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RESEARCH MEMORANDUM

TRANSONIC FREE-FLIGHT DRAG RESULTS OF FULL-SCALE MODELS OF 16-INCH-DIAMETER RAM-JET ENGINES

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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TRANSONIC FREE-FLIGHT DRAG RESULTS OF FULL-SCALE MODELS OF 16-INCH-DIAMETER RAM-JET ENGINES

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SUMMARY

A free-flight investigation of the drag on four full-scale models of 16-inch-diameter ram-jet engines was conducted over a Mach number range of 0.6 to 1.43. Data were obtained at different internal air-flow rates by inserting annular restrictors in the outlet of the models. The first two models investigated are discussed herein; these were launched from an airplane at a pressure altitude of 35,000 feet. During the free-fall, the models were rocket propelled to supersonic velocities, and then decelerated through the transonic range before impact.

The highest total-drag coefficient, based on the maximum cross-sectional area, was 0.63 at a free-stream Mach number of 1.15. This high value, encountered with model 1, which had the larger annular restrictor, was largely due to the high base drag. In the transonic Mach number range of 0.98 to 1.15, the base-drag coefficient constituted 63 to 67 percent of the total-drag coefficient for both models. The external-drag coefficient, exclusive of base drag, for model 1 increased from a subsonic value of 0.105 to a maximum value of 0.215 at a Mach number of 1.30 as compared with an increase of from 0.105 at a Mach number of 0.90 to 0.170 at a Mach number of 1.30 for model 2. Good correlation was obtained with a similarly designed 16-inch-diameter ram-jet engine, which was investigated at higher Mach numbers in the Lewis 8- by 6-foot supersonic wind tunnel.

INTRODUCTION

As part of an investigation of the drag on 16-inch-diameter ram-jet engines, four models were dropped from a pressure altitude of approximately 35,000 feet and were rocket propelled to a Mach number of 1.43. This phase of the program was conducted to evaluate the component drag coefficients throughout the transonic range. The four models were geometrically similar to the 16-C-type ram-jet engines described in reference 1. An annular restrictor was inserted in the outlet of each model to reduce the air flow to that encountered during combustion. Data were obtained at various inlet mass-flow ratios and outlet-pressure ratios by using a different blocked area in each model. These data were recorded by radio-telemetering and radar-tracking equipment on continuous records.

Drag results are presented herein for models 1 and 2 which accelerated to Mach numbers of 1.43 and 1.31, respectively, and then decelerated through the transonic range after the termination of the rocket-boost period. In this investigation, which was conducted by the NACA Lewis laboratory, the facilities of the NACA Langley Pilotless Aircraft Research Station, Wallops Island, Virginia were used.

SYMBOLS

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The following symbols are used in this report:

A_i cowl-inlet area (sq ft)

A_0 free-stream tube area of internal air flow (sq ft)

C_{D_b} base-drag coefficient

C_{D_e} external-drag coefficient

C_{D_i} internal-drag coefficient

C_{D_t} total-drag coefficient

M_0 free-stream Mach number

p_b base static pressure (lb/sq ft)

p_j jet or outlet static pressure (lb/sq ft)

p_0 free-stream static pressure (lb/sq ft)

Re Reynolds number based on model length

t_0 free-stream static temperature ($^{\circ}R$)

APPARATUS AND PROCEDURE

The models consisted of an outer shell with four stabilizer fins at the rear and a centrally located body in the diffuser section. A schematic diagram including dimensions and position of the instrumentation is shown in figure 1. The models were light-weight facsimiles of the NACA 16-C-type ram-jet engine, which was designed to operate with a normal shock at the inlet at a free-stream Mach number of 1.6, a total-temperature ratio of 3.9 across the combustion chamber, and a combustion-chamber-inlet Mach number of 0.21. The 50° spike of the center body was so located that an attached conical shock would intercept the lip of the outer shell at a free-stream Mach number of 1.8. The outer shell, which extended from the end of the cowl to the exhaust outlet, was cylindrical. The restriction plug because of its construction caused the model to have a flat base at the exit as shown in figure 1. The specifications of the two models investigated are as follows:

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	Model 1	Model 2
Length (in.)	175	175
Maximum diameter (in.)	16	16
Outlet jet diameter (in.)	8.75	9.75
$\text{Area}_{(\text{base})}/\text{area}_{(\text{max. cross sectional})}$	0.701	0.629
Gross weight (lb)	420	441
Gross weight minus rocket fuel (lb)	348	346

The models were propelled by a solid-fuel rocket housed in the combustion-chamber section of the ram-jet engine. The rockets used were Jato 14-DS-1000 (in model 1) and Jato 14-AS-1000 (in model 2); the average thrust of the rockets was 1000 pounds for a 14-second duration.

The model contained a 10-channel telemetering transmitter. Continuous and simultaneous records were made of the following data:

(1) Axial net acceleration

(2) Free-stream total pressure

(3) Free-stream static pressure

(4) Inlet static pressure

(5) Inlet total pressure

(6) Diffuser total pressure

(7) Outlet static pressure

(8)-(10) Base static pressures

A radar-tracking unit, type SCR-584, with optical tracking facilities was used to determine the position of the model in space at approximately 0.1-second time intervals. An atmospheric survey was conducted by the release airplane in order to determine the ambient pressure and temperature throughout the flight-altitude range. A weather balloon was released from the ground and tracked by the radar in order to correct the computed space velocity for the effect of wind on the model.

The models were released from an airplane at a pressure-altitude of 35,000 feet and a free-stream Mach number of 0.55. After release, rocket ignition occurred in approximately 12 seconds for model 1 and 20 seconds for model 2. During the 14-second burning period, the rocket thrust and the force of gravity accelerated model 1 to a Mach number of 1.31 at a pressure altitude of 22,750 feet and model 2 to a Mach number of 1.43 at a pressure altitude of 15,400 feet.

