Operational Experience in the Langley Expansion Tube with Various Test Gases

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Abstract

MEASURED time histories of test section pitot pressure and tube wall pressure, along with measured flow velocity, were used to examine flow characteristics in the Langley expansion tube with various test gases. The effects of quiescent test gas pressure, quiescent acceleration gas pressure, type of acceleration gas, and secondary diaphragm thickness on quasisteady test flow duration and freestream and post-normal-shock flow conditions were determined. These data demonstrate the existence of a 200-300 μs quasisteady flow, sufficient to establish flow about blunt axisymmetric and two-dimensional models. For a given test gas, the range of operating conditions producing useful flow is not nearly as flexible as theoretical analyses have indicated. However, the capability of testing with arbitrary test gases results in the generation of a wide range of real-gas, hypersonic-hypervelocity flow conditions.

Contents

The Langley expansion tube[1,2] is basically a cylindrical tube with a 15.24-cm i.d. divided by two (primary and secondary) diaphragms into three sections. The operating sequence for the expansion tube,[3-5] which is shown schematically in Fig. 1, begins with the evacuation of all three sections, the test gas and acceleration gas being introduced into the intermediate section and acceleration section, respectively, and the driver section pressurized with the driver gas. Upon rupture of the high-pressure diaphragm, an incident shock wave is propagated into the test gas. The shock wave then encounters and ruptures the low-pressure secondary diaphragm. A secondary incident shock wave propagates into the quiescent acceleration gas, while an upstream expansion wave moves into the test gas. In passing through this upstream expansion wave, which is being washed downstream since the shock-heated test gas is supersonic, the test gas undergoes an isentropic unsteady expansion resulting in an increase in the flow velocity and Mach number.

Figure 1 illustrates that at the acceleration section exit (test section location), a sharp increase in pitot pressure occurs upon arrival of the incident shock. Following a period of constant pressure, a second sharp increase in pressure occurs, which is much larger in magnitude than the first and corresponds to the arrival of the acceleration gas-test gas interface. Following the interface arrival, the test gas pitot pressure is constant; this period of constant pressure represents the useful test time, and is terminated by the arrival of the tail of the expansion fan.

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Results were obtained with an unheated helium driver at a nominal pressure of 34.5 MN/m^2 and dry air, CO_2, N_2, Ar, and He test gases. Both air and helium were used as the acceleration gas for air test gas, whereas the acceleration gas was the same as the test gas for carbon dioxide and helium. The quiescent test gas pressure for carbon dioxide was varied from 3.45 to 68.95 kN/m^2, and the quiescent acceleration gas pressure varied over a range for all gases. The secondary diaphragm was Mylar and thicknesses from 6.35 to 355.6 μm were tested. Intermediate-section and acceleration-section lengths were 4.66 and 16.98 m, respectively. Centerline pitot pressures were measured 7.62 cm downstream of the tube exit and acceleration-section wall pressures were measured 1.83 m upstream of the tube exit, unless otherwise specified. Test section conditions were determined using computational schemes for real-air[6] and real-gas mixtures,[7] based on three flow properties measured in the immediate vicinity of the test section. The three measured expansion-tube flow parameters serving as input were pitot pressure, freestream static pressure, and freestream velocity. The freestream static pressure was assumed to be equal to the expansion-tube wall pressure measured just upstream of the test section. The freestream velocity was assumed to be equal to the acceleration gas-test gas interface velocity, which for the majority of the present conditions was deduced to be equal to the incident shock velocity into the acceleration gas.[2]

The flow conditions obtained after expansion are dependent on a number of factors, one of the more important being the density (or, for ambient temperatures, the pressure) of the quiescent acceleration gas.[3,5] Figure 2 illustrates the effect of quiescent acceleration gas pressure p_{10} on the time history of centerline pitot pressure and acceleration-section wall pressure for CO_2 test gas at a quiescent pressure p_1 of 3.45 kN/m^2. (The optimum value of p_1 for all test gases was found to be approximately 3.45 kN/m^2.) Centerline pitot pressure $p_{t,c}$ essentially increased linearly with time for values of p_{10} less than 1.33 N/m^2, and tended to become more constant with time over a longer time period with further increase in p_{10}. However, continued increase in p_{10} ushered in another

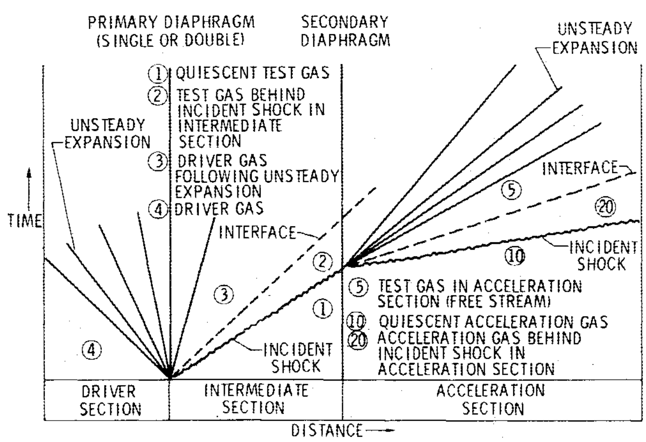

Fig. 1 Schematic diagram of expansion tube flow sequence.

