Alternate Speakers: M. R. Nichols and R. W. Boswinkle, Jr., FSA

1949 BI IAL (NICHOLS)

Talk Presented in Induction Aerodynamics Laboratory

at May 1949 Biennial Inspection at Langley

AIR INLET RESEARCH

For a number of years, the NACA has been conducting a broad program of research on air inlets. The more important types being studied currently are illustrated in this chart.

The nose inlet, shown here (CHART I), is aerodynamically the most efficient of the subsonic inlets and is directly applicable to jet engine installations. The subcritical characteristics of this inlet have been well defined. Comprehensive design charts are available both for the basic inlet and for the inlet with protruded central bodies typical of jet-engine accessory housings or propeller spinners. What has been needed has been more information on the characteristics of this inlet at transonic speeds.

Some information on this subject has recently been obtained by tests of several NACA 1-series nose inlets up to and beyond their force-break Mach numbers. External drag data obtained by means of wake surveys are shown here for the shortest inlet and here for the longest inlet. The solid-line curves are for the design condition for which the inlet-velocity ratio, that is, ratio of the velocity of the flow entering the inlet to the free-stream velocity, was high enough to avoid a negative pressure peak on the lip. The dashed-line curves are for the zero flow condition, for which the most severe pressure peak occurred on the lip. The x's on the curves indicate the measured critical Mach number.

We see first that although the critical Mach number was affected by the rate of internal flow the force-break Mach number was not. Secondly, a large margin existed in all cases between the critical Mach number and the force-break Mach number. Both of these findings tend to relax our previously established design requirements which were based on the critical Mach number and the minimum inlet-velocity ratio for avoiding a negative pressure peak on the lip.

Total pressures were measured just inside the entrance for these inlets as shown and when equipped with several spinners. In the design ranges, the ram recovery was found to be very nearly 100 percent throughout this range of Mach number and also at a supersonic Mach number of 1.2.

(CHART I) As I mentioned before, fairly complete data have been published on the cowling-spinner combination, shown here, but without the propellers. The additional need of the designer is information on the effects of the propeller shanks on the internal flow.

Some preliminary results have already been obtained in a pilot investigation at low speeds of the cowling-spinner combination shown here (CHART III). This model was tested with several sets of 8-blade dual-rotating propellers and with propellers removed. The propeller shown by the shading had the thinnest shanks tested, only 12-percent thick. These shanks extended all the way to the spinner surface. The propeller shown by the dotted lines had conventional round shanks.

The ordinate of these curves is the ram recovery at the cowling inlet in terms of the free-stream dynamic pressure; the abscissa is the inlet-velocity ratio. With the thin-shank propeller operating in the design cruise condition for which it was designed, the ram recovery was about the same as with the propeller removed, and was over 95 percent for all inlet-velocity ratios above 0.5. With the round-shank propeller, the ram recovery in this range of inlet-velocity ratio was 12 to 16 percent less than the ram recovery with the thin-shank propeller. At the Mach number of 0.8, for which the installation was designed, severe compressibility effects on the round shanks would increase the differences between the ram recoveries obtained with the two propellers. These and other similar data obtained in the investigation stress the necessity for using thin-blade shank sections and clean junctures at the propeller-spinner intersection.

Research on this problem is continuing with emphasis on the study of practical propeller-spinner intersection configurations. So far these have been only low-speed studies. Promising arrangements will be tested at high speeds as soon as possible.

(CHART I) The NACA 1-series nose-inlet data also are directly applicable to the design of the external lines of the <u>rotating cowling</u>, shown here. This cowling is heavier than the cowling-spinner combination and presents far more difficult structural and de-icing problems. However, it has several important advantages. The radius of the external intersections of the propeller with the cowling are relatively large so that very thin propeller sections can be used at this point. Also, the propeller root sections are enclosed by fixed fairings in the internal ducting. Hence they do not affect the internal flow and thick propeller-blade root sections can be used. Information on which to base the internal design of this cowling is currently being obtained.

The use of the nose inlet is frequently ruled out because of the necessity for locating equipment such as guns, ammunition, radar scanner, etc., in the fuselage nose. Also the large fuselage volume occupied by the ducting between the inlet and the engine also is objectionable. These considerations have led in many cases to the use of other types of inlets, such as the wing-root inlet, shown here. With this type of inlet, additional problems are encountered. The first is the problem of controlling or bypassing the fuselage boundary layer. This problem may be particularly difficult at transonic speeds because of shock-boundary-layer interaction. The second is the problem of designing the inlet so as not to reduce the maximum lift of the wing or introduce undesirable compressibility effects.

Several satisfactory wing-root inlets have been developed for specific airplanes. However, systematic design data for arrangements suitable for very high-speed aircraft have not been obtained. To supply this need, basic theoretical and experimental research on the section characteristics of wing inlets is being conducted at the Ames Laboratory. An exploratory investigation for the very important case of an inlet in the root of a swept wing has started at Langley.

