TURBULENT FLAME ANALYSIS OF THE IGNITOR FOR THE 8 FT. HIGH TEMPERATURE TUNNEL OF NASA LANGLEY RESEARCH CENTER

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ABSTRACT

The 8 FT. High Temperature Tunnel of NASA Langley Research Center is a unique world class facility, because of the wide range of working parameters. Experimental test of ramjets and scramjets require high air temperatures in the range of 1300 K to 2200K and high pressure between 13.79E6 Pa and 27.58E6 Pa. The 8-FT HTT can simulate flight at Mach 4 to 7; ramjets go as low as Mach 3 and up to 6.5; scramjets go from Mach 5 to Mach 11. Mass concentration of air of 23% at the test section is required. A new fuel injection system and airfoil type fuel injectors is being designed, together with a new ignitor. The new ignitor consists of micromixer, a diverging feed to a hot wire ignitor with flame holders and a secondary injection of a high velocity large methane jet into the hot reaction products from the Ignitor. The booster's flame penetration is an important parameter to have a successful ignition of the tunnel. The ignition of the fuel injector array is by a quasi stable ignition scheme. A stable pilot flame is created with the equivalence ratio being about 3 with methane and air. This flame, which is rich and produces carbon monoxide and hydrogen, is excellent for the booster's secondary ignition of a very high velocity jet of methane at velocities up to Mach 1. This combination of yields a large and vigorous flame which is directed across the injection sites of the main airfoil fuel injectors. Prompt and reliable ignition of the main array of airfoil fuel injectors is assured.
The pilot ignitor with its secondary jet of high speed fuel is designed such that the length and spreading of the secondary diffusion flame is maximized. To do, the large jet of methane has velocities of up to Mach 1 and is extremely unstable since no flame holder exists and the heat gain from the jet passing through the ignitor flame is trivial. The stability and reaction process is initiated by the hot hydrogen, carbon monoxide and water. These specie plus the methane and air react quickly and provide an ignition and stability mechanism. The secondary jet has a very high transonic speed and by itself is unstable. If the right amount of energy is imparted to the secondary jet, its size becomes large since the main fuel injector array is very large and must be ignited quickly as the main fuel injection is at such high rates that delayed ignition could result in serious problems with pressure surges. In some respects, the device appears primitive, using technology that is old, but with some new techniques that result in a massive ignition flame suitable for the main fuel array that has about 500 injection sites. The main fuel is injected at velocities well above the lift velocity and is also theoretically unstable. Stability is achieved by injector geometry, pair effects to create a slight negative pressure gradient, a step at the end of the injector and tabs at the throat of the pair injectors. These effects create side vortical flow that bring partially reacted species that are hot back to the ignition site thus always supplying a continuous ignition source, and thus, stability. Therefore since the fuel injection of the main array is at such high velocities and at so many sites, a unique Ignitor had to be devised.
The following experimental data verifies the flame stability. Figure 1 shows that the type and size of the Ignition flame generated by the ignitor and the large jet of methane. The stability reaction first occurs in about 25 to 50 cm. and is denoted as R1. The flame in this region is very pale blue and has visible violent oscillations. The secondary reaction of the bulk of the methane flow occurs at about 1.25 meters from the exit of the methane jet. The flame just prior to this becomes very large radially as well. At one atmosphere, it is intense blue; at high pressure it is white from the carbon dioxide radiation. The process is accompanied by abundant noise not yet measured. The flame has a peak at about 60 cm. and mixes thereafter with the surrounding air with the temperature decreasing. This is typical and expected. Mass conservation was used to calculate the exit velocity. As the velocity increases, the size of the flame increases, showing that the peak only moves upward sightly but the fullness of the reaction zone and post reaction/mixing zone increases from the increase in mass flow. At about 259 m./s. the nature of the temperature profile changes. It is noted that two peaks of temperature appear. At Mach 1 the 2 peaks are quite pronounced. Repeated experiments provided the same results. The explanation of this phenomena is that the flame is ignited and stabilized by an air flame at an equivalence ratio of 3.3. The ignitor flame produces $\mathbf{CO}$ and $\mathbf{H_2}$ which are very hot, about 1550K to 1660 K. The hot $\mathbf{CO}$**,** $\mathbf{H_2}$ and $\mathbf{CH_4}$ react quickly and form the first temperature peak which as expected has a higher temperature than the second. This reaction is complete in about 0.5 to 0.6 milliseconds, at about 50 cm. As the reacting fluids slow from heat addition and some mixing effects,

