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DEVELOPMENT OF SEEDING TECHNIQUES  
FOR SMALL SUPERSONIC WIND TUNNEL

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## NASA LEWIS 1FTx1FT SUPERSONIC WIND TUNNEL

The NASA Lewis 1x1 foot supersonic wind tunnel is used to experimentally verify computational methods. This tunnel, which is continuous running, operates from laboratory-wide high pressure air and vacuum systems. As such, the air does not recirculate but makes a single pass through the tunnel. The Mach number is varied with interchangeable nozzle blocks and has a range from Mach 1.6 to 4.0. Dry and filtered air is available up to pressures of 3 atmospheres. The air enters the tunnel system through a plenum having flow straighteners and 6 fine mesh screens. The exit of the plenum provides smooth contraction with an area ratio of approximately 20 that, along with the screens, provides a uniform flow for the nozzle. (See fig. 1.)

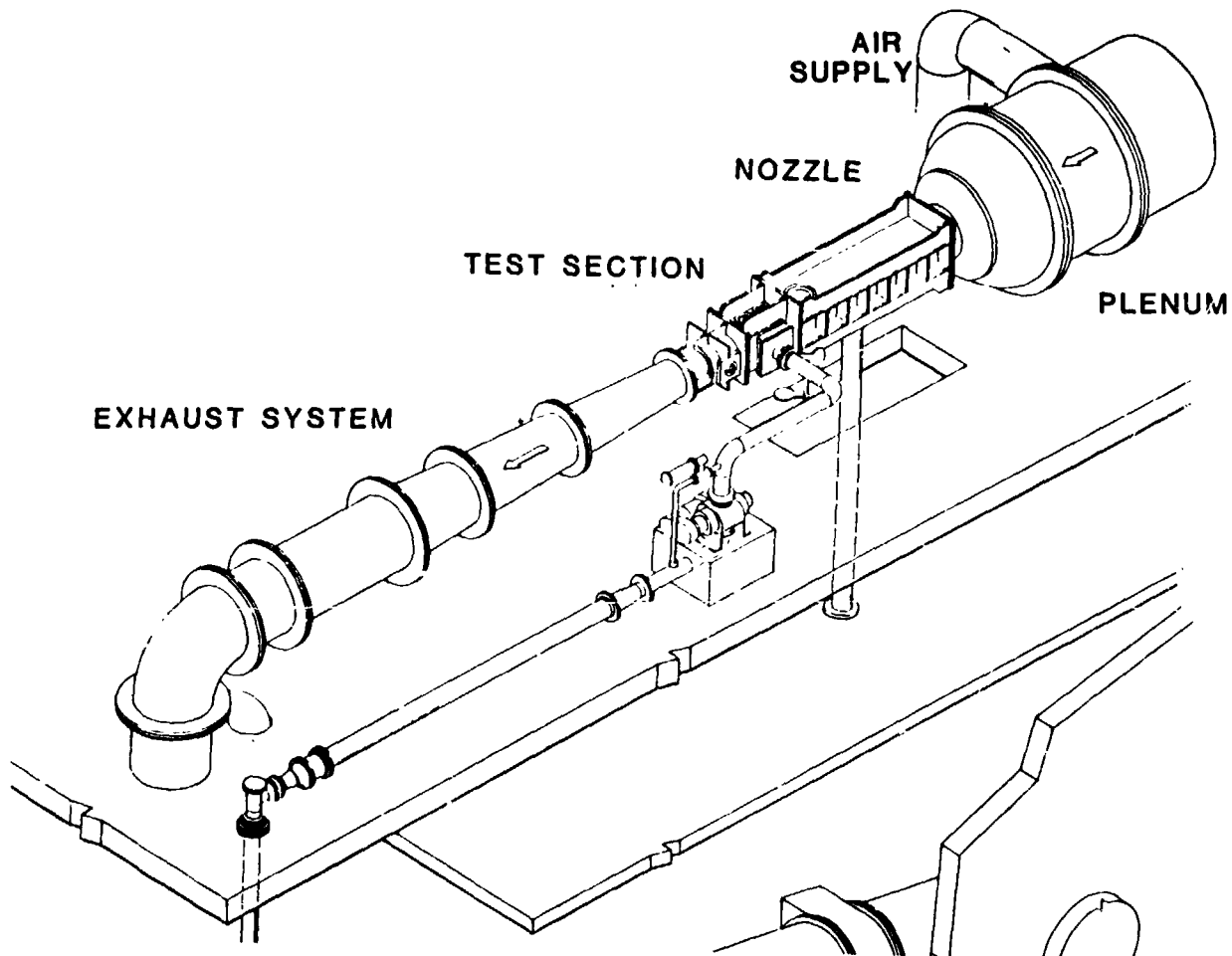


Figure 1

## TUNNEL TEST SECTION

A test section downstream of the nozzle blocks is available for studies. This section, which is .65 m long, has two ports of tunnel height and .5m in length that are used for windows, model installation and instrumentation. Downstream of this test section is a transition and diffuser section which ducts the flow into the vacuum exhaust system. In the test described here, a flow blockage cone was installed in the transition section to stabilize a normal shock in the test section. This cone could be actuated axially to position the shock at the desired location. (See fig. 2.)