Another alternate to the nose inlet is the fuselage scoop. Here again the fuselage boundary layer introduces the same problems that I mentioned for the wing-root inlet.

For the conventional protruded scoop, several investigations have established satisfactory design procedures and have demonstrated satisfactory boundary-layer removal systems.

The submerged scoop is receiving considerable attention at the present time due to the possibility of reducing adverse compressibility effects and at the same time reducing the ingestion of foreign material. The particular design illustrated here is the NACA submerged inlet which has been developed and extensively investigated at the Ames Laboratory. The lip of this scoop is flush with the fuselage surface. The approach ramp diverges from the basic fuselage surface at an angle of about 7° and is bounded at its top and bottom by sharp-edged trumpet-shaped ramp walls. At the lower inlet-velocity ratios, typical of high-speed flight, the boundary layer along the fuselage here and here does not enter the inlet, but is entrained in the vortices formed along the edges and is carried over the top corners of the inlet. Thus, the ramp walls act as an automatic boundary-layer-control device and additional boundary-layer control is not absolutely necessary.

Recent tests with boundary-layer control applied to the approach ramp by means of suction through a porous surface, however, have shown that gains of 3 to 12 percent in the high-speed range of inlet-velocity ratio can be obtained by removing only 2 to 4 percent of the entering flow. This work is continuing.

In any case, with or without boundary-layer control, extensive tests have shown that the inlet can provide a high ram recovery in the high-speed condition for Mach numbers up to about 0.9. The most serious limitation of the inlet appears to be the rapid decrease in ram recovery that takes place when the inlet-velocity ratio is increased from the high-speed value to the values encountered in take-off and climb.

(CHART IV) More recently a different type of submerged scoop has been studied at the Langley Laboratory. As shown here, this arrangement consisted essentially of a conventional protruded scoop located in a depression or dimple in the fuselage surface deep enough to allow the outside of the lip to be level with the surrounding surface. The ramp floor angle relative to the fuselage surface was rather large, about 18°, so that the installation was appreciably shorter than the standard NACA submerged inlet. Self-activating boundary-layer control was provided by a bypass duct with the air entering here and leaving here.

These curves present ram recoveries inside at the end of the diffuser of this scoop as a function of the inlet-velocity ratio for several suction flow quantities. This parameter is the suction quantity divided by the inlet area times the free-stream velocity.

In general, suction increased the ram recovery. With the higher flow quantities, ram recoveries of 90 percent or more were obtained over this range of inlet-velocity ratios which is wide enough to cover most of the important flight conditions. Of course, the amount of suction air is rather large and its drag must be taken into account in computing the overall gain in net thrust. Further work is required before this inlet can be recommended for application to an airplane.

I now turn you over to Mr. who will discuss some of our research on supersonic inlets.

LANGLEY BIENNIAL INSPECTION

1949

AIR-INLET RESEARCH

Supersonic Inlets

All of these inlets which have just been discussed are essentially subsonic inlets. A different type of inlet is required by the supersonic aircraft or missile. The one shown here is the single-shock inlet, which is functionally similar to the subsonic nose inlet in that the projecting control cone permits most of the compression to take place ahead of the entrance. Adequate information has been obtained to permit the design of this type of inlet for a high ram recovery for a very wide range of supersonic Mach numbers.

A shadowgraph of the flow around a single-shock inlet at a Mach number of 2.7 is shown at the top of this next chart. For this typical design condition, the shock off the nose of the cone enters the inlet so that the external flow is entirely supersonic. For this case, the drag can be evaluated accurately by the use of the characteristic theory.

A corresponding shadowgraph of the flow about a multiple-shock or Oswatitsch inlet, designed for the same Mach number, is shown in the lower part of the chart. It has long been known that pressure recoveries can be obtained with this type of inlet which are a few percent higher than those for the single-shock inlet. However, this increase is obtained at the expense of an increase in the maximum diameter of the body which results in higher external drag. Furthermore, as shown here, it is usually found experimentally that shock-induced separation effects produced a detached normal shock ahead of the entrance which also increases the drag.

A comparison of these two photographs shows that the slope of the shock here is much higher for the multiple-shock inlet than for the single-shock inlet. This is qualitative evidence of the much higher drag of the multiple-shock inlet. Until recently, the drag could not be calculated for this case where the external flow is partly supersonic and partly subsonic. A new method developed at this Laboratory, however, now permits such calculation. The method requires only a shadowgraph or Schlieren photograph, such as this one, which shows the outline of the detached bow shock. The calculation of the drag for these two cases shows that the external drag coefficient of the multiple-shock inlet is actually 35 times greater than that for the single-shock type. At the same time, the pressure recovery was only about 7 percent higher. Application of these results to a typical ram-jet installation shows a markedly higher net thrust for the single-shock type. These and similar results lead to the conclusion that for Mach numbers of 2.5 or greater, the single-shock inlet provides higher net thrust than any other available design.

