Scramjet Research

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Motivation

Increasing interest in supersonic and hypersonic flight, particularly through the use of scramjets, has lead to several recent research efforts focused on supersonic combustion and flame holding. Because jets in supersonic crossflow are one of the primary methods of fuel delivery in scramjets, understanding the complex interaction between the jet and the freestream is an important part of the research necessary to bring scramjets into widespread use.

Improved understanding of regimes of flame stability and methods by which stability can be improved, including flameholders and plasmas, will also be required. Towards these goals, a new expansion tube facility has been constructed at Stanford University for research into combustion processes and flame stabilization in scramjet combustor environments.

Overview

The predicted operating range of proposed scramjet engines is quite extensive, covering large ranges of thermodynamic and aerodynamic variables in the combustor flow. In order to fully simulate these conditions, a facility with a widely variable range of test gas pressures, temperatures, and Mach numbers is required. The expansion tube provides a useful method for producing the conditions needed to simulate scramjet combustor conditions since it allows relatively easy reproduction of a broad range of gas conditions. The properties of the test gas in an expansion tube are independently controllable by simple variations of fill pressure, without the necessity of replacing costly nozzles, as is required in most other types of flow facilities. Thus, the setup time required to change conditions is approximately the same as the short turnaround time between tests.9

Because the expansion tube is an impulse facility, significant savings in cost of materials, energy, and manpower to operate and maintain the facility are realized when compared to continuous flow facilities with similar testing capabilities. By allowing the independent selection of pressure, temperature, and Mach number of the test gas, expansion tubes allow for the complete reproduction of both the thermodynamic and aerodynamic conditions of the desired flow. This allows the duplication of conditions present in the combustor section of scramjets flying over a wide range of altitudes and Mach numbers.

In contrast to other impulse facilities such as shock tubes and shock tunnels, expansion tubes can produce high velocity test gas without exposing the gas to high intermediate temperatures, thus preserving more realistic flow chemistry. Additionally, the ability to integrate fast acting valves into the high speed control system of the facility allows for the study of reactive and non-reactive jets interacting with the test gas. The primary disadvantage of the expansion tube is its short test time, but modern data acquisition and analysis hardware effectively utilizes the available time. 10

Work on construction of the 6 inch expansion tube began in early September, 2004. A series of calculations and models of various complexities was undertaken during October, 2004, to predict the conditions and test times attainable with the facility, and to ensure that the desired test conditions could be achieved with sufficiently long test times. A master plan was then created to define the overall facility size, performance range, functionality, and equipment to be installed. The major design work was finished in March, 2005, and major fabrication of parts was completed by July,

2005. The first useful data were taken in August, 2005, and development and integration of diagnostic facilities, test models, and instrumentation began along with a program of simultaneous facility characterization and early experimental data collection.

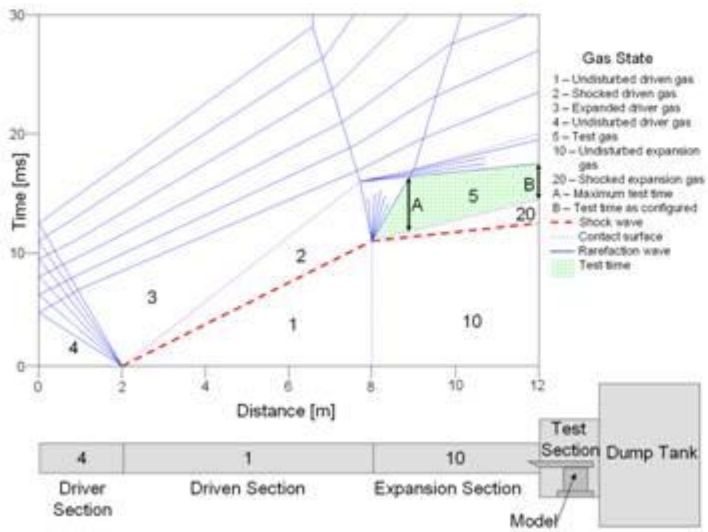

Figure 1: Distance versus time (x-t) diagram showing the configuration of a generic expansion tube and the processes that occur during a test

