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PARTICLE GENERATION EXPERIENCE IN LANGLEY'S 16-FOOT TRANSONIC TUNNEL

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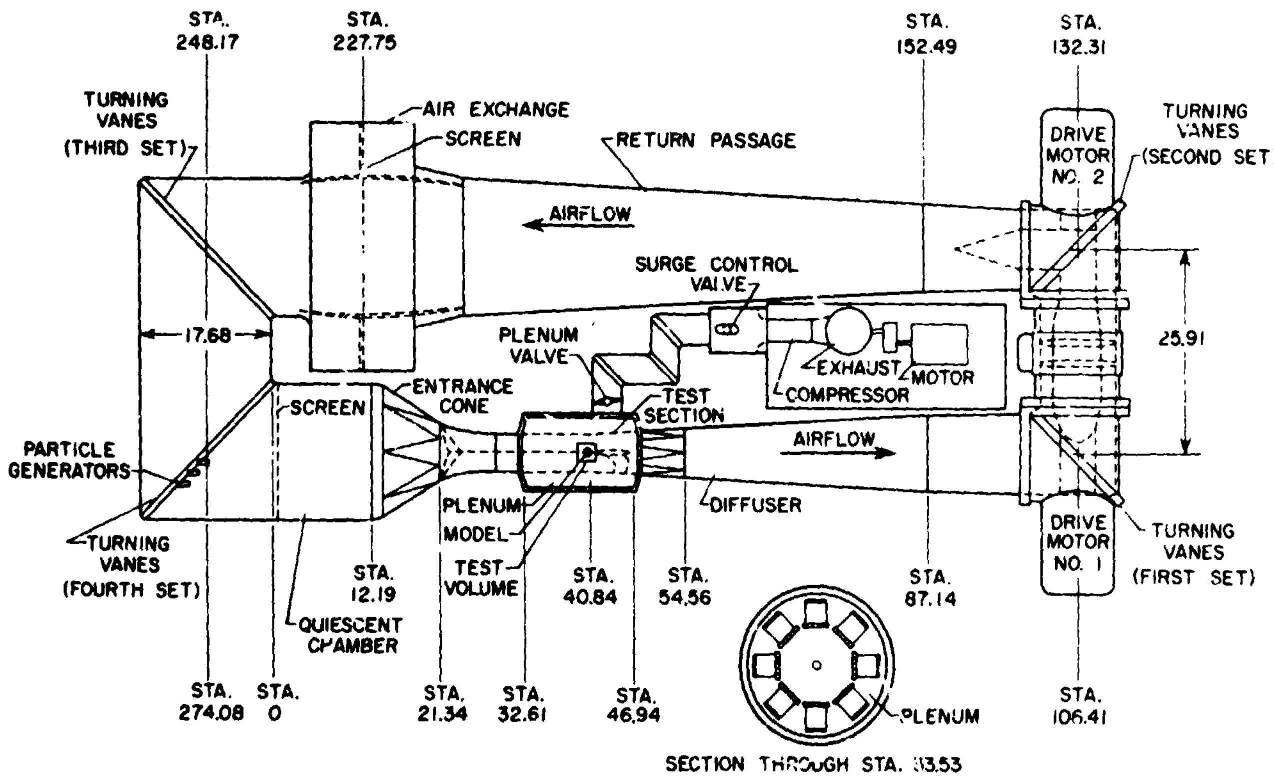
THE LANGLEY 16-FOOT TRANSONIC TUNNEL

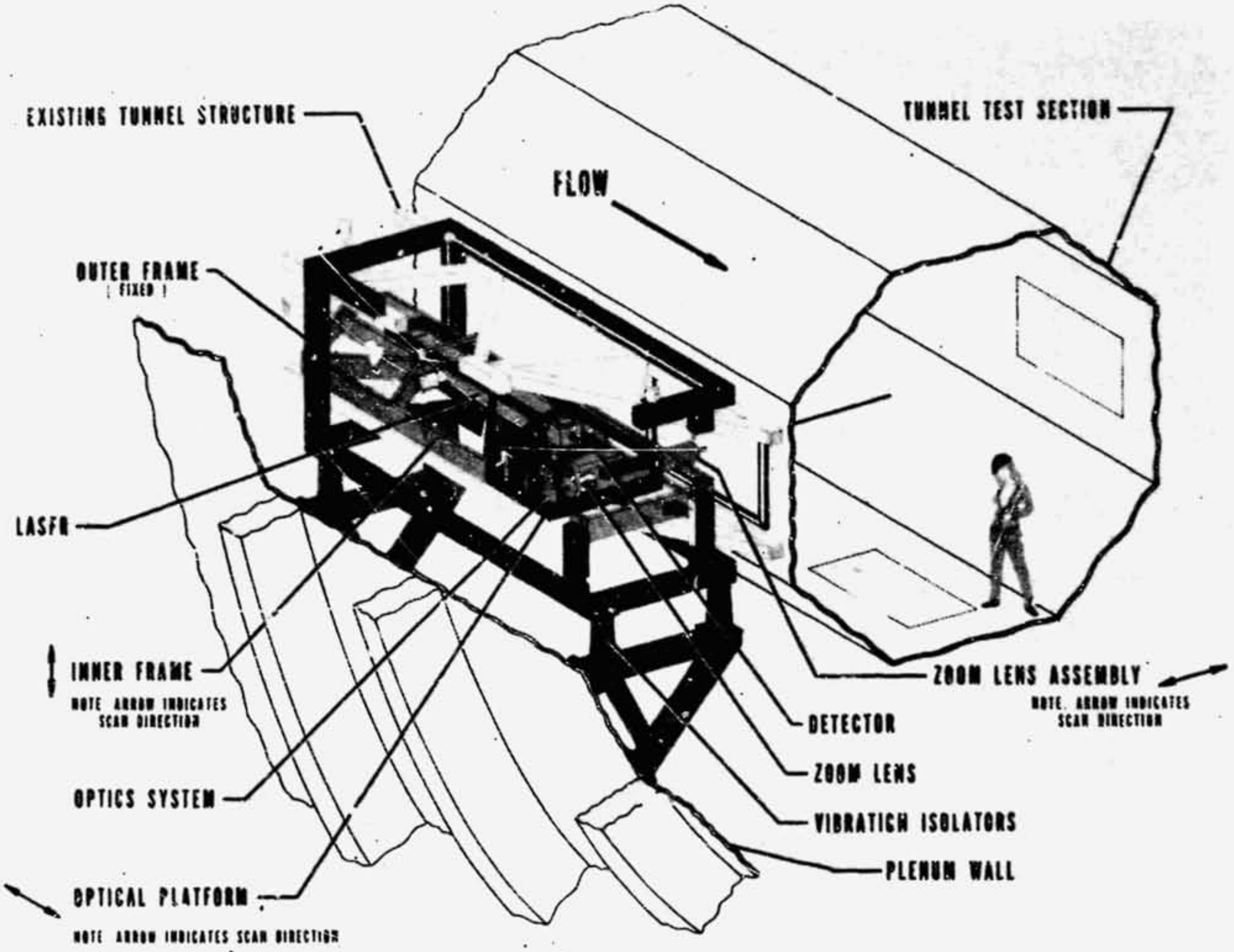
The Langley 16-Foot Transonic Tunnel is a single-return, continuous-flow, atmospheric tunnel which uses air exchange for cooling. The tunnel speed is continuously variable from Mach 0 to 1.30. The test section is a regular octagon in cross-section with slots at the corners of the octagon. The laser velocimeter optics, laser, photomultipliers, etc. are mounted in the test section plenum chamber which surrounds the test section. The test volume is approximately a 1-meter cube about the tunnel center line centered on tunnel station 40.84 meters. The seeding system particle generators are mounted on the upstream side of the fourth set of turning vanes approximately 49 meters upstream of the test volume. At this point the tunnel has a diameter of 17.68 meters which meant that installation of the generators was a difficult procedure. It might be noted that particle generation had to be continuous as when the generators were turned off the data rate rapidly deteriorated to zero.



