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A THREE-DIMENSIONAL FLOW EXPANDER AS A DEVICE TO INCREASE THE MACH NUMBER IN A SUPERSONIC WIND TUNNEL

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SUMMARY

A preliminary investigation of a simple 5° conical-flow expander was made to determine the feasibility of using this type of device to increase the Mach number in the test section of a supersonic wind tunnel. The inlet-to-exit area ratio of the nozzle was that required to increase one-dimensional flow from a Mach number of 3.88 to 5.5. The Mach numbers obtained at the expander exit varied from about 5.1 at the centerline to about 5.4 near the walls. No difficulty in operation of the main wind tunnel was experienced.

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INTRODUCTION

Experimental research in the hypersonic speed range has been limited by the lack of high Mach number test facilities. On the other hand, many supersonic wind tunnels exist for the Mach number range below 4.0. In most cases, redesigning wind tunnels for higher Mach numbers or even building new nozzles for the interchangeable type is a costly and time consuming operation. It appears desirable, therefore, to explore the possibility of creating high Mach numbers in the existing facilities by simpler means which would leave the original facility more or less intact.

In order to obtain the higher Mach numbers, it is, of course, necessary to further expand the supersonic stream. This can be accomplished either two or three dimensionally, that is, by Prandtl-Meyer expansions about flat plates or by a divergent closed channel. It is not clear, however, whether or not such expansion systems would establish full supersonic flow or what the nature of the boundary-layer shock-wave interaction would be at the expander exit. This preliminary investigation of a flow expander system obtains experimental data to help resolve these questions, and the expander tested was designed for simplicity rather than for a uniform flow field at the exit. An axisymmetric flow expander consisting of a section of a 5° cone was chosen therefore as a simple model to demonstrate the feasibility of the system and was tested in the Lewis 2- by 2-foot Mach 3.88 wind tunnel. The inlet-to-exit area ratio of the expander was chosen to provide an exit Mach number of 5.50 on the basis of one-dimensional isentropic-flow theory.

APPARATUS AND TESTS

The flow-expander channel with an area ratio of 3.83 was designed as a simple segment of a 5° half-angle cone, as shown in figure 1. Boundary-layer displacement effects were not considered because of the preliminary nature of the investigation. In order to decrease the possibility of flow separation in the expander, the static-pressure rise at the channel exit was relieved somewhat by turning the conical-nozzle walls to the axial direction at the exit.

The expander was mounted in the wind tunnel by means of a single sweptback support strut from the top wall. The maximum blockage of the channel was about 55 percent of the theoretical blockage of the Mach 3.88 wind tunnel. The Mach number near the expander exit was determined from measurements of the total pressure behind a normal shock with a 13-tube pitot rake that was 10 inches in height. Wall-surface static pressures were measured inside the channel from flush orifices.

The test conditions corresponded to normal operation of the Mach 3.88 tunnel, that is, atmospheric air was dried and heated, passed through the tunnel, and then into the exhausters. The normal operating total temperature was 200° F and the dew point varied between -20° and -40° F.

RESULTS AND DISCUSSION

The purpose of this investigation was to determine whether or not a three-dimensional flow-expander channel would establish full supersonic flow. Preliminary calculations indicated that the normal shock at starting would go through the channel even with back pressures as high as four times the tunnel free-stream static pressure. On the other hand, the static-pressure rise across the trailing shock wave of the expander channel was estimated to be slightly in excess of a safe value to prevent separation of a turbulent boundary layer (ref. 1).

The tests indicated no difficulties in starting either the main tunnel stream or the expander flow. No separation at the expander exit was indicated by the wall static pressures (fig. 2) or by the pitot rake. Figure 2 indicates that the static pressure at the expander exit was probably about twice the calculated value, and hence the critical pressure ratio may not have been exceeded.

Figures 2 and 3 indicate that although the flow in the nozzle was far from ideal one-dimensional flow or even radial flow (flow originating at a point source having uniform Mach numbers in a spherical plane), the resulting flow field at the exit was not too far from the design value of 5.5. Figure 3 indicates that the Mach number varied from about 5.1 at the expander centerline to about 5.4 near the walls. In general, the most favorable test area for this particular design can be seen to occur downstream of the expander exit.