(CHART 1) - As in the subsonic case, practical considerations often require the use of a scoop-type inlet located aft along the fuselage rather than a nose inlet. Again the main problem is the disposal of the fuselage boundary layer. The arrangement illustrated here is one of a series of scoop-type inlets being investigated at the Ames Laboratory. It incorporates a wedge-shaped ramp to obtain some external compression, slots at the bottom sides of the scoops to bleed off some of the entering boundary layer, and an internal contraction to afford a small amount of internal supersonic compression. The pressure recovery of this inlet is appreciably lower than that for a single-shock nose inlet, and it is believed that the external drag is much greater. The investigation of this type of inlet is continuing with the two objectives of increasing the pressure recovery and at the same time measuring and reducing the external drag.

Mr. will now present a demonstration of the flow phenomena associated with a single-shock inlet in two-dimensional flow.

Presented alternately by Robert E. Pendley and Ralph P. Bielat, 8-Foot, at IAL.

pcc
5-20-49

Inlet Demonstration at M = 1.5

Introduction.- Over the normal range of power plant operation the air induction system is subjected to a wide range of flow conditions. It has been shown by a previous speaker that at subsonic speeds air inlets may be designed to operate efficiently throughout the flow range. At supersonic speeds, however, efficient operation is limited to those conditions wherein the entire stream immediately ahead of the inlet enters the duct. In the demonstration to be given here, a two-dimensional adaptation of single shock inlet previously described will be operated over a range of back pressures to show the effect of varying back pressure on the internal and external flow pattern. The tunnel Mach number is 1.5.

In the upper part of this chart we have a cross-section drawing of the setup to be used during the demonstration. Air enters the system flowing from left to right, passes through a converging-diverging passage to the region normally occupied by the power plant. The effect of varying the power plant operation will be simulated in this demonstration by a remotely-controlled throttle in the diffuser exit.

At the design conditions all the air directly ahead of the inlet should enter the system through oblique shock waves attached to the apex of the inner body and at the duct lips. A normal shock followed by subsonic flow should stand in the minimum section of the duct.

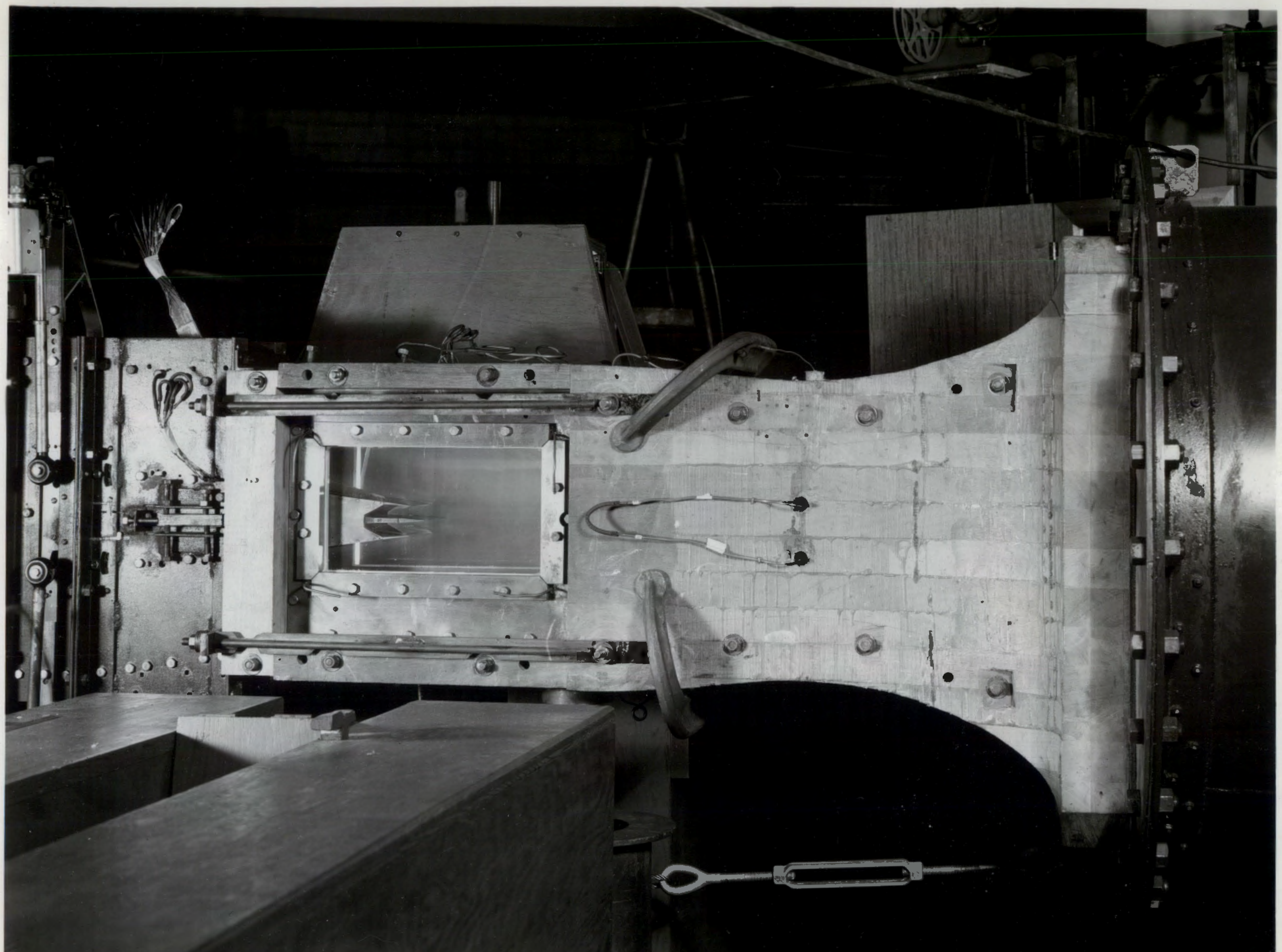
Reducing the back pressure causes the normal shock to move downstream to higher Mach number regions. Increasing the back pressure above the design point theoretically causes an abrupt detachment of the bow wave in which condition the external drag is greatly increased.