METHODS OF CALCULATION 2360

The free-stream velocity was calculated both by differentiating the space-time curve obtained from the radar data and by integrating the total acceleration-time curve obtained from the telemeter data. The velocity was corrected for the effects of the wind to obtain the velocity relative to the air. The Mach number was computed from this corrected velocity and the ambient temperature which was obtained from the atmospheric-survey data. The total drag is equal to the product of the net acceleration multiplied by the mass of the model. These values were computed after the termination of rocket boost when only drag and gravity forces were acting on the model. The base-pressure drag was calculated from the static pressures measured on the flat base at the rear of the model. The internal drag was calculated from the total change in momentum of the internal air flow. This calculation involved obtaining the free-stream conditions from the atmospheric survey, computing the internal air flow at the inlet from the static- and total-pressure measurements, and computing the outlet velocity from the air flow and outlet static-pressure measurement. The total temperature was assumed constant from the free-stream to the outlet during the decelerating phase of the drop. The external drag, which includes the pressure and friction drags on the external surfaces and the additive drag, is the difference between the total drag and the sum of the base and internal drags.

ACCURACY

Experience based on the agreement obtained from different models operating under similar conditions as well as the reproducibility of the data obtained during this program indicate that the telemeter error was approximately 1 percent of the full range of the individual instruments. The radar and optical tracking equipment is believed accurate within 1 percent of the true value. On this basis, it is reasonable to expect that the probable error in the computed quantities is of the following magnitude: M_0, ±0.01; p_b/p_0, ±0.015; C_{D_t}, ±0.018; C_{D_b}, ±0.011; C_{D_i}, ±0.017, and C_{D_e}, ±0.028.

RESULTS AND DISCUSSION

The free-stream conditions encountered during each drop are shown in figure 2 wherein the Reynolds number was based on a model length of 14.3 feet.

The variation of the total-drag coefficients, based on maximum cross-sectional area, with Mach number are shown for both models in
2360 figure 3. Inasmuch as the accelerometer measured the acceleration resulting from the net force (thrust minus drag) acting on the model, data are shown only for deceleration where the rocket thrust was known to be zero and only gravity and drag forces were acting on the model. The data indicate a sharp increase in drag through the transonic Mach number range of 0.93 to 1.15. The maximum total-drag coefficient for both models occurred at a free-stream Mach number of 1.15. Model 1 had a maximum total-drag coefficient of 0.63, which was equal to a 50-percent increase in drag over the subsonic value of 0.42. Model 2 had a maximum value of 0.575 as compared with a subsonic value of 0.43.

At the present time, only experimental data are available on the transonic base drag resulting from the lower-than-atmospheric pressure existing on flat bases. The base-static pressures, expressed as a ratio to the free-stream static pressure, encountered during the drop are shown in figure 4 as a function of the free-stream Mach number. The latest experimental data were recently reviewed (in an unpublished paper); the average values for solid bodies of revolution with flat bases and cylindrical rear sections have been added to figure 4 for comparative purposes. The base-pressure ratios of models 1 and 2 are substantially lower than this data indicating that higher base drags were encountered in the present investigation. The models used in this investigation, however, had annular bases and were considerably larger both in length and diameter than the solid bodies; part of the discrepancy may in someway be due to the exhaust jet issuing from the center of the base. The data from both models indicate a sharp drop in base-pressure ratio in the transonic range. At a free-stream Mach number of 1.43, the base pressure was only 43 percent of the free-stream pressure for model 1. The data are shown both with and without the rocket thrust, which varied the jet-static-pressure ratio slightly at a given Mach number. From this limited amount of information, it is impossible to ascertain the effect of jet-static pressure on the base pressure. The base-pressure static orifices were located as shown in figure 1. For model 1, two of the orifices were located approximately in line with one of the stabilizing fins. The base-pressure data from these two taps agreed with the data from a third tap located on the annular center line midway between the fins. It is believed that for the range of this investigation the wake of the fins had little or no effect on the uniformity of the base-pressure distribution.

The effect of Mach number on the base- and internal-drag coefficients during the decelerating phase of the flight is shown in figure 5. As expected, model 1 because of the larger base area had a higher base-drag coefficient at a given Mach number than model 2. The magnitude of the effect of the decrease in base-pressure ratio through the transonic Mach number range, noted in the previous figure, is more clearly illustrated by the large increase in base-drag coefficient (fig. 5). The maximum base-drag coefficient for model 1 was 0.42 at a Mach number of 1.15. This value is 75-percent higher than the subsonic value of 0.24 and 45 percent higher than the supersonic value of 0.29. The internal-drag coefficient of model 1 was less than that of model 2 because the smaller exit diameter of model 1 provided lower internal air velocities through the model.

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The external-drag coefficients shown in figure 6 include the friction and pressure drag acting on the external surfaces and the additive-drag acting on the entering streamline at the inlet but does not include base drag. As the two models were geometrically similar, it may be assumed that the friction drag was approximately the same for both. Therefore, the differences in external-drag coefficient were due to the combined effect of cowl pressure and additive drag. From the results of a supersonic-wind-tunnel investigation of a similarly designed 16-inch-diameter ram-jet engine (reference 2), it was determined that at a Mach number of 1.5 a decrease in mass-flow ratio was accompanied by a decrease in cowl drag and an increase in additive drag. Although compensating, the increase in additive drag was shown to be much greater than the decrease in cowl drag. It may therefore be expected that in the supersonic range of this investigation, model 1 operating at lower mass-flow ratios would encounter a higher external drag than model 2. The external-drag coefficient for model 1 increased from a subsonic value of 0.105 to a maximum value of 0.215 at a Mach number of 1.30. Model 2, which operated at a higher mass-flow ratio, encountered an increase in external-drag coefficient of from 0.105 at a Mach number of 0.90 to 0.170 at a Mach number of 1.30. The external-drag coefficient for model 1 was compared in figure 6 with the external-drag coefficient (reference 2) of a similar 16-inch-diameter ram-jet operating supercritically at approximately the same Reynolds number. The corresponding mass-flow ratios for the tunnel model appeared to be a reasonable extension of the mass-flow ratios of the free-flight model. Therefore, it may be assumed that the external-drag coefficient of the tunnel model would be a reasonable extension of the free-flight data inasmuch as excellent correlation was obtained in the Mach number range of 1.43 to 1.50 where the external-drag coefficient for the flight model was 0.21 as compared with 0.20 for the tunnel model.

