III. DESCRIPTION OF RESEARCH

It is the purpose of this investigation to establish a satisfactory experimental setup for particle-flow drag reduction experiments. Specifically, the objectives of this research are to:

1. Establish the best calibration function for hot-wire anemometers under the conditions of the experiment.
2. Determine a method to produce a constant static pressure along the test plate.
3. Determine the factors in leading-edge separation on the test plate.
4. Determine flow conditions in the wind tunnel test section which affect the boundary layer.
5. Establish a suitable method for reducing boundary layer data to determine if a similar boundary layer exists.
6. Determine if the boundary layer over the test plate is two-dimensional in nature.
7. Determine an acceptable method of tripping the boundary layer to turbulence and to condition it to the required thickness.

IV. APPARATUS

A. WIND TUNNEL

The UMR subsonic wind tunnel is a closed circuit, single return tunnel as shown in Figure 7 (top plan). The test section has an internal width of 4 feet, height of 3.67 feet, and a length of 11 feet. It is constructed of plywood with Plexiglas sides. Portions of the

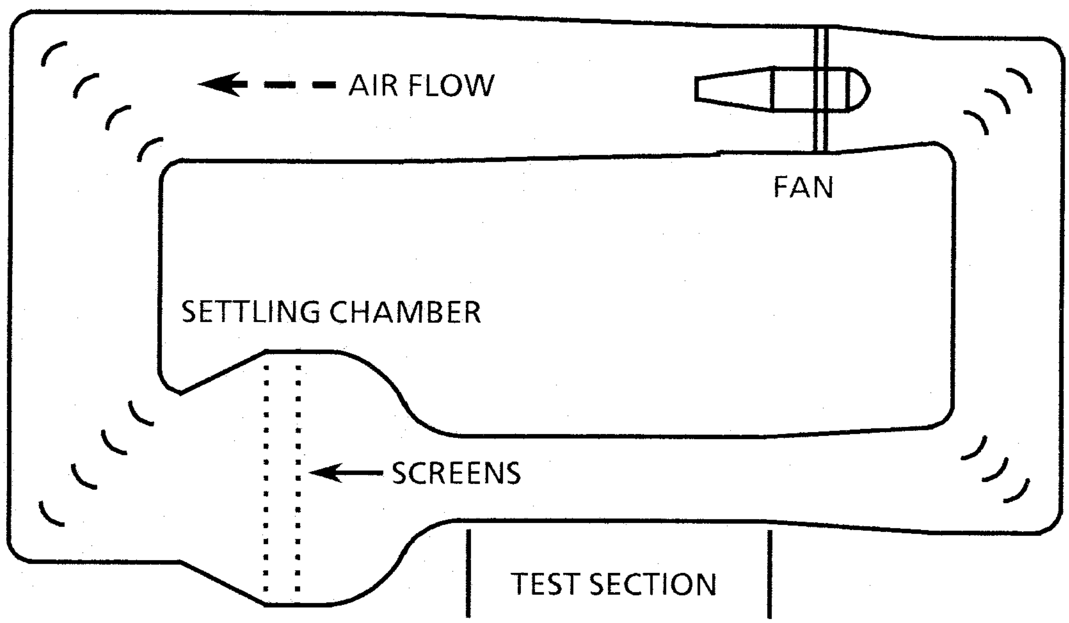

Figure 7 - University of Missouri-Rolla 32 inch by 48 inch wind tunnel

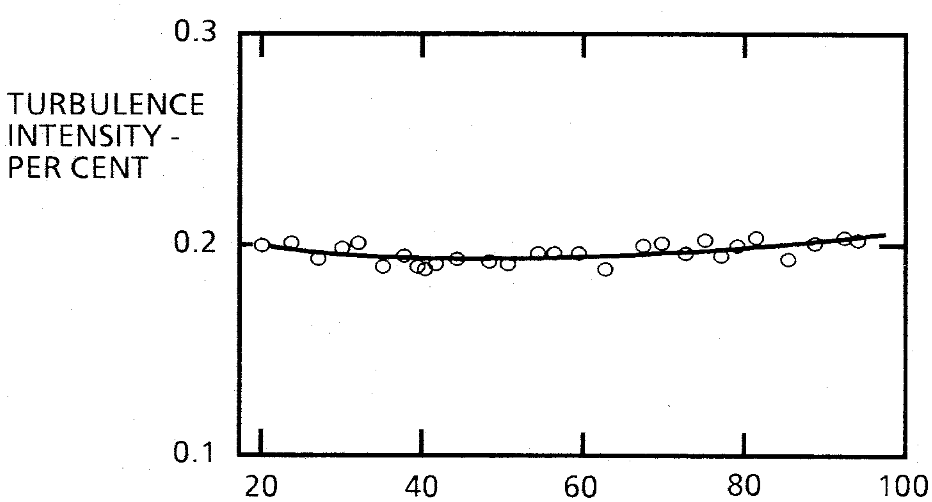

Figure 8 - Test section turbulence

tunnel exposed to the weather are made of steel sheet and channel sections. The settling chamber has a contraction ratio of 9 to 1 and has two screens to equalize the tunnel velocity profile and reduce turbulence intensity. Both screens are a square 14 mesh (14 wires per inch across the mesh) with a wire diameter of 0.020 inch for the upstream screen and 0.022 inch for the downstream screen. Open area of the screens is about 70% of total area. Both the open area ratio of the screens and the contraction ratio follow Bradshaw's recommendations[27] for boundary layer testing. Figure 8 illustrates the variation of turbulence intensity in the test section at the center of the cross-section, 59 inches from the beginning of the test section. This was measured with a single hot-wire anemometer. Since the single wire measures turbulence intensity along the flow and in one orthogonal coordinate, the total turbulence intensity may actually be on the order of 0.24%, assuming isotropic turbulence. The wind tunnel velocity profile is indicated in Figure 9 and Figure 10.

