AIAA 97-0663

Improvements to the UTA High Reynolds Number Transonic Wind Tunnel

W. S. Stuessy
J. L. Peeples
B. R. Mullins, Jr.
The University of Texas at Arlington
Arlington, TX

35th Aerospace Sciences Meeting & Exhibit
January 6-10, 1997 / Reno, NV

IMPROVEMENTS TO THE UTA HIGH REYNOLDS NUMBER TRANSONIC WIND TUNNEL

W. Scott Stuessy,* Jennifer L. Peeples,† and Baxter R. Mullins, Jr.‡
The University of Texas at Arlington
Aerodynamics Research Center
Arlington, Texas 76019

ABSTRACT

The high Reynolds number, transonic Ludwieg concept tunnel at The University of Texas at Arlington has been returned to service with improved facility pressure monitoring systems. An improved response static pressure measuring system has been incorporated. The calibrated range of operation has also been extended to allow for testing at higher Reynolds numbers. Comparison of the improved pressure measurement system is compared with the previous system. The effect of increased Reynolds number upon the response of the new system is also discussed.

INTRODUCTION

The Ludwieg tube concept was first proposed as a high-Reynolds number, transonic flow simulation by K. Ludwieg of Germany in 1957.[1] Numerous Ludwieg tube tunnels are in existence, both in the U.S. and in Europe. The facility at the University of Texas at Arlington (UTA) was initially developed at AEDC in the early 1970's as a pilot tunnel to evaluate the proposed Air Force concept for the National Transonic Facility. Extensive evaluation studies of the operational characteristics and flow quality were conducted at AEDC between 1971 and 1975.[2]

The facility was donated to UTA in 1978 and placed into service in 1984 after development of the necessary mechanical, pneumatic, electronic control, and data acquisition systems.[3] The tunnel was moved to a new complex in 1986.[4] The facility was reactivated in early 1996 after several years of inactivity and improvements were made to the pressure measurement system.

The three tunnel pressure measurement systems were all modified by reducing the internal volume of each one thereby improving the response. The new systems were checked and calibrated to a centerline probe. The facility was next checked and calibrated at higher operating pressures than had been previously demonstrated.

THEORY OF OPERATION

Ludwieg tube tunnels are based on an unsteady expansion wave concept to acceleration high-pressure air stored within a charge tube to transonic Mach numbers. The expansion wave produces a flow process that is similar to the flow within the driver tube of a conventional shock tube. A schematic of the UTA Ludwieg tube is shown in Figure 1 and the idealized wave diagram in Figure 2. The components of the tunnel consist of the charge tube, convergent nozzle, test section, ejector flap section, diffuser, and starting valve.

Flow in the tunnel is initiated by charging the entire system to the desired charge tube pressure level, and then rapidly opening a starting valve to initiate flow. This action generates an unsteady expansion wave that propagates upstream through the diffuser, test section, nozzle, and into the charge tube to initiate the flow towards the open valve at the downstream end of the system. Once the expansion wave clears the convergent nozzle, steady flow within the test section is maintained for the time duration it takes the expansion wave to travel the length of the charge tube, reflect, and return to the test section. The 33.8 m (111 ft) length of the charge tube provides a theoretical steady flow period of 185 msec; however, this time is reduced to about 120 msec due to the time period actually required to open the starting valve and by the unsteady flow phenomena associated with the flow initiation in the plenum cavity surrounding the porous walled test section. Subsequent wave reflections occur, but their complex nature results in a deterioration of flow quality.

Normal isentropic flow acceleration through a converging nozzle would normally be limited to the attainment of sonic flow at the nozzle exit; however, the effect of mass removal relieves the choking effect and permits acceleration of the flow to supersonic speeds in the constant area test section. The range of suction mass flow

*Faculty Research Associate, Department of Mechanical and Aerospace Engineering, Senior Member, AIAA
†Graduate Research Assistant, Department of Mechanical and Aerospace Engineering, Student Member, AIAA
‡Adjunct Associate Professor, Department of Mechanical and Aerospace Engineering, Senior Member AIAA