The magnitudes of the base-, external-, and internal-drag coefficients relative to the total drag as expressed in the coefficient form are shown in figure 7. It is readily apparent that the total-drag coefficient is high largely because of the high base-drag coefficient encountered. For example, in the transonic Mach number range of 0.98 to 1.15, the base-drag coefficient for both models constituted between 63 to 67 percent of the total-drag coefficient. In the subsonic and supersonic regions, the base-drag coefficient was equal to approximately one-half of the total-drag coefficient. If aircraft design requirements necessitate a flat base, it is therefore obvious that the over-all drag can be substantially reduced if this base drag is reduced or eliminated. One such method in which air was bled out of the base in order to reduce the suction effect of low-base pressure has been investigated (reference 3).

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SUMMARY OF RESULTS

In an investigation of the drag on two full-scale models of 16-inch-diameter ram-jet engines which were rocket-propelled in free flight up to a Mach number of 1.31 and 1.43 and then decelerated through the transonic range, the following results were obtained:

1. The external-drag coefficient, exclusive of base drag, for model 1 increased from a subsonic value of 0.105 to a maximum value of 0.215 at a Mach number of 1.30 as compared with an increase of from 0.105 at a Mach number of 0.90 to 0.170 at a Mach number of 1.30 for model 2. Good correlation was obtained with the external-drag coefficient of a similarly designed 16-inch-diameter ram-jet engine which was investigated at higher Mach numbers in the Lewis 8- by 6-foot supersonic wind tunnel.

2. The highest total-drag coefficient of 0.63 occurred with model 1 at a Mach number of 1.15. The high total-drag coefficients encountered were largely due to the high base drags on the flat base at the rear of the model. In the transonic Mach number range of 0.98 to 1.15, the base-drag coefficient constituted 63 to 67 percent of the total-drag coefficient for both models. In the subsonic and supersonic regions, the base-drag coefficient approximated one-half of the total drag coefficient.

3. The base-pressure ratio on the annular base was substantially lower than that previously encountered on blunt bases of small-scale bodies of revolution which indicated that higher base drags had occurred.

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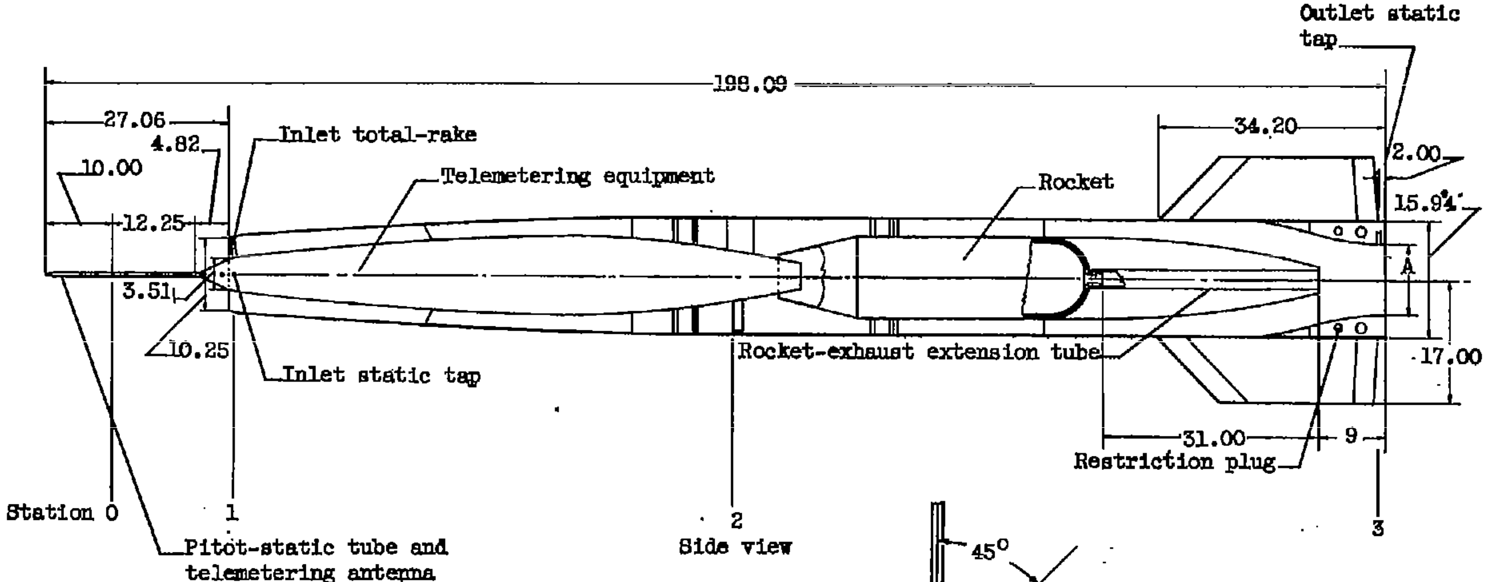
2. Nussdorfer, T., Wilcox, F., and Perchonok, E.: Investigation at Zero Angle of Attack of a 16-Inch Ram-Jet Engine in 8- by 6-Foot Supersonic Wind Tunnel. NACA RM E50L04, 1951.

3. Cortright, Edgar M., Jr., and Schroeder, Albert H.: Preliminary Investigation of Effectiveness of Base Bleed in Reducing Drag of Blunt-Base Bodies in Supersonic Stream. NACA RM E51A26, 1951.



Model	Dimension A	Base-static orifice	Radius
1	8.75	1	6.13
1	8.75	2	6.13
1	8.75	3	6.97
2	9.75	1	5.38
2	9.75	2	6.34
2	9.75	3	7.44

