A PLIF Observation of the Impingements of NTO/MMH Simulants for a 5-lb_f Rocket

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Abstract

The applications of low-thrust NTO/MMH bipropellant thrusters are mainly on the attitude control of missiles as well as the attitude and altitude control of satellites. The hypergolic effect of NTO/MMH impingement produces the required combustion for thrust production. That is, the atomization and mixing of impinging jets are crucial for thruster's performance. This research used simulants (matching density, viscosity and surface tension) to perform NTO/MMH cold-flow impinging experiments. Experiments were conducted with 0.3mm orifices oriented to have a +30°/-30° impinging angle. The total flow rates of the working fluids were controlled at a constant value (~8.00 g/s) to meet the total propellant flow rate for a 5-lb_f MMH/NTO thruster, and the ratios of mass flow rates (O/F) of oxidizer (NTO) and fuel (MMH) varied from 1.0 to 2.2. PLIF technique and statistical analysis were employed to examine the probability distributions of mass as well as the local mixture ratio distributions for the different sprays at 10mm downstream from the impinging point. By knowing the mixture ratios, the distributions of the adiabatic flame temperatures were also calculated.

The proximate probability distributions of the doublet impinging sprays showed an obvious shifting and concave to the side of the lower momentum jet. The most uniform and symmetrical mass distribution of droplets occurred at the momentum ratio of the jets close to unity (O/F≈1.2) and the break up of MMH jet was less uniform than that of NTO jet for MMH's higher surface tension (Figure 1). A good mixing of the simulants was also shown at O/F=1.2, but a small high-temperature was estimated due to the required stochiometric combustion of O/F=2.5 (Figure 2). Better temperature distributions were showed at higher O/F ratio (=1.4~2.0), where the high-temperature area was always located at MMH jet's side. It is shown in Figure 1 that NTO, liquid with lower surface tension, was easier to be atomized and distributed in a wider area at lower O/F ratio. As the O/F ratio increased, distributions of the NTO spray became more concentrated, while the distributions of the MMH spray became wider and more uniform. By assuming a constant specific heat of the product gas, the average exhaust temperatures and the thermal efficiencies were estimated and plotted in Figure 3, where the most adequate O/F ratio for MMH/NTO doublet-impinging control can be identified to fall in the range of 1.6~1.8.

For triplet impingements (O-F-O) of MMH/NTO simulants, the sprays always have un-shifted and uniform distributions (O/F=1.0~1.8), and the uniformity increases as O/F ratio increased. (see Figure 4) Comparing to the doublet impingements, triplet impingements produced high temperature areas that always located symmetrically to the center axis, and produced compatible or better mixing throughout the O/F ratio investigated. Estimated thermal efficiencies for triplet impinging design of MMH/NTO combustion showed a small increase from 0.78 to 0.86 corresponding to O/F ratio from 1.0 to 1.6.

In order to investigate the effects of momentum and surface tension on impinging spray, observations of like-doublet impingements of water and acetone/water solution were performed at unity momentum ratio. The PLIF results showed that the increase of jet velocity first concentrated spray distribution, when above a characteristic velocity, jets then started to breakup and mix with each other more effective. The observation indicated that the jet with lower surface tension had a smaller characteristic impinging velocity, and the spray distributed more uniform in a smaller area than that of the higher surface tension one. It is concluded that momentum and surface tension of the impinging jets are crucial for the mixing phenomena of impinging sprays.

Keyword: MMH, NTO, hypergolic, atomization, simulant, surface tension, mixture ratio, momentum ratio, PLIF