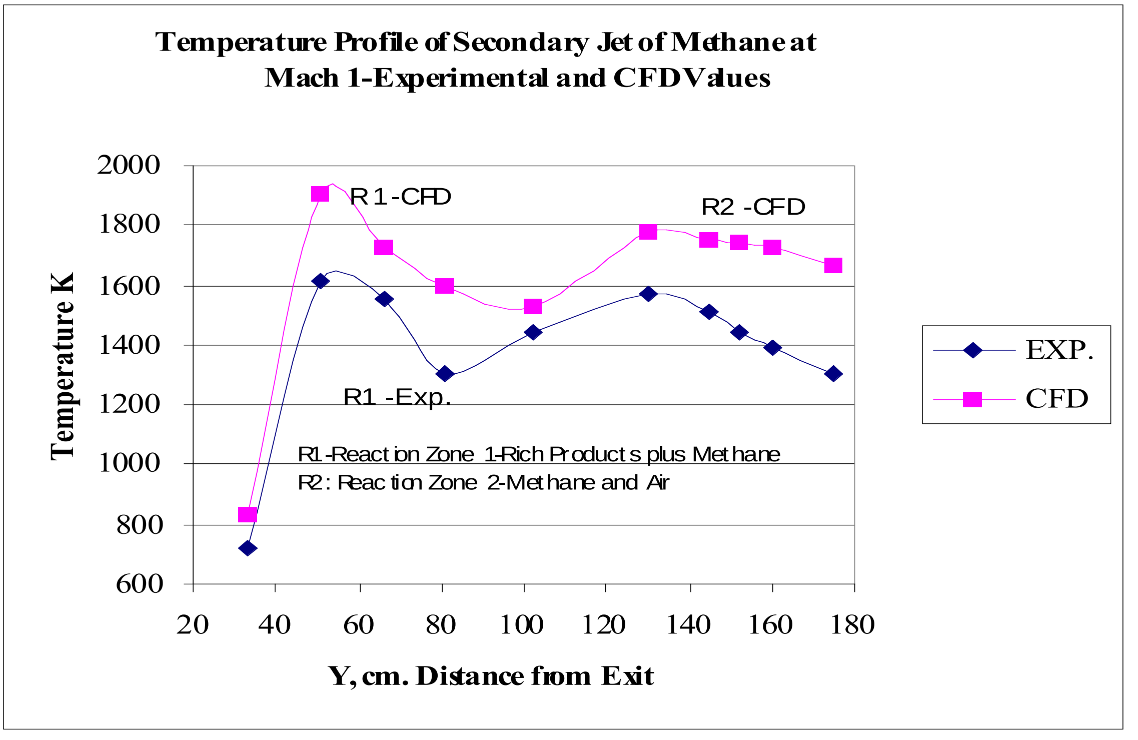
the main methane from the boost completes its reaction at a little over 1.2 m from the exit. Downstream the reacting gases mix with the air and temperature decreases with distance. The visible nature of the flame also supports this conclusions. The flame at Mach 1 is very noisy but small radially at first. At about 60 cm. it appears to increase dramatically in radius. This means that no matter how high the pressure is in the boost line, it will be stable since sonic flow is a limiting condition. The penetration by the boost is more than adequate and should easily ignite the array of fuel from the airfoil injectors. There is never any need to be concerned about having too high boost velocity. Keeping the Pilot Ignitor at an equivalence of about 1 in the initial ignition and then changing with slow passage from 1 to 3 and a boost line pressure of about 82.74E4 pascals, the process will occur as above described. It is not convenient to dwell too much on the effects of pressure of the flame length since these effects are minor. The major effect of pressure is to increase the flame's intensity and its radiance primarily from the oxides of carbon and from the water and from radicals of these specie. This is caused by the absorptance of energy by these molecules and the re-radiation of this energy; at low pressure the flame appears blue in a dark space. The major specie for this are **C2**, **CH.** At high pressure, the flame appears white, probably from intense radiation from **C**, $\mathbf{C_2}$ and $\mathbf{CO_2}$. The symmetrical molecules such as nitrogen and oxygen do little in these processes.

The objectives of these analysis are to propose empirical equations that would predict flame lengths of the ignitor in the 8 FT. High Temperature Tunnel. Empirical equations of length flame and temperatures at atmospheric conditions are obtained using FLUENT results validated by experimental data. The Finite-Rate Reaction Model, with temperature and composition-dependent specific heat capacity and viscosity, of the CFD FLUENT code was used.

Experiments were carried out in the Atmospheric Controlled Combustion Apparatus (ACCA) of NASA Langley Research Center. Different fuel diameters and different fuel velocities provides the data to enunciate the empirical equation of L/D =f(V), where L is the length flame, D fuel injector diameter and V fuel velocity. Fuel diameters between 1.58 mm. to 9.52 mm. were studied. Velocities were selected to have the same Reynolds number for all the experiments. The length of flame is the output parameter measured in the experimental data and determined by FLUENT. Both results are very close, reasonable and acceptable for this study. The same empirical equation at low pressure is valid at high pressure based on the results from FLUENT.

The results helped the design engineers of the 8 Ft. High Temperature Tunnel to define the correct diameter of fuel orifices of injectors and fuel and air velocities. A final 3 dimensional case using FLUENT was the simulation of the combustion processes of both the ignitor and fuel injectors, to examine the size of the flame and its effect on the fuel injectors and liners of the 8 Ft.High Temperature Tunnel. This model considered the effects of mass flow to the pilot ignitor and booster, exit velocities of the pilot and booster, angle of the booster relative to the center line, and other pertinent ignitor characteristics. The output of this case defines the ignitor flame characteristics such as spreading rate, convective temperature profiles and heat transfer coefficients around the airfoil fuel injectors and at the surfaces of the liners.

In conclusion the present study helps the designer of the airfoil fuel injector and of the ignitor of the 8 Ft. High Temperature Tunnel to verify the high performance and reliability of successful ignition of the tunnel.



Temperature Profile of Secondary Jet of Methane at Mach 1-Experimental and CFD Values
2000
1800
1600
1400
1200
1000
800
600
Temperature K
20
40
60
80
100
120
140
160
180
Y, cm. Distance from Exit
R1-CFD
R2 -CFD
R1 -Exp.
R1-Reaction Zone 1-Rich Products plus Methane
R2: Reaction Zone 2-Methane and Air
EXP.
CFD