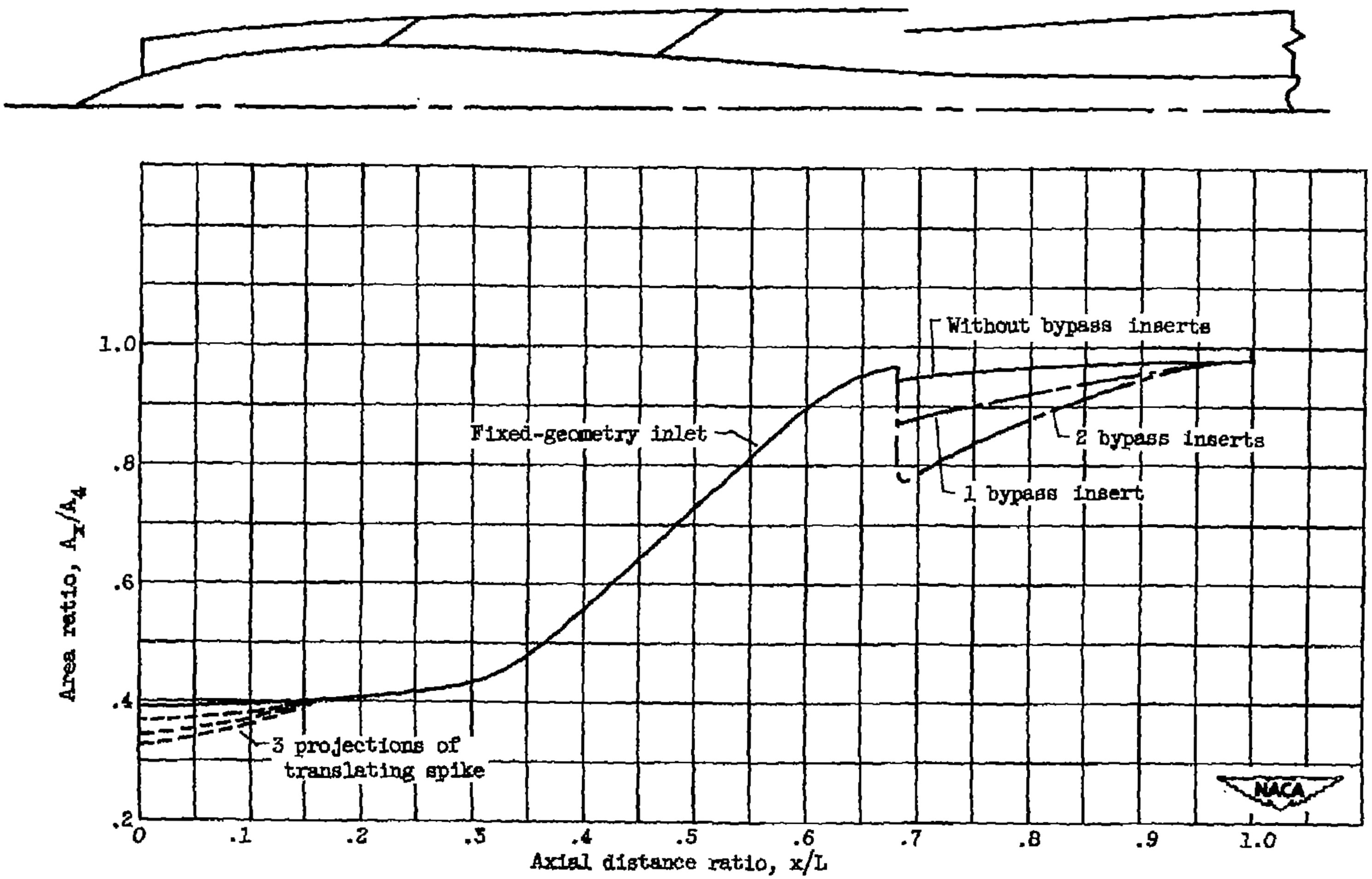