The use of a tunnel Mach booster may require an increase in the temperature of the expanded stream to avoid liquefaction of the air components. Since it is necessary to add heat in the subsonic part of the tunnel, the amount of heat added can be kept to a minimum by heating only the center core of the tunnel flow that is taken into the expander. Some experimental results of such heat addition to a supersonic wind tunnel are reported in reference 2.

CONCLUDING REMARKS

A preliminary investigation of a simple conical-flow expander channel indicated that the use of this type of device is feasible to increase the test Mach numbers available from conventional wind tunnels. The extent of application of such a technique will be limited by the pressure rise at the expander exit that will cause separation of the channel boundary layer.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, August 28, 1958.

REFERENCES

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2. Rousso, Morris D., and Beheim, Milton A.: Preliminary Investigation of a Technique of Producing a Heated Core in a Supersonic Wind-Tunnel Stream. NACA RM E54K02, 1955.

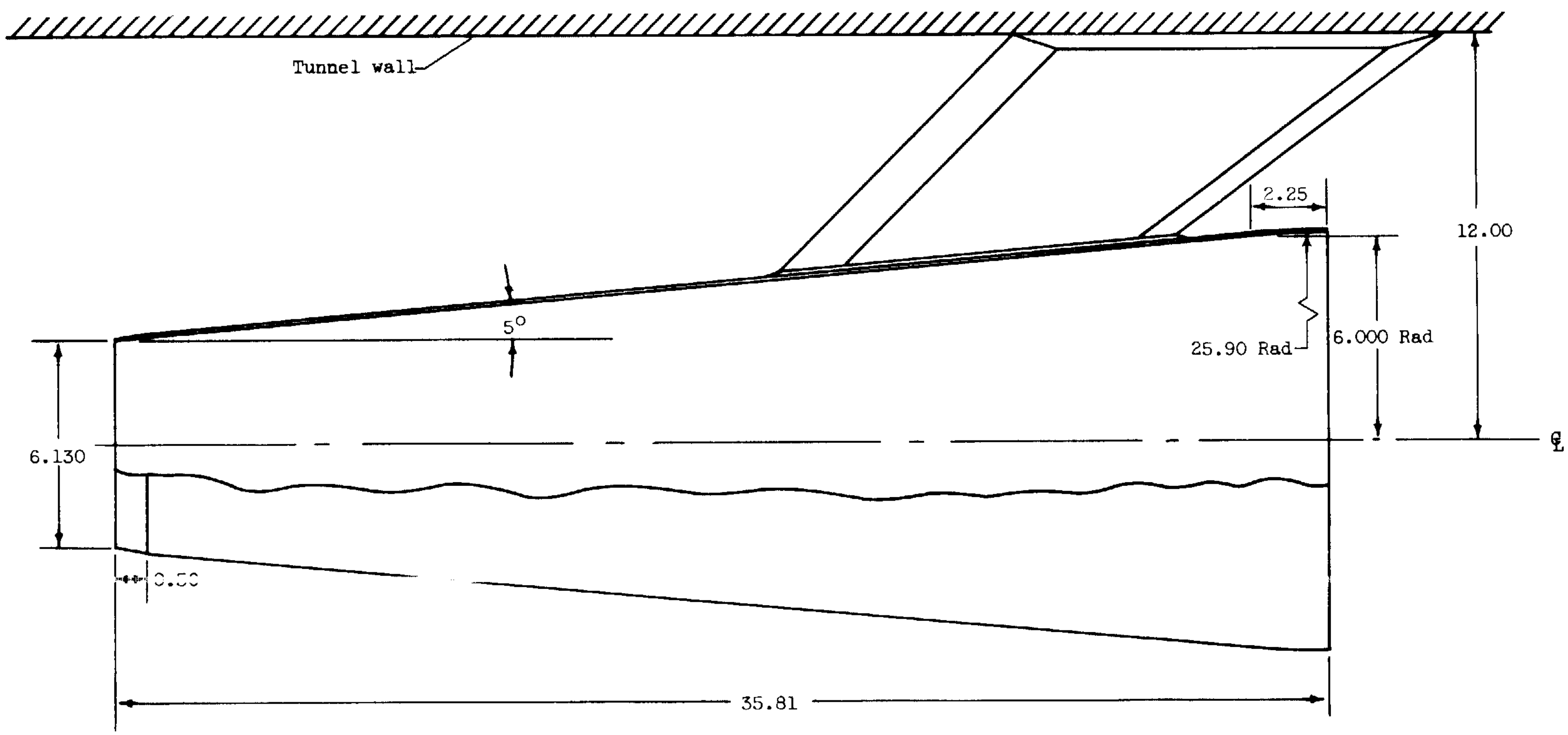

Figure 1. - 5° Conical-flow expander nozzle and support strut. All dimensions in inches.