SECTION THROUGH STA. 33.53 (LOOKING DOWNSTREAM)

SCHEMATIC OF THE LANGLEY 16-FOOT TRANSONIC TUNNEL LASER VELOCIMETER

This is a schematic of the laser velocimeter system as it is installed in the test section plenum chamber. The plenum chamber is a 9.75 meter diameter cylinder which surrounds the test section. The laser and optics etc. ride on a scan platform which allows movement in two directions: vertically and horizontally. The capability of scanning the sample volume across the tunnel is provided by a zoom lens system. Unfortunately, the plenum chamber is not the most hospitable location for the installation of the delicate optics and electronics. The ambient noise level has been measured to be in excess of 150 dB at some Mach numbers and the g level has exceeded 10. The scan platform is currently being rebuilt to compensate for the harsh environment.



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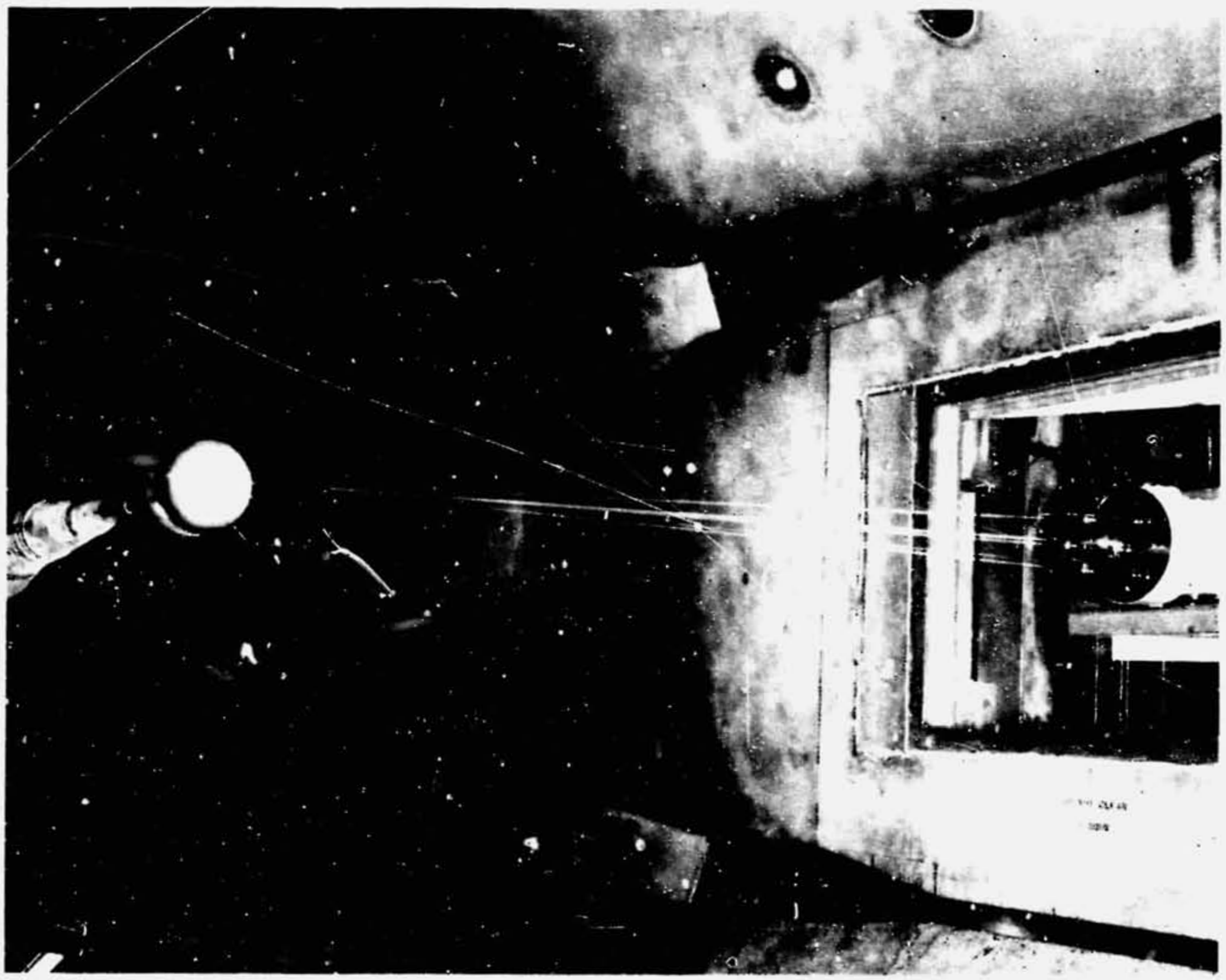
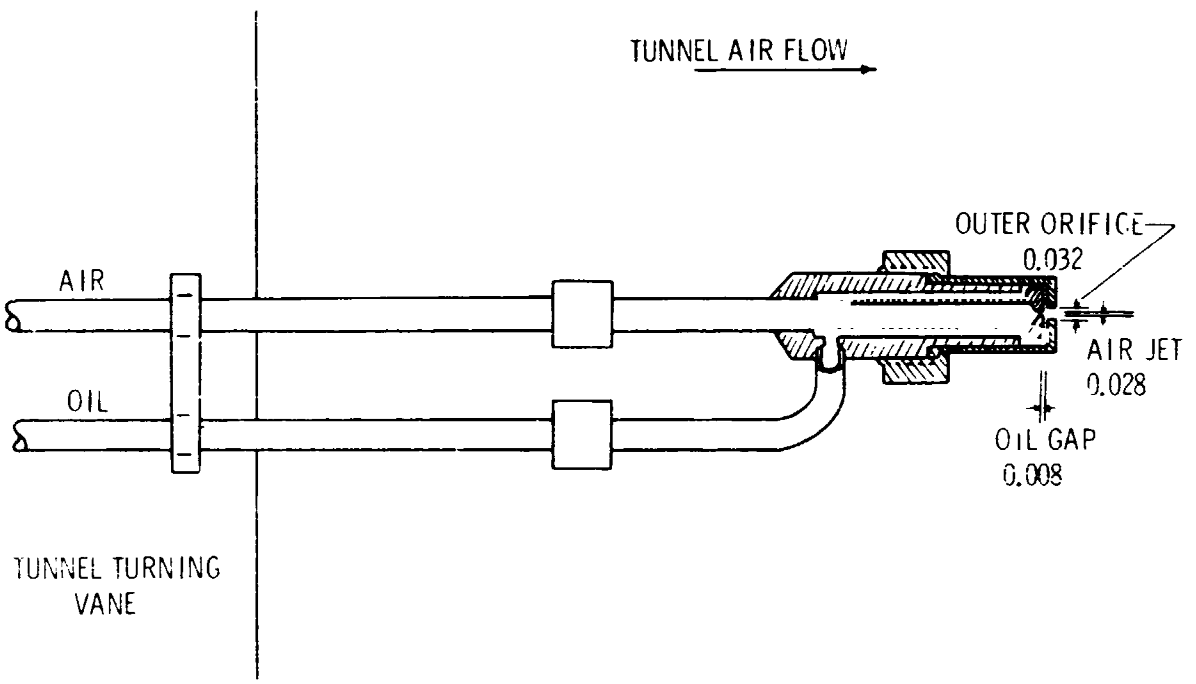
LASER VELOCIMETER CALIBRATION MODEL

In order to assess the performance of the laser velocimeter system (including seeding) it is desirable to experimentally test a configuration which can be readily computed (to provide a standard) and which presents a stringent test of the laser velocimeter's capabilities. The configuration which has been used since the proof of concept tests which were done in 1975 is a hemisphere-cylinder model. This model is simple enough that its flow can be computed reliably, but the stagnating stream-line presents a severe test of the laser velocimeter and the capability of the seeding system to deliver small enough particles that the lag problem does not invalidate the data.