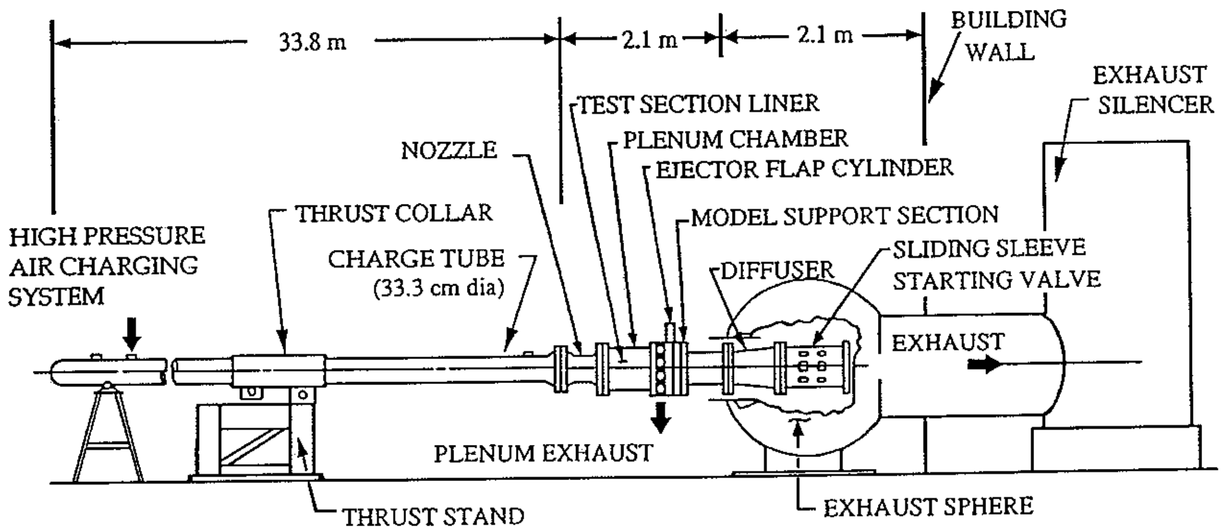

Fig. 1. Elevation view of The University of Texas at Arlington's HIRT facility.

rates for the HIRT facility allows acceleration to a maximum Mach number of about 1.2.

The starting process is greatly complicated by the presence of the ventilated walls and the surrounding plenum cavity required for collecting the suction flow and discharging it to the surroundings. Figure 3 illustrates the starting process for the plenum cavity. When the initial expansion wave generated by opening the downstream main starting valve reaches the test section, the initial effect is to pump flow from the plenum cavity into the test section through the porous walls. This flow from the cavity into the test section is reversed by rapidly pumping the cavity to the atmosphere through the plenum exhaust system before the test section flow can approach an equilibrium steady flow condition.

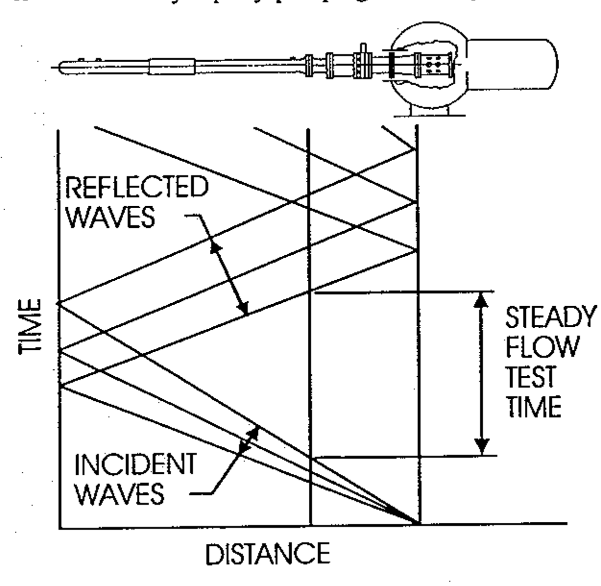

Fig. 2. The Ideal Wave Diagram for the HIRT Tunnel.

FACILITY

The capabilities of the tunnel include a Mach number range of 0.5 to 1.2, with a corresponding Reynolds number range of 4×10^7 to 43×10^7 per meter (1×10^6 to 11×10^6 per inch) as shown in Figure 4. A unique capability of the HIRT tunnel is the ability to independently vary Mach and Reynolds numbers over the full operating range of the tunnel. The test section employs a conventional AEDC porous wall design with a rectangular cross section measuring 18.5 cm (7.28 in) x 23.2 cm (9.15 in), and is 64 cm (25.4 in) long. The porous walls minimize shock wave reflections from the tunnel walls as well as provide for substantial alleviation of tunnel wall interference effects. The porous wall design also allows acceleration to low supersonic Mach numbers using the porous walls and a fixed-area-ratio convergent nozzle. Data from AEDC indicate a practical limit for airfoil testing of about 15×10^6 chord Reynolds number, determined by the practical model size limitation of the tunnel.