The demonstration setup is mounted directly behind this display stand. The wooden block houses the tunnel proper. The test inlet can be seen at the left side of the observation window. The flow field around the inlet will be projected onto this screen from conventional schlieren optical system. An operator within the control house will operate both the tunnel and the throttle at the diffuser exit. Dark spots on the screen are imperfections in the glass.

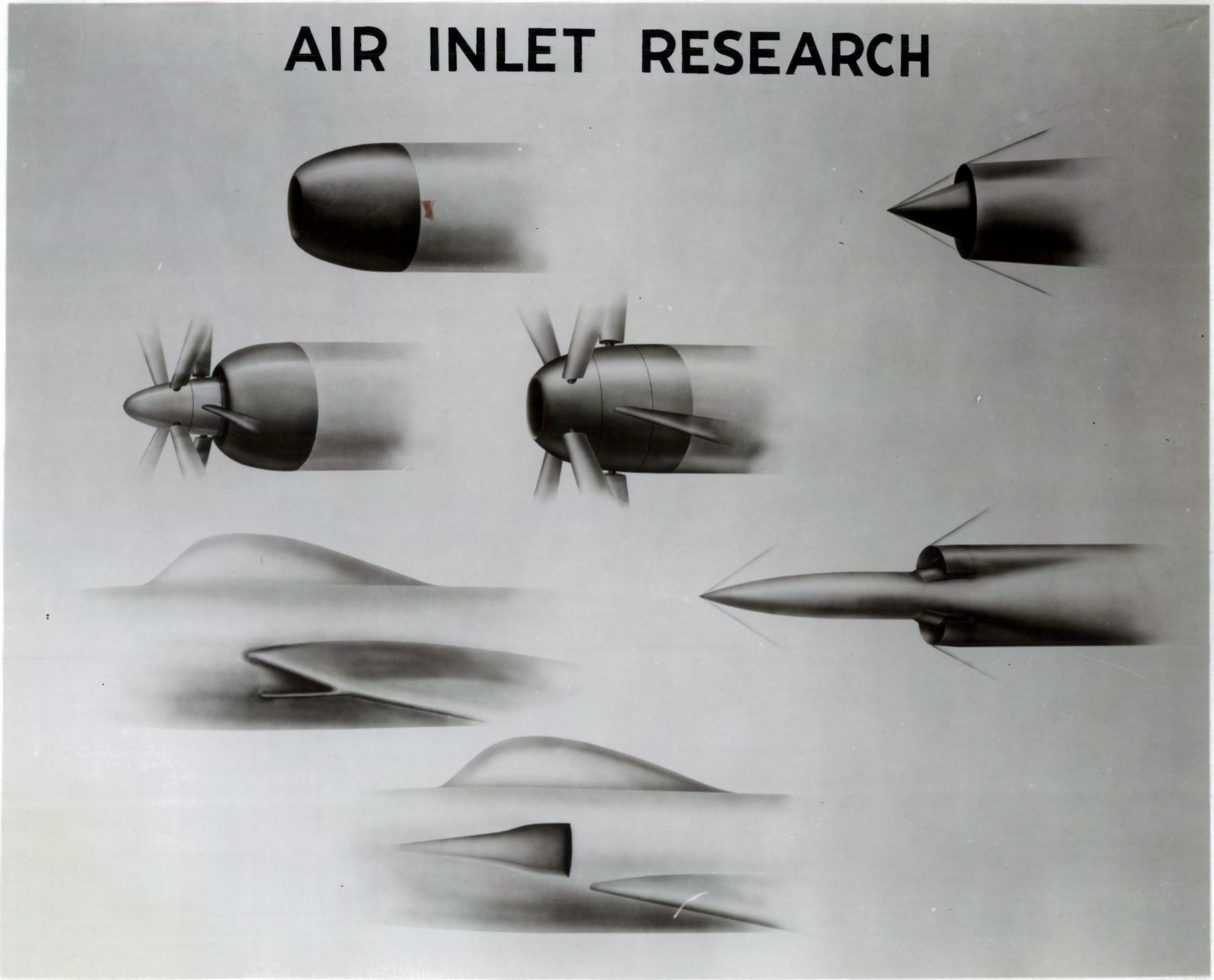
We are starting the tunnel with the throttle fully open. Although the flow ahead of the body is subsonic, local supersonic Mach numbers have been reached in the internal passages. A normal shock characteristic of tunnel starting will approach the inlet from the left. Due to high humidity conditions, condensation may be present and the shock pattern will not be toosharply defined. The Mach number at the inlet is 1.5. The back pressure is being increased by closing the exit throttle.