PROOF OF CONCEPT TEST PARTICLE GENERATOR

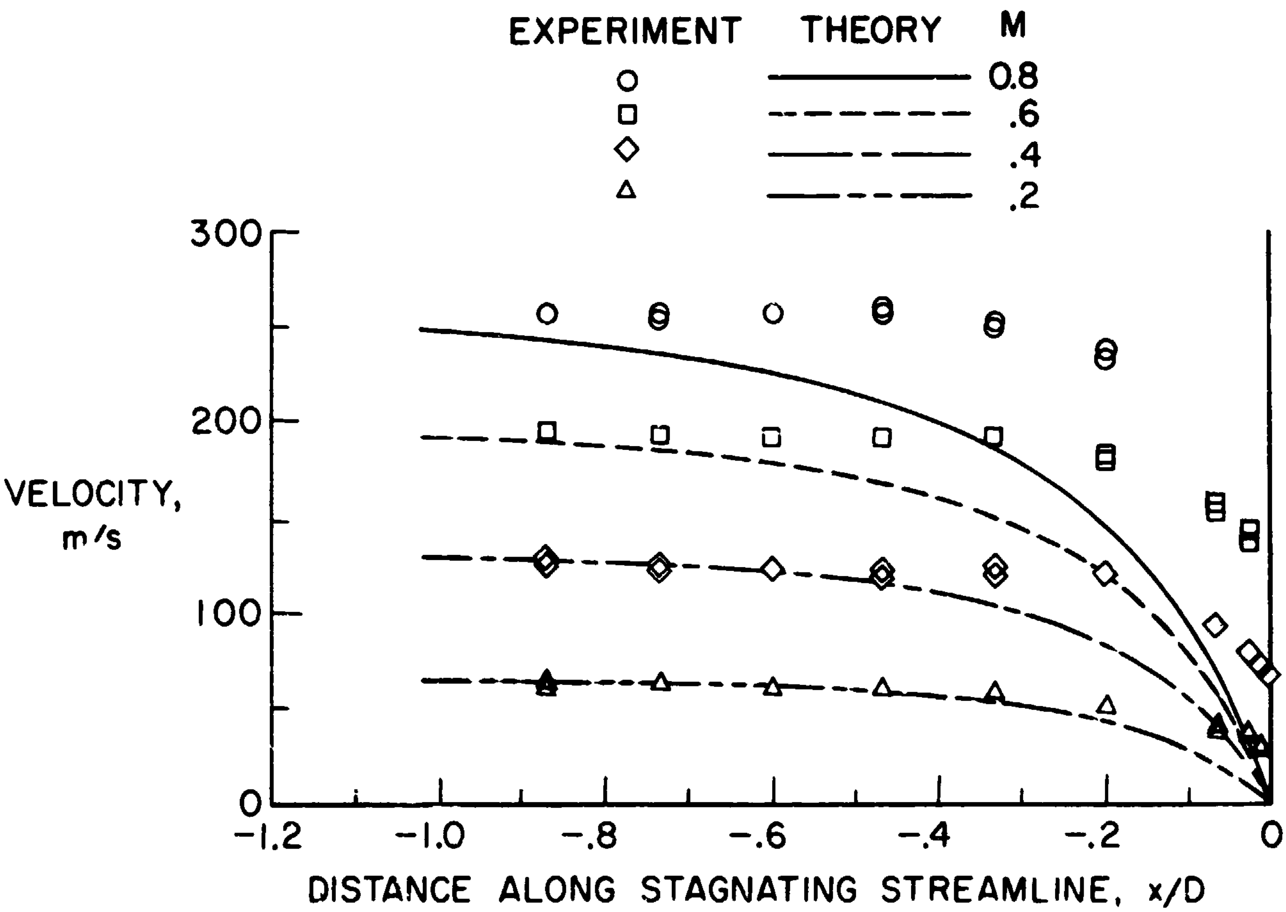
This is a sketch of the particle generator used in the proof of concept test in 1975. It is described in detail in reference 1. This generator was designed to utilize a liquid seed material. For the 1975 test a mineral base lubricating oil of viscosity index SAE 10 was used because of concerns about flammability and health aspects. Unfortunately, the particle size produced by these generators was extremely large. This problem will be addressed in the following figures. In addition, the tunnel became coated with the oil, a technician fell and broke his arm, and it required in excess of $25,000 to clean the tunnel.



PROOF OF CONCEPT TEST DATA

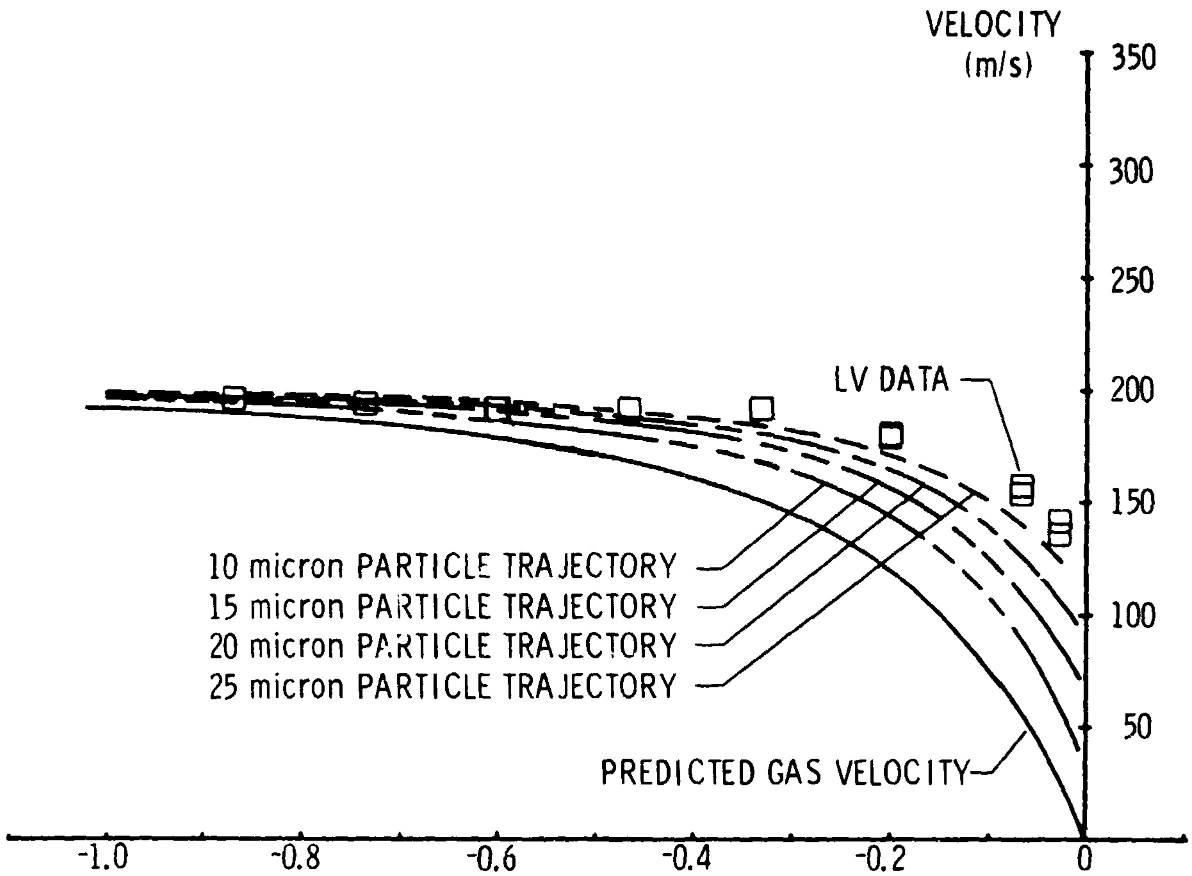
In the proof of concept test the hemisphere-cylinder stagnating streamline was surveyed at Mach numbers from 0.2 to 0.8. As can be seen from the figure, the laser velocimeter data does not agree very well with the predicted flow velocity, especially at the higher Mach numbers and near the stagnation point. This immediately points to a particle which is too large and whose inertia is such that the particle will not follow the strongly decelerating stagnation streamline. The proof of concept test is documented more fully in reference 2.