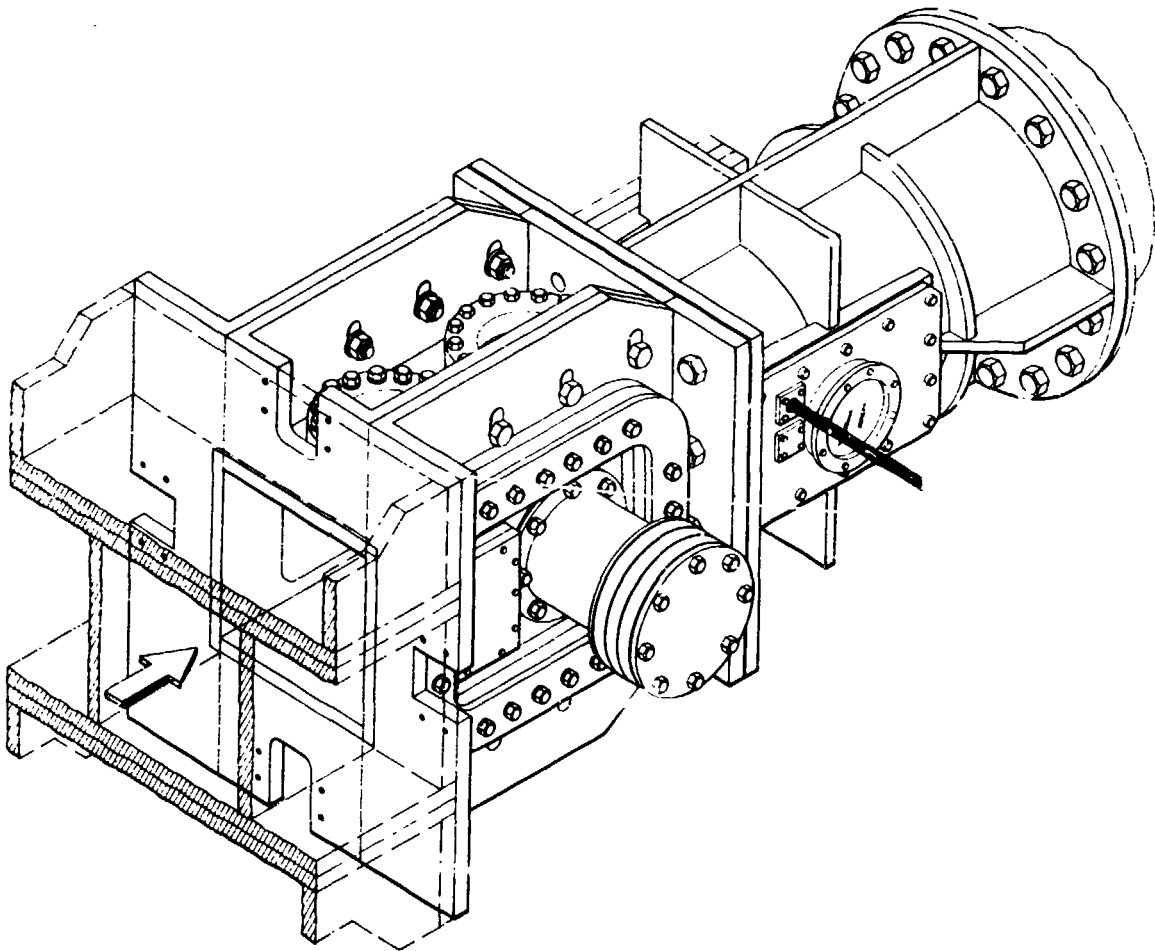


Figure 2

SCHLIEREN-FLOW VISUALIZATION

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The normal shock-tunnel wall boundary layer interaction was investigated at Mach number 1.6. Figure 3 shows the results of a Schlieren flow visualization of the shock-boundary layer interaction. This photograph, which extends approximately 10 cm from the tunnel floor, shows the bifurcated or "lambda" shock structure. In this photograph the flow is from right to left.