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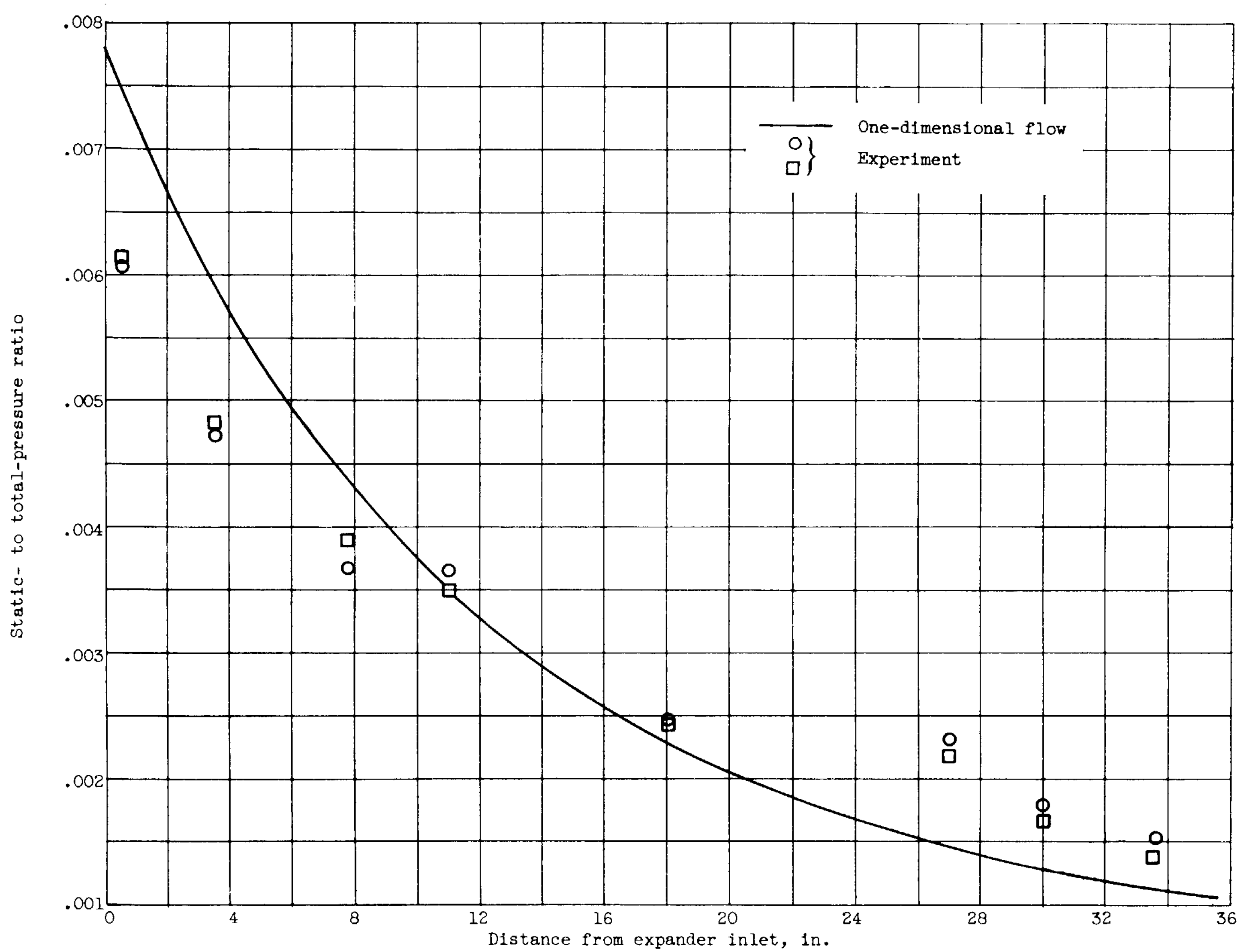
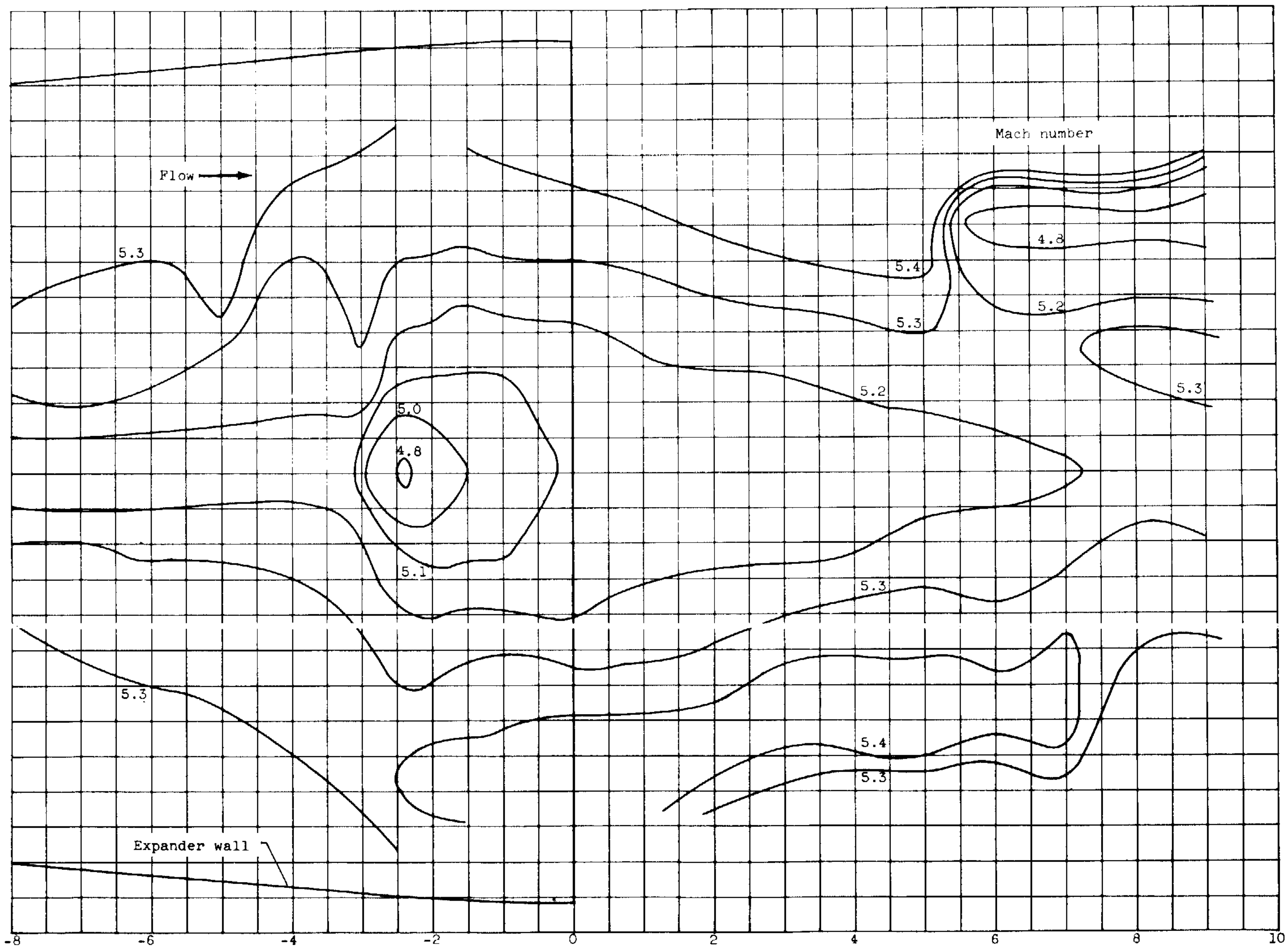