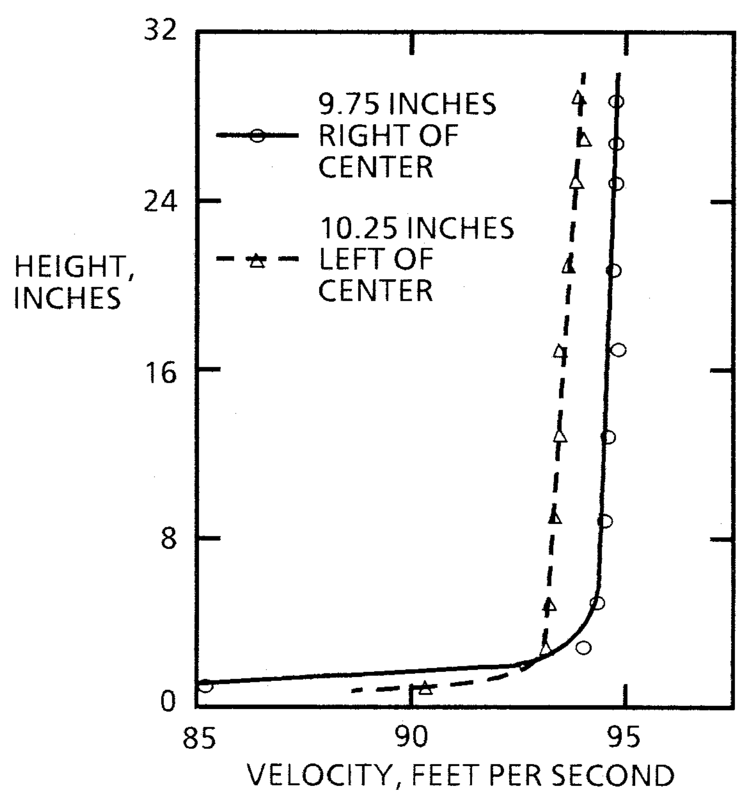

Figure 9 - Vertical velocity profiles in wind tunnel test section

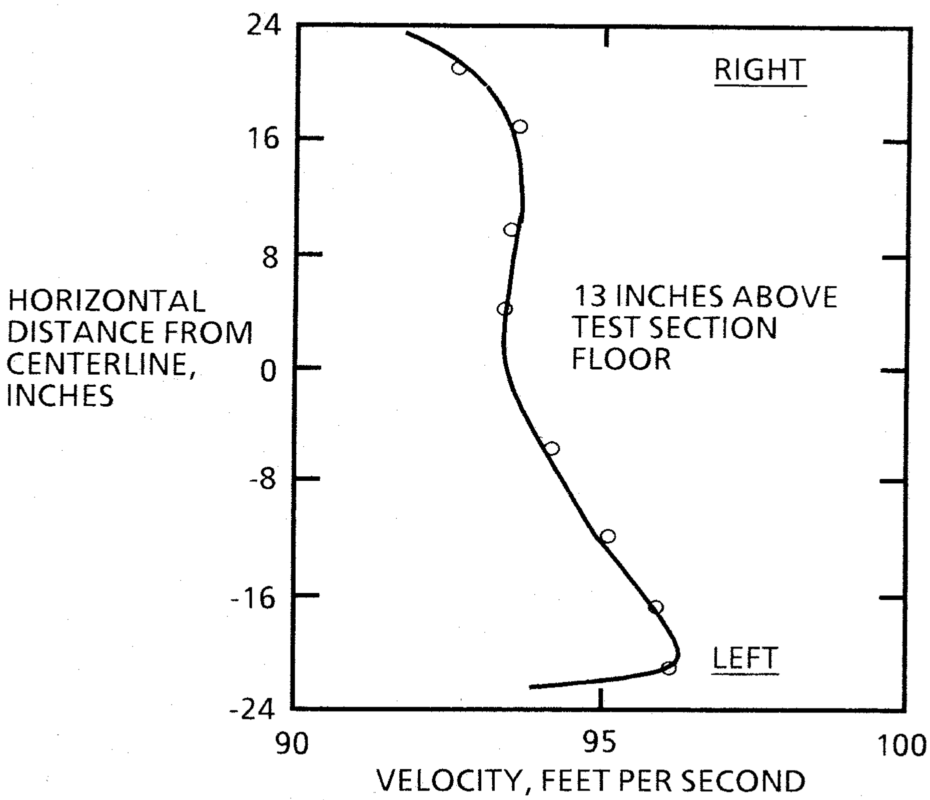

Figure 10 - Horizontal velocity profile in wind tunnel test section

The power plant for the wind tunnel is a 350 horsepower Caterpiller diesel engine. This engine drives a Sundstrand PV-27 variable displacement hydraulic pump, which in turn drives a Sundstrand MF-27 fixed displacement hydraulic motor. The motor is directly connected to the wind tunnel fan, a Joy model AR600-290D1248 Axivane Fan, through a driveshaft provided with universal-joint couplings at each end. The airflow power system, through its variable pitch fan blade settings, and variable speed hydraulic transmission, provides a wide range of tunnel velocities with variable control of velocity within the range allowed by the fan pitch. Feedback command control of fan speed is performed by a Moog controller and a D.C. tachometer. For the present experiments, maximum speed of the system was approximately 150 feet per second, with a response of the controller as in Figure 11.