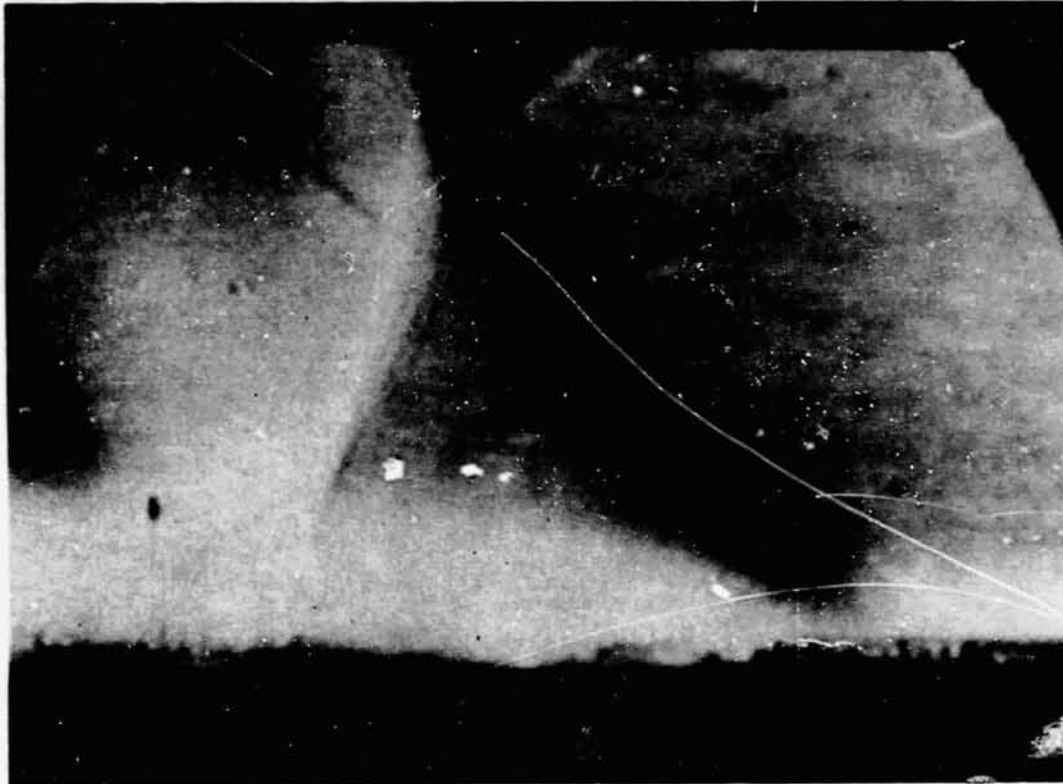


Figure 3

SURFACE OIL FLOW VISUALIZATION ORIGINAL PAGE IS  
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The pressure gradient from the shock at the relatively high Mach number of 1.6 causes substantial flow separation in the wind tunnel. In figure 4 surface oil flow visualization is used to define the three-dimensional separated regions produced by the shock interacting with the tunnel boundary layer. In this figure, an oil-fluorescent dye mixture was applied upstream and allowed to flow downstream through the interaction region. The results were photographed through the Schlieren window. The oil clearly defines a large separation bubble in the corner of the test section at the location of the shock.

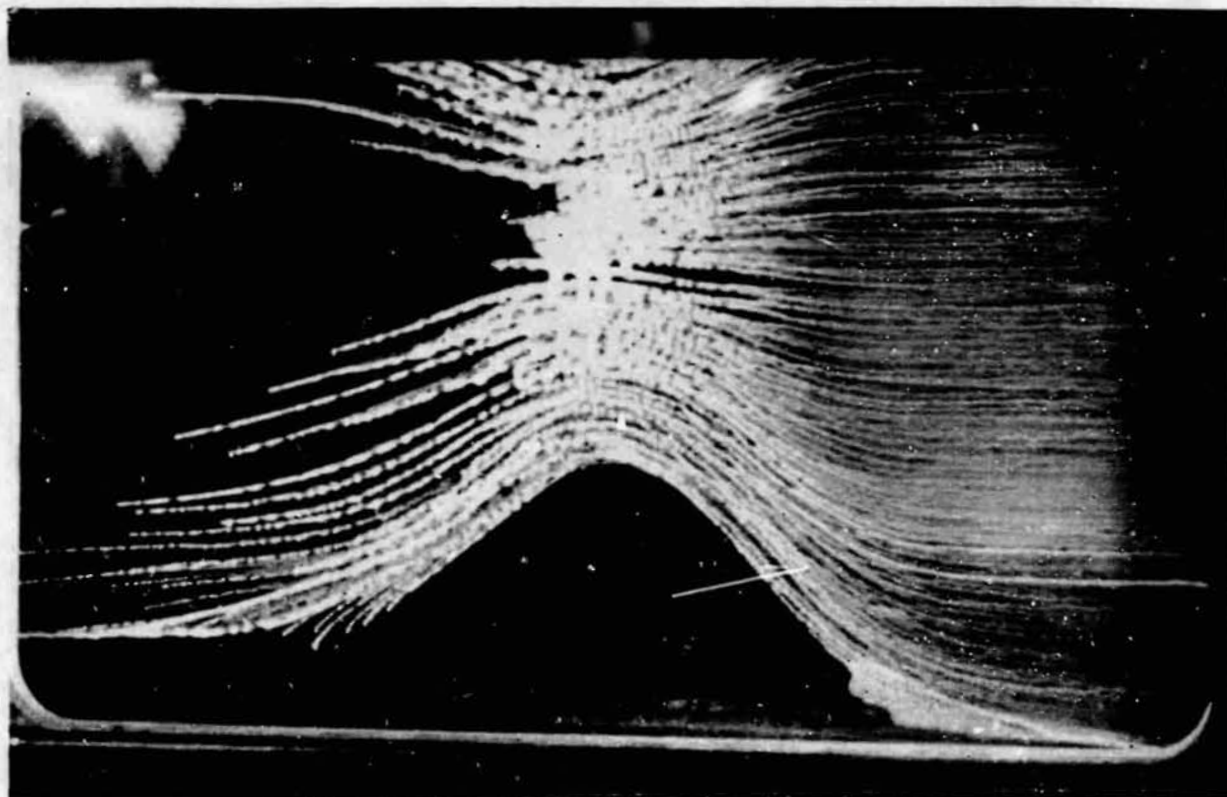


Figure 4

## SURFACE OIL FLOW VISUALIZATION

In figure 5, a photograph of a slightly different surface oil flow visualization technique was used. Here the oil is applied over the entire surface of the tunnel and then the normal shock established in the test section. Using this technique, the surface flow structure in the separated region is defined. The surface oil flow shows the reverse flow in the separated region.

