



EXPERIMENTS TO ASSESS THE INFLUENCE
OF CHANGES IN THE TUNNEL WALL BOUNDARY LAYER ON
TRANSONIC WALL CROSSFLOW CHARACTERISTICS

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE 37389

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ARNOLD AIR FORCE STATION, TENNESSEE 37389

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FOR THE COMMANDER

Carlos Tirres

CARLOS TIRRES
Captain, USAF
Research & Development
Division
Directorate of Technology

Robert O. Dietz

ROBERT O. DIETZ
Director of Technology

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tunnels in the Mach number range from 0.95 to 1.15. The displacement thickness studied is comparatively thin and represents typical values which will be encountered in future high Reynolds number transonic tunnels. Based on the change in static pressure measured on a cone-cylinder model, it is shown that a factor of two variation in the tunnel wall δ^* results in an equivalent wall porosity change of less than one percent in the range $0.13 \leq \delta^*/d \leq 0.28$, where d is the wall hole diameter.

PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65807F. The research was conducted from November 1974 through January 1975 by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project No. V37A-32A. The author of this report was R. F. Starr, ARO, Inc. The manuscript (ARO Control No. ARO-VKF-TR-75-45) was submitted for publication on April 29, 1975.

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1.0 INTRODUCTION

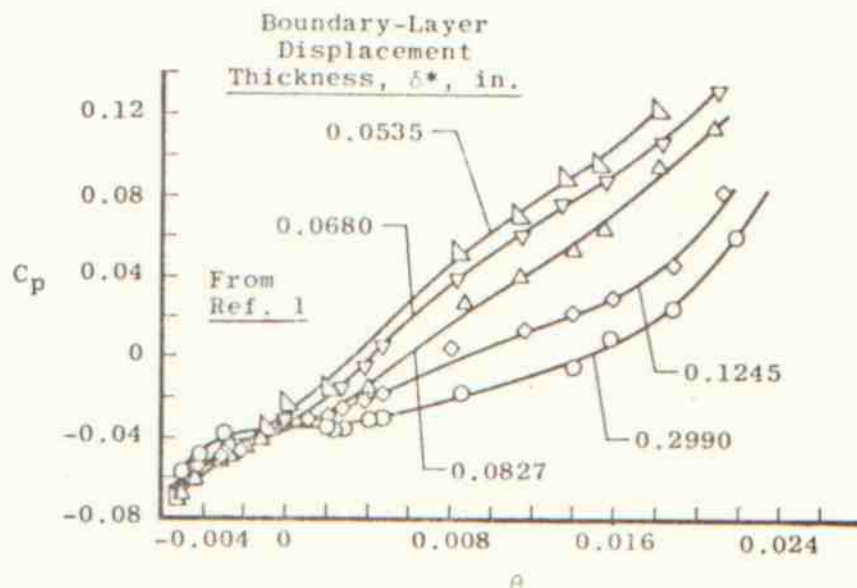
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Currently, there is great interest in advanced high Reynolds number transonic facilities and several major development programs are underway in both the USA and Europe to investigate several different types of high Reynolds number transonic wind tunnels. Wall boundary-layer changes occur as the free-stream Reynolds number is varied in each type of tunnel under consideration, and the wall boundary-layer thickness changes with time during the course of the run in some of the tunnel types.

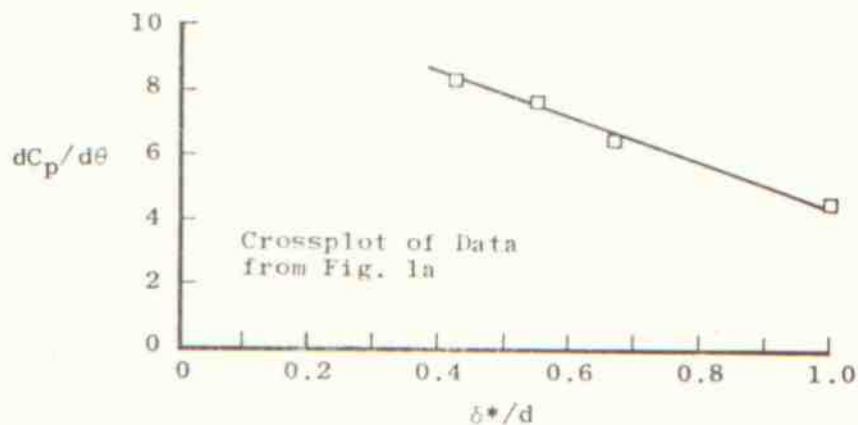
In the test section of a transonic facility, flow properties at the semiopen tunnel wall play a first order role in establishing the correct aerodynamic flow over the model under test. The wall boundary condition, or wall crossflow characteristic, has been shown to be somewhat sensitive to the wall boundary-layer properties. Figure 1a, which is taken directly from Ref. 1, illustrates the variation in the wall crossflow characteristic, $dC_p/d\theta$, for changes in the boundary-layer displacement thickness, δ^* , under the constraints of that particular experiment ($\delta^*/d > 0.5$). These experimental results are presented in a slightly different form in Fig. 1b which illustrates that a factor of two change in δ^* , for a given hole diameter, produces nearly a 50-percent change in the wall crossflow characteristic. Comparing the trends shown in Fig. 1b with more recent wall crossflow data obtained in a tunnel having walls of variable porosity (Ref. 2 gives an expression for the variation of $dC_p/d\theta$ with wall porosity, τ_w , as $dC_p/d\theta = 5 - 5/12 \tau_w$), it appears that this factor of two change in δ^* could be equivalent to a wall porosity change of about three percent which cannot be ignored based on the experimental work reported in Ref. 3. For transonic testing, then, special care must be taken to ensure that variations in model aerodynamics which appear with changing free-stream Reynolds number are not actually the result of an altered wall crossflow character or conversely that real Reynolds number variations on the model are not offset by wall crossflow changes (δ^* or τ_w induced).