HEMISPHERE STAGNATING STREAMLINE VELOCITY MEASUREMENTS



PROOF OF CONCEPT PARTICLE SIZE ANALYSIS

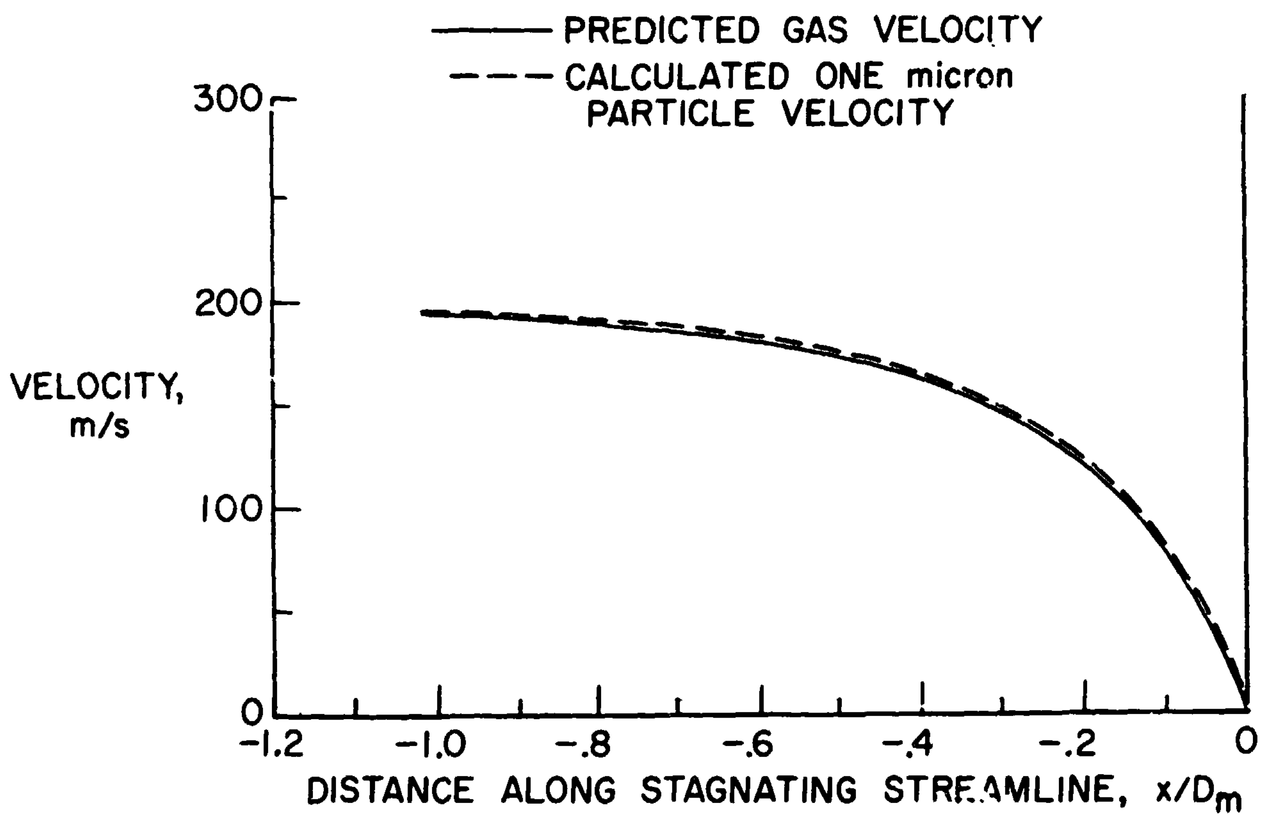
The size of the particles produced in the proof of concept test was analyzed using a procedure which predicts the lag of a given particle. The predicted stagnation streamline velocity data was adjusted for a variety of particle sizes and the results compared with the measured laser velocimeter data for a Mach number of 0.6. As can be seen, the particles produced by the particle generator were at least 25 microns or larger. Obviously, for a successful laser velocimeter system the particles would have to be much smaller than 10 microns.