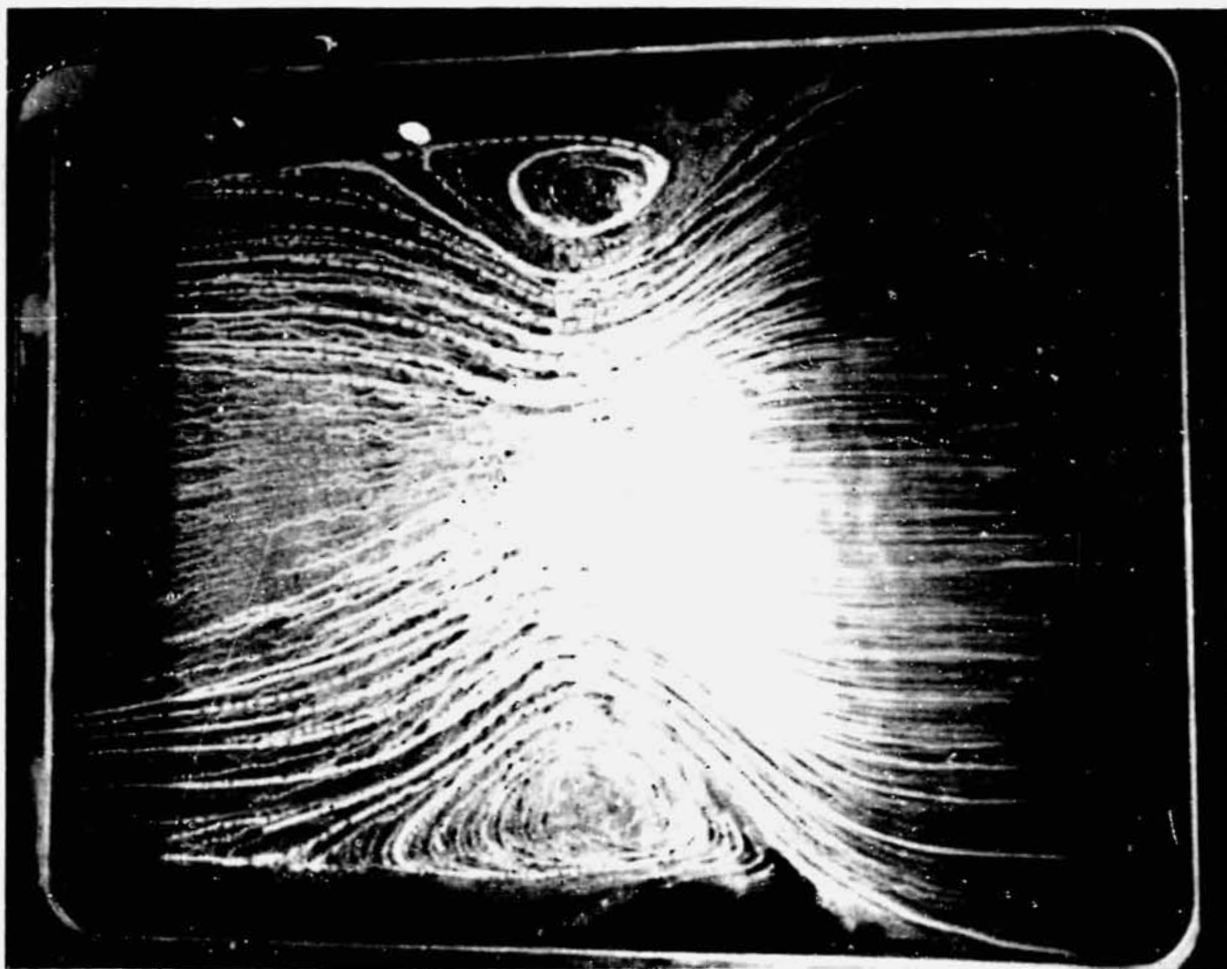


Figure 5

SURFACE OIL FLOW VISUALIZATION

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The three-dimensional nature of the separation is shown in figure 6. In this photograph, the results of a surface oil flow visualization are shown from an upstream location. This view was taken after the tunnel was shut down and the tunnel nozzle block removed. In the mid-floor region, the oil flow was disrupted by the line of an access port blank. The separated region on the floor defined by the oil flow is nearly identical to that on the side wall. These results give a picture of a quarter section of an axisymmetric separated flow region in the corner.