The object of this study is to make a preliminary assessment of the sensitivity of wall crossflow parameters to changes in the tunnel wall boundary layer. The intent is to quantify any apparent boundary-layer-induced crossflow changes in terms of an equivalent wall porosity change. In particular, the crossflow properties present in Ludwig tube type transonic tunnel were of primary interest because of the thick wall boundary layer that will exist. The Ludwig tube transonic wind tunnel used in these experiments is described in Ref. 4. The wall boundary-layer thickness in a Ludwig tube changes about a factor of two during the course of a tunnel run. To provide additional data the tunnel stagnation pressure was varied by a factor of four, thereby producing a basic 30-percent change in boundary-layer thickness at any given time during the run. The strength of waves generated by a cone-cylinder model, which reflect off of the tunnel wall and return to the model, was used as the primary indicator of wall boundary condition changes.

Detailed measurements of the tunnel wall boundary layer with and without the cone-cylinder installed, sidewall static pressure measurements, and a careful centerline static calibration were made at many test conditions.



a. Wall pressure coefficient as a function of the flow angle at the wall for a range of δ^*



b. Wall crossflow characteristic as a function of δ^*/d

Figure 1. Influence of boundary-layer displacement thickness on crossflow characteristics of perforated wall with 60-deg inclined holes, hole diameter 1/8 in., wall thickness 1/8 in., open-area ratio 6 percent at $M_\infty = 1.2$.

2.0 EXPERIMENTAL APPARATUS

2.1 PILOT TRANSONIC TUNNEL, PILOT HIRT

The AEDC-VKF Pilot High Reynolds Number Facility (Pilot HIRT) is a laboratory-scale model of a high Reynolds number transonic facility. A schematic drawing of the tunnel is given in Fig. 2. This facility can be charged to 800 psia which produces a maximum stagnation pressure of about 500 psia in the transonic speed range. The Ludwig