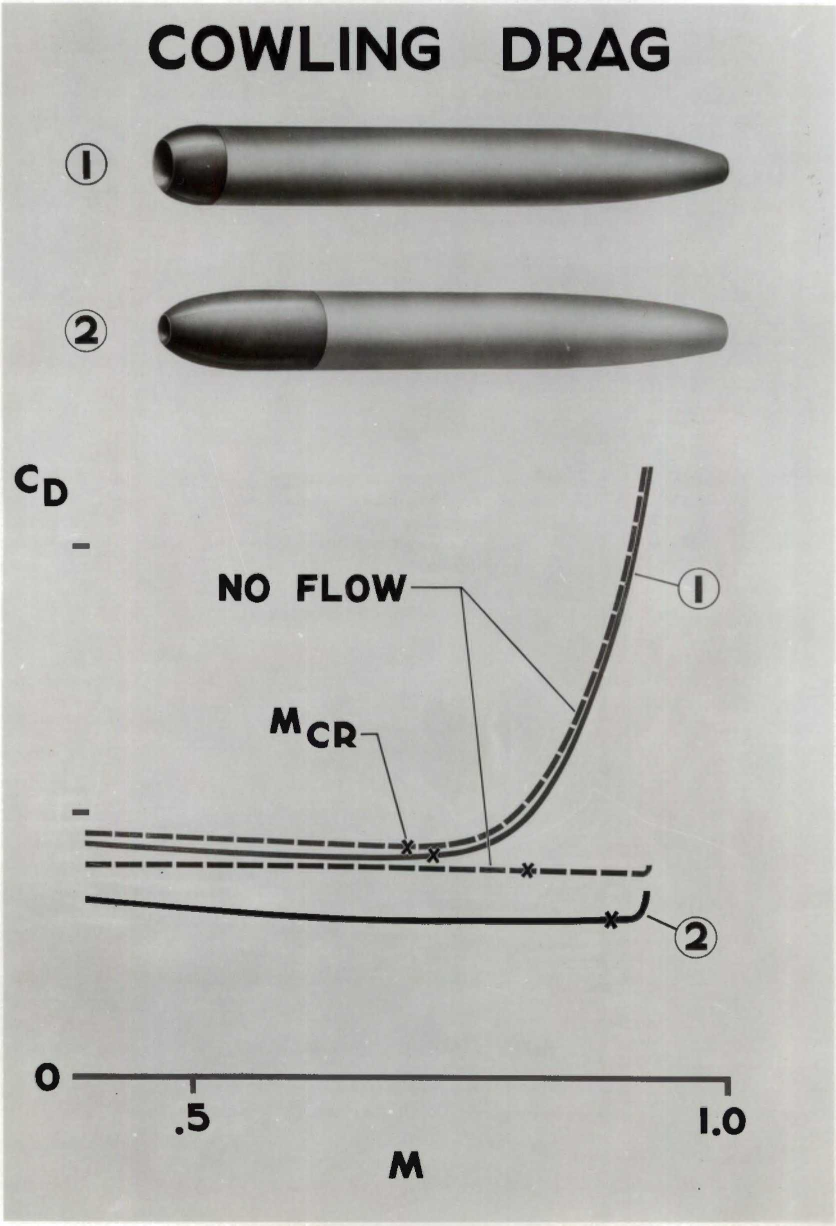
Note: (a) The normal shock is moving forward; (b) the external flow is constant; (c) the bow wave has now become detached -- this is a high drag condition.

The throttle will now be opened gradually and the process reversed. Note the attachment of the shock is gradual rather than abrupt as predicted by non-viscous flow theory. The same cycle will be repeated quickly. This concludes the demonstration.

