Thermodynamic Characteristics of a Blunt Two-Dimensional Resonance Tube

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Theme

A SIMPLE resonance tube consists of a round or rectangular tube with one closed end and the other end open. When the open end is placed in a coaxial, high-velocity gas jet, strong longitudinal oscillations may occur in the gas trapped in the tube. This resonance condition can be initiated easily for various geometrical configurations. For example, resonance has been observed for tubes placed in supersonic wind tunnels, supersonic freejets issuing from a correctly expanded nozzle, subcritical compressible jets, and in the compression regions of an underexpanded sonic freejet. Resonance conditions, in sufficiently long tubes, are accompanied by tube endwall temperatures T_w significantly higher than the corresponding jet stagnation temperature T_0. These thermal effects have been attributed to the periodic motion of compression or shock waves in the resonance tube. For subsonic and low Mach number supersonic jets, the fundamental resonance frequency is independent of the jet Mach number and can be approximated by $f=c/4L$, where c is the speed of sound in the jet, and L is the length of the resonance tube.

Sprenger[1] was the first investigator to report the thermal aspects of the resonance tube. Application of this gasdynamic resonance phenomenon to the rocket ignition problem was proposed first by Conrad and Pavli,[2] and the reported results demonstrated the feasibility of utilizing the resonance effect to ignite stoichiometric mixtures of gaseous hydrogen and oxygen.

This paper reports the results of an experimental investigation of a simple two-dimensional resonance tube. The leading edge of the resonance tube was blunt in order to simulate the geometric configuration of proposed rocket ignition systems. The jet was generated by a converging subsonic or sonic nozzle of exit height D. Thermodynamic characteristics of the fluid near the endwall of the resonance tube were determined for a range of jet stagnation pressures P_s, nozzle-resonance tube separation distances S, and resonance tube lengths L. Strong resonance conditions, as indicated by high endwall temperatures, were obtained for both supercritical and subcritical jet pressure ratios, P_s/P_a, where P_a is the ambient pressure.

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Index categories: Nonsteady Aerodynamics; Subsonic Flow; Supersonic and Hypersonic Flow.

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Contents

Of primary interest in this experimental investigation was the determination of the temperature and thermal effects in the vicinity of the resonance tube endwall. Time-averaged endwall temperatures were measured for each of the ranges of the test parameters. Figures 1 and 2 summarize some typical endwall temperature results. For $S/D=1.0$, the inlet to the resonance tube is located within the first expansion cell for the sonic jet. It is obvious that no resonance condition exists, and the slight temperature increase above the jet stagnation temperature is most likely due to the inherent viscous dissipation. From one-dimensional gasdynamics without resonance, the ideal maximum endwall temperature would be the jet adiabatic stagnation temperature.

For $S/D=2.0$, the peak endwall temperature is obtained for $L/D=10$ and a pressure ratio (P_s/P_a) below the critical point. Hence, the jet is subsonic and resonance heating is occurring without the presence of a trip. Sprenger[1] had observed a somewhat similar condition. However, for his axisymmetric resonance tube it was necessary to place a thin fiber near the exit of the nozzle. No other published results currently are available for the two-dimensional case as described in this paper. The actual mechanism of this thermal effect currently is being investigated.

For $S/D=3.0$, two temperature peaks are observed for the larger values of L/D. Again, the first peak is in the subcritical

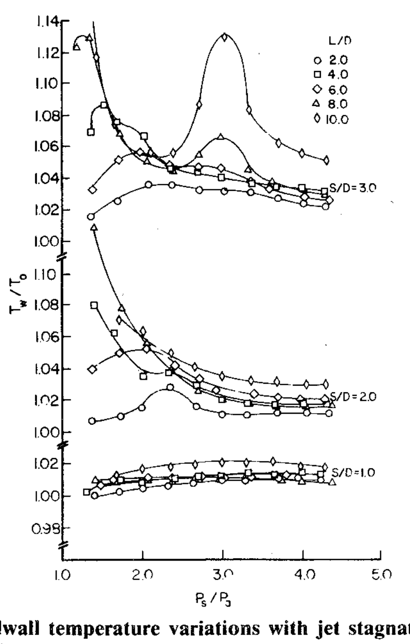

Fig. 1 Endwall temperature variations with jet stagnation pressure ($S/D=1,2,3$).

