A NUMERICAL STUDY OF MIXING AND COMBUSTION IN HYPERVELOCITY FLOWS THROUGH A SCRAMJET COMBUSTOR MODEL

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Abstract

Interest in high speed, air-breathing propulsion systems such as scramjets has revived in recent years fueled to a large extent by the National Aerospace Plane (NASP) program. These vehicles are expected to fly trans-atmospheric and as a consequence, the Mach number level within the engine/combustor would be rather high (M > 5). Ground based testing of such scramjet engines requires a facility that can not only achieve the right Mach number, but also have the proper pressures and temperatures to simulate the combustion processes. At present, only pulse type facilities can provide such high enthalpy flows. The newest of these is the free-piston shock tunnel, T5 located at GALCIT. Recently, a generic combustor model was tested in T5, and the experimental data from that study is analyzed in the present report.

The available experimental data from T5 are essentially the static pressures on the injection wall and the one opposite to it. Thus a principal aim of the present study was to validate the available experimental data by using a proven CFD tool and to then investigate the performance characteristics of the combustor model, such as, the mixing efficiency and combustion efficiency. For this purpose, in this study, the code GASP [1] has been used.

A schematic of the combustor model is shown in Figure 1. The flow is supersonic along the length of the combustor. Earlier investigations have revealed that for the 15° fuel injection considered here, the recirculation zone near the injector is negligibly small. Thus the governing equations that were solved were the Parabolized form of the Navier-Stokes (PNS) equations. The finite-rate chemical reactions of gaseous hydrogen and air are modeled by the seven species, seven reactions model of Drummond, Rogers and Hussaini [2]. The grid used was three dimensional. No slip boundary conditions were enforced on all the solid walls, and the centerline of the floor of the combustor was taken to be an axis of symmetry. The flow was taken to be turbulent right from the leading edge of the combustor walls.

Based on the information provided above, the time-varying form of the governing equations were integrated until convergence to a steady state was obtained. Some selected results are presented and discussed next.

Figures 2 and 3 show comparisons between computations and experimental data obtained in this study, for the static pressure distributions on the lower and upper walls of the combustor, respectively. The agreement is seen to be satisfactory. In T5, measurements were done at two different levels of pressure. One set of measurements (Low Pressure) were made under test conditions corresponding to a nominal static pressure at the combustor inlet of 18.3 kPa. The other set (High Pressure) corresponded to a nominal inlet static pressure of 43.9 kPa. At low pressure, both "hot" and cold hydrogen injection runs were made, whereas at high pressure only runs with hot hydrogen injection were performed. Thus we need to examine two issues related to the combustor performance. One is a comparison between hot and cold injection results and the other is the comparison between high and low pressure results.

The performance comparisons will be made in terms of two parameters -- Mixing and Combustion efficiencies. Mixing efficiency is a number between 0 and 1, and is defined as the fraction of the least available reactant that can undergo complete reaction, without further mixing. Combustion efficiency is the fraction of the least available reactant that has reacted completely. Figure 4 shows a plot of mixing and combustion efficiencies for hot and cold injection cases. It is clear that cold injection has higher mixing and combustion efficiencies. This can be attributed to the higher value of the ratio of jet to free stream velocity for cold injection. Figure 5 illustrates the comparison of mixing and combustion efficiencies between high and low pressure results with hot injection. High pressure is seen to result in higher mixing and combustion efficiencies. This results from two effects. One is the higher jet penetration and the other is due to the higher value of the (H_2 -- Air) equivalence ratio for the high pressure case.

Further work needs to be done to refine the grid and also to examine the issue of spatial uniformity of the injectant concentration distribution in the cross-flow plane.

References:

1. Walters, R. W., Slack, D. C., Cinella, P., Applebaum, M., and Frost, C., "A Users Guide to GASP", NASA Langley Research Center/Virginia Polytechnic Institute and State University, Revision 0, 1990.

2. Drummond, J. P., Rogers, R. C., and Hussaini, M. Y., "A Detailed Numerical Model of a Supersonic Reacting Mixing Layer", AIAA Paper 86-1427, June 1986.

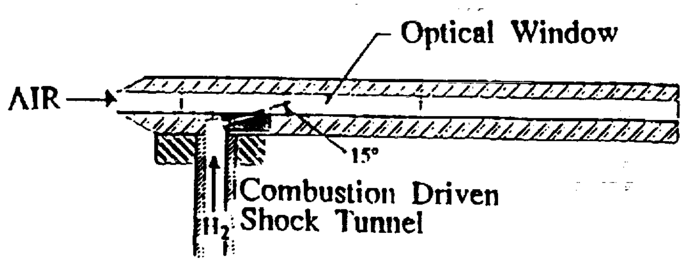

Fig. 1 A schematic of the Rectangular Combustor Model (1 in. x 2in. x 28 in.)

