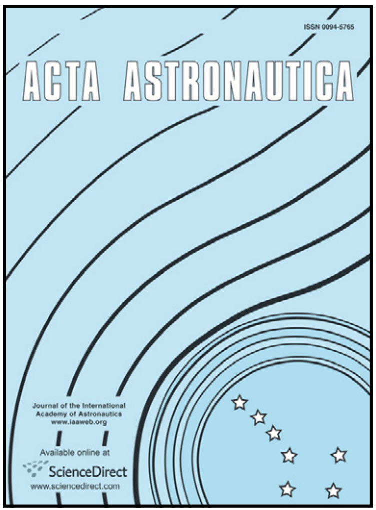

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Lagrangian modelling of turbulent spray combustion under liquid rocket engine conditions

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Abstract

In the field of liquid rocket propulsion, the use of computational design tools, such as computational fluid dynamics (CFD) solvers, may provide a great deal of help to proceed with the primary design choice. Considering the complexity of rocket engine geometries, as well as associated fluid flow conditions, the use of Reynolds-Averaged Navier-Stokes (RANS) numerical simulations remains very popular. Important modelling efforts are therefore still required to provide reliable computational models able to describe the complex interaction that takes place between turbulence and chemistry in such cryogenic high-speed flows. The present manuscript reports the results of some recent investigations conducted in this field. The modelling analysis relies on a Lagrangian framework, the salient features of which consist in approximating the Lagrangian path in a reduced composition space made up of the *mixture fraction variable*, i.e. a conserved scalar introduced to represent the variations of composition, and a *progress variable*, i.e. a reactive scalar to follow the departures from chemical equilibrium. The retained methodology allows to presume the joint probability density function of the two scalar fields without invoking the assumption of statistical independence between them. Equivalence ratio fluctuations induced by the vaporization of the liquid phase are considered as additional sources terms appearing in the transport equation of the mixture fraction variance. The transport of the corresponding mean scalar dissipation rate (SDR), which is a key quantity in the corresponding closure, is also affected by the vaporization processes. The proposed model has been implemented into the U-RANS CFD code *N3S_Natur*, while the liquid phase is described using a Lagrangian module. The capabilities of the computation model are evaluated through a detailed comparison with the experimental databases gathered on the ONERA Mascotte test bench. The corresponding test rig consists of a low-speed round jet of liquid oxygen surrounded by an atomizing high-speed co-flowing jet of gaseous-hydrogen. The obtained results confirm that (i) the additional fluctuations induced by the vaporization processes play an important role, (ii) the influence of transient droplet heating on turbulent combustion must be taken into account.

Keywords: Propulsion, Rocket Engine, Two-Phase Flow, Turbulent Combustion Modelling

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1. Introduction

For many years liquid-propellant rocket engines have been used as the primary propulsion system in most launch vehicles and spacecraft. Moreover, hydrogen is a reference fuel for scramjet and rocket applications [1] as it delivers the highest possible heat release within the shortest possible kinetic time. The wide range of flammability of hydrogen combined with its high diffusivity promote the ignition of reactive mixtures in extreme conditions. With its high specific impulse due to an exceptionally low molecular weight, hydrogen has been widely used as a propellant in liquid rocket engines, from the well-known Space Shuttle Main Engine (SSME) to the engine retained to propel the upper stage of the European launcher *Ariane*. Clearly, hydrogen is the bedrock of the global conception of a cryogenic engine. Indeed, before reaching the combustion chamber in the gaseous phase, liquid hydrogen runs across channels that surround the propulsive nozzle. These pipes, which act as a regenerative cooling system, safeguard the nozzle throat from melting by allowing liquid hydrogen to absorb high heat fluxes through the chamber walls [2]. In the particular case of expander engines, all of the energy that supports the cycle is supplied by the corresponding heat transfer to the propellant. The heat added to the propellant is used as work potential to power the turbines that feed the whole system. Finally, with its high energy release when burning with oxygen and its good characteristics as a coolant [3], hydrogen appears, in rocket engines, as the main supplier of energy in two senses. The only drawback when using hydrogen, with the exception of production costs, is its density, only 0.09 kg/m^3 at standard pressure and temperature, 8000 times smaller than the density of gasoline and this is the reason why hydrogen is stored under cryogenic conditions.

In a rocket engine, fuel, i.e., hydrogen, and oxidizer, i.e., oxygen, are delivered at the injection plate through hundreds of coaxial injectors. Gaseous hydrogen (GH_2)

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