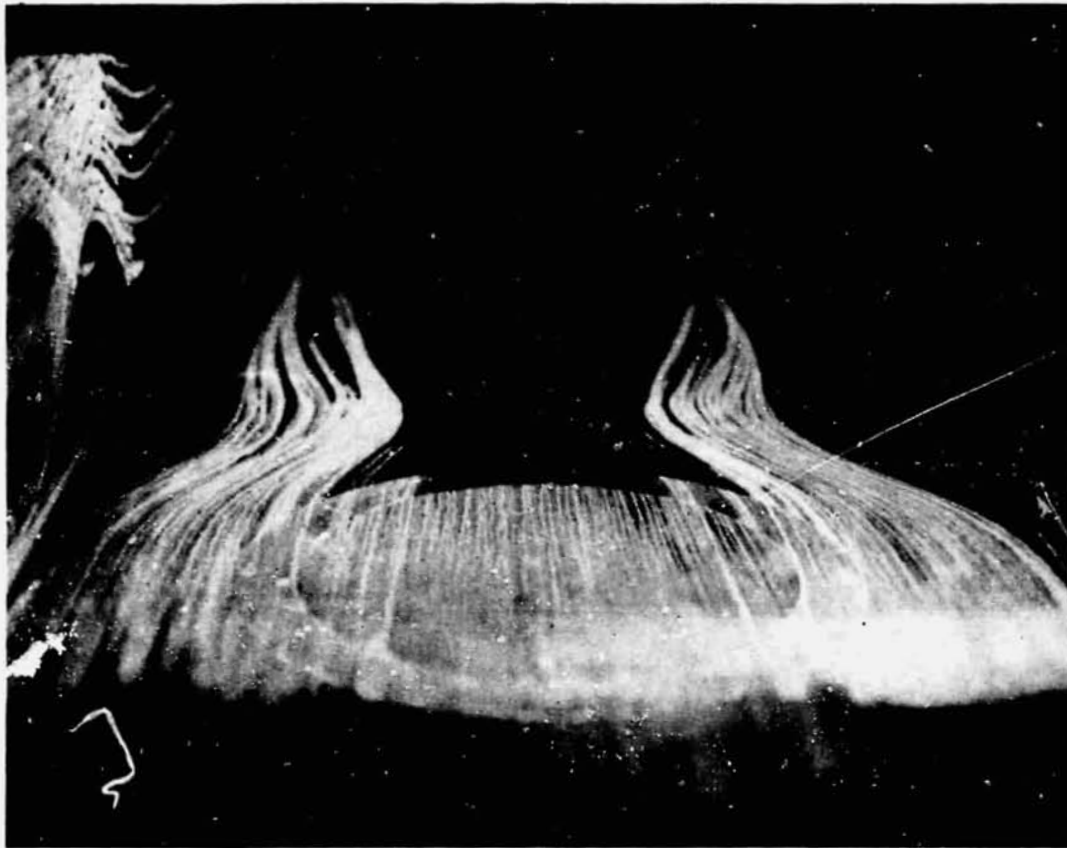


Figure 6

## PARTICLE GENERATOR

A schematic of the particle generator used in this experimental investigation is shown in figure 7. The design is based on a technique presented in Ref. 1 and is referred to as a evaporation - condensation generator. In this design, the seed material, DOP, is introduced along with a diluting gas through an atomizing nozzle. This mixture passes through a heating section that vaporizes the DOP. The vapor is then slowly cooled, allowing the oil to condense on residue nuclei. This creates a monodisperse aerosol. The mean diameter can be controlled by using an oil-alcohol mixture and varying the concentration of this mixture. For the tests described here, the oil concentration was maintained at 20% by volume.

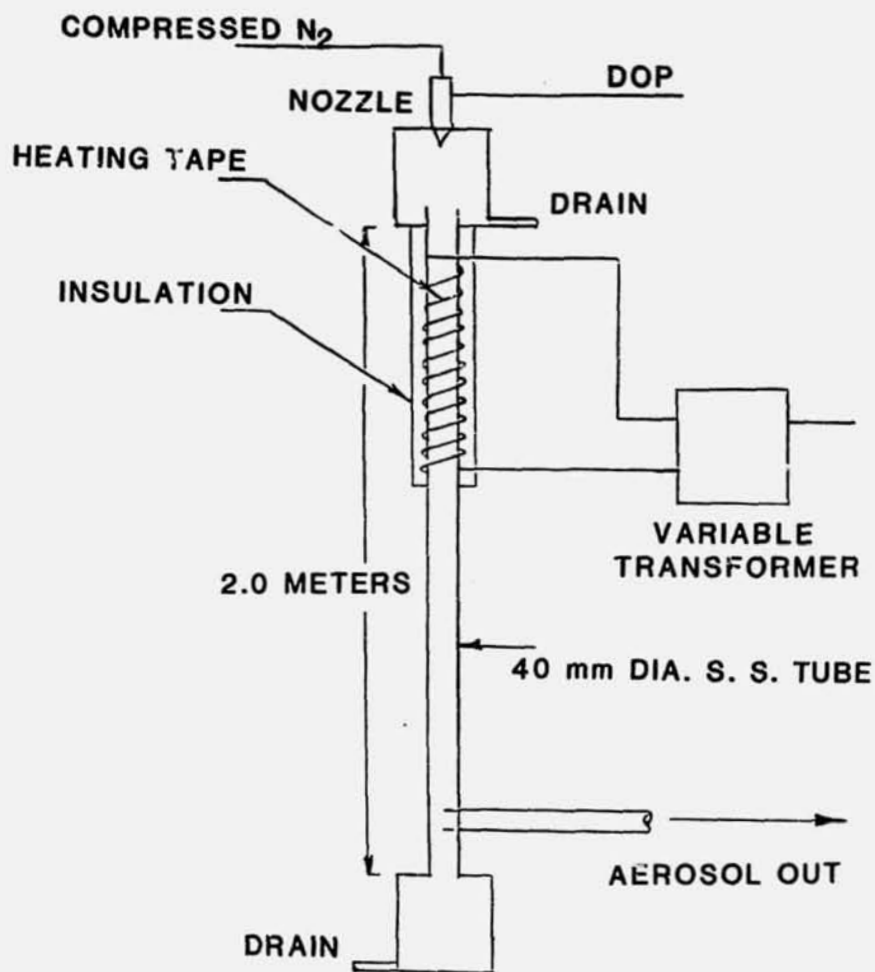


Figure 7



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PARTICLE GENERATOR

Figure 8 is a photograph of the evaporation - condensation particle generator. The generator is located approximately 10 meters upstream of the tunnel plenum. The seed is injected into the flow at a location where the air has passed through a pair of parallel filters and the two streams are combined into a single pipe. This location provides for good mixing of the seed with the flow. This technique seeds the entire tunnel flow and does not provide a means for directing the seed material to any location in the tunnel flow.