O/F=1.0
Momentum ratio = 0.66

O/F=1.2
Momentum ratio = 0.96

O/F=1.8
Momentum ratio = 2.15

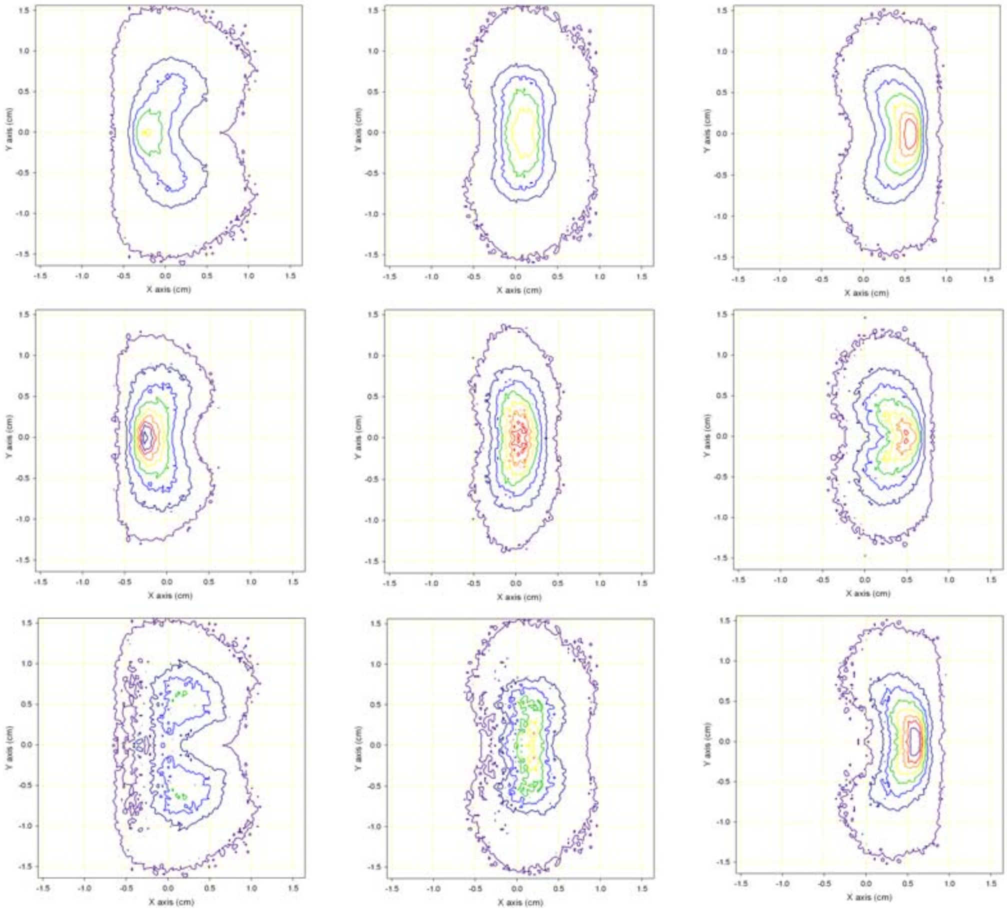

Figure 1 The 2-D probability distributions of total mass (top row), mass of MMH simulant (second row), and mass of NTO simulant measured at 1 cm from the impinging point for doublet impingements of NTO/MMH simulants. The outer constant probability contours were 5e-5/cm^2 and the interval of the adjacent contours was 5e-3/cm^2.

O/F=1.0
Momentum ratio = 0.66

O/F=1.2
Momentum ratio = 0.96

O/F=1.8
Momentum ratio = 2.15

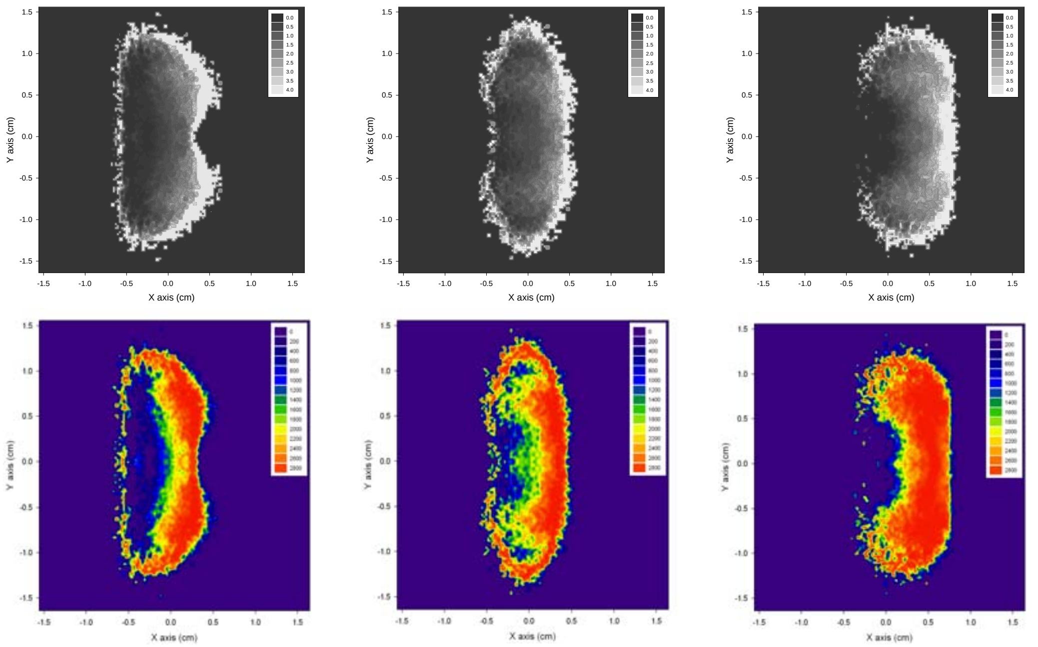

Figure 2 The estimated local mixture ratio distributions (top row) and the adiabatic flame temperature distribution for NTO/MMH doublet impinging combustion.

