ABSTRACT

A supersonic Ludwieg tube has been constructed at Purdue University to study the phenomenon of boundary layer transition. The facility is capable of Mach 4 quiet flow. During the construction of the new Mach 6 Ludwieg tube, a possible modification of the old facility was discussed. The modified Ludwieg tube would allow the testing of airfoils at transonic speeds. One of the critical issues in the design of a high-speed wind tunnel is the basic geometry, more specifically, the number of throats and the location with respect to the test section. This issue was investigated by comparing three transonic wind tunnels; the Ludwieg tube at Marshall Space Flight Center, the cryogenic Ludwieg tube of DLR, and the Ludwieg tube at the University of Texas at Arlington. The Ludwieg tube at DLR had an adaptive wall, the Ludwieg tube at Marshall Space Flight Center had a single throat downstream of the test section, and the Ludwieg tube at the University of Texas had ejector flaps downstream of the test section.
INTRODUCTION

It has been almost a century since the first manned aircraft designed and built by the Wright Brothers flew, and several advanced methods for designing airfoils and simulating flowfields using high-powered computers have been developed. However the final word on the aerodynamic performance of a vehicle and/or a vehicle component must still come from wind tunnel testing [5]. Today, with the severe budget cuts in the aerospace industry and research area, it is crucial that wind tunnels are capable of operating at low cost [3]. To further complicate matters, boundary layer transition tests done in noisy facilities with pressure fluctuations and noise in the freestream flow do not properly simulate the quiet flow of actual flight [4]. The answer to the above two problems is the Ludwieg tube, a wind tunnel design first proposed by Ludwieg of Germany [7].

Many Ludwieg tubes have been built around the world due to the low cost of construction and operation [9]. Ludwieg tubes have an advantage over a conventional blowdown type wind tunnel because of the high Reynolds number and high quality flow. According to the author of reference [8], “The authors are unable to conceive of a fundamentally quieter process for providing the nozzle airflow”. This is due to the shockless inlet design of the Ludwieg tube [8]. A more detailed explanation of the Ludwieg tube is available in reference [4] and [8].

In the early 90’s, a Mach 4 Ludwieg tube was built at Purdue University to study high speed boundary layer transition. A schematic of the facility is available in Figure 1. A new Mach 6 Ludwieg tube with a larger test section and longer test time is currently under construction to replace the Mach 4 Ludwieg tube. A few possibilities for the future use of the older facility have been discussed, and one option would be to modify the wind tunnel so that airfoils at transonic speeds can be tested. This would require a new contraction to accelerate the flow to a desired Mach number. The test section Mach number range will be decided on and reported in future reports.

One of the crucial issues in the modification of the Ludwieg tube is the overall duct geometry, more specifically, the number of throats and the placements relative to the test section. For example, a supersonic wind tunnel must have a throat upstream of the test section to accelerate the flow past sonic speed, and a second throat downstream of the test section to slow down the flow back to subsonic speeds. This can be seen in the schematic of the Purdue Ludwieg tube in Figure 1. All supersonic wind tunnels known to the author are designed specifically with this geometry. Transonic wind tunnels, however, can be designed in a few other ways than a supersonic wind tunnel. They could have two throats, one downstream and one upstream of the test section, or one throat, either downstream or upstream of the test section. This issue was investigated by comparing three transonic wind tunnels, the Ludwieg tube at Marshall Space Flight Center, the cryogenic Ludwieg tube of DLR, and the Ludwieg tube at the University of Texas at Arlington. This paper will focus on the qualitative design of the overall duct geometry, from the contraction to the diffuser.
MARSHALL SPACE FLIGHT CENTER LUDWIEG TUBE

Much of the following has been from reference [7].

The Ludwieg tube of MSFC (Marshall Space Flight Center) was originally proposed in 1965 so that supersonic research could be done inexpensively. The facility was built in 1969 with an interchangeable nozzle design. Three supersonic nozzles were built to produce test section Mach numbers of 1.4, 1.7, and 2.0. For subsonic testing, a sonic nozzle can be inserted to produce Mach numbers from 0.25 to 0.77. This Ludwieg tube has a charge tube length of 378 feet, with an inner diameter of 52 inches. The charge tube can be pressurized to a maximum of 700 psia. Immediately downstream of the charge tube is the settling chamber. The test section has a circular cross-section, with an inner diameter of 32 inches.