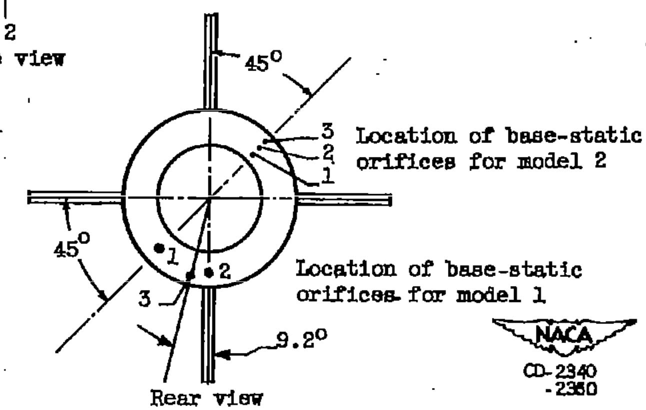
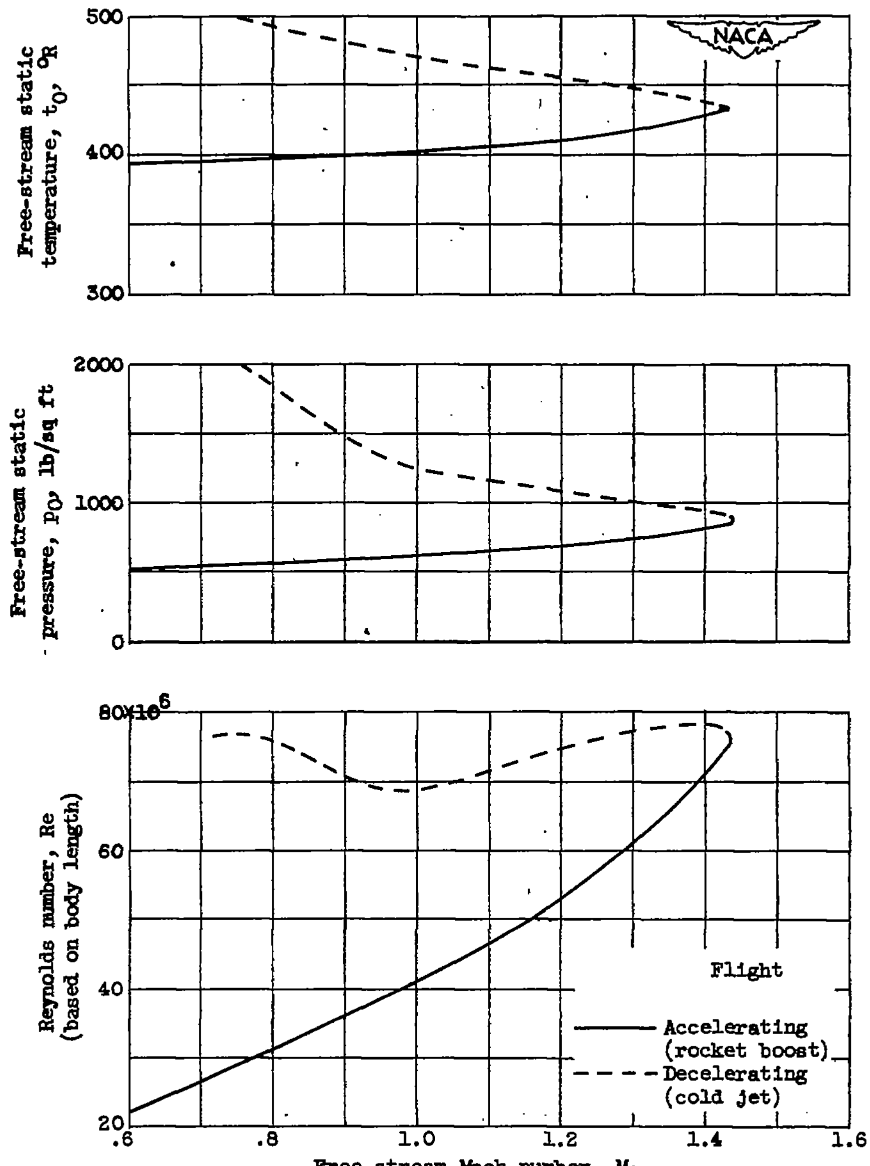


Figure 1. - Schematic diagram of drag model of 16-inch-diameter ram-jet engine. (All dimensions in inches.)



(a) Model 1.

Figure 2. - Free-stream flight conditions as function of free-stream Mach number.

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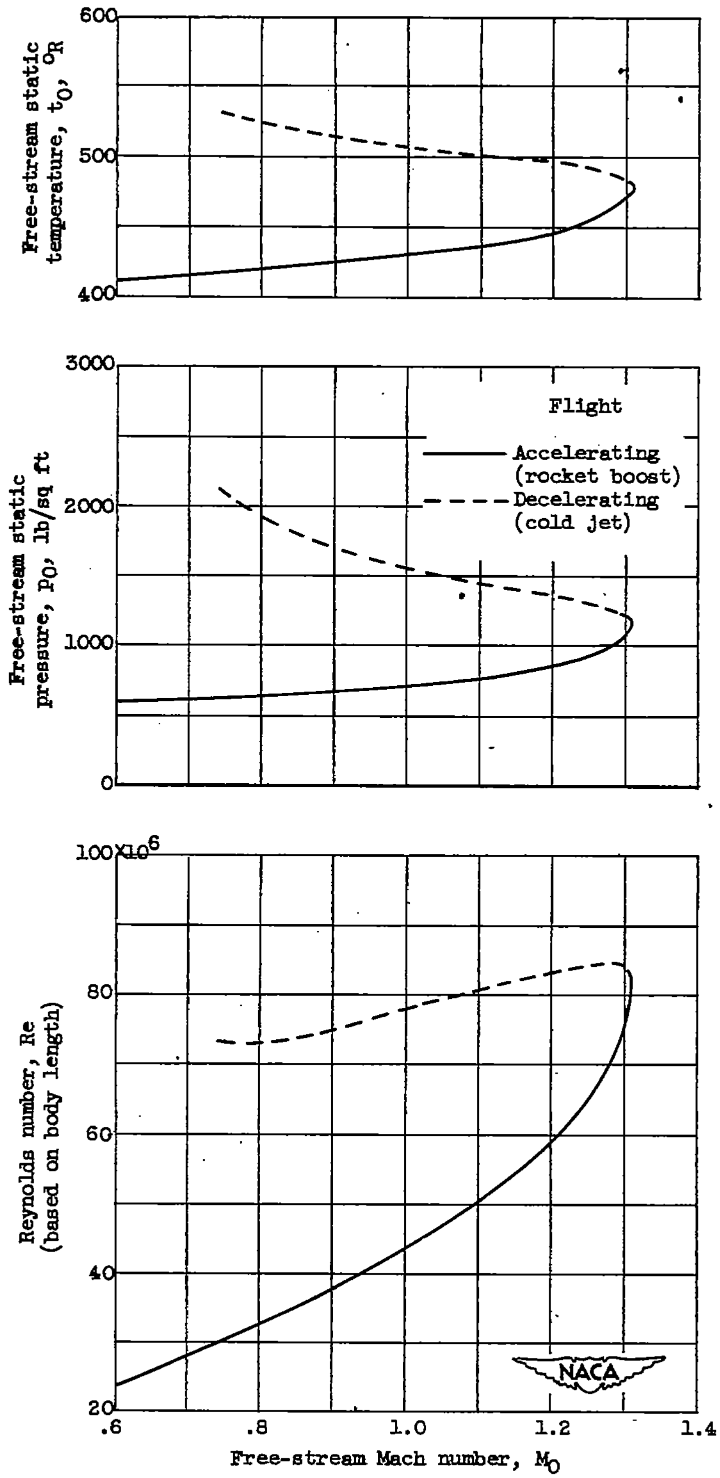

