Experimental Studies of a Ludwieg Tube High Reynolds Number Transonic Tunnel

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Theme

A SIGNIFICANT justification for a much higher Reynolds number ground test capability in the transonic regime has developed in the past few years. An extensive experimental investigation of a high Reynolds number transonic wind tunnel employing a Ludwieg tube air storage system has been undertaken at AEDC to assess the utility of such a device.[1] The transonic starting process and starting time of this impulse facility have been carefully evaluated and the spatial and timewise quality of the test section flow analyzed. Studies of the aerodynamic flow response time at transonic speeds and measurements of the pressure distribution and forces on selected models have been undertaken. Also, studies of the influence of plenum volume on test section flow quality have been completed.

Contents

A schematic drawing of the pilot tunnel is given in Fig. 1. It can be charged to 800 psia and produces a maximum stagnation pressure of about 500 psia in the transonic speed range. A transition section with a contraction ratio of 1.6 channels the flow from the circular charge tube into a rectangular test section which is 7.3 in. × 9.15 in. The porous walls are of conventional design with 60° inclined variable porosity holes. The plenum chamber which encloses the test section has a volume which is about 1.8 times the test section volume (neglecting the volume of the wall support structure). The plenum is exhausted directly to atmosphere through a choked orifice-valve system. Both a diaphragm and fast-acting valve have been used as the main starting device in the tests which will be described.

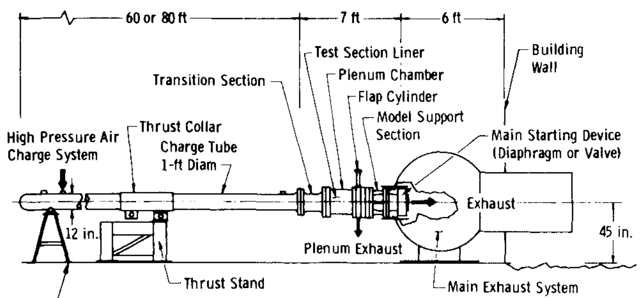

Fig. 1 Pilot HIRT schematic.

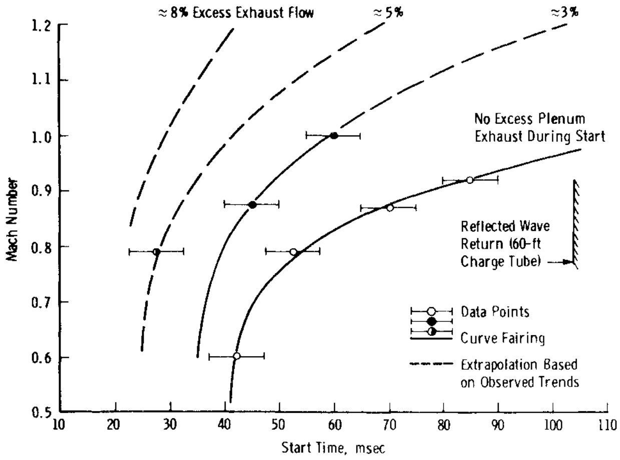

Fig. 2 Pilot HIRT start times for various excess plenum flow rates during the start.

The tunnel run is initiated by opening the main starting device and the plenum exhaust system. The duration of the first cycle of the blow time of this pilot tunnel is 105 or 135 msec depending on the charge tube length. The duration of the steady portion of the run will be discussed later.

The most critical area of study involved the starting wave process and start time of the tunnel. The required high quality transonic measurements can only be made if tunnel conditions are constant for the duration of the useful run and if the steady conditions are established spatially throughout the test section.

In the pilot tunnel, three devices are provided to facilitate fast tunnel starts and these are the following: 1) a plenum exhaust which can be opened independently from the main tunnel exhaust; 2) a controllable plenum exhaust system which can provide an excessive plenum exhaust flow during the starting process and be throttled to the lower exhaust flow required during the steady run; and 3) a flap system in the tunnel wall which can be opened to increase the flow area between the test section and plenum chamber during the tunnel start.

Experimental results have shown the most pronounced influence of the controllable plenum exhaust mode of operation on the tunnel start time (Item 2). The tunnel start time can be significantly reduced by employing the excess plenum exhaust as needed in the start. This is shown in Fig. 2.

The axial uniformity of Mach number is usually regarded to be a prime measurement of test section flow quality in transonic tunnels. A centerline pressure pipe with ten static orifices was used in the pilot tunnel to make this measurement. The blockage of this static pipe is 0.6%. The axial Mach number distribution is given in Fig. 3 for three charge pressures.

Sources of disturbance which cause fluctuations or timewise

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Index categories: Research Facilities and Instrumentation; Subsonic and Transonic Flow; Aircraft Testing (Including Component Wind Tunnel Testing).