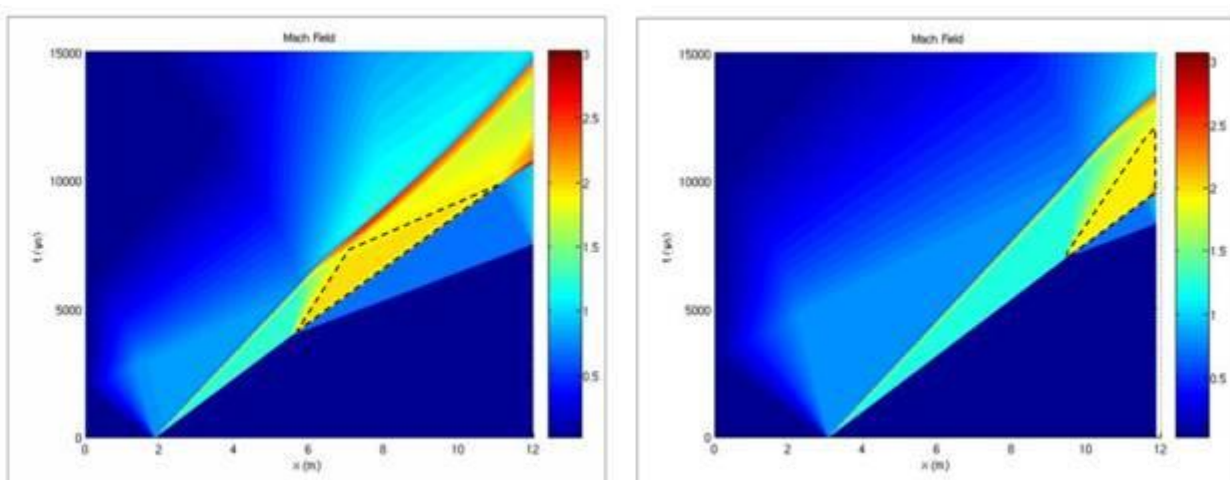

Figure 2: 1-D inviscid model of an expansion tube with varying tube layout. With the primary diaphragm located 2 meters from the endwall and (a) the secondary diaphragm located 5.7 meters from the endwall, the test gas, shown as a black triangle, does not reach the tube exit. However, (b) by moving the secondary diaphragm to 9.7 meters, the test gas reaches the tube end and useful test time is obtained.

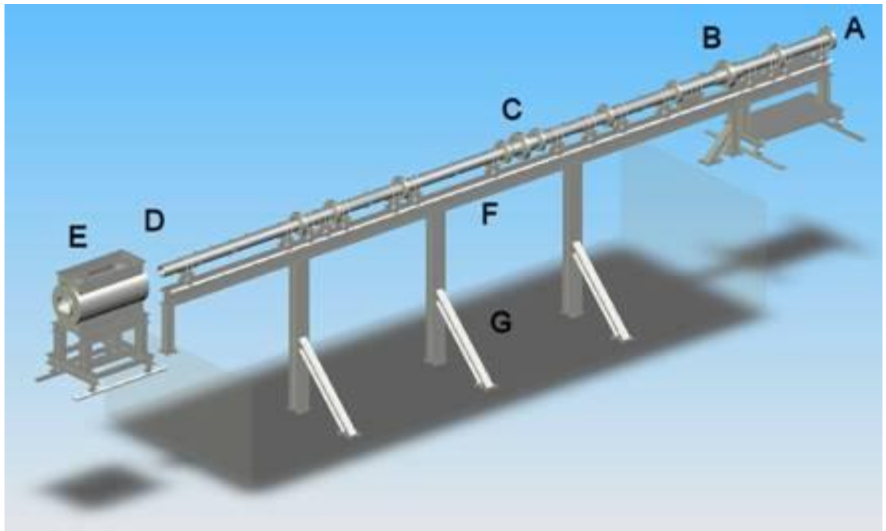

Figure 3: Model of the Stanford 6 inch expansion tube. A is the upstream endwall, B is the primary diaphragm, C is the secondary diaphragm, and D is the test section (not shown in this view). Between A and B is the driver section, mounted on its transverse rolling support carriage, between B and C is the driven section, and between C and D is the expansion section. E is the dump tank and support carriage. F is the support girder and guide track for the tube section rollers. G is the region under the false floor where the supports are anchored to the concrete foundation.