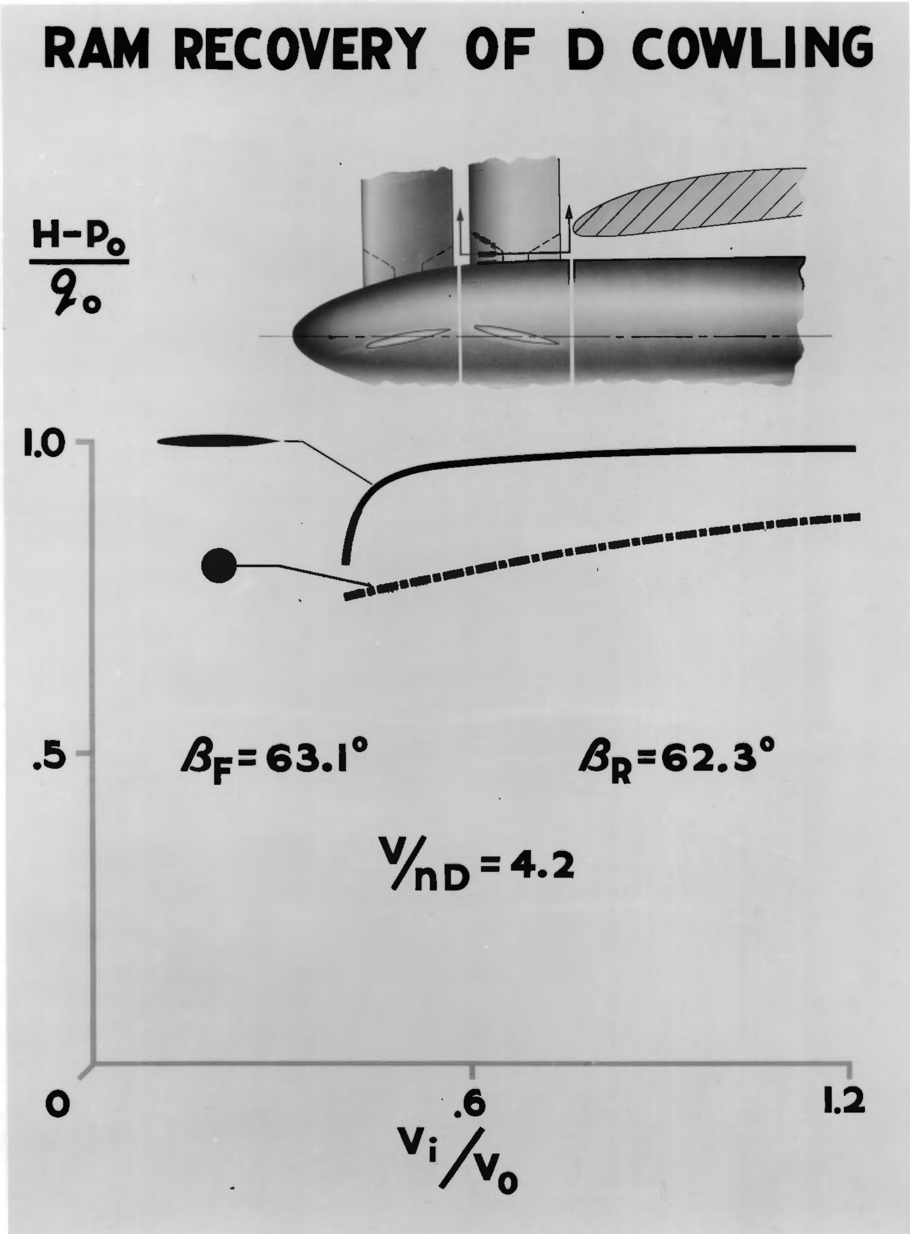


NACA
LAL 61113

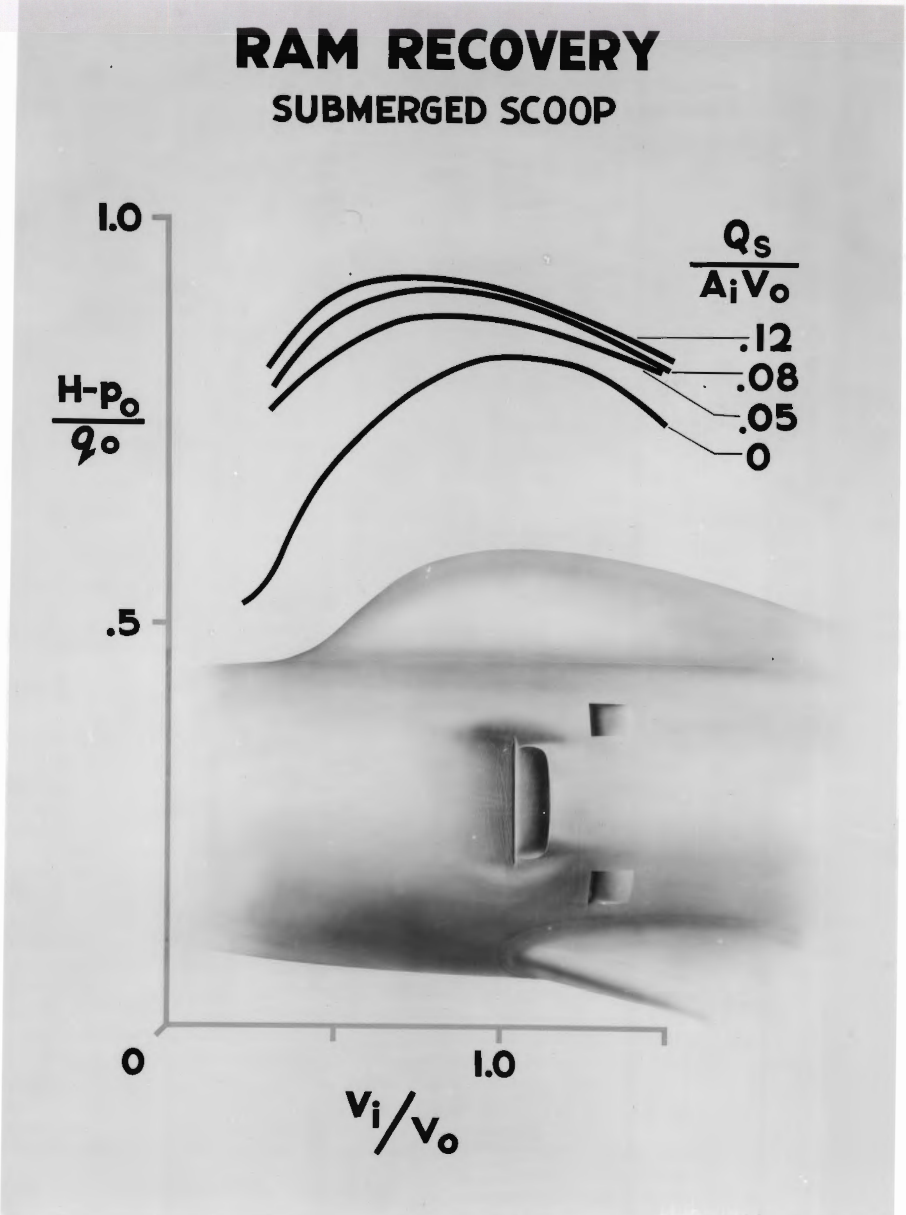

AIR INLET RESEARCH