(b) Model 2.

Figure 2. - Concluded. Free-stream flight conditions as function of free-stream Mach number.

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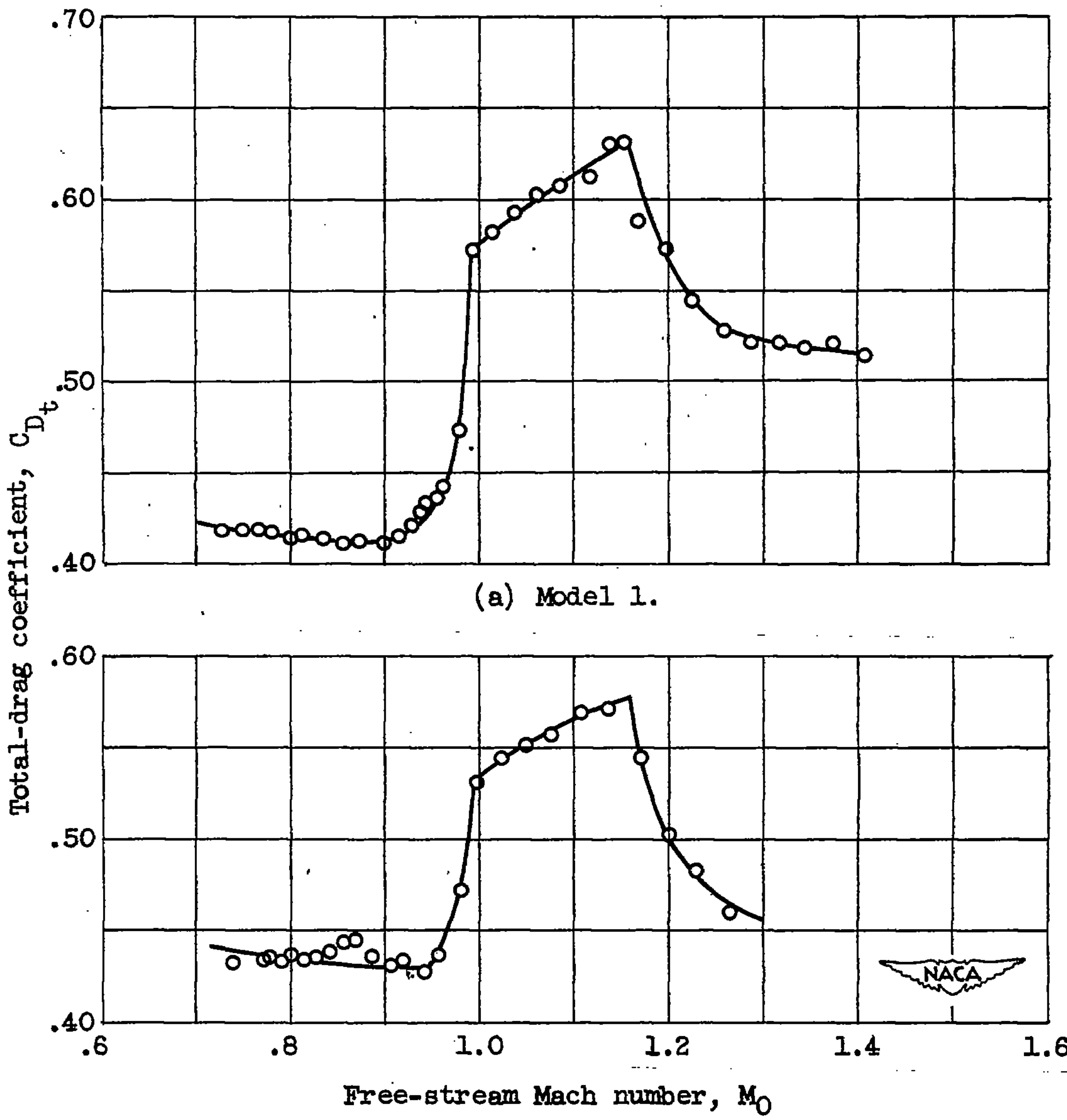

(b) Model 2.

Figure 3. - Effect of free-stream Mach number on total-drag coefficient.