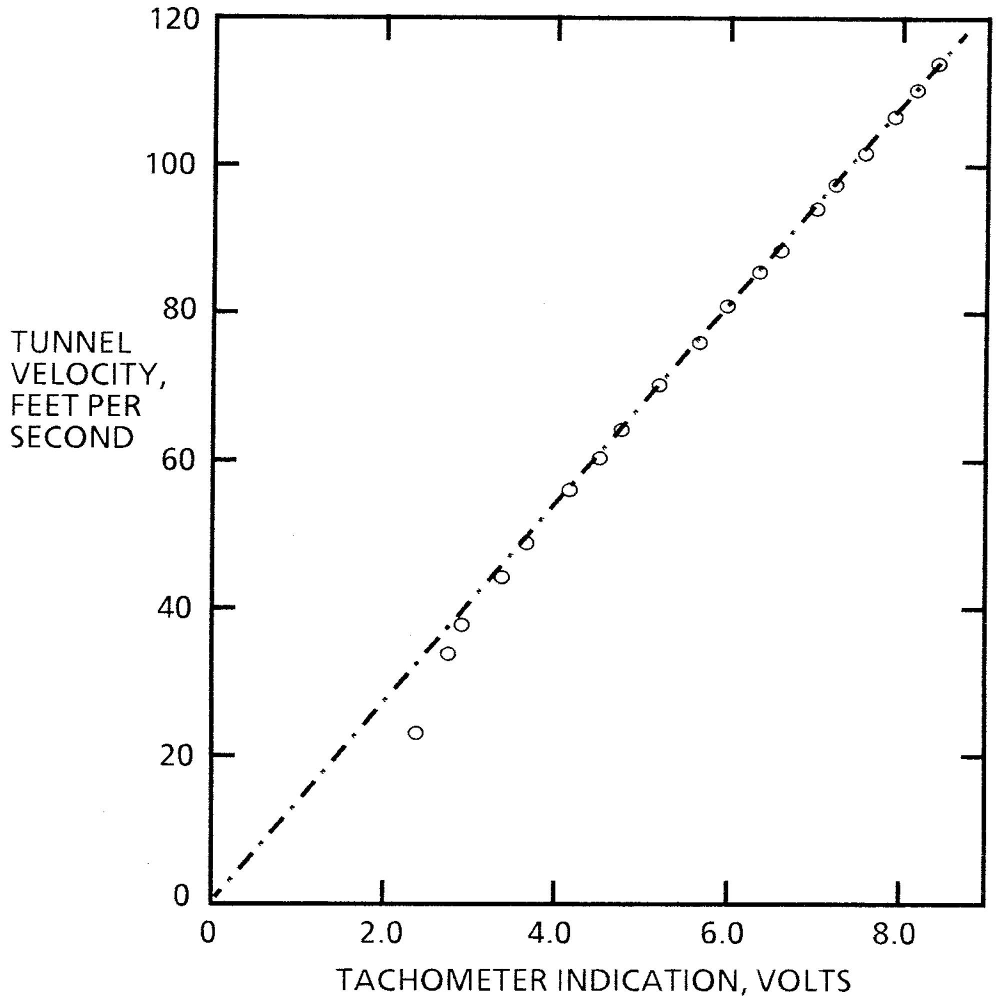

Figure 11 - Test section air velocity and fan speed indication

B. FLAT PLATE, NOZZLE, AND FALSE WALLS

A general illustration of the flat plate is shown in Figure 12. This is the final plate configuration, the earlier versions are discussed in Appendix B, along with the detailed development of the plate system. The final plate consists of a lower base plate of aluminum to which the upper dummy surfaces and middle test plate are attached. The forward fairing provides some flow conditioning, and the trailing edge fairing provides

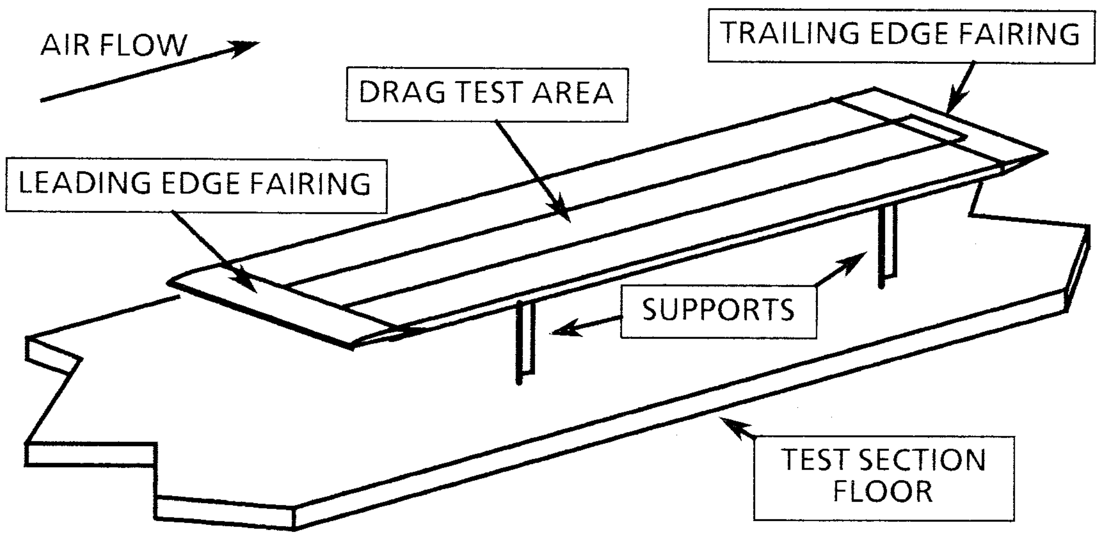

Figure 12 - Boundary layer test article.

streamlining and a housing for the Revere model UMP1-.005-A load cell drag transducer. The center top test plate is suspended on six air bearings, with four more used for alignment. These air bearings were custom made for the plate. Readings from the strain-gage type load cell were taken by a BLH Strain Gage Signal Conditioner connected to a Fairchild Digital Panel Meter, or by a Vishay Instruments 2100 System Strain Gage Conditioner and Amplifier System, an intermediate amplifier constructed for extra gain, and a Soltec Corporation Model 3314 Strip-Chart Recorder.