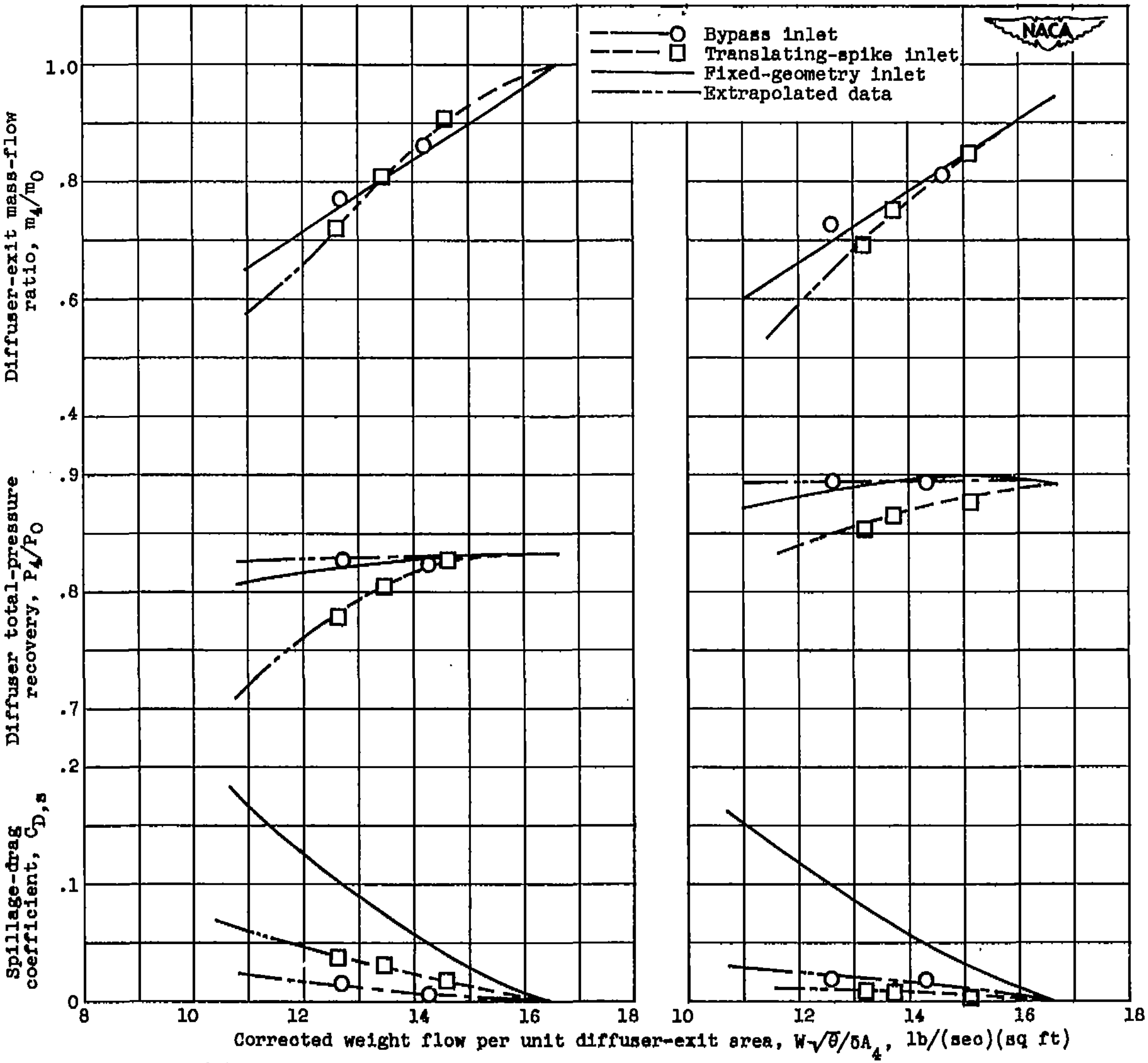