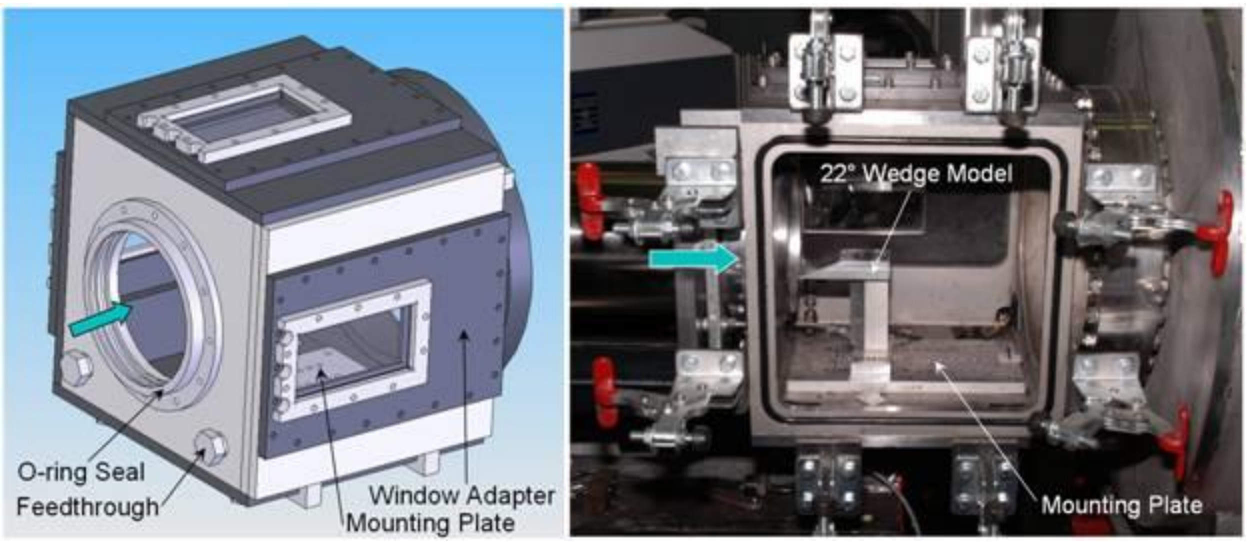

Figure 4: Test section. Solid model (a) and photograph (b) with the access cover removed and a 22° wedge model installed for Schlieren imaging.

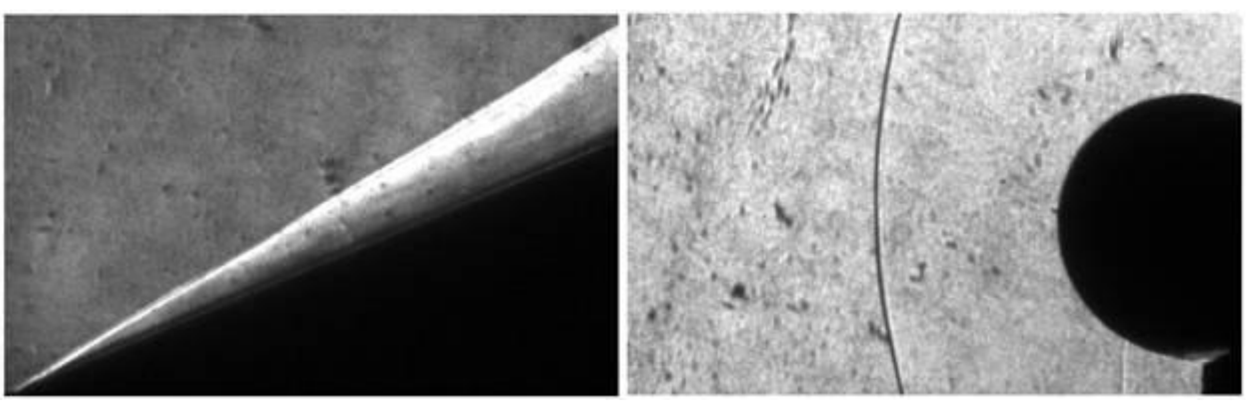

Figure 5: Example Schlieren images as used for facility characterization with (a) a 22° wedge indicating flow at Mach 6.3 and (b) a circular cylinder indicating flow at Mach 1.85.