The final nozzle configuration is shown in Figure 13. The main feature is a streamlined support strut of such a length that the wake from the nozzle tube passes below the test plate. The particles are injected into the flow at an upward angle to

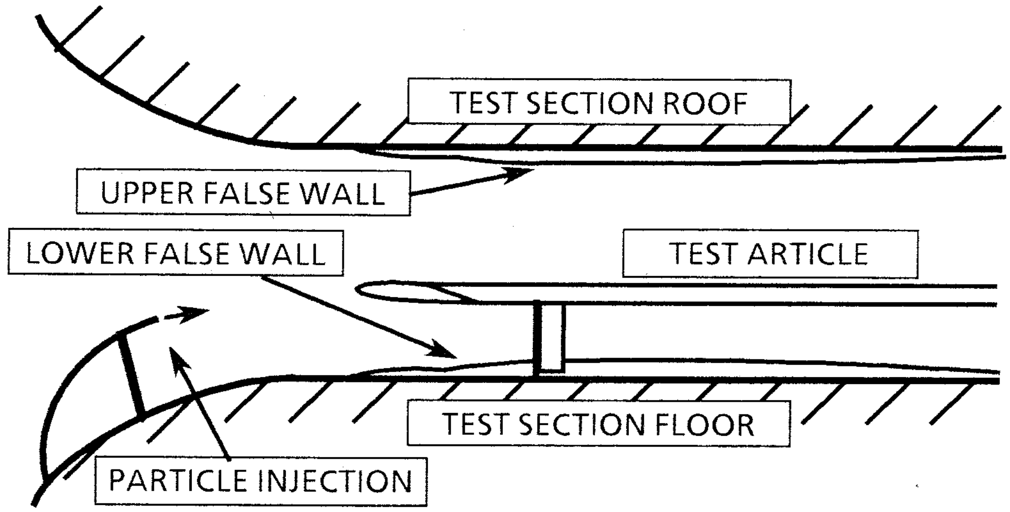

Figure 13 - Wind tunnel test section schematic with nozzle, plate system, and false walls.

impinge on the test plate. The nozzle versions are discussed in detail in Appendix B. The nozzle provides particle injection over the test plate with the minimum of interference and disturbance. Particles are delivered to the nozzle by the pressurized system shown in Figure 14.

The final false wall configuration is shown in Figure 13. Previous false wall versions are discussed in detail in Appendix B. The false wall provides a constant pressure over the length of the test plate.