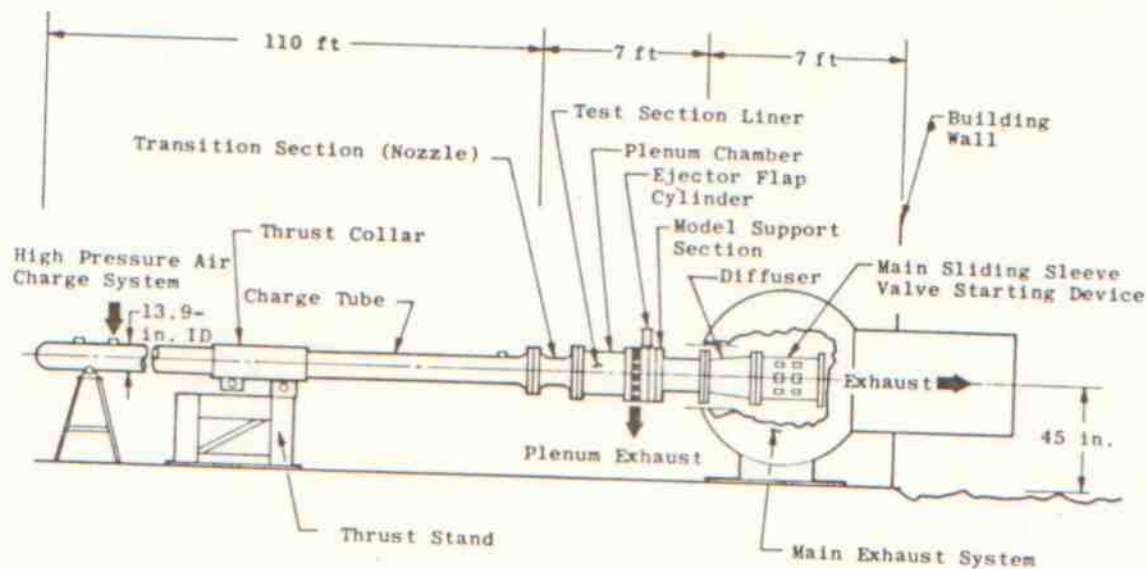
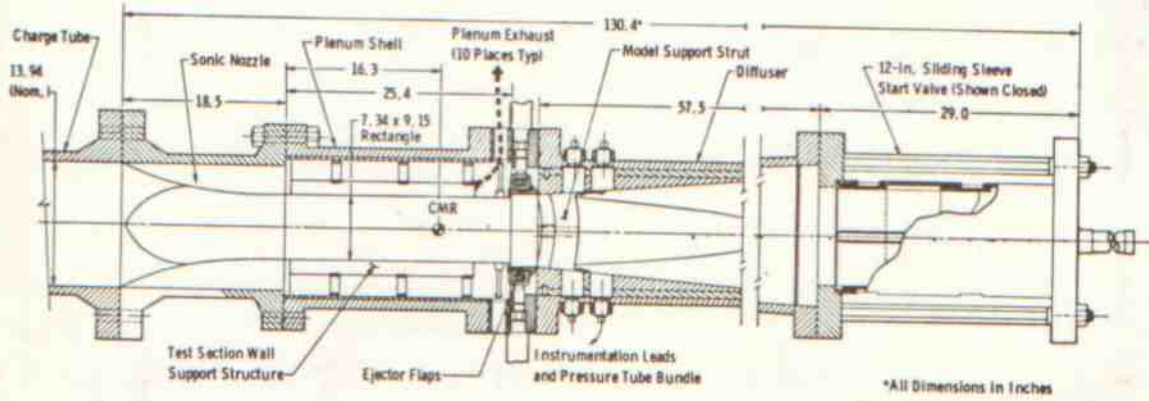


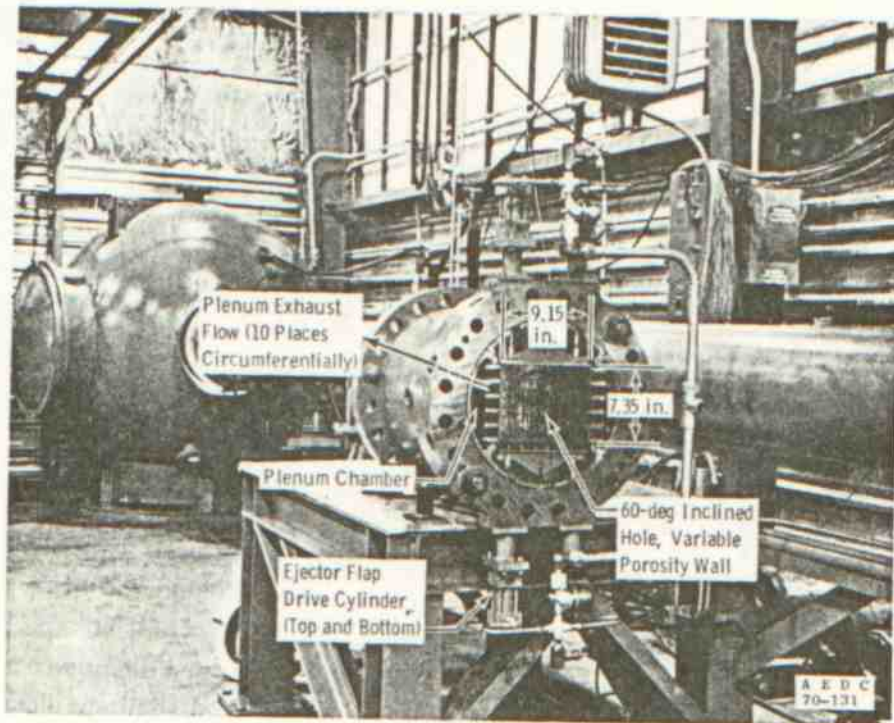
Figure 2. Sketch of AEDC/VKF Pilot HIRT facility.