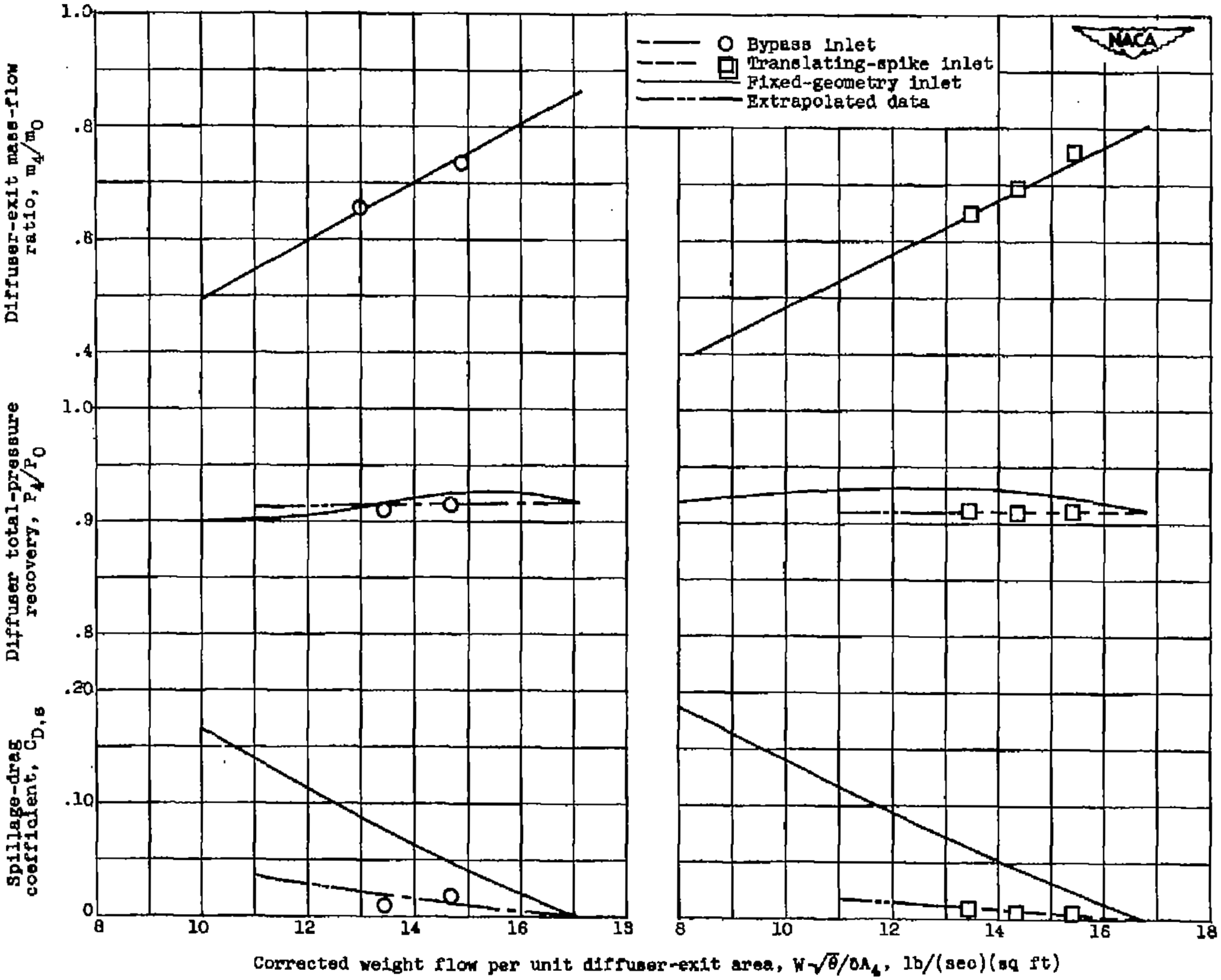
Figure 1. - Subsonic-diffuser area variation.