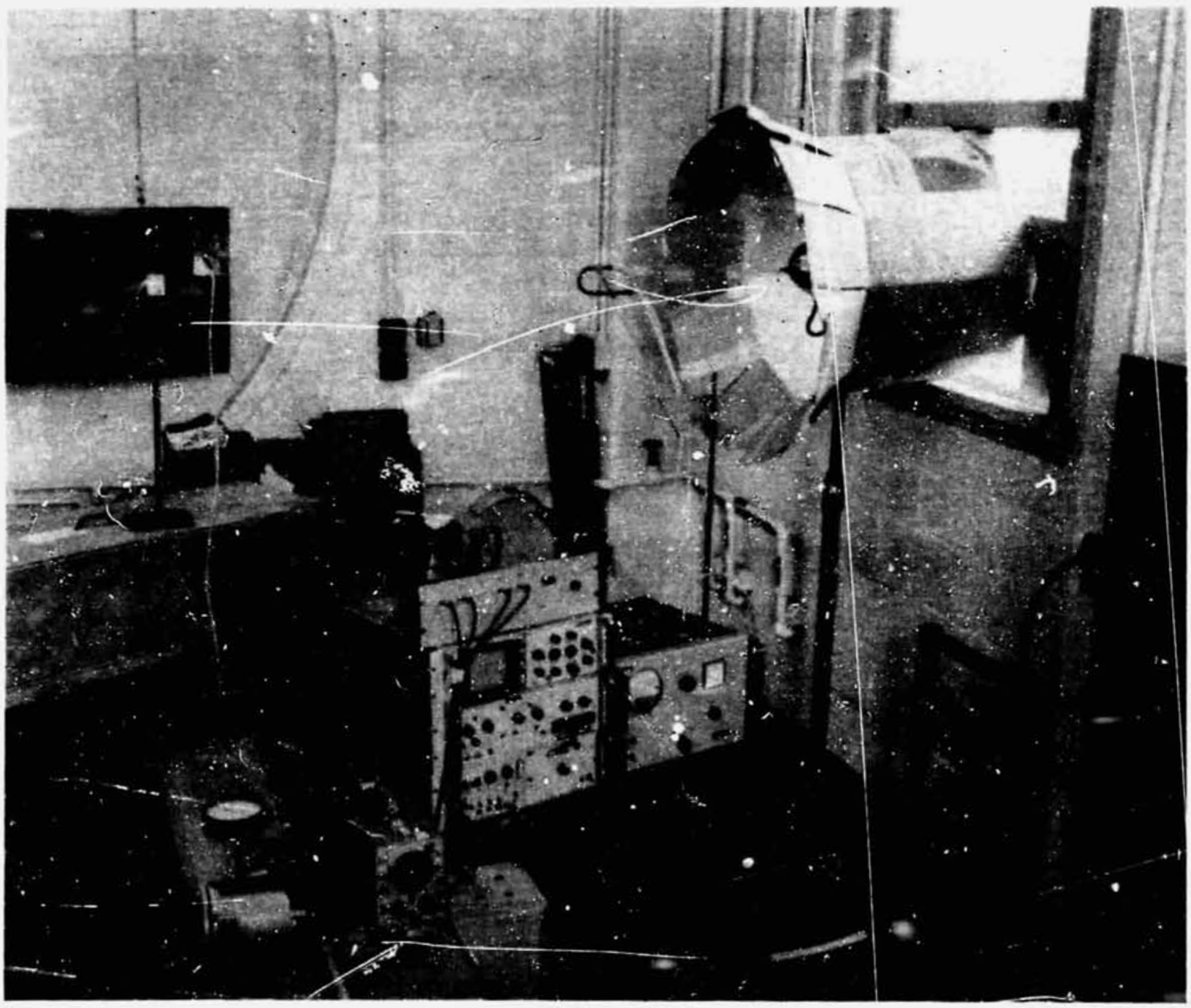
PREDICTED LAG OF A ONE MICRON PARTICLE

In order to determine the necessary size for the production laser velocimeter system the particle analysis procedure was carried to particles of one micron in size. As can be seen, a one micron particle will follow the stagnation streamline flow quite well. This became the goal for further research in the generation of particles. In addition, it was determined that the seeding material had to be volatile enough not to accumulate on the walls of the tunnel but not volatile enough to present a significant explosion hazard.

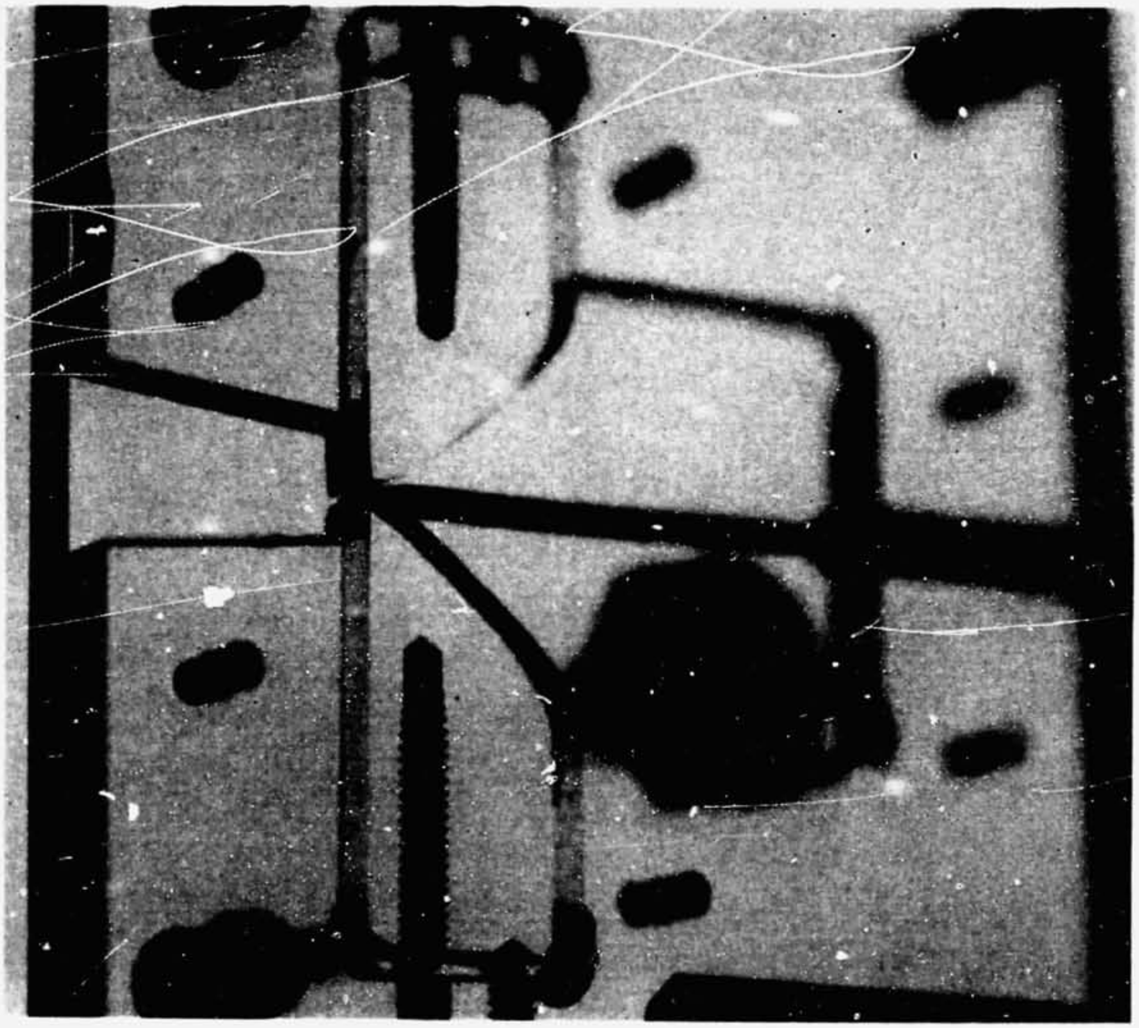
COMPUTED LAG OF A ONE-MICRON PARTICLE IN HEMISPHERE FLOW FIELD



Shortly after the decision to develop a production laser velocimetry capability for the 16-Foot Transonic Tunnel and the necessary seeding system to produce significant quantities of one micron particles was made the only person at Largley who knew anything about particle generation, Mr. William V. Feller, retired. Fortunately, we were able to hire Mr. Feller under contract to continue his research on particle generation. This is a photograph of his research set-up in a corner of the 16-Foot Static Test Facility. Here one can see a prototype generator set-up blowing into a sampling tube which leads to a Royco particle size analyzer. The pedestal fan surrounded by the cardboard is a ducted fan to generate a wind tunnel effect. With this apparatus Mr. Feller was able to develop a prototype generator which did produce one micron particles.