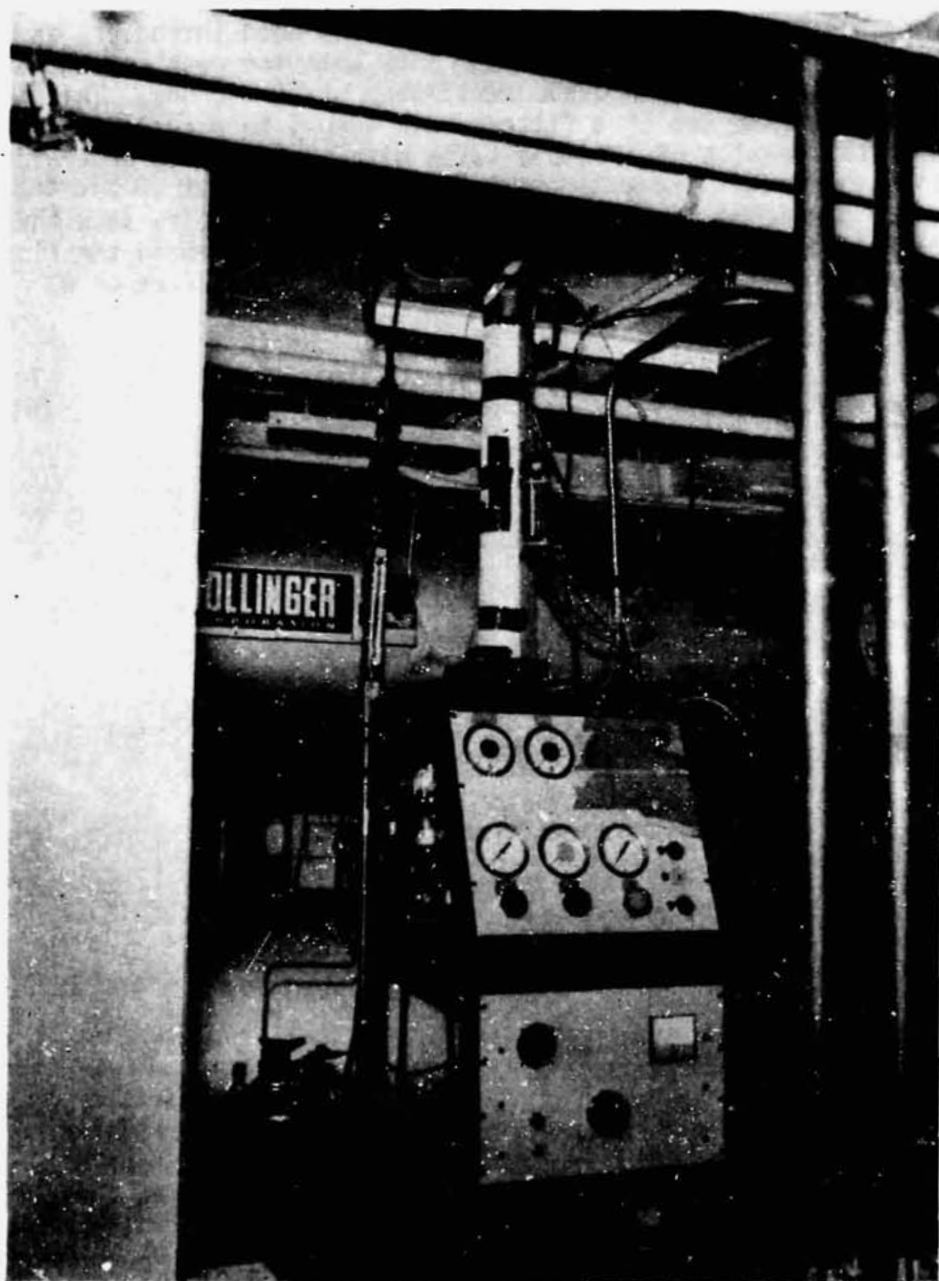


Figure 8

## PARTICLE SIZER RESULTS

Since this experiment involves large pressure gradients in high speed flow, the goal of the seeding technique was to produce sub-micron seed particles to follow the flow. In addition, the number density of the particles present should be sufficient to allow useful data rates over the region of measurements. The tunnel flow was sampled in the test section using a 10 mm dia. impact probe. These air samples were analyzed with a TSi Inc. Aerodynamic Particle Sizer (APS 33). In figure 9a the results of the sample for the tunnel operating with no seed introduced is shown. These results show a relatively clean flow with the peak concentration of less than 10 particles per cubic centimeter at .8 microns. This is consistent with the use of a filtered air supply to drive the tunnel. In figure 9b the results of a sample taken with the particle generator operating are shown. Here the peak concentration is at .8 microns at nearly 400 particles per cubic centimeter. These results show that the seed clearly dominates the naturally occurring particles in the flow. Additional information on the generator is given in reference 2.

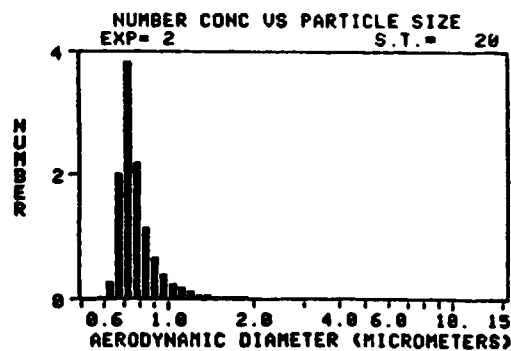
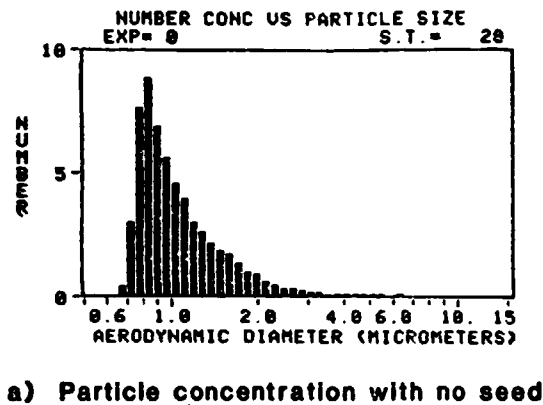