(a) Flight Mach number, 2.0.

(b) Flight Mach number, 1.8.

Figure 2. - Comparison of inlet characteristics at zero angle of attack.



(c) Flight Mach number, 1.6.

(d) Flight Mach number, 1.5.

Figure 2. - Concluded. Comparison of inlet characteristics at zero angle of attack.

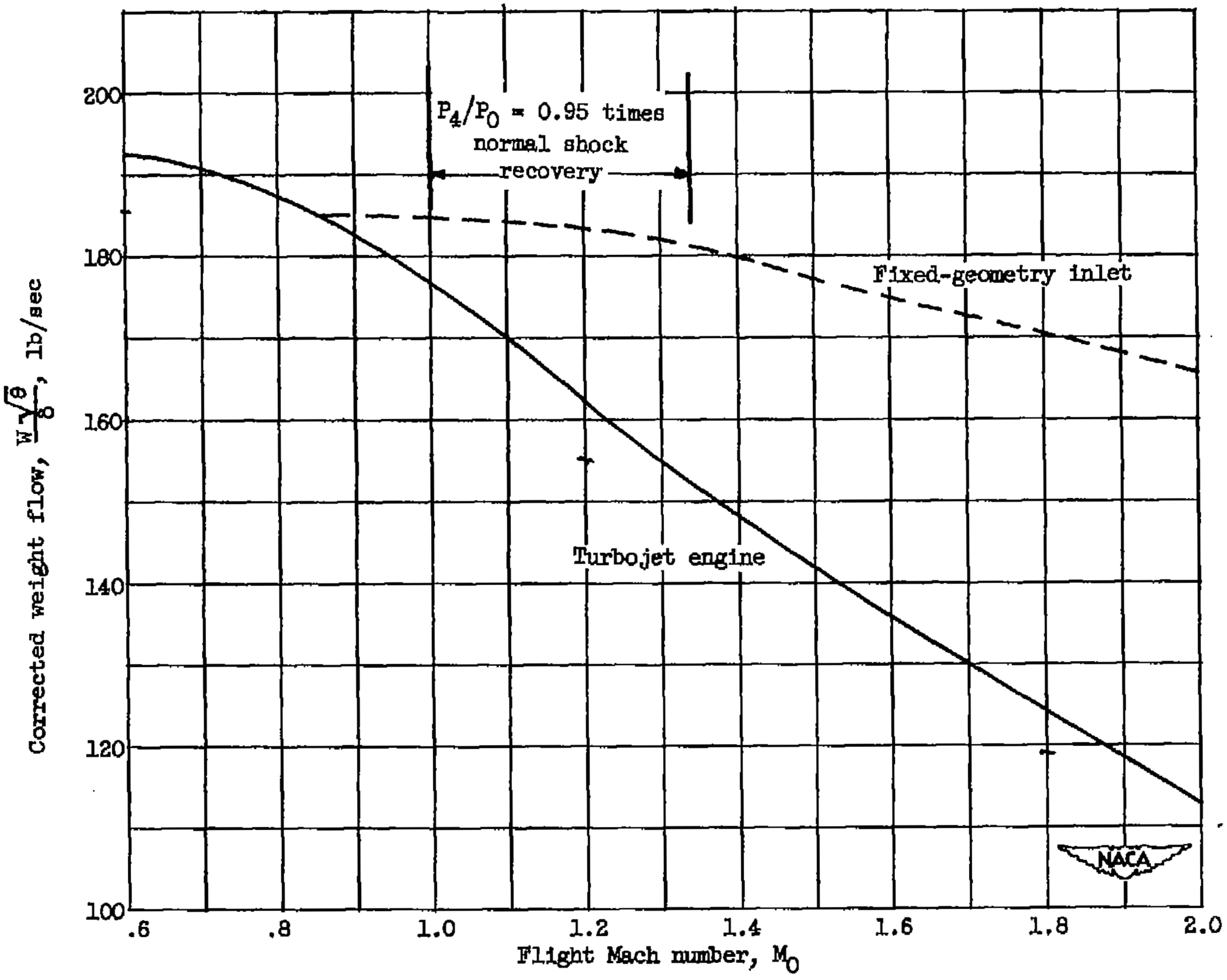


Figure 3. - Variation of corrected weight flow with flight Mach number at altitude of 35,000 feet for turbojet engine and maximum inlet capacity at critical inlet flow and assumed pressure recoveries. Inlet sized for choking at minimum inlet area at flight Mach number of 0.85.