Ludwieg Tube

The charge tube is 35.5 cm (14 in) in diameter and 33.8 m (111 ft) long. It can be charged to a maximum pressure of 4.55 MPa (660 psia), which produces a steady flow stagnation pressure of about 3.44 MPa (500 psia). The nozzle is 47 cm (18.5 in) in length, and has a contraction ratio of 2.27. The nozzle provides a transition from the circular geometry of the charge tube to the rectangular test section geometry. The test section measures

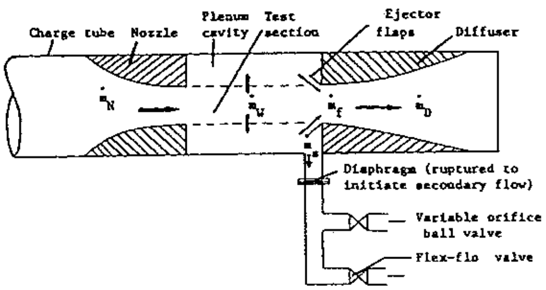

Fig. 3. Plenum cavity starting process.

18.5 cm (7.3 in) by 23.2 cm (9.15 in), and is 64.5 cm (25.4 in) long. The porous walls are of conventional design, consisting of two stacked plates with 60-deg inclined holes and having a tapered porosity pattern in the upstream one third of the test section. The porosity can be varied manually from 3.5 to 10 percent by moving one plate relative to the other. This adjustment capability is provided on all four walls. The variable porosity walls provide for wave cancellation for supersonic flow in the tunnel, and provide an effective means for partially alleviating tunnel wall interference effects. They also allow the attainment of low supersonic Mach numbers with a fixed area ratio convergent nozzle. The test section is surrounded by a plenum cavity that has a volume approximately 1.75 times the test section volume. Details of the nozzle, test section, diffuser, and starting valve are shown in Figure 5.

The ejector flaps at the downstream end of the test section are 7.62 cm (3.0 in) long and can be opened to provide a maximum gap height of 2.29 cm (0.9 in). Flow in the plenum cavity is exhausted to atmosphere

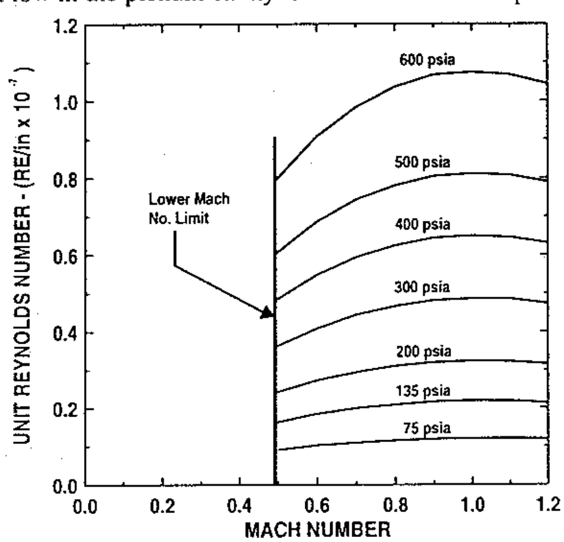

Fig. 4. Operational capability of the Ludwieg tube transonic wind tunnel.

through the system as shown in Figure 3. Eight 5.08 cm (2 in) I.D. flexible hoses are attached around the test section and connected to a common manifold. Downstream of the manifold is a diaphragm holder consisting of two plates held together by a Grayloc clamp. Mylar diaphragm material of the required thickness is ruptured at a specified time interval from the start of the run by means of a plenum exhaust cutter (PEC) that is actuated by a pneumatic cylinder. Downstream of the diaphragm assembly, the 15.2 cm (6 in) diameter plenum exhaust line vents to atmosphere through a 6-inch variable orifice ball valve for which the open area is preset at a prescribed value prior to a run.

The first section of the diffuser contains another transition section with contours designed to change smoothly from the rectangular cross-section to a circular cross-section. Downstream of the transition is a conical diffuser with a 3-deg wall angle and an exit diameter of 40.6 cm (16 in). Provisions for mounting a model support sting are provided at the diffuser entrance.