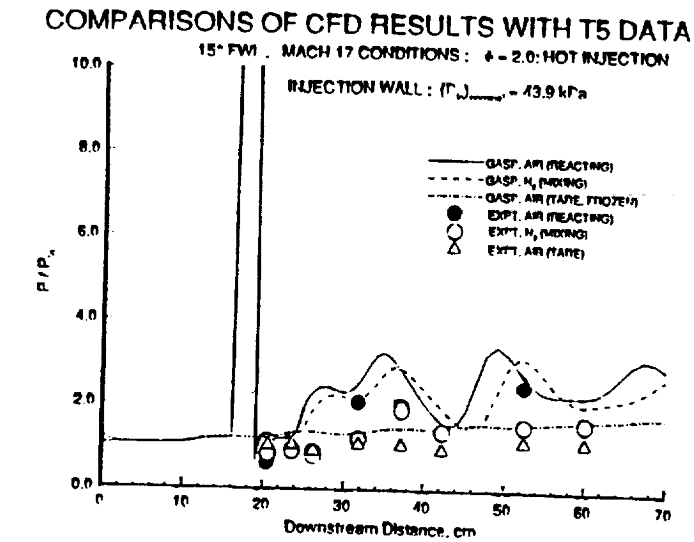

Fig. 2 Static Pressure Distribution on the Centerline of the Injection Wall

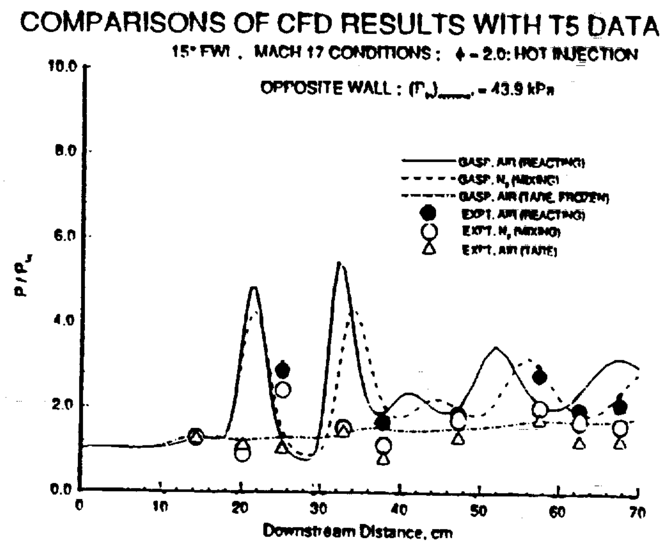

Fig. 3 Static Pressure Distribution on the Centerline of the Opposite Wall

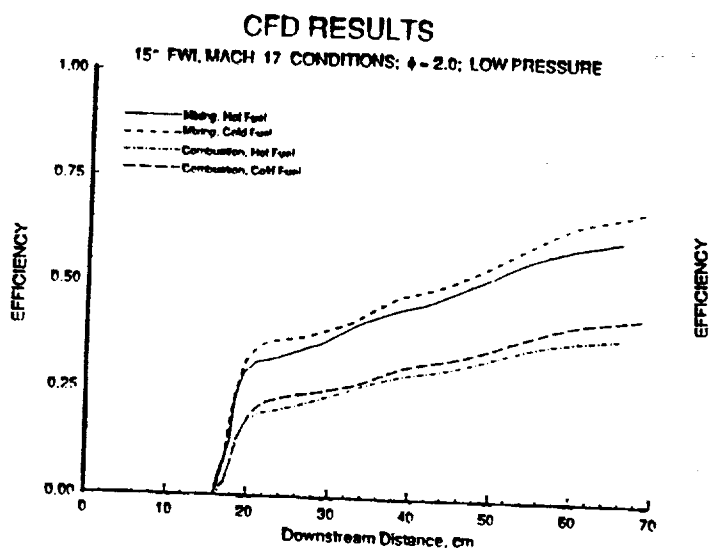

Fig. 4 Variation of the Mixing and Combustion Efficiencies; Hot vs. Cold Injection

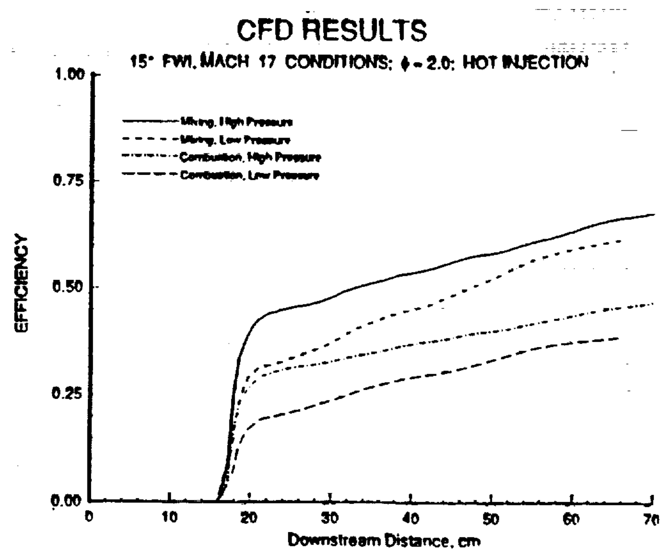

Fig. 5 Variation of the Mixing and Combustion Efficiencies; High vs. Low Pressure