3022

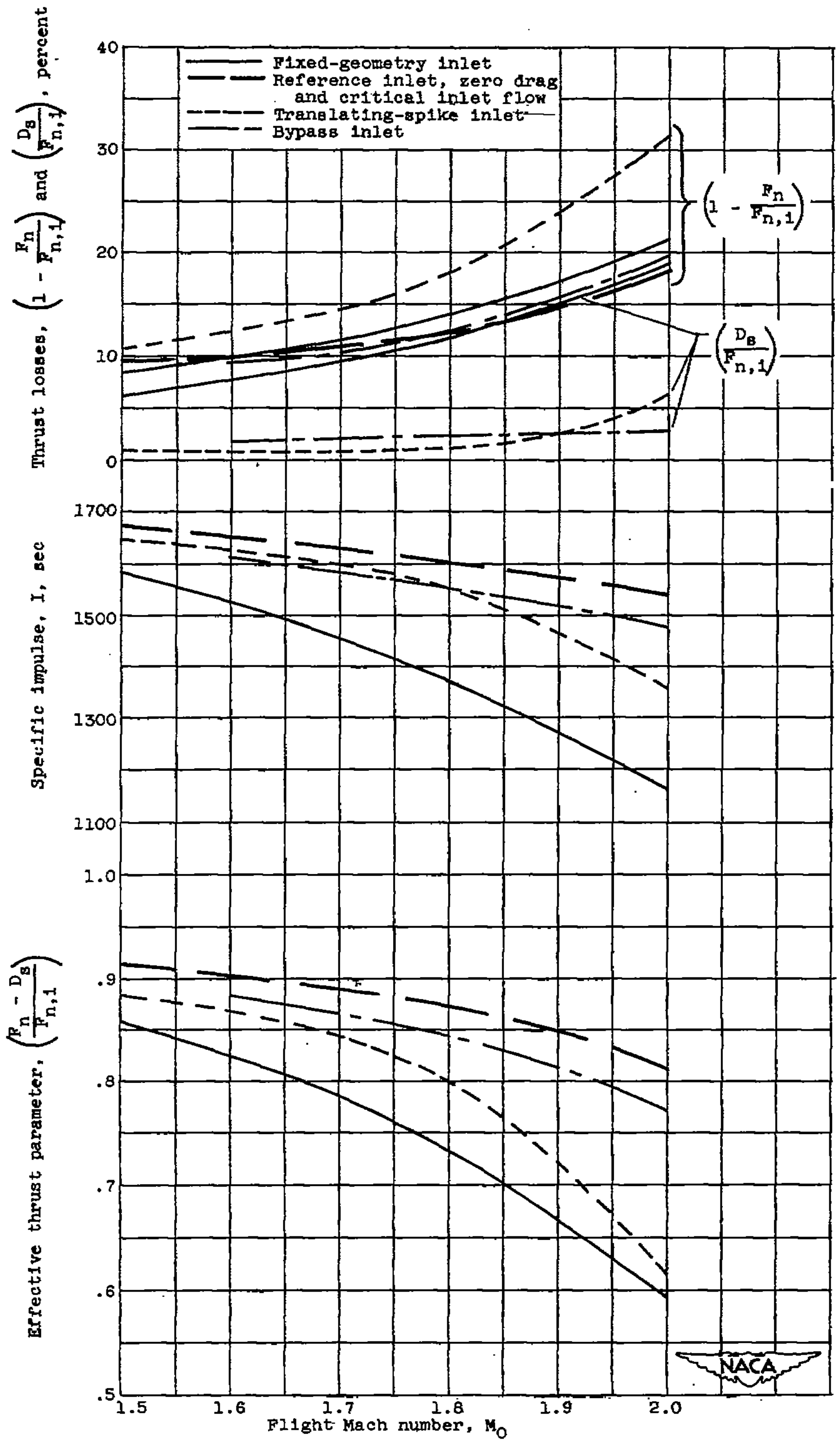


Figure 4. - Performance of turbojet engine utilizing various inlets at altitude of 35,000 feet.

[redacted]