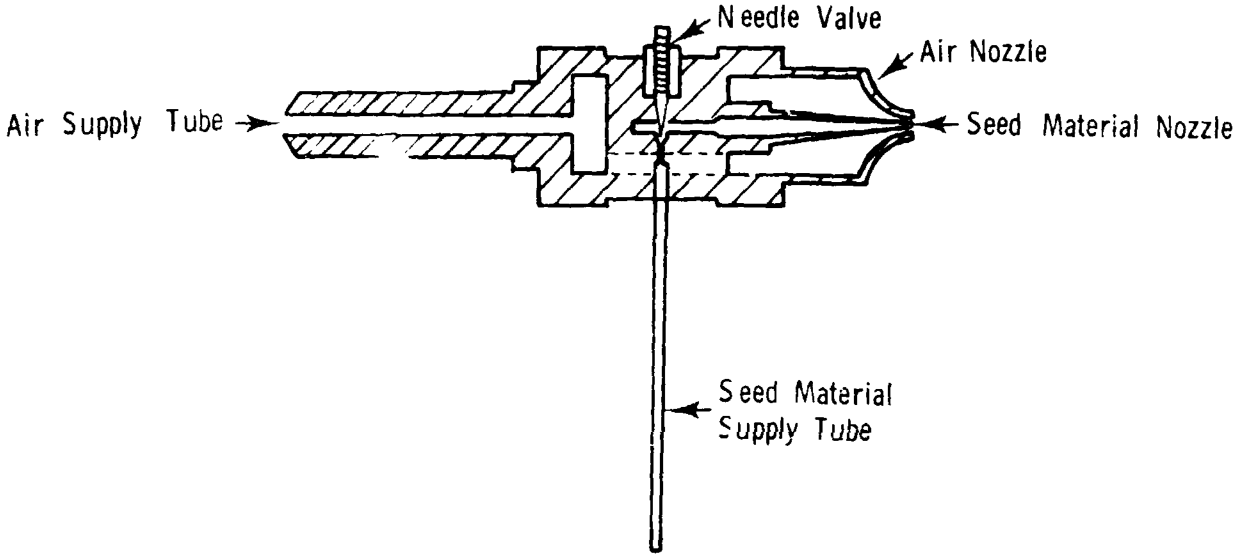


This is a close-up photograph of the prototype seeding generator developed by Mr. Feller. The basic design consists of a two-dimensional air nozzle with the tube carrying the seed material centered in it. The tube carrying the seed material has been flattened at its end to another two-dimensional nozzle with a throat height of approximately 0.008 cm. In operation, air is exhausted through the air nozzle, the lowered static pressure at the air nozzle throat draws the liquid seed material through the supply tube, and the thin jet of seed material is then broken up into small droplets of the desired size. Kerosene was picked as the seed material for this generator as it has sufficient volatility to ensure that there would be no accumulation on the tunnel walls and for the amount that would be introduced into the tunnel there would be no fire or explosion hazard. The Royco particle size analyzer indicated that this generator design produced a distribution of particles over a range of sizes from below one micron to no larger than three microns.



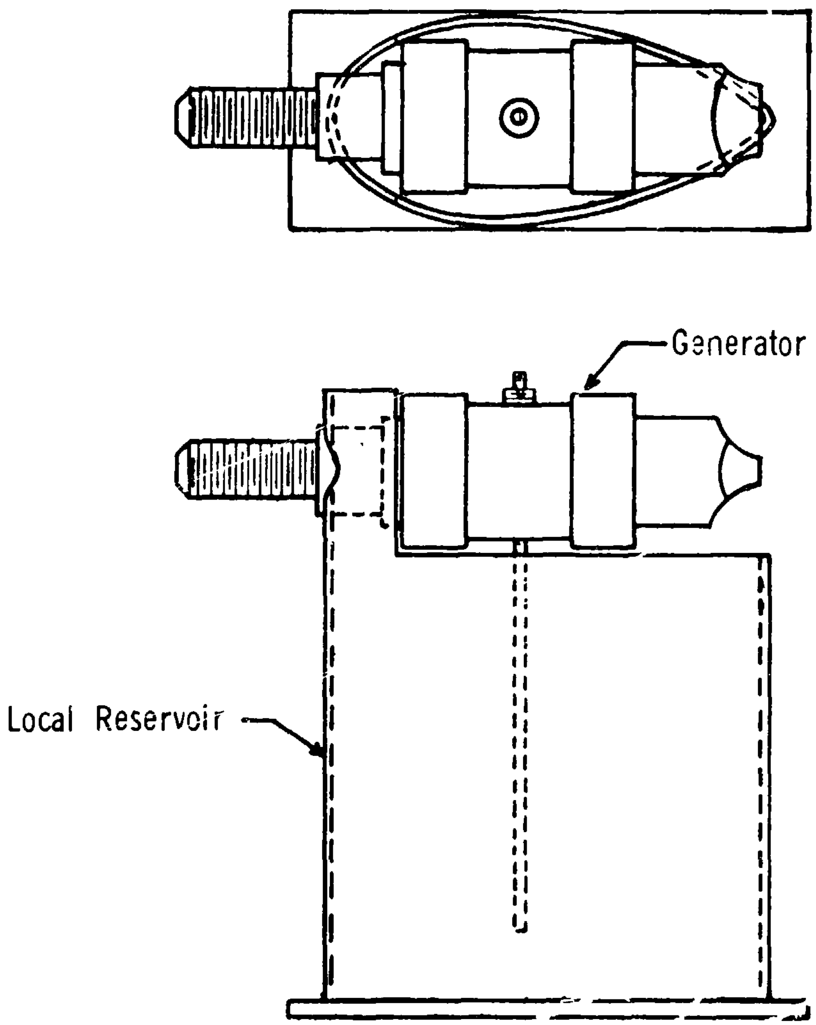
PRODUCTION SEEDING GENERATOR DESIGN

This is a cross section of the final seeding generator design. It is a scaled up version of the prototype. It was constructed of brass instead of the plexiglass of the prototype. The seed material nozzle throat height was kept to approximately 0.008 cm. The number of particles generated can be regulated by the needle valve which controls the amount of seed material allowed to pass through the generator.



SEEDING GENERATOR ASSEMBLY

This is a sketch of an individual seeding generator assembly. It consists of a single generator and a local reservoir for the liquid seed material. When mounted in the tunnel the local reservoir is fed by gravity from a tank mounted on the tunnel turning vanes above the generator arrays.



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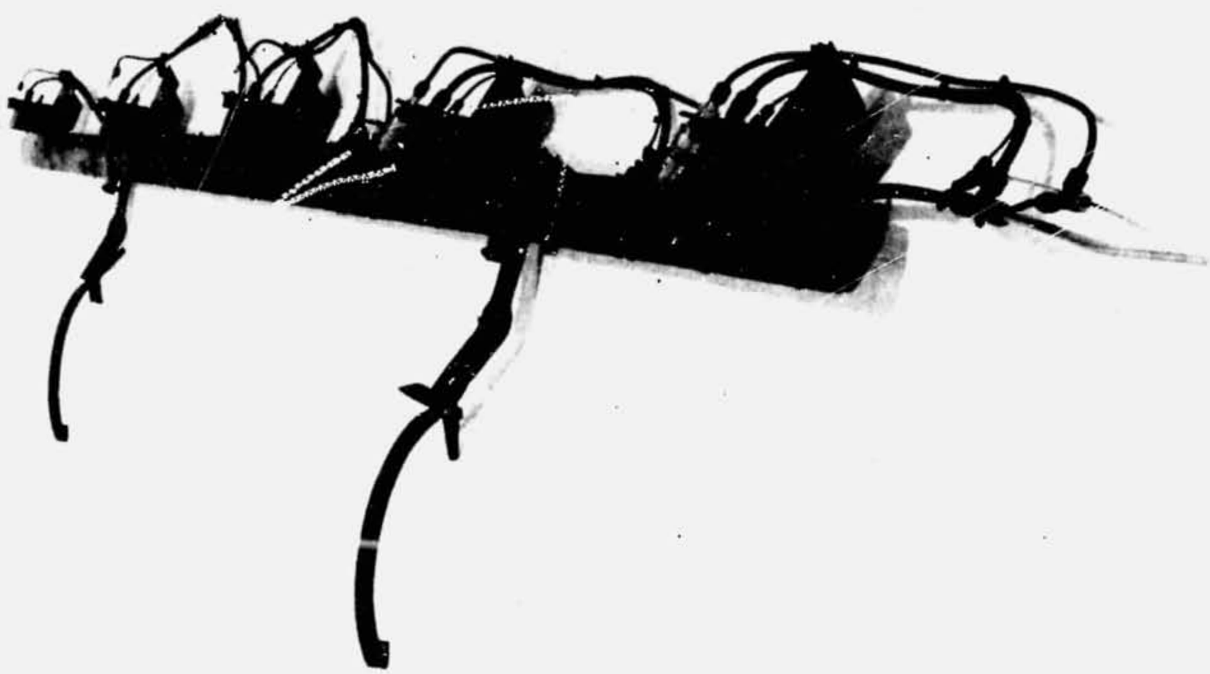
SEEDING GENERATOR ARRAY

This is a photograph of an early version of one of the generator arrays which are mounted on the tunnel turning vanes. In this photograph only two generators are mounted on the local reservoirs. In the production seeding system there are two of these linear arrays of ten generators each mounted on the turning vanes. The arrays are spaced 2.03 meters apart with one plane 1.83 meters above the tunnel centerline and the second 0.2 meters below the tunnel centerline. The generators are spaced 0.46 meters apart on the streamline tubing support which also serves as a part of the overflow and drain system for the liquid seed material. The arrays were mounted on the turning vanes in such a manner that when facing upstream six generators were to the left of the tunnel centerline, three to the right of the centerline, and one on the centerline. Since the tunnel flow contains some swirl it is impossible to determine beforehand exactly which generator will be required to seed a given area of the test section. The generators are controlled in pairs from the control room by solenoid valves which regulate the air supplied to the generators. Choice of the generators in use was based on visual observation of the seed material passing through the laser beams and the data rate measurements.