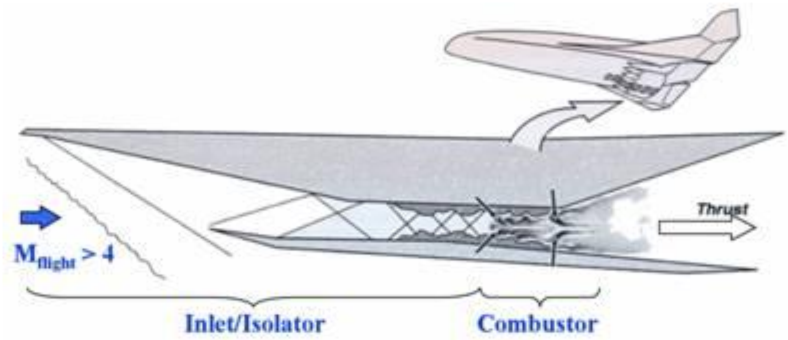

Figure 6: Generic scramjet showing the complex inlet shock system

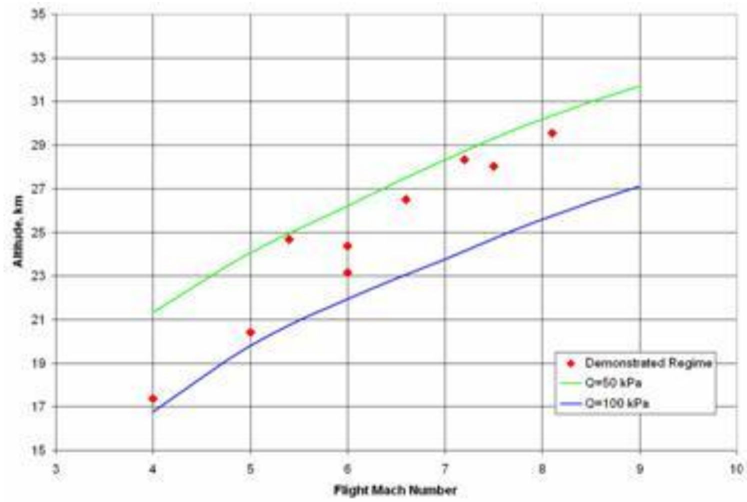

Figure 7: Demonstrated performance regime.

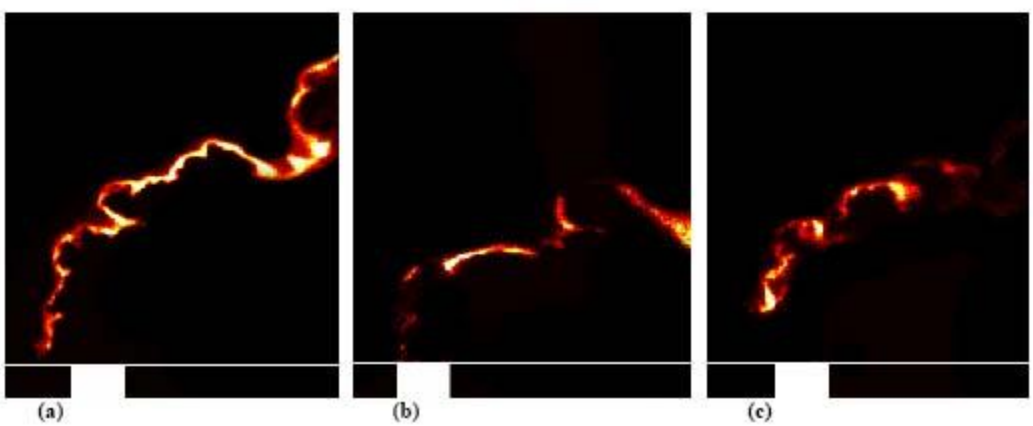

Figure 8: OH PLIF images of various regimes of burning: (a) strong combustion at T0 = 3100 K, T = 1375 K, P = 25 kPa and J = 4 (b) patchy combustion at T0 = 2500 K, T = 1375 K, P = 25 kPa and J = 2, and (c) combustion with extinction at T0 = 2500 K, T = 1375 K, P = 25 kPa and J = 4. The jet diameter and plate surface in each image are as marked, and all images are corrected for incident laser sheet intensity.