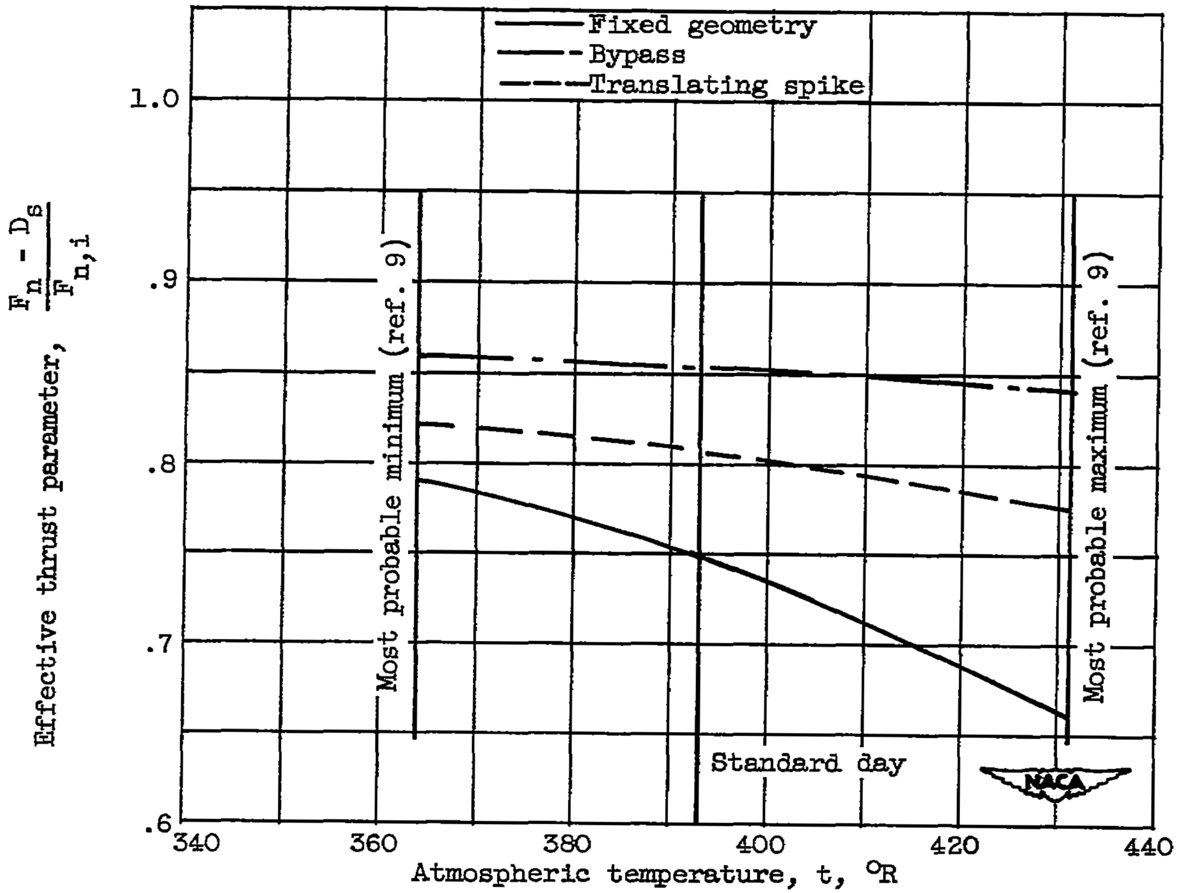
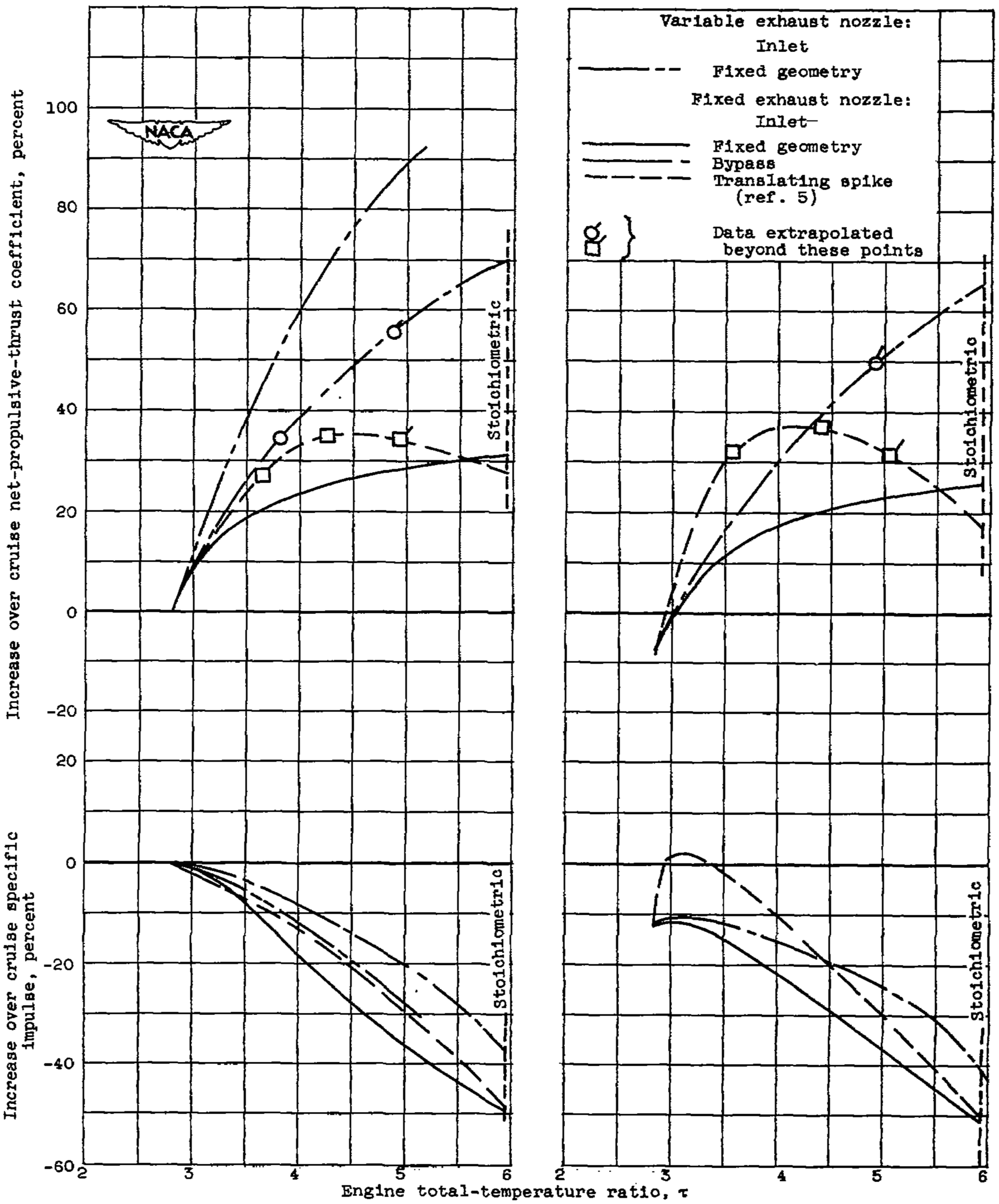


Figure 5. - Effect of atmospheric temperature variation on effective thrust ratio. Flight Mach number, 1.8; altitude, 35,000 feet; inlet sized for choking at minimum inlet area at flight Mach number of 0.85.