Figure 9

## LV SYSTEM

For the normal shock experiment described here, an independent check on the seed material's ability to follow the flow is available. Away from the influence of the wind tunnel boundary layers, the normal shock provides essentially a step change in the axial velocity of the flow. By using a Laser Velocimeter (LV) system to measure this velocity change, an idea of the ability of the seed and LV system to resolve the high velocity gradients present can be determined. Figure 10 is a schematic of the LV system used in this experiment. The system is a dual beam configuration using on-axis forward scatter. This system produces a good signal-to-noise ratio that allows use of the smallest possible seed. The focal length of the transmitting lens was 250 mm with a 22 mm beam spacing. A focal length of 600 mm was used for the collecting lens. The LV system including the laser was mounted on a 3-axis table that could be remotely controlled.

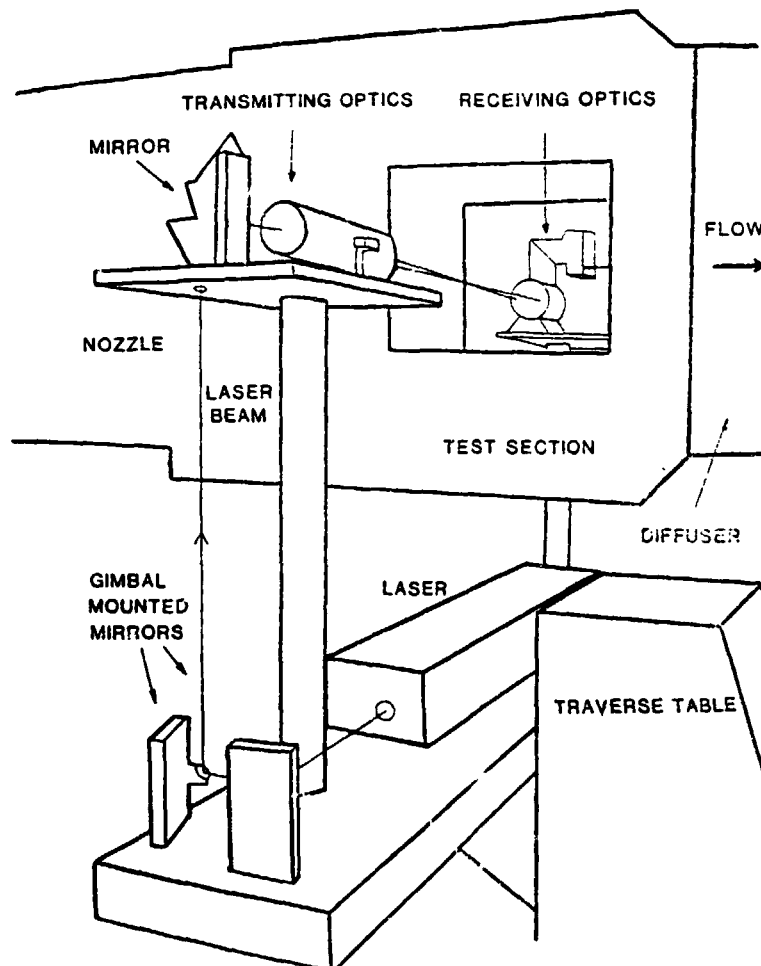
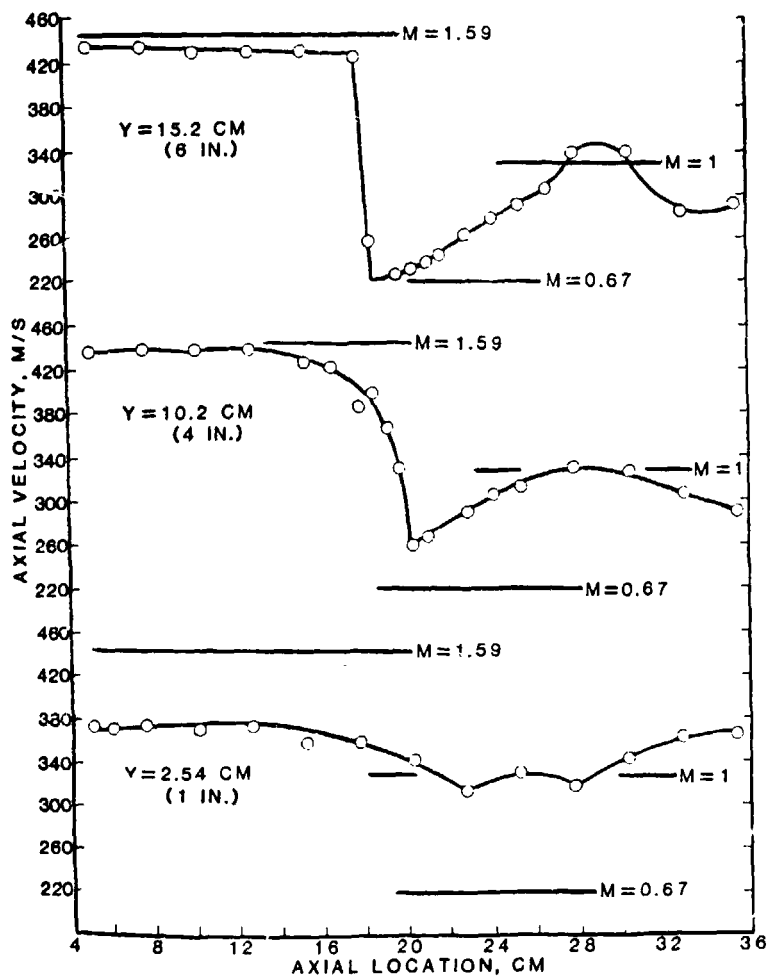