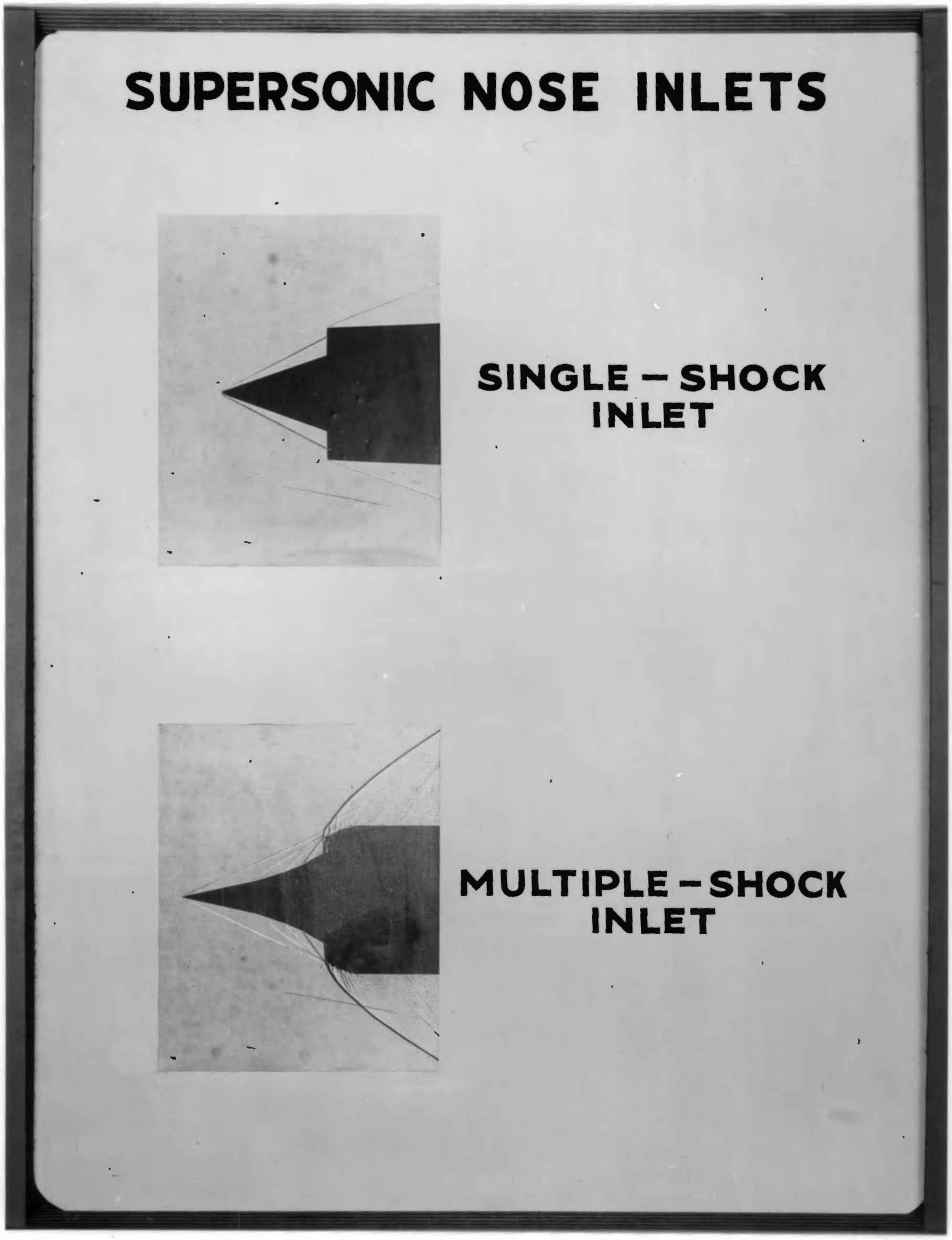
NACA
LAL 61115


RAM RECOVERY OF D COWLING
H-P0
q0
1.0
.5
0
.6
1.2
βF=63.1°