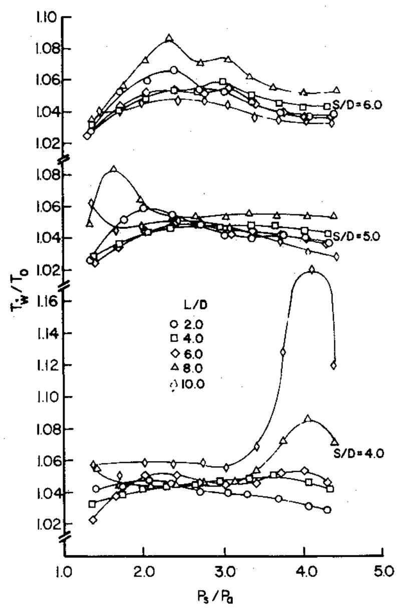

Fig. 2 Endwall temperature variations with jet stagnation pressure ($S/D=4,5,6$).

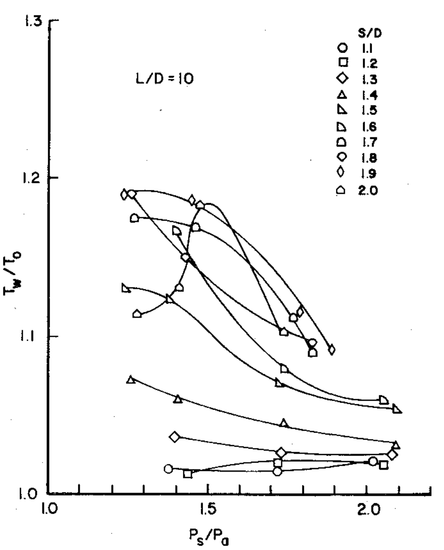

Fig. 3 Endwall temperature variations with subcritical jet stagnation pressures.

pressure region. The second peak occurs when the nozzle has reached sonic speed and the jet is underexpanded. The resonance tube entrance is located in the second compression cell of the periodic jet. This latter condition has been the most common flowfield for the majority of the previously reported investigations.

Figure 2 shows that the only significant temperature increase is observed for $L/D=10.0$, $S/D=4.0$, and $P_S/P_a=4.0$. Since the location of the jet compression cells is related to the jet pressure ratio, it can be concluded that the second cell is located near $S/D=4.0$ for the higher jet stagnation pressures. Previously reported optical studies[3,4] have verified this conclusion.

From Fig. 1, it is apparent that significant endwall temperature changes in the subcritical region occur between $S/D=1.0$ and 2.0. More detailed measurements in this region were made for the longest resonance tube. These data are

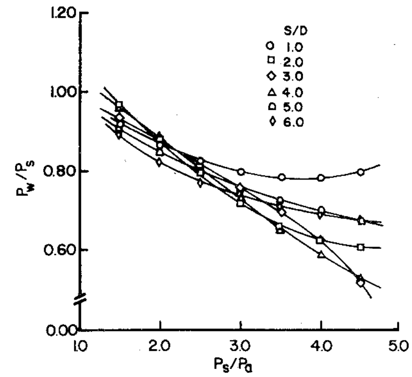

Fig. 4 Summary of average endwall pressure variation with jet pressure ratio.

shown in Fig. 3. As can be observed, there is a gradual increase in the peak endwall temperature from $S/D=1.0$ to $S/D=1.8$. For the three largest values of S/D, the peak temperature is approximately the same. However, from the current data, the variation with stagnation pressure is significantly different for the three cases.

Using the basic temperature data, the maximum endwall temperatures were determined for a given set of geometric parameters (L/D, S/D). These results indicated that the first compression cell or zone of instability is around $S/D=2.0$ and the second at $S/D=4.0$, depending on the particular pressure ratio. In this investigation, the highest peak endwall temperatures were obtained for subcritical pressure ratios and relatively low S/D values.

For each of the jet pressure ratios and geometric parameters, the average endwall pressure P_w was recorded. Without the existence of the gasdynamic resonance phenomenon, the measured pressures would be representative of the jet centerline pitot pressure. It was observed that the measured endwall pressure was essentially independent of the length of the resonance tube. Therefore, each of the data sets for a fixed separation distance (S/D) was fitted by a third-order polynomial using a least-squares method. The resulting curves are shown in Fig. 4. These curves, when compared with the temperature results, do not seem to show any close correlation between endwall pressure variation and endwall temperature variation. Sprenger,[1] in his experiments with sharp leading edge, axisymmetric resonance tubes had observed direct correlation between these two parameters. As pointed out in an earlier paper,[4] this difference may well be related to the specific leading-edge geometry of the present resonance tube.

Acknowledgment

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