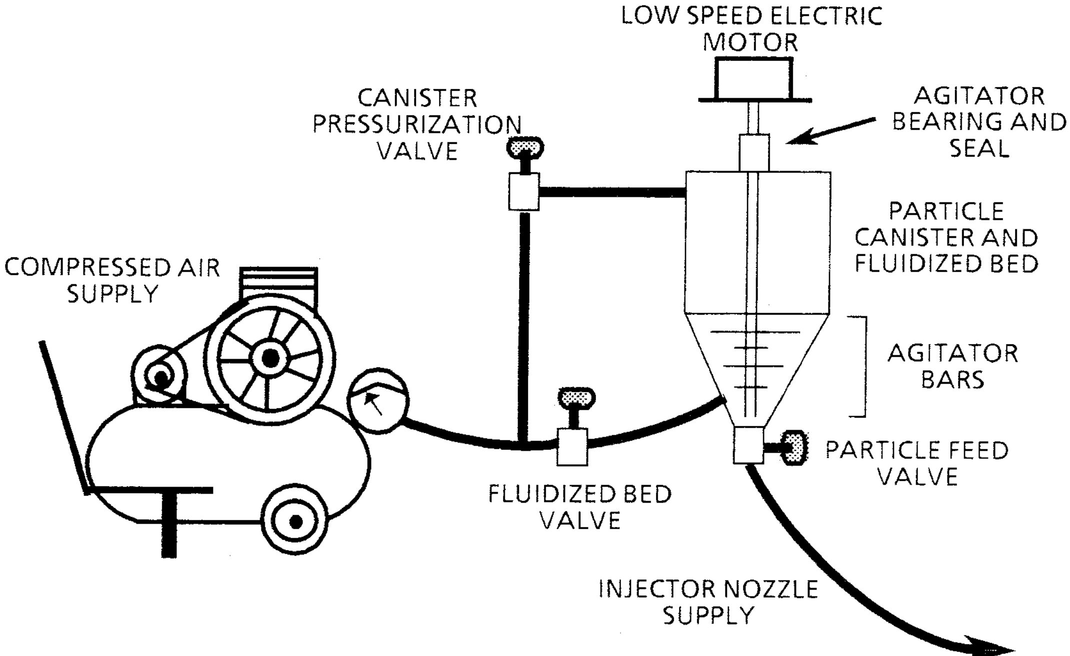

Figure 14 - Particle feeder schematic

C. INSTRUMENTATION

Readings of tunnel test section velocity were taken with a standard pitot-static probe. Pressure readings of the probe were taken on a T.E.M. Engineering Model 513 Micro Projection Manometer. During static calibration tests of hot-wire probes, a Meriam Instruments Company Model 34FB2 Micro-Manometer was used to obtain the chamber pressures. To obtain barometric pressure during the tests, a Princo Instruments mercury barometer was used. Readings were corrected for gravitational field effects and temperature.

A DISA 55D00 Universal Hot-Wire Anemometer was used in all tests, as shown in Figure 15. Calibration of the probes in the tunnel was performed against a pitot-static probe. Probes used were DISA type 55.A.22 and 55.A.25 single-wire probes, and 55.F.14 boundary layer probes. Additionally, some calibrations were performed with a DISA Model 1125 Calibrator.

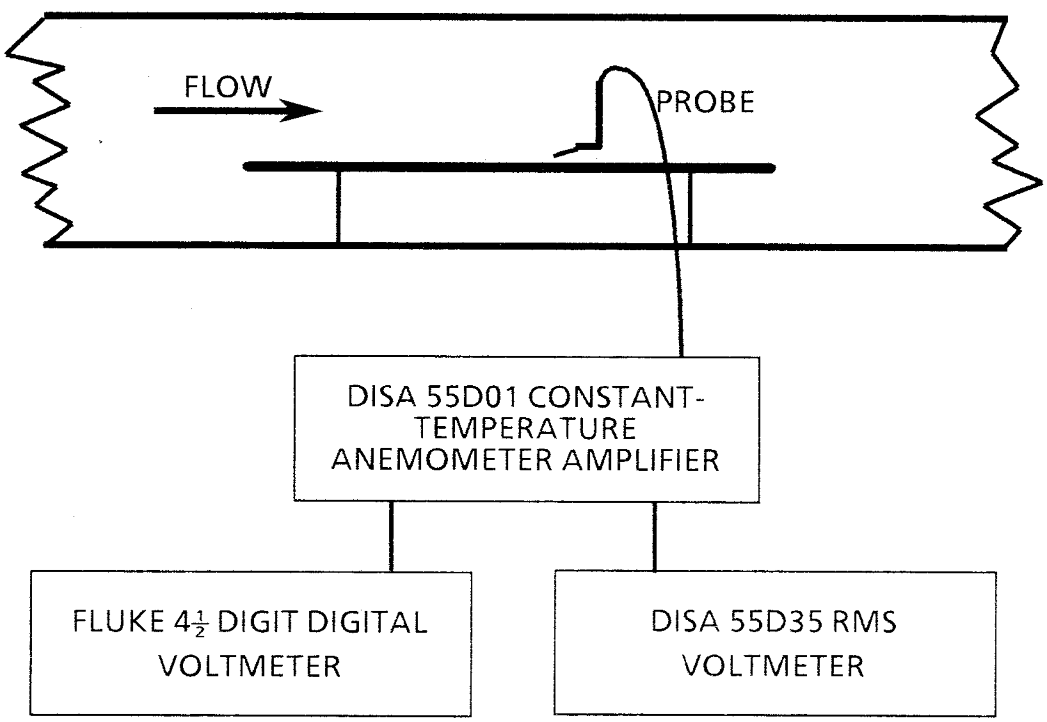

Figure 15 - DISA 55D00 Universal Hot-Wire Anemometer block diagram.