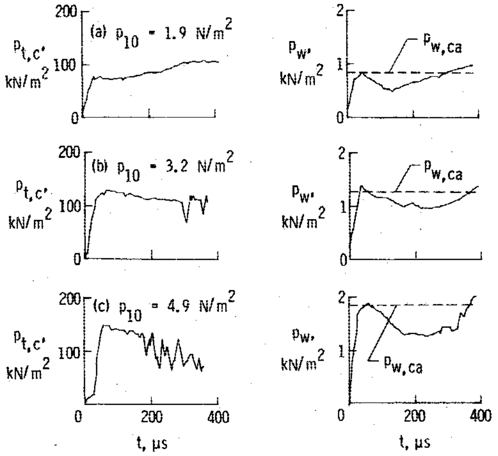

Fig. 2 Time history of centerline pitot pressure and tube wall pressure for CO_2 test gas.

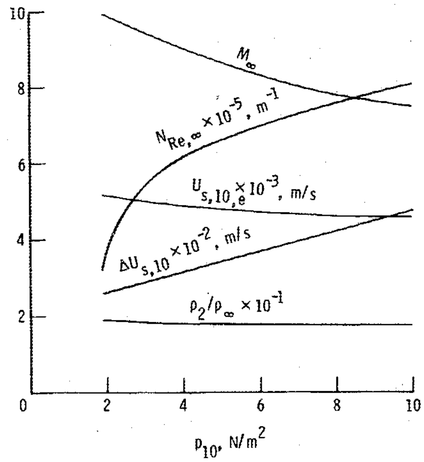

Fig. 3 Effect of quiescent acceleration gas pressure on various flow quantities for CO_2 test gas.

trend for which the quasisteady test flow period diminished with increasing p_{10}. For the range of p_{10} considered, a value of p_{10} around 3.2 N/m^2 appeared to provide the maximum test flow period. Note that for the lowest values of p_{10} the acceleration gas flow period is too brief to be observable on the pitot pressure traces. Measured wall pressures for CO_2 were characterized by a sharp increase upon incident shock arrival followed by a monotonic decrease and then an increase. For the value of p_{10} yielding the "best" pitot pressure time history, the maximum measured wall pressure immediately behind the shock and predicted[4] static pressure $p_{w,ca}$ were in good agreement; the difference between measured and predicted pressures increased to approximately 25% at a time of 200 μs.

The trends of $p_{t,c}$ and p_w with time for air, helium, nitrogen, and argon test gases were similar to those for CO_2, the only significant difference being the appearance of "spikes" in pitot pressure during the quasisteady flow period for air, nitrogen, and argon. Thus, for all test gases examined, a rather limited range of quiescent acceleration gas pressure was observed to yield quasisteady pitot pressure and wall pressure for a flow duration of approximately 200-300 μs, which is sufficient to establish flow over blunt test models.[8] Values of p_{10} outside this small range led to flow conditions unsatisfactory for model testing.

Figure 3 shows the effect of quiescent acceleration gas pressure on 1) incident shock velocity at the tube exit $U_{s,10,e}$, 2) attenuation of the incident shock velocity along the acceleration section $\Delta U_{s,10}$, 3) freestream Mach number, 4) freestream unit Reynolds number, and 5) normal shock density ratio (primary factor governing the flowfield about blunt bodies at hypersonic speeds) for CO_2 test and acceleration gases. The incident shock velocity decreased with increasing p_{10}, as expected,[3-5,9] and the attenuation in incident shock velocity increased with increasing p_{10}. The incident shock velocity was also observed to decrease with increasing p_{10} for helium, argon, air and nitrogen test gases, although the attenuation for the monatomic gases argon and (especially) helium was small. In general, the value of p_{10} has a relatively small effect on calculated freestream and post-normal-shock flow conditions. For example, increasing p_{10} for CO_2 by a factor of 5 decreases the density ratio by only approximately 10% and freestream Mach number by 20%. Because helium behaves as an ideal gas at the present expansion tube conditions,[2] the range of normal shock density ratio generated in this facility using different test gases is 4-19. The upper value of density ratio is nearer to the maximum value expected for Martian or Venusian entry than previously published experimental data, and is believed to be the highest value generated in a ground-based facility for which shock shapes were measured about a stationary model at hypersonic conditions.[10]

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