Figure 2. - Comparison of nozzle wall static-pressure variation with one-dimensional flow theory.



Distance from expander exit, in.

(a) Vertical plane.

Figure 3. - Mach number contours in planes through nozzle centerline.

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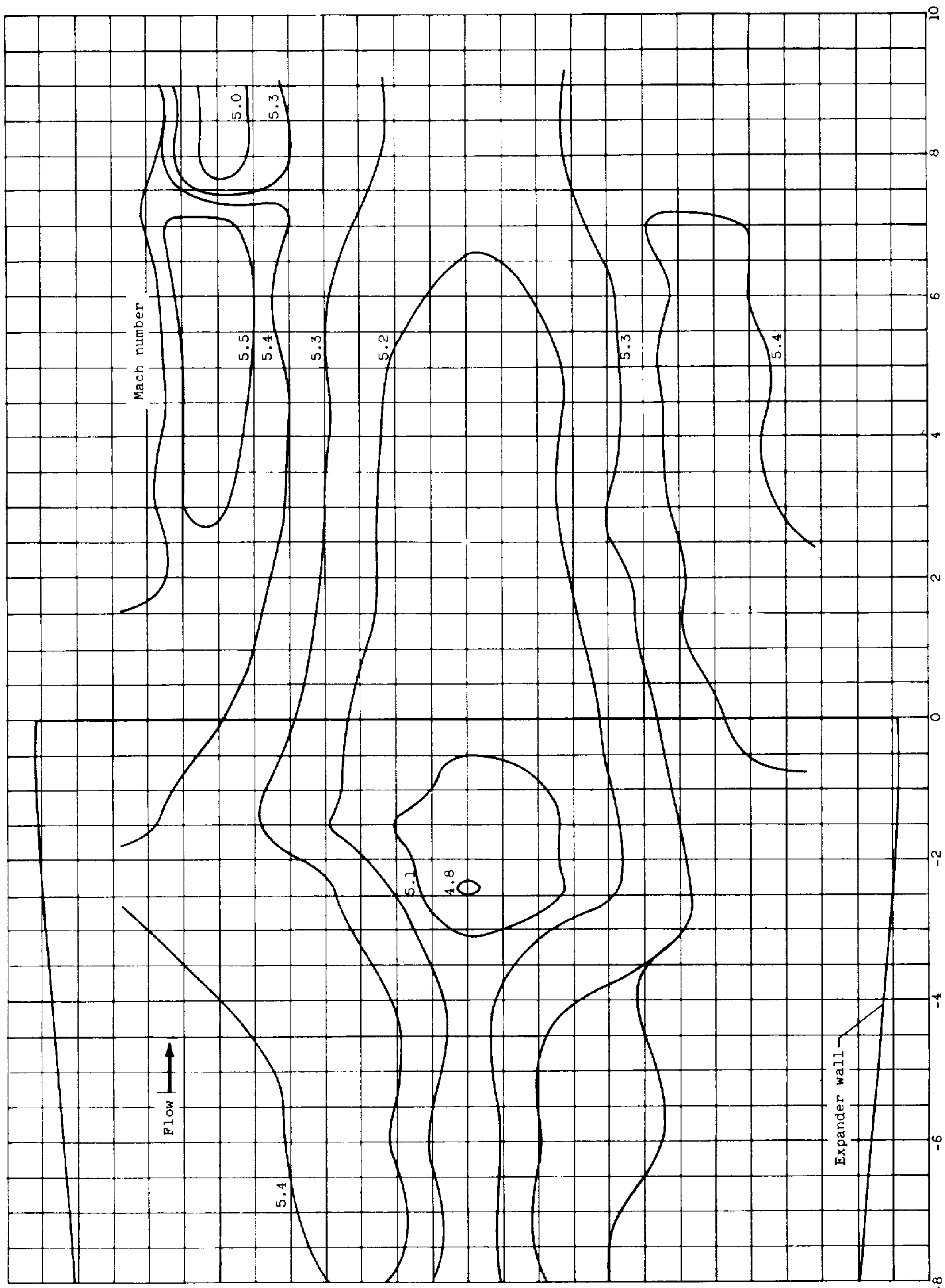

(b) Horizontal plane.

Figure 3. - Concluded. Mach number contours in planes through nozzle centerline.