A traverse was designed and constructed for these tests. It is detailed in Appendix C. The traverse mechanism provides an accuracy of 1×10^{-4} inch vertically and 0.015 inch horizontally, with a resolution of 0.001046 inch per increment or step of drive. Drive is provided by two NAPCC KA82954-M3 stepper motors with 7.5 degree resolution. Traverse travel is approximately 12 inches horizontal and 26 inches vertical. The traverse mechanism is located inside the wind tunnel test section and normally travels on two rails for movement along the length of the test section. This is shown in Figure 16. The traverse mechanism accepts a wide variety of instruments and is used for hot-wire traversing of the flow field in the tunnel and the test plate boundary layer. Calibrations of hot-wires were performed against a pitot-static probe ahead of the plate system. The traverse also supported a small pitot-static probe for measurement of pressure along the test plate.

To measure the height of the boundary layer probe above the surface of the plate, a Scientific Instruments cathetometer was used. By observing the distance between the probe wire and the image of the wire in the surface of the plate at a small angle, the height of the probe above the surface could be obtained. The cathetometer has a resolution of 0.01 millimeter. This measurement was taken at the minimum distance between the hot-wire and the test surface, and then the traverse mechanism and readout provided the distance reading as the probe was moved away from the surface.

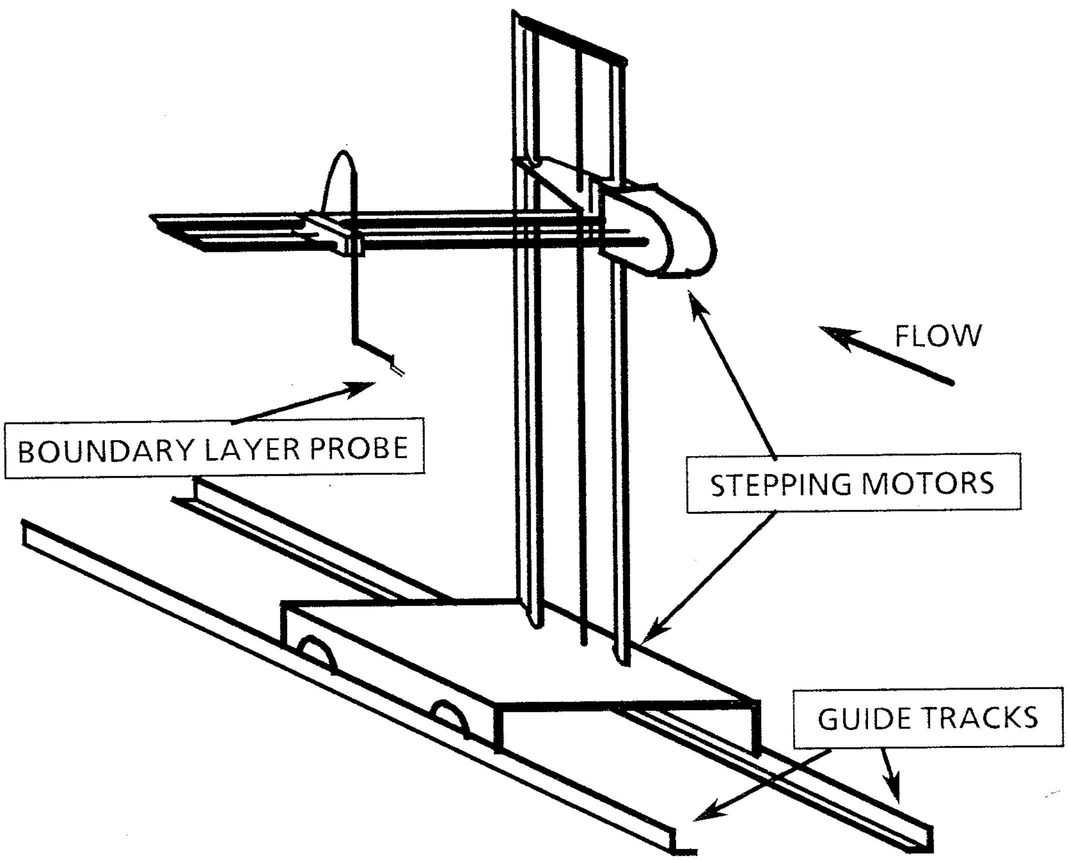

Figure 16 - Traverse installation in wind tunnel test section. Boundary layer probe shown.