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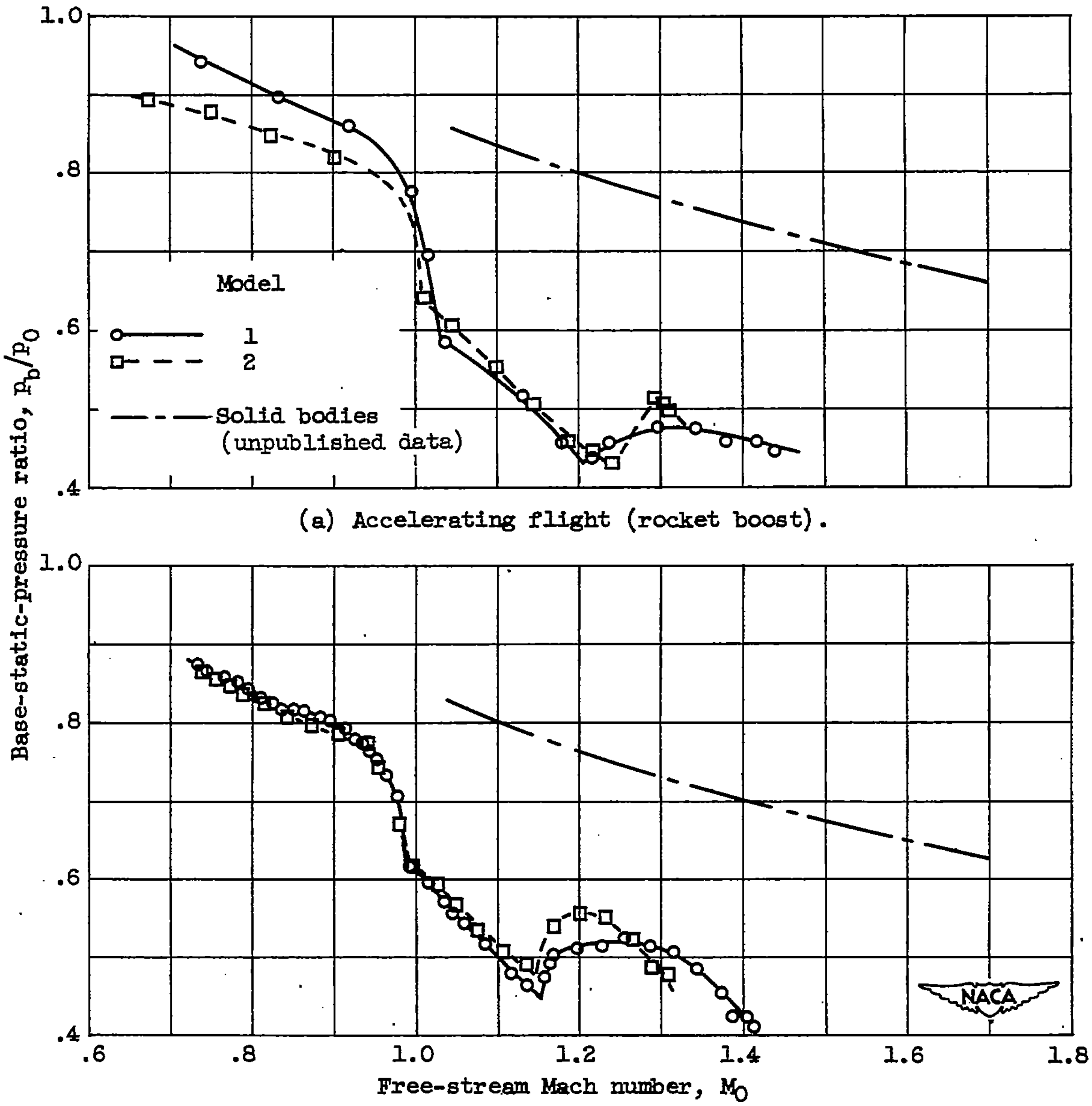

(a) Accelerating flight (rocket boost).

(b) Decelerating flight (cold jet).

Figure 4. - Base-static-pressure ratio as function of free-stream Mach number.

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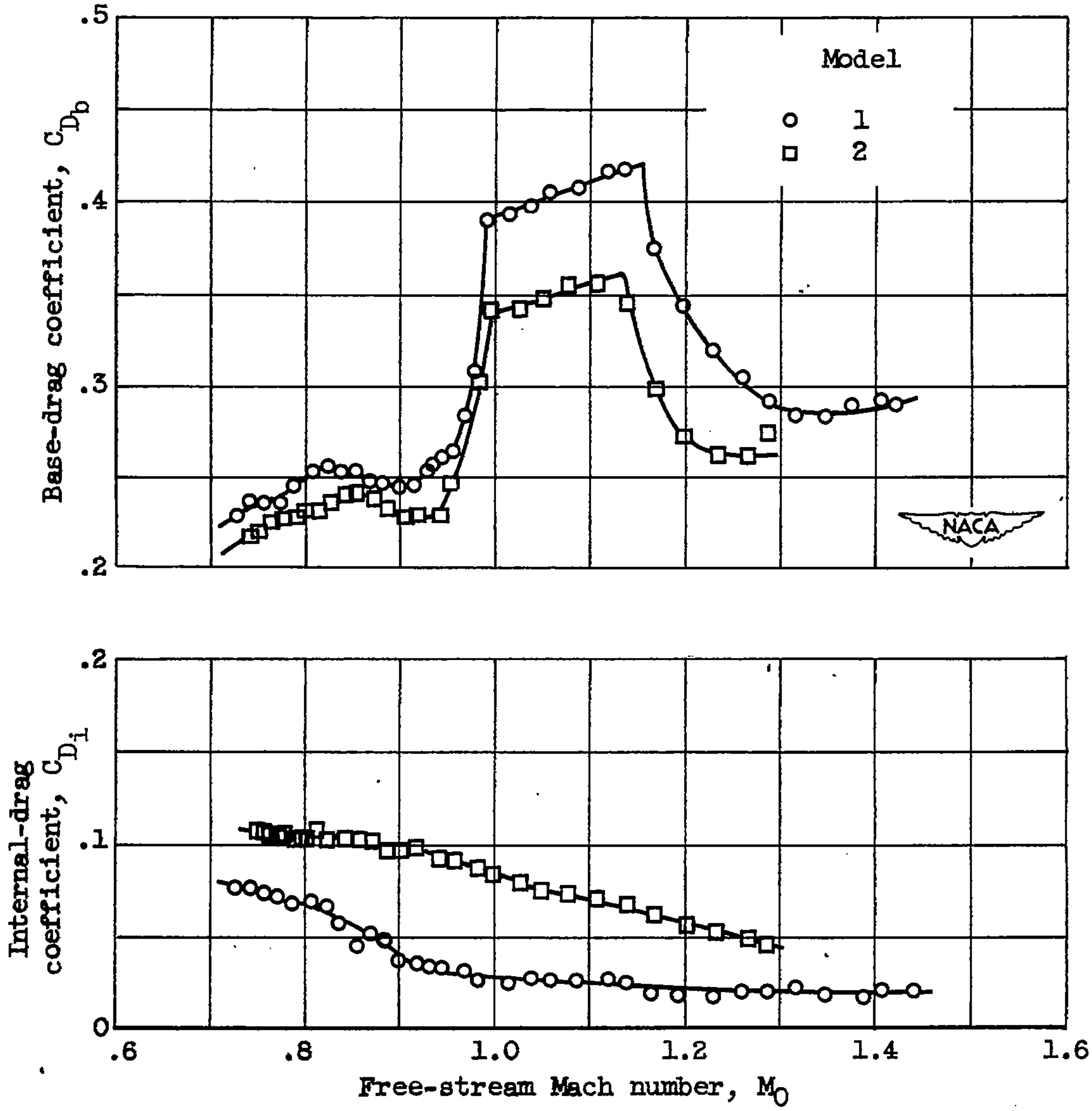

Figure 5. - Effect of free-stream Mach number on base- and internal-drag coefficients.