3022



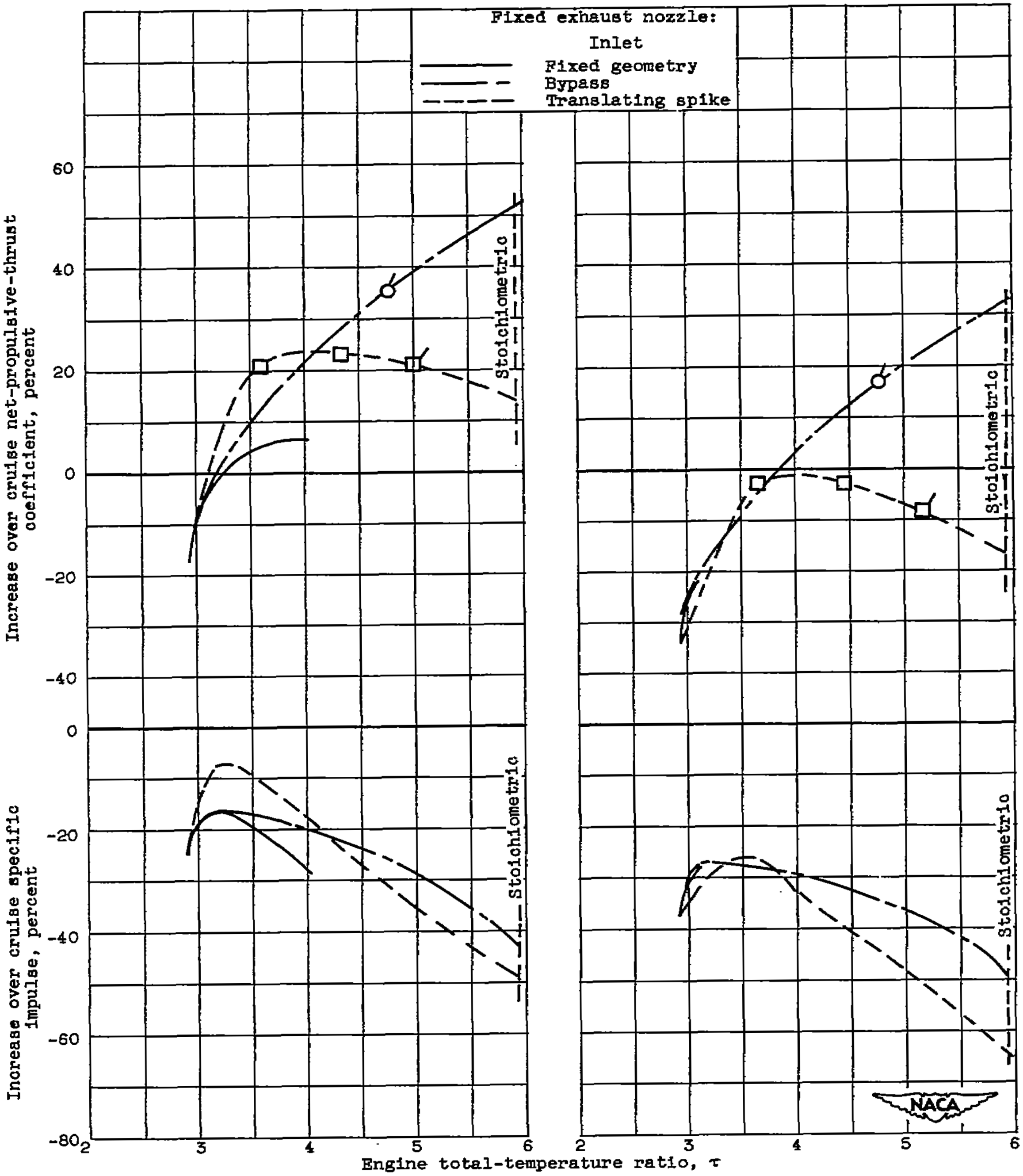
(a) Angle of attack, 0°.