A diagram of this Ludwieg tube is shown in Figure 2. In this setup, the tunnel is set to operate at a test section Mach number of 0.47. The interest lies in the contraction, which is the region between the settling chamber and the test section. The contraction is a converging nozzle, seen on subsonic wind tunnels. Directly downstream of the test section is a throat, shown by a tiny spike which comes down, to decrease the cross-sectional area. This wind tunnel is of single throat design, with the throat placed downstream of the test section.

THE CRYOGENIC LUDWIEG TUBE OF DLR

Much of the following has been from reference [2].

The Ludwieg tube at DLR is a cryogenic wind tunnel that can run at temperatures down to 100K. The charge tube is 130 meters long and has a diameter of 0.8 meters. This is equivalent to 426.5 ft and 2.62 ft respectively. The wind tunnel can run at a stagnation pressure of up to 1 MPa which is equivalent to 145 psi. The test section is equipped with slotted and adaptive walls. A schematic of this facility is shown in Figure 3. The general geometry of this tunnel cannot really be defined, since the adaptive walls allow for different nozzle shapes. For example, the walls can be adjusted so that the upstream sections can be used to continue the fixed nozzle, resulting in a converging-diverging nozzle, or the walls can be adjusted otherwise.

For testing above unity, the Mach number can be extended to about 1.5 by adjusting the walls to have a throat before the test section. This makes sense because although a Mach number of 1.5 may still be considered to be in the transonic range, it is without a doubt supersonic, and that requires a choking before the test section. The Ludwieg tube of DLR is unique because the walls can adjust to any of the three throat configurations. Unfortunately, the reference did not give a discussion on how the walls are set for subsonic testing.
THE UTA LUDWIEG TUBE

Much of the following has been from references [6] and [9].

The Ludwieg tube at UTA (University of Texas at Arlington) was originally a facility at the AEDC (Arnold Engineering Development Center), and was donated to the University of Texas in 1978. A schematic of the facility can be found in Figure 4. The charge tube is 111 ft long and has an inner diameter of 14 inches. It can be charged to a maximum of 660 psia, which produces a stagnation pressure of about 500 psia. The test section is rectangular, which has dimensions of 7.28 x 9.15 inches. The nozzle is consisted only of a converging section, which connects the charge tube directly to the test section. Immediately downstream of the test section is the diffuser, making the test section of this wind tunnel essentially the throat.

With this type of design, the tunnel cannot operate above sonic speed, but the installment of ejector flaps and relieving the choking effect allows the tunnel to run at a maximum Mach number of 1.2. Without these ejector flaps, this wind tunnel would not be capable of supersonic testing.

CONCLUSION

The problem of throat quantities and their placements in high-speed wind tunnels was investigated by comparing three existing Ludwieg tubes. Each had their unique way of establishing the Mach number desired. The Mach number has to be controlled by placing throats upstream and/or downstream of the test section to obtain the desired Mach number, but it was found that alternative ways exist to get around that problem. For instance the Ludwieg tube of UTA used ejector flaps to relieve the choking effect, thus allowing supersonic operation without a throat upstream of the test section. The cryogenic Ludwieg tube of DLR allowed for virtually any geometry by using the adaptive walls.

As mentioned earlier, cost reduction will be one of the important keys to the success of the Purdue University Ludwieg tube. Adaptive walls and ejector flaps may allow for a more advanced operation of the tunnel, but would also increase the cost of modification. Out of the three wind tunnel geometries mentioned earlier, only one wind tunnel of that design was in existence; the Ludwieg tube at MSFC, which was designed with a contraction upstream of the test section and a throat downstream of the test section. The other two wind tunnel designs were not investigated, but it is the author’s opinion that since a transonic Ludwieg tube of single throat downstream of the test section exists, this may be the best way to modify the Ludwieg tube at Purdue University. However, this is only if the testing at supersonic speeds can be sacrificed, and/or it is acceptable to build another nozzle dedicated to supersonic testing.
Figure 1 – Diagram of Purdue Mach 4 Ludwieg Tube

Figure 2 – Diagram of the Marshall Space Flight Center Ludwieg Tube
Figure 3 – Diagram of the Cryogenic Ludwieg Tube of DLR

Figure 4 – Diagram of the UTA Ludwieg Tube
REFERENCES