A 30.5 cm (12 in) and a 40.6 cm (16 in) diameter sliding sleeve valves (SSV) are available as a main starting valves. The sliding sleeve valve is driven by a pneumatic cylinder and requires approximately 60-80 msec to open (depending on the charge tube pressure and pneumatic cylinder pressure). The larger SSV takes longer to open than the smaller one.

The 16-in diameter sliding sleeve valve has twenty-seven, 3-in diameter ports in 3 rings around the valve body. The valve is opened and closed by a pneumatic cylinder and the valve can be opened in approximately 80 msec. Each of the 27 ports is a short pipe nipple which can be capped to adjust the mass flow rate out of the valve. The main tunnel flow, as well as that from both branches of the plenum system, empties into a large exhaust sphere. From there the flow exits the building through a 1.22 m (4 ft) diameter duct and into a silencer which turns the flow upward before being exhausted to atmosphere.

Subsystems

A control board is used to regulate and control the pressurized air from its supply system. A low pressure compressor provides control air for various pneumatically controlled remote valves. A high pressure compressor is used for pressurization of the charge tube as well as pressurizing the FFV, SSV-OPEN, SSV-CLOSE and PEC actuators. Each subsystem has one accumulator that is charged to a required pressure level. In the event that a run needs to be aborted, dump valves and vent lines are provided to vent pressurized air to the atmosphere.

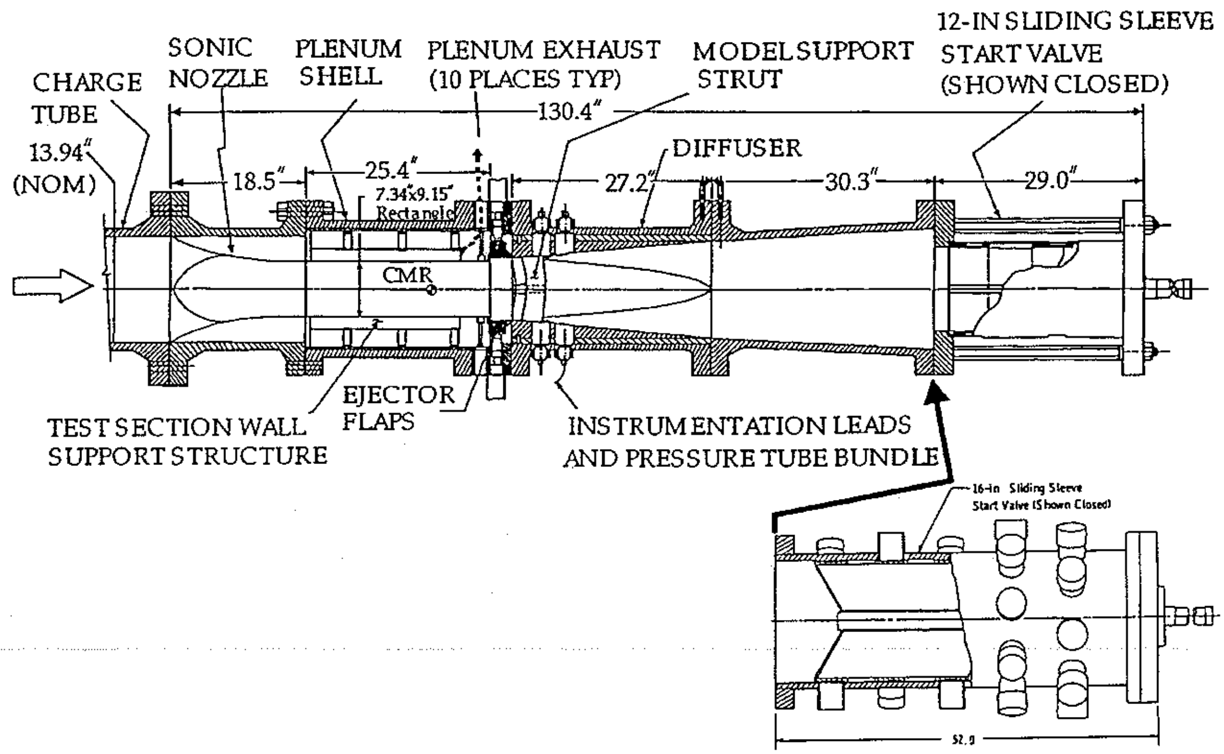

Fig. 5. Sectional view of the nozzle, test section, diffuser and both large and small sliding-sleeve starting valves of the HIRT facility.