βR=62.3°
V/nD = 4.2
Vi/V0

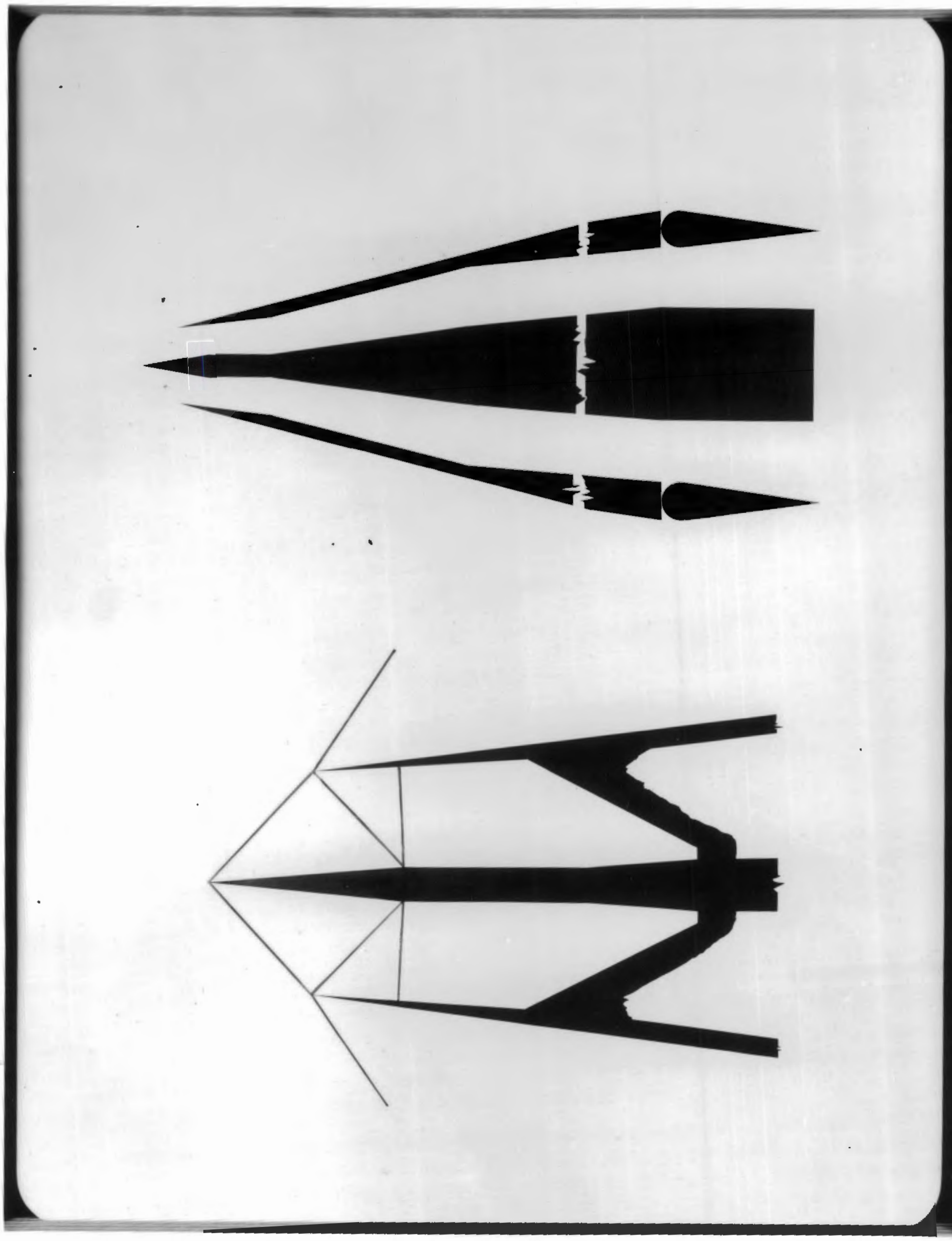
LAL 61116



NACA
LAL 61117



NACA
LAL 61118



LAL 61119