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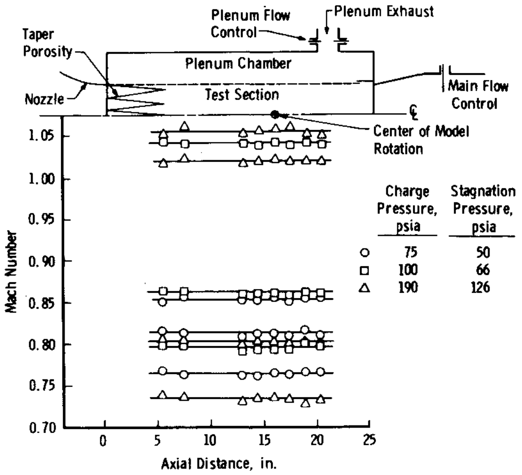

Fig. 3 Mach number distributions for various charge pressures.

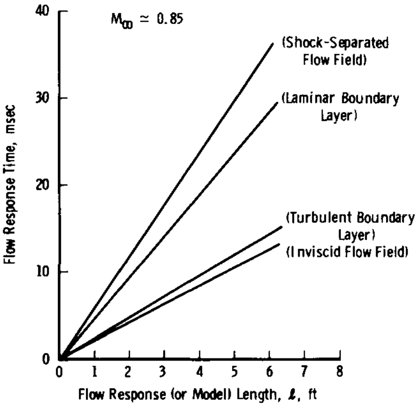

Fig. 5 Flow response time for selected flowfield types and a range of body lengths.

variations in flow pressure (noise) exist in all wind tunnels. Measurements of these pressure fluctuations have been made in conventional transonic tunnels. Similar measurements were made in Pilot HIRT for comparison with those of the more conventional transonic tunnels and to provide a further indication of the flow quality available from a short-duration facility. These data were presented in Ref. 1. Even though the pressure level in Pilot HIRT is significantly above that of existing tunnels, the percentage of fluctuation in the freestream static pressure is the same as in existing tunnels ($\bar{p}/p \approx 1\%$). The spectral content of the noise indicates that it is dominated by the relatively high-frequency wall hole noise and that the tunnel is relatively free of low-frequency oscillations.

An understanding of the flow process in the charge tube of any Ludwieg tube tunnel is a basic requirement for properly mating the test section and storage system to minimize flow disturbance during the tunnel run. The primary potential source of poor quality flow from the charge tube is the turbulent boundary layer which grows on the wall. The boundary layer can grow to a substantial fraction of the charge tube diameter for the long charge tubes typical in this type tunnel, producing radial and timewise gradients in flow properties if not constrained by proper selection of lengths and contraction ratios.

Boundary-layer survey rakes were installed in the pilot tunnel at the charge tube exit, the contraction exit, and the center of model rotation in the test section. The experimental data from the charge tube, along with Becker's theory[2] and an improved theory, are plotted in Fig. 4. It can be seen that the improved theory agrees closely with all the experimental data and that the influence of growth within the wave is properly predicted. The trend in boundary-layer thickness with increasing Reynolds number is adequate but will be studied further.

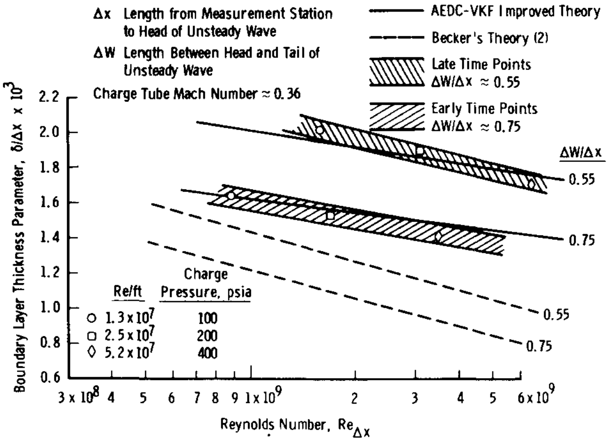

Fig. 4 Variation of boundary-layer thickness parameter with Reynolds number (in the charge tube).

The fundamental question to be answered before advocating short-duration testing in any speed range concerns the time required for the flowfield over the body to reach a steady-state condition. The result of both analytical and experimental studies is summarized in Fig. 5. These results have been confirmed by pressure distribution measurements on a 2-in.-chord C-141 airfoil model and force measurements on a family of cone models in the pilot facility. These pressure and force measurements are in excellent agreement with other transonic facility data.

In addition, the effect of plenum volume on transonic tunnel performance has been studied experimentally and reported in Ref. 3, and the tunnel exhaust noise (environmental impact) has been experimentally and analytically studied and reported in Ref. 4.

References

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