tube storage system (charge tube) is 13.9 in. in diameter and is 110 ft long. A transition section with a contraction ratio of 2.25 channels the flow from the circular charge tube into a rectangular test section which is 7.3 by 9.15 in. The test section-plenum chamber is shown in more detail in Fig. 3. The porous walls are of conventional design with 60-deg inclined holes. The porosity can be varied manually by moving one porous plate relative to another (two plates constitute a wall). When the holes are fully aligned, the porosity is ten percent. The cutoff plate motion is upstream to reduce porosity. An ejector flap section is located at the back of the porous plates. The flaps are on all four walls and can be set to a greater opening during the tunnel starting process and reduced to the desired setting during the steady run (Fig. 3). 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 the choked orifice-valve system shown in Fig. 4. The desired auxiliary flow rate through the plenum system is obtained by adjusting the orifice and by opening or closing the quick-acting valve illustrated in Fig. 4. The plenum exhaust flow is initiated

by rupturing a diaphragm in the line. The volume of the plenum chamber and the plenum exhaust lines is about 2.5 times the test section volume. A model support section, diffuser, and main starting device are located downstream of the test section (see Fig. 3). A fast-acting sliding sleeve has been used as the main starting device in the tests which will be described. This valve opens in 20 to 30 msec. All of the exhaust air is channeled out of the building through the exhaust sphere (Fig. 2).



a. Pilot HIRT nozzle, test section, plenum, diffuser and start valve line drawing



b. Photograph of the test section—plenum
Figure 3. Details of Pilot HIRT facility.

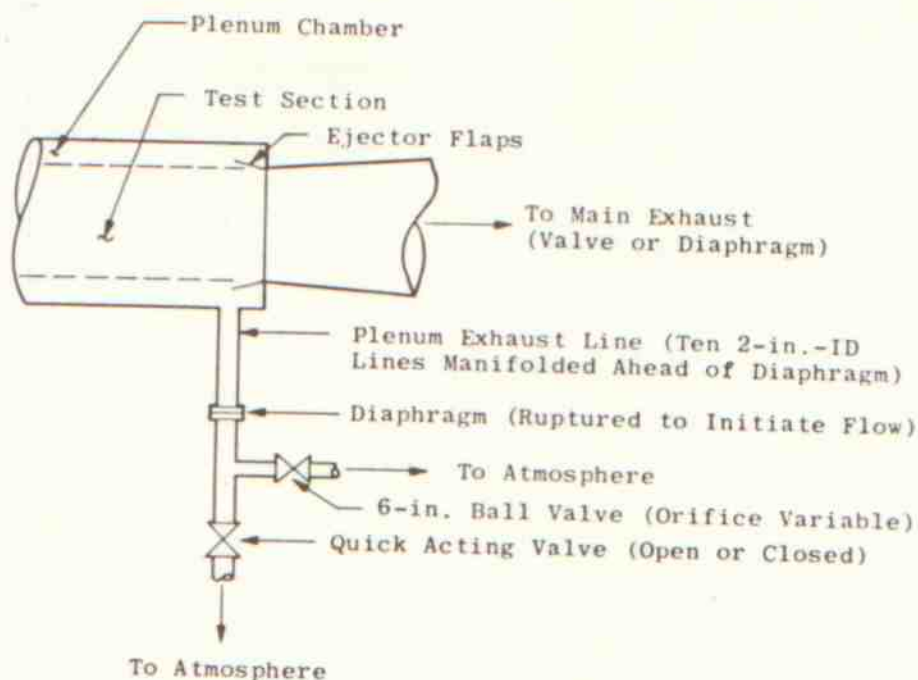


Figure 4. Pilot HIRT plenum exhaust system.

After the tunnel is pressurized to the desired pressure, a tunnel run is initiated by opening the main starting device. The plenum exhaust system is required for Mach numbers above 0.95. The duration of the first cycle of the run of this pilot tunnel is about 185 msec, and the tunnel starting process consumes the first 80 msec of this time. The duration of the steady portion of the run is about 100 msec. The tunnel operating conditions are established from a stagnation pressure measurement made in the charge tube just ahead of the nozzle and from a plenum chamber static pressure measurement made at the plenum shell wall near the center of model rotation.

2.2 INSTRUMENTATION

The pressure measurements during this series of experiments were obtained with small Kulite® semiconductor transducers. These transducers were located external to the tunnel and connected to the cone-cylinder model or the boundary-layer rake through tubes about 0.07 in. in diameter and 2 ft long. The tunnel-monitoring pressure measurements (stagnation and plenum pressures) were obtained similarly. The response time of these tubing configurations to a step input is about 20 msec at the pressures at which Pilot HIRT operates. A few test section wall pressure and tunnel monitoring pressure measurements were also obtained with the transducer located at the point of measurement to eliminate tube lag and provide a better measurement of pressure transient characteristics with time during the run.