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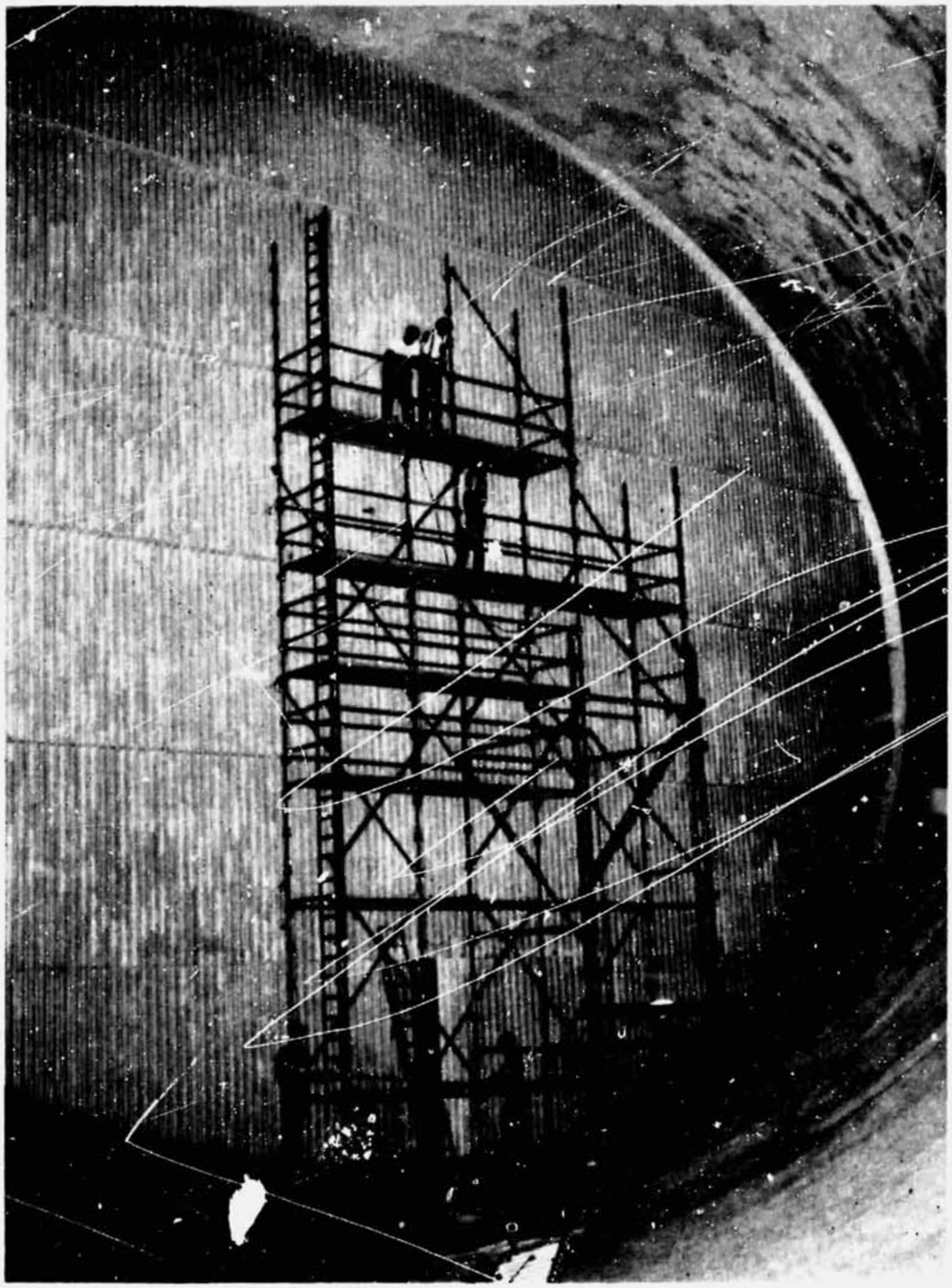
SEEDING SYSTEM INSTALLATION

This is a photograph looking downstream at the turning vane location where the generator arrays are mounted (during the installation process). The tunnel at this location is 17.68 meters in diameter and the installation was a considerable task.



PARTICLE SIZE DISTRIBUTION

After the seeding generator system was installed the hemisphere-cylinder model was installed in the tunnel and laser velocimeter data were taken. Unfortunately, these data indicated that the particle size reaching the test section was considerably larger than the one micron desired size (which had been verified by the Royco particle size analyzer). A number of theories were advanced to try to explain this phenomenon but none was really satisfactory. At this point Mr. Cecil Nichols became involved. He investigated the particle generators with the TSI aerodynamic particle sizer. This figure shows the results of sizing kerosene particles from the generators. As can be seen, the size distribution goes as high as ten microns. This is unacceptable. Evidently, the optical particle size (which is what is measured by the Royco sizer) is not the same as the aerodynamic particle size (which is what is measured by the TSI sizer). The aerodynamic size is the size which is applicable to the particle flow following capability. As a result it was decided to investigate other seeding materials.

TSI AERODYNAMIC PARTICLE SIZER
SA KEROSENE

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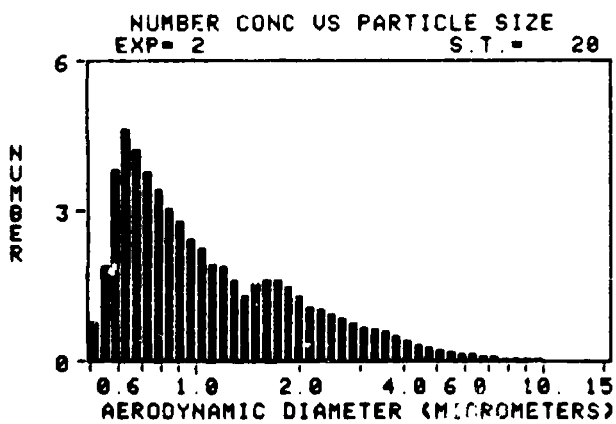
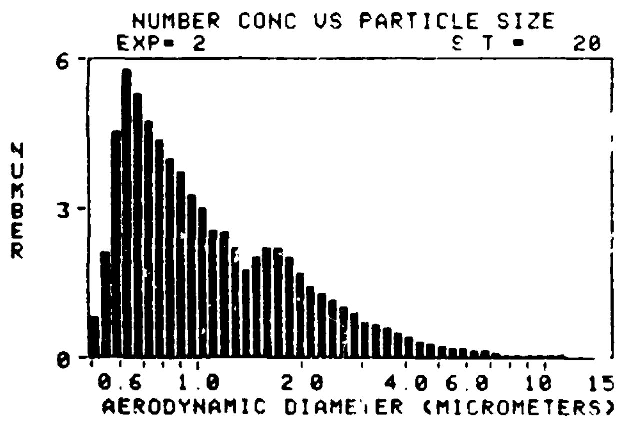
DIL. RATIO: 1:1 EFFIC. CORRECT.: NONE DENSITY: 1