(b) Angle of attack, 3°.

Figure 6. - Ram-jet engine performance with various inlets. Flight Mach number, 2.0; altitude, 35,000 feet and up.

[redacted]

3022



(c) Angle of attack, 6°.

(d) Angle of attack, 9°.

Figure 6. - Concluded. Ram-jet engine performance with various inlets. Flight Mach number, 2.0; altitude, 35,000 feet and up.

[redacted]

3022

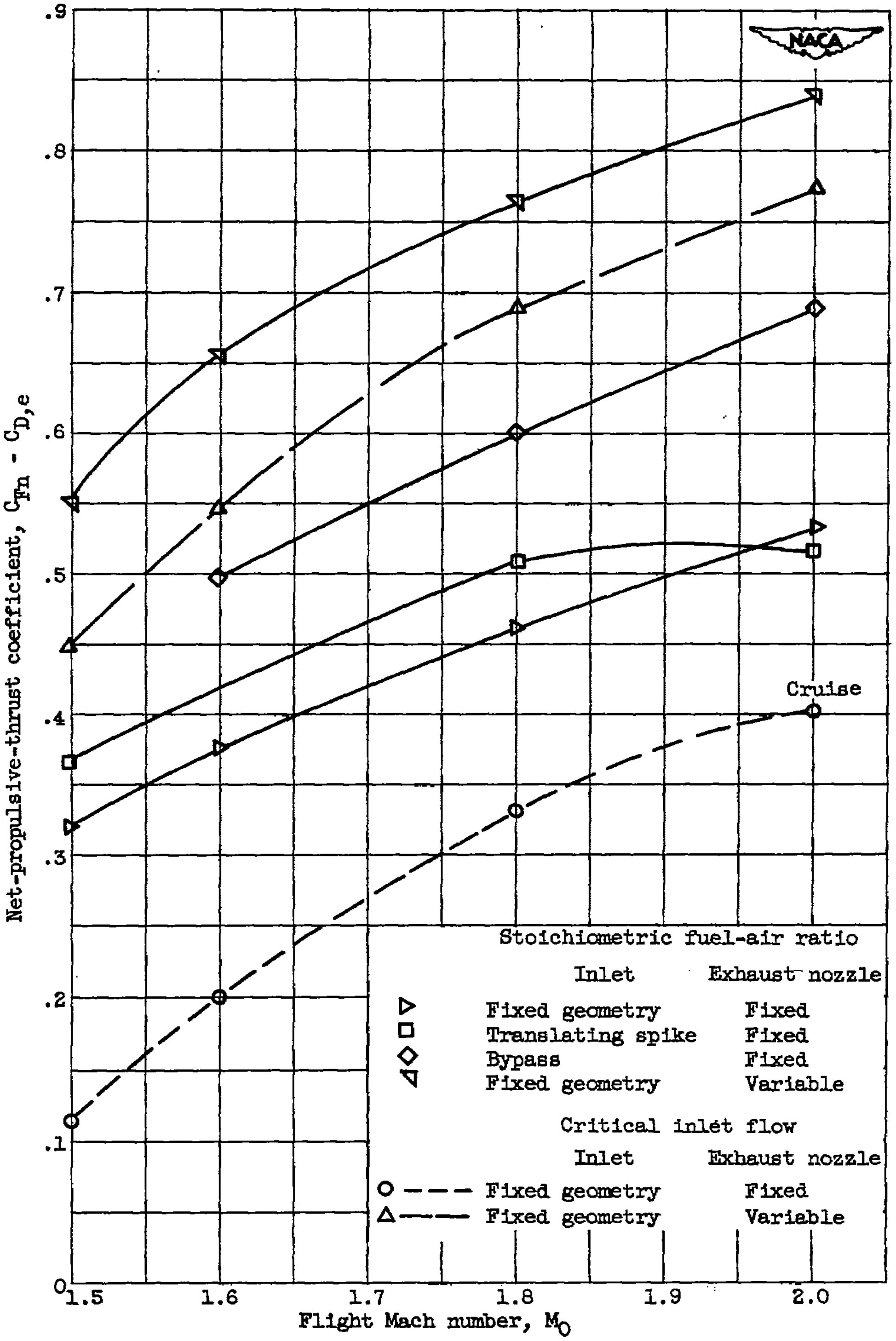


Figure 7. - Variation of net-propulsive-thrust coefficient with flight Mach number for various methods of ram-jet operation.

[redacted]

[redacted]