Figure 10

## LV RESULTS

Some results of the LV measurements are shown in figure 11. The top plot represents the velocity along the tunnel centerline along with one-dimensional normal shock results for the tunnel Mach number. The results show good agreement. The increase in velocity after the snock is a result of the separation bubbles, which produce an area change and cause a deviation from the one-dimensional flow. The bottom plots represent the velocity along lines that are progressively closer to the tunnel side wall. These plots show the effect of the bifurcated shock and boundary layer on the velocity. That is, the axial gradients are substantially reduced.

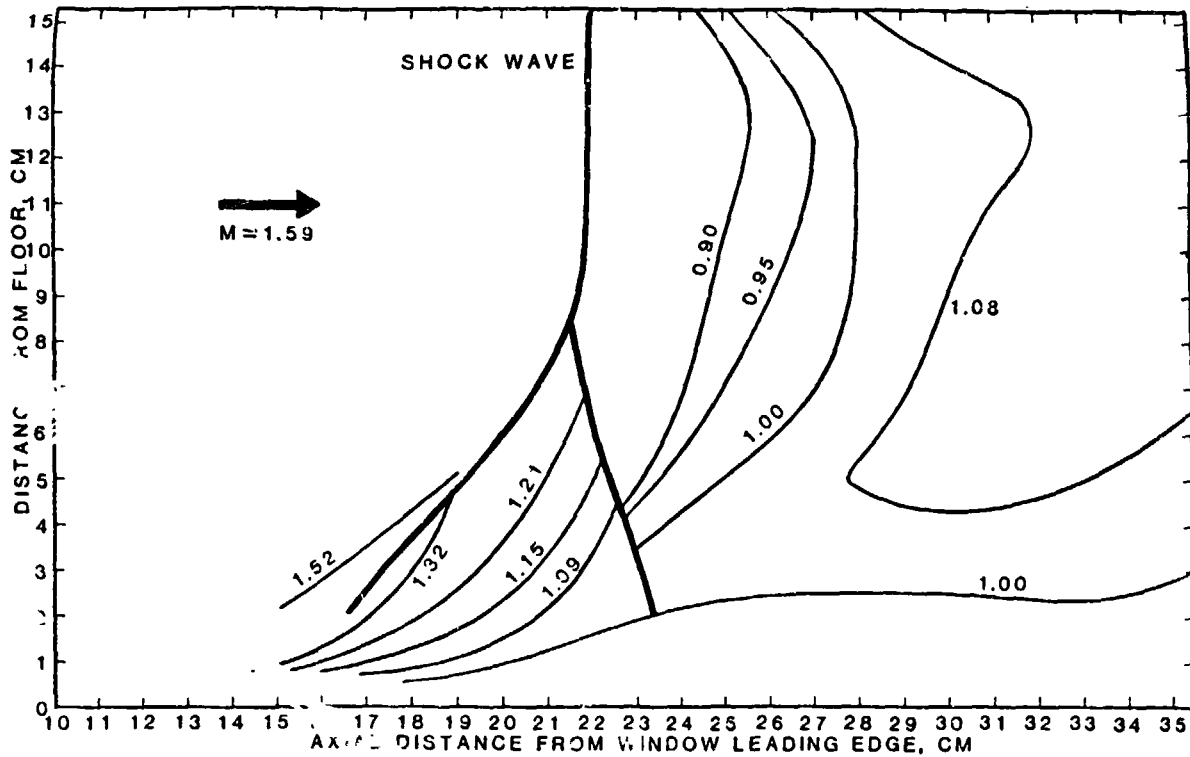


AXIAL VELOCITY AT MIDSPAN FOR GIVEN  
DISTANCE FROM TUNNEL FLOOR

Figure 11

## LV RESULTS

A Mach number contour has been constructed from the velocity measurements and is shown in figure 12. This plot represents the flow through the bifurcated shock-boundary layer interaction. These measurements were taken at the mid-tunnel plane and represent the most nearly two-dimensional interaction in the tunnel. These results are similar to those of reference 3.



**MACH NUMBER CONTOUR AT MIDSPAN FOR 3-D FLOW**

Figure 12

## REFERENCES

1. Liu, Y. H., Whitby, K. T., Yu, H. H. S., "A Condensation Generator for Producing Monodispersed Aerosols in the Size Range .036  $\mu\text{m}$  to 1.3  $\mu\text{m}$ ," *Journal De Recherches Atmospheriques*, PP. 397-406, 1966.
2. Chriss, R. M., An Investigation of the Interaction of a Normal Shock Wave with a Turbulent Boundary Layer by Laser Anemometry, M. S. Dissertation, University of Toledo, 1984.
3. East, L. F., "The Application of a Laser Anemometer to the Investigation of Shock Wave Boundary Layer Interactions," Royal Aircraft Establishment Technical Memorandum Aero 1666, Feb. 1976.