Solenoid valves are used to release the accumulated pressure into a pneumatic actuator or cylinder at the prescribed time to start the wind tunnel. Two solenoid valves are used to control the charge tube pressure. One is used to control the flow into the charge tube. The other is used to bleed the charge tube in case pressurization over the required level should occur, or in case the run needs to be aborted.

Data Acquisition / Electronic Control Systems

Located adjacent to the test section, the tunnel control system[5] operates solenoid valves that open the sliding sleeve valve to initiate tunnel flow, cuts a diaphragm to start the plenum exhaust system flow, and closing a flex-flow valve in the plenum exhaust flow line after culmination of the starting transient. The control system also sends a signal to the data acquisition system to initiate data acquisition. The sliding sleeve valve is then closed after the completion of the test run. Once the run is completed, the data is transferred from the data acquisition system to the main computer located inside the control room. The data is then processed while the tunnel is being prepared for the next run.

The instrumentation includes a single Kulite XTS-1-190-200 pressure transducer with a pressure rating of 1.38 MPa (200 psi) and can be operated up to 2.75 MPa (400 psi), several Kulite ITQS-500F-500SG pressure transducers with a pressure rating of 3.44 MPa (500 psi), and an Optoelectronics precision Thermometer T-100 temperature sensor. The pressure transducers are used to measure the charge tube total, charge tube static, test section plenum cavity, and test specific pressures during the test. The temperature sensor is used to obtain the temperature prior to a test run. The standard procedure is to use the charge tube stagnation pressure transducer as a reference signal for calibration of the static pressure transducers during charging of the tunnel. The Kulite transducers used for normal data acquisition are not temperature compensated, and do not maintain their calibration over long periods of time. The normal calibration procedure that was developed at AEDC included calibrating the transducers against an accurate temperature compensated transducer during the charging cycle. The same procedure is used at UTA. The ITQS-500F-500SG transducers are calibrated against the single XTS-1-190-200 transducers during the charging operation at three points near the pressure expected during the test. The single XTS-1-190-200 pressure transducer is temperature compensated and has very little drift over time while the other transducers can drift with time. This method substantially reduces the errors associated with the drift.

The instrumentation is connected to a DSP technology data acquisition system which has the capability of 100 kHz sampling rate, 12 bits of accuracy, and 48 channels each with its own amplifier and analog to digital converter to allow for simultaneous sampling of all channels. The system has 512 Kilobytes of memory available for distribution to the channels being utilized. The data acquisition system is connected to a 486-DX, 33 MHz IBM-compatible PC via a GPIB 488 bus for data retrieval, storage, and manipulation.

Once the tunnel flow has been started and the plenum diaphragm has been cut, the steady state conditions are defined by the interactions of the secondary flow through the ball valve, the ejector flap opening, the wall porosity, the tunnel blockage, and the main valve characteristics. The wall porosity and the test section blockage (ratio of model cross sectional/area test section area) are of secondary importance in determining the mean test section flow.

Starting Transient

The leading edge of the expansion waves generated by opening the sliding sleeve valve and cutting the plenum exhaust system diaphragm should reach the test section at the same time. The differing characteristics of the pneumatic actuation systems necessitated an experimental evaluation of the proper time delay settings for operation of the various starting sub-systems. The determination of the time delays between actuation of the various starting mechanisms is largely accomplished by an empirical process. The stagnation and static pressures in the charge tube appear to stabilize in about 60-70 msec, but the test section static pressures do not approach equilibrium values until much later. AEDC test data showed starting times on the order of 80 msec are possible.[2]

EXPERIMENTAL RESULTS

A centerline probe was installed in the test section to obtain the axial pressure distribution through the test section. The front part of the probe mounts in the downstream end of the charge tube, whereas the downstream end mounts in the model support section of the diffuser / transition section. Pressure taps are available throughout the nozzle and test section. Eleven ports were chosen in the region where the models are normally mounted.

These measurements are supplemented by static and total pressure measurements in the charge tube just upstream of the nozzle entrance. The total pressure measurement allows a Mach number to be calculated for the centerline probe static pressure measurements.

Test Section Mach Number Variation

The axial Mach number distribution within the test section for a range of test section Mach numbers is shown in Figure 6. The data scatter is within about ±0.50 percent, which is comparable to published data from the AEDC calibration. The Mach number variation for the data shown in Figure 6 was obtained by control of the plenum exhaust flow rate by variation of the plenum exhaust system ball valve setting.