KEROSENE-ALCOHOL MIXTURES

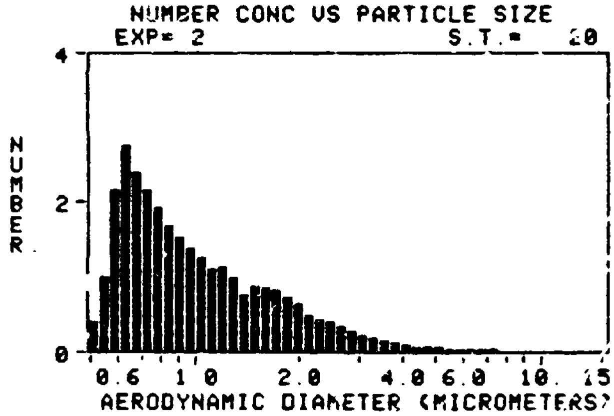
At this point in time Mr. Nichols was investigating the use of Kaolin particles suspended in ethyl alcohol as a seed material. It was decided to investigate the use of this mixture in the existing generators in the tunnel. However, since the local generator reservoirs, tanks, pumps etc. were full of kerosene it was decided to do some additional investigation of other seeding mixtures during the transition from kerosene to alcohol. Various combinations of alcohol and kerosene were tried and the results are documented in the next three figures. Use of a 50% kerosene - 50% alcohol mixture resulted in a shift downward in the particle size but there were still too many large particles. Similarly, 25% kerosene - 75% alcohol and 10% kerosene - 90% alcohol resulted in further shifts in the particle size distribution toward the smaller particles; however, there were still too many large particles for acceptable performance.

TSI AERODYNAMIC PARTICLE SIZER
50%KEROSENE-50% ETOH
SAMPLE # 1 DATE 2/28/84 SAMPLE TIME: 20 SEC
DIL. RATIO 1:1 EFFIC. CORRECT. NONE DENSITY 1



TSI AERODYNAMIC PARTICLE SIZER
25% KEROSENE-75% ETOH

SAMPLE # 1 DATE. 2/28/84 SAMPLE TIME: 20 SEC DENSITY 1
DIL. RATIO 1:1 EFFIC. CORRECT.: NONE



TSI AERODYNAMIC PARTICLE SIZER
10% KEROSENE-90% ETOH

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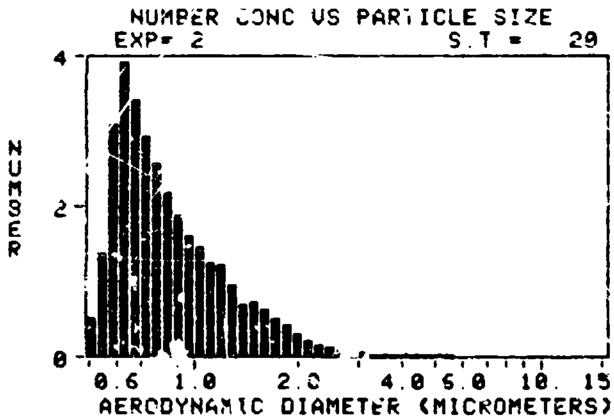
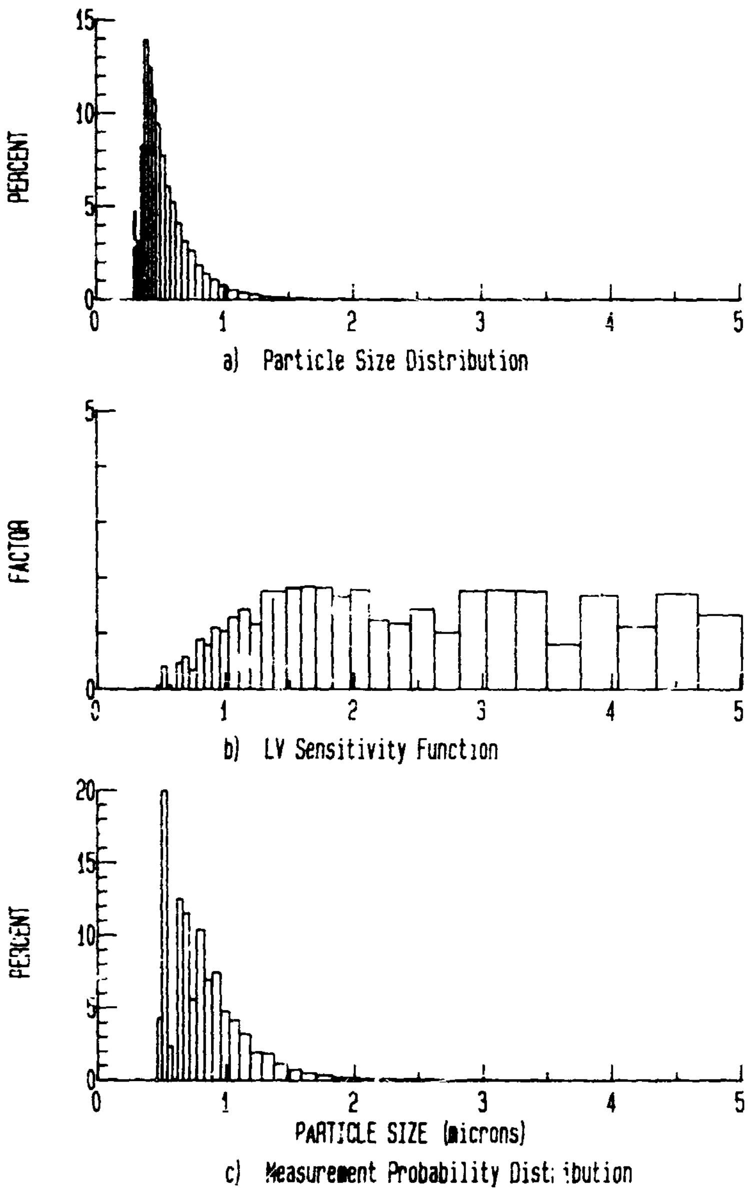


ALCOHOL - KAOLIN SEEDING MIXTURE

After transitioning to pure alcohol in the seeding system, Kaolin particles were mixed in the alcohol. This last figure is taken from the paper by J. F. Meyers (ref. 3) and shows the particle size distribution resulting from the generators using the Kaolin - alcohol mixture. This distribution, while not monodisperse at one micron, does give a satisfactory distribution until such time as monodisperse one micron particles can be obtained in large quantities at reasonable cost. It also might be noted that there was some concern that the Kaolin particles might clog up the seed nozzles since the slit is so narrow; however, to date this has not occurred.



c) Measurement Probability Distribution

REFERENCES

1. Feller, W. V., and Meyers, James F.: Development of a Controllable Particle Generator for Laser Velocimeter Seeding in Hypersonic Wind Tunnels. Presented at the Symposium on Laser Anemometry, Bloomington, Minnesota, October 22-24, 1975.

2. Putnam, Lawrence E. and Meyers, James F.: Measurement of Flow Fields in a Large Transonic Wind Tunnel Using a Laser Velocimeter. Presented at the AIAA General Aviation Technologyfest, Wichita, Kansas, November 13-14, 1975.

3. Meyers, James F.: Estimation of Particle Size Based on LDV Measurements in a De-Accelerating Flow Field. Wind Tunnel Seeding Systems for Laser Velocimeters, NASA CP-2393, 1985, pp. 29-52.