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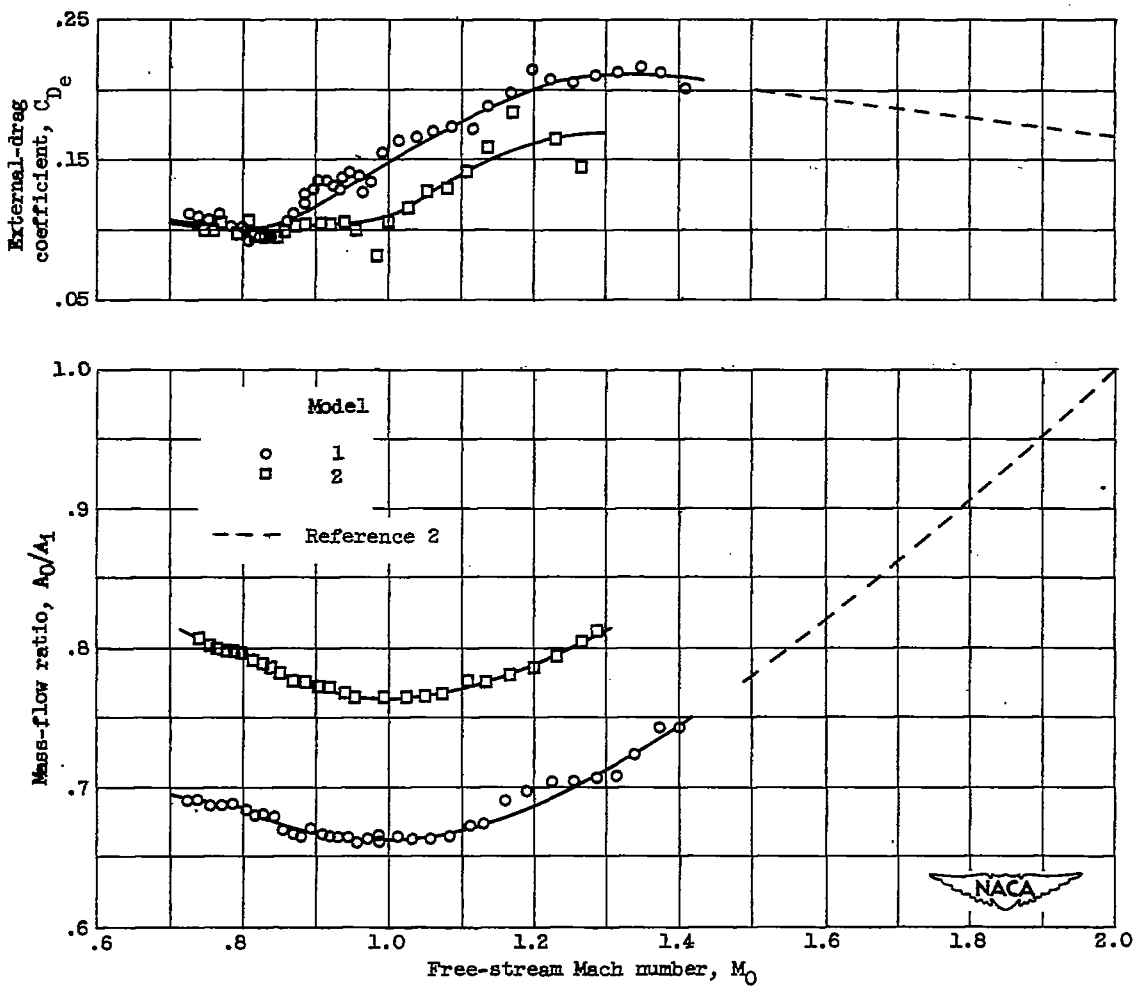
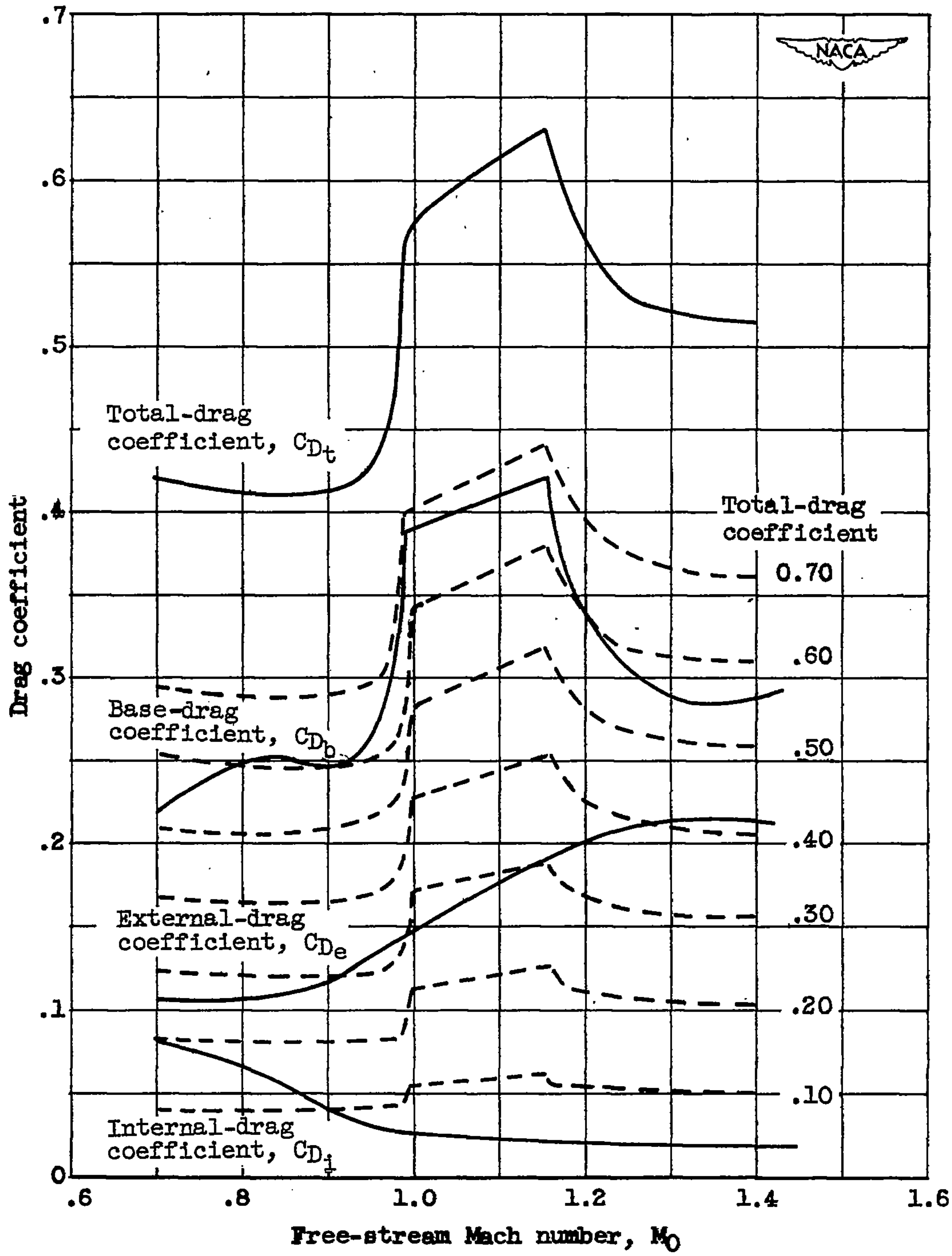
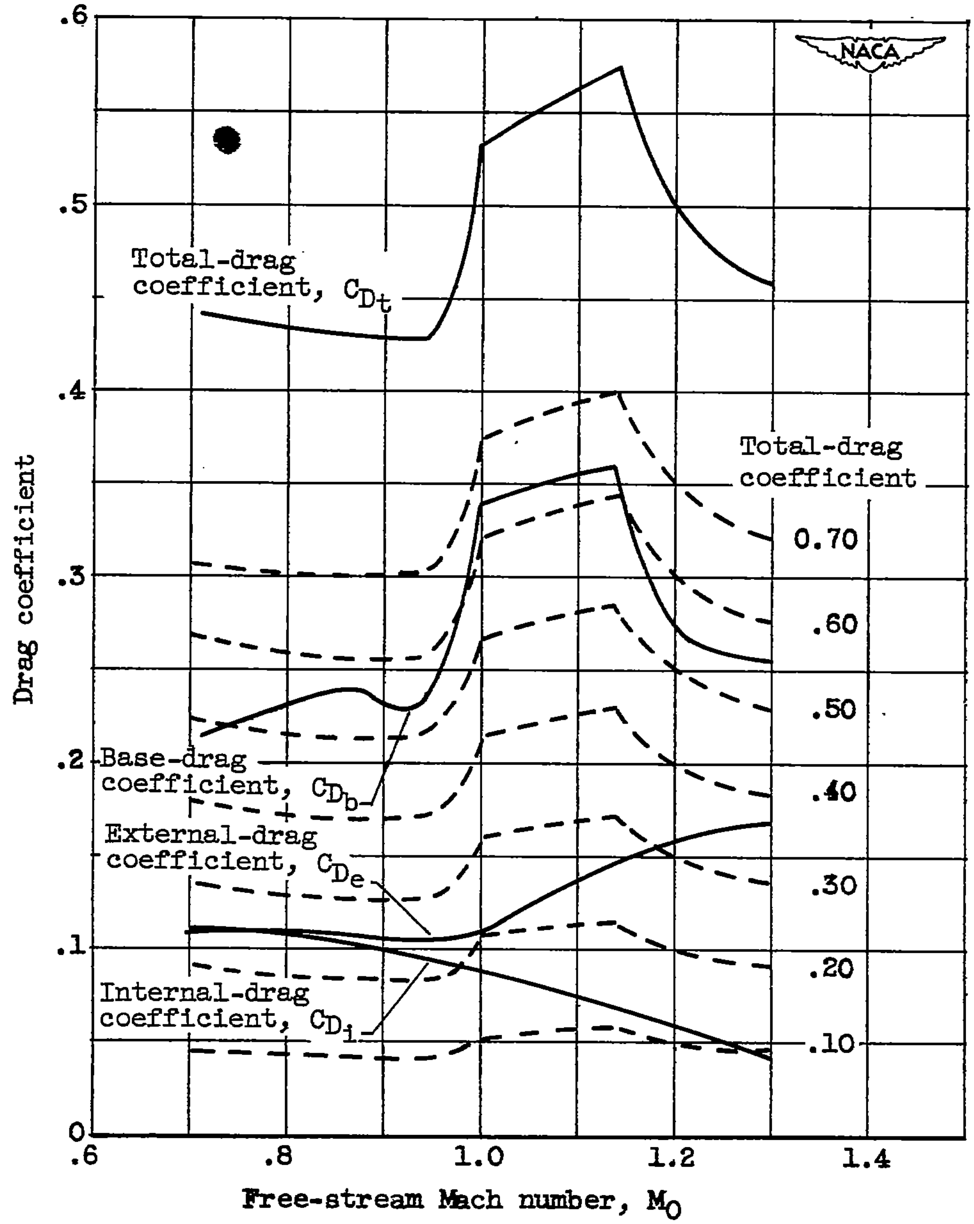


Figure 6. - External-drag coefficient and mass-flow ratio as functions of free-stream Mach number.



(a) Model 1.

Figure 7. - Effect of free-stream Mach number on relative magnitude of base-, external- and internal-drag coefficients.



(b) Model 2.

Figure 7. - Concluded. Effect of free-stream Mach number on relative magnitude of base-, external- and internal-drag coefficients.