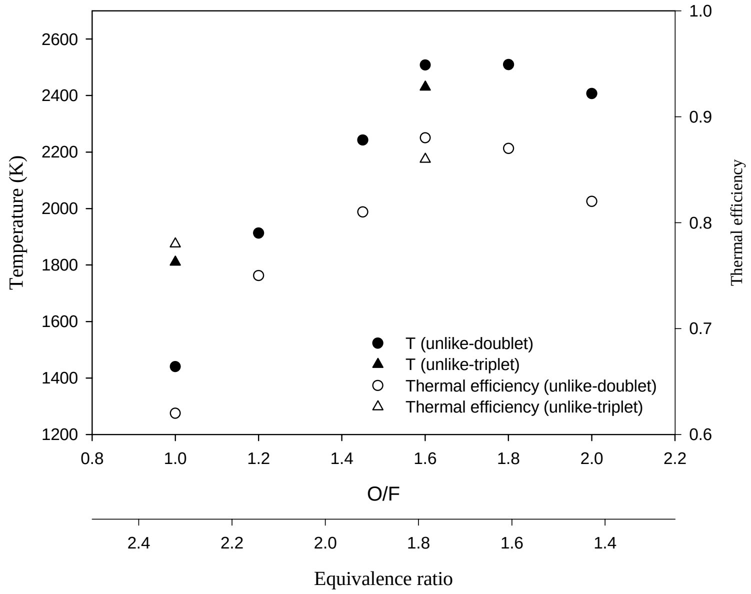

Figure 3 The estimated average exhaust temperatures and the thermal efficiencies for NTO/MMH impinging combustion at different O/F ratio with a total propellant flow rate 8g/s.

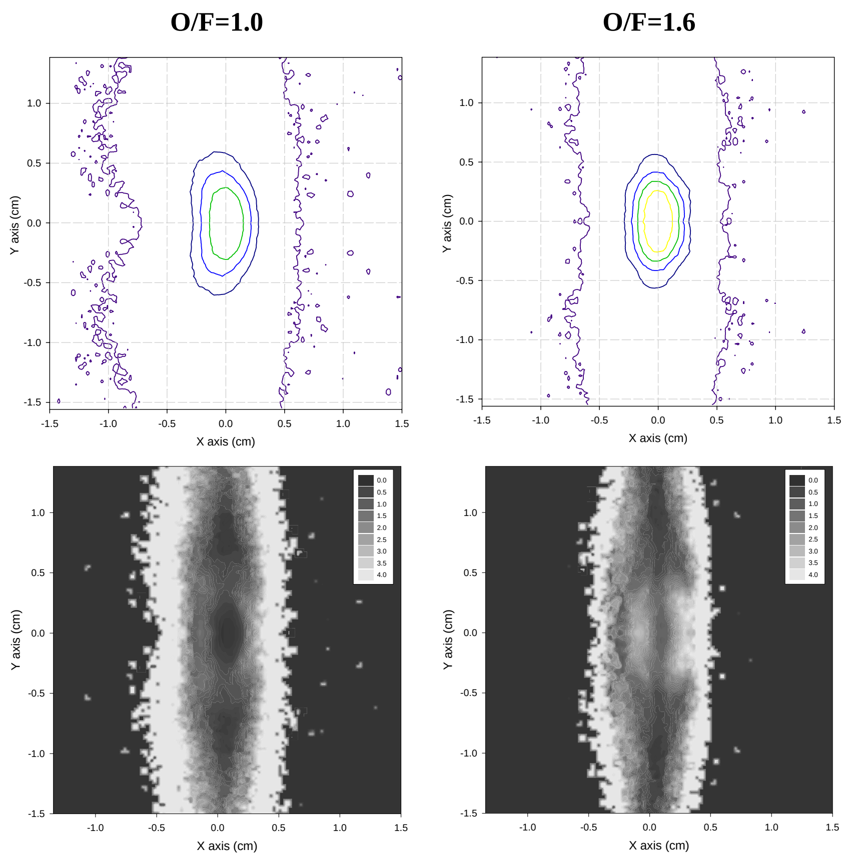

Figure 4 The 2-D probability distributions of total mass (top row) measured at 1 cm from the impinging point and the distribution of the estimated local mixture ratio for triplet (O-F-O) impingements of NTO/MMH simulants. The outer constant probability contours were 5e-5/cm^2 and the interval of the adjacent contours was 5e-3/cm^2.