Modifications or Improvements

The tunnel monitoring probes and instrumentation consists of a charge tube total system, a charge tube static system, a charge tube temperature system, and a plenum cavity system. The charge tube systems are located just upstream of the nozzle in the charge tube. The total pressure system is actually two total pressure probes whose pressure lines are mechanically connected. Two transducers are used to measure the total pressure. The XTS-1-190-200 transducer is used for charge pressure monitoring and for the calibration standard against which all other facility transducers are calibrated against. The second transducer is used for obtaining the run data.

The charge tube static system consists of a static pressure probe and one transducer. The plenum chamber pressure system consists of four static probes mounded in the chamber surrounding the test section. Originally, all four probes were connected together to mechanically average the pressure and was measured with a single transducer. The charge tube temperature probe obtains the temperature just before initiation of the expansion wave.

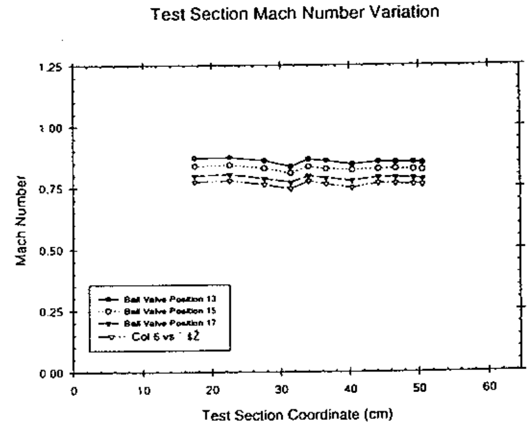

Fig. 6. Test section Mach Number variation along the centerline.

The charge tube total and static probes were not changed or altered, but the external tubing from the tunnel was shortened as much as practically possible. The total pressure system was shortened from 37.5 to 28 in. of 1/16-in ID tubing. The static pressure tubing was shortened form 25.75 to 9.75 in. using the same tubing. The tubing internal to the probes was left unchanged.

The plenum pressure system was totally replaced with new components before satisfactory results were obtained. Initially, only the probes themselves were replaced. The original probes were 14 in. long with a 0.180-in ID with four 0.063-in diameter static ports around the probe. The probes were replaced with probes of the same length and outside diameter, but with an ID of 0.083-in. The tubing from the probes to the transducer was not changed and was 1/16-in OD x 0.042-in ID. The response was greatly improved, but gave non-repeatable results after a few tunnel runs. Examining the probes, it was found that debris associated with clay used to fill model attachment holes, thin-film remaining on model due to machining, oil, and occasionally fine particles left in the tunnel was filling and plugging the smaller probe ports. Replacing the tubing with 1/16-in ID tubing and providing separate transducers for each of the four probes, provided very a sound and repeatable response.

Typical pressure measurements for the charge tube total, static, and plenum pressure systems are shown in Figures 7, 8, and 9. Figure 7 shows the original system and is used as a benchmark to judge the improvements. Figure 8 shows the total, static, and plenum pressures for the new system. The response of the static and total pressures are comparable to the previous configuration. These two systems were only changed by shortening the tubes. The internal volume of the new system was not significantly reduced and only a small improvement, if any, was expected. The steady flow plateau in the data was about 120 milliseconds duration.

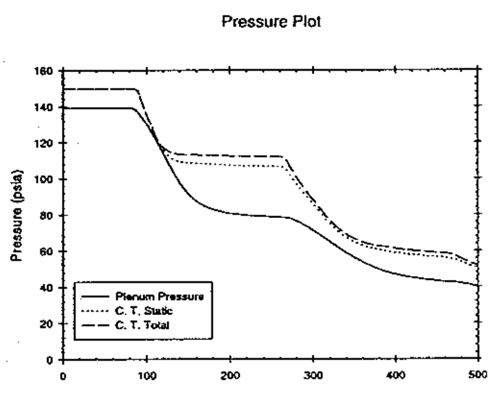

Fig. 7. Pressure v. Time contours as determined using the original pressure system.

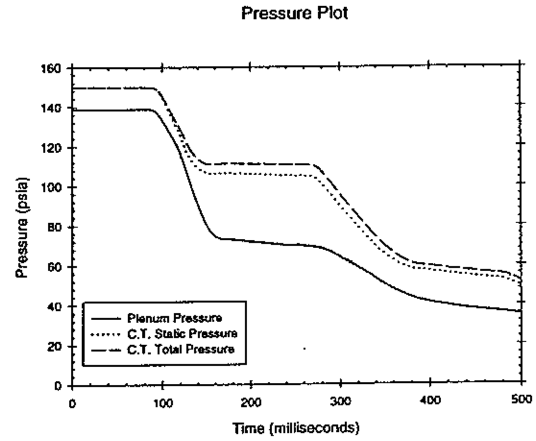

Fig. 8. Pressure v. Time contours using a modified pressure system consisting of only the four new probes.

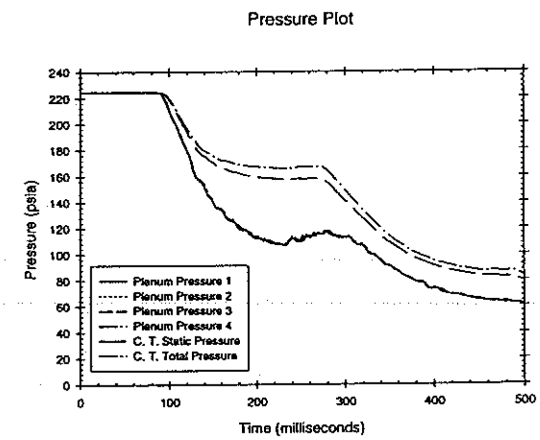

Fig. 9. Pressure v. Time contours using the new pressure probe/measurement system.

The original plenum pressure measuring system yielded about 30 msec of steady-state pressure. The new plenum pressure measuring system volume was reduced considerably with a corresponding increase in measured steady-state pressure of nearly 110 msec as shown in Figure 8. Figure 9 shows pressure traces from the system after the four transducers were installed and larger tubing used to connect the transducer to the probe. This graph is at a higher charge pressure. Due to this higher pressure the charge tube total and static pressures have taken longer to respond and the constant pressure plateau has been reduced from 120 msec to about 90 msec.

The plenum pressure is of comparable duration. All four pressure measured nearly identical readings throughout the run. This supports the theory of free flowing the plenum cavity.

CONCLUSIONS

The transonic wind tunnel facility at The University of Texas at Arlington has been returned to service. The facility pressure monitoring systems are much more responsive after several improvements. The charge tube total and static pressure systems response is comparable to their previous response. The plenum pressure system responds comparable to the charge tube system.

The modified system allows a measured region of constant pressure flow of about 120 msec for an initial charge tube pressure of 150 psia. The constant pressure region is reduced to about 90 msec for an initial charge tube pressure of 225 psia. The transonic facility has been checked out and calibrated with a centerline probe for Mach numbers near 0.8 and a Reynolds number of 14×10^7 per meter (3.5×10^6 per inch).

The current systems all measure absolute or gage pressures with respect to the atmosphere and Mach numbers are calculated relative to these pressures. Measuring the total pressure and then measuring the dynamic pressure with a differential pressure transducer would provide a more accurate means of determining Mach number. Mounting a small static probe or a pitot-static probe in the test section would provide the most accurate measurement of flow quantities. Plans are underway to include a small pitot-static probe with a differential pressure transducer.

REFERENCES

1 Ludwieg, H. "Tube Wind Tunnel - a Special Type of Blowdown Tunnel," Paper presented at the Eleventh meeting of the AGARD Wind Tunnel and Model Testing Panel, Scheveningen, Holland, July 1957.

2 Starr, R. F. and Schueler, C. J., "Experimental Studies of a Ludwieg Tube High Reynolds Number Transonic Tunnel," AEDC-TR-73-168, December 1973.

3 Wilson, D. R. and Chou, S. Y., "Development of the UTA High Reynolds Number Transonic Wind Tunnel," AIAA Paper 85-0315, AIAA 23rd Aerospace Sciences Meeting, Reno, Nevada, January 14-17, 1985.

4 Wilson, D. R., "Development of the University of Texas at Arlington Aerodynamics Research Center,: AIAA Paper 88-2002, AIAA 15th Aerodynamic Testing Conference, San Diego, CA, May 18-20, 1988.

5 Engelhardt, J. P., "A Transonic Wind Tunnel Electronic Control Unit and Total Pressure Survey of a Vortex," M. S. Thesis, The University of Texas at Arlington, December 1989.