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NUMERICAL SIMULATION OF A SINGLE ALUMINUM DROPLET BURNING IN A PROPELLANT ENVIRONMENT

O. Orlandi*, S. Gallier*, Y. Moonsamy* and N. Cesco**
(o.orlandi@safran-sme.fr)
* Herakles (SAFRAN group), Centre de Recherche du Bouchet
F-91710 Vert le Petit, France
** Centre National d'Etude Spatial (CNES),
F- 75612 Paris, France

ABSTRACT

The aim of this study is to investigate the combustion of aluminum droplet in a propellant gas like environment by a numerical approach. A focus is performed on the unsteady aspect in order to estimate its effect on the burning time and to identify the influent parameters on the combustion.
In a first step, a numerical model is built on the basis of a multispecies reacting system for a pressure of 1 bar. A two-dimensional axisymmetric configuration is considered for a spherical droplet for which the temperature evolution is estimated. The 2D Navier-Stokes equations are solved for the gas phase with the in-house numerical tool CPS. This code considers a Arrhenius modeling for the kinetics and the transport coefficients are evaluated for each species on the basis of Lennard-Jones potential. The mixture laws are derived from dynamic viscosity, thermal conductivity and diffusion coefficients. The aluminum mass flow rate vaporized at the droplet surface is assumed to be controlled by the thermal flux resulting from the difference between the flame and the surface temperatures. In a simplified approach, the droplet temperature is uniform and its value is given by the thermodynamically equilibrium at the aluminum gas/liquid interface. In a second step, the validation of the model is performed in the case of the combustion of a single droplet in air. Results show a good agreement with already published numerical and experimental data. The combustion time obtained for a 100µm droplet diameter quite well fits the Widener-Beckstead correlation. A specific point is made for validation purposes on the regression rate modification by the convective stream. In this case, the Ranz-Marshall correction law is found to properly estimate the mass flow rate as it was formerly shown in the reference [1]. For low frequency oscillations of the oxidizer mass flow, it is confirmed that the Ranz-Marshall law is still valid.

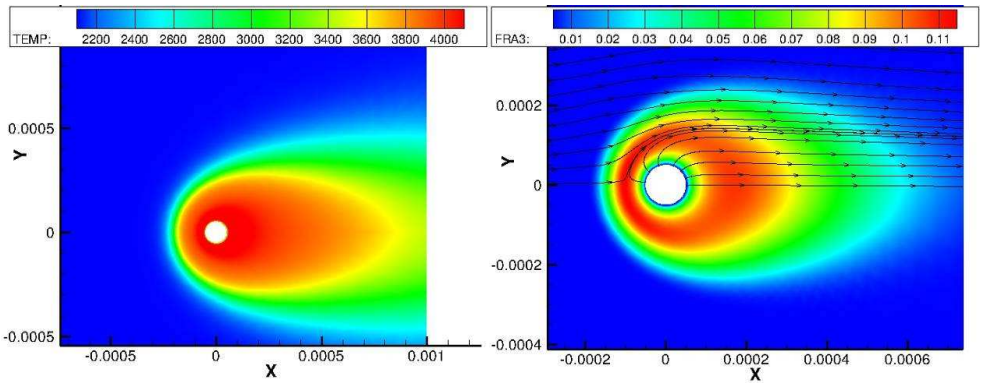

Figure 1- Temperature and AlO mass concentration for the combustion of an aluminium droplet in air

A series of calculation is performed in the case of propellant gas environment (AP/HTPB type). The aim of this study is to define a law corresponding to the Ranz-Marshall formulation to approximate the effect of the convective flow on the vaporization. The result is that the vaporization rate is less sensitive to the convective stream in the propellant gas environment than in air.

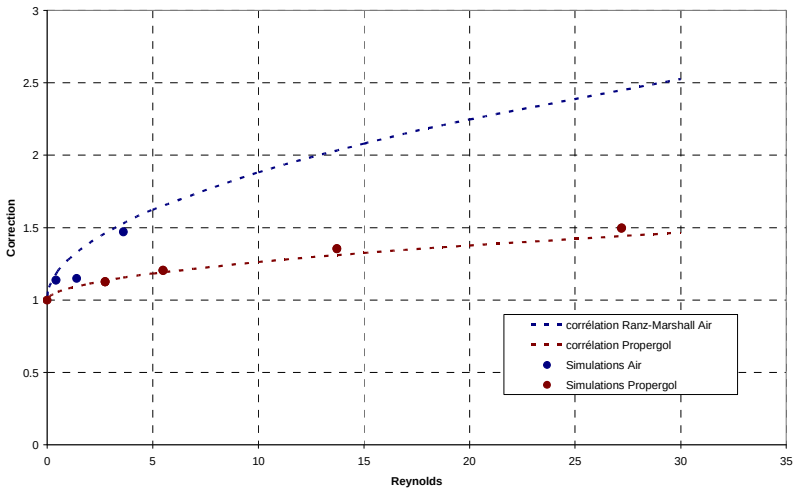

Figure 2- Convective effect on vaporised mass flow correction

The combustion time is evaluated by the instantaneous vaporization rate (typically of 2kg/m²/s but depending on the surrounding gas velocity). In parallel, an ALE simulation is used to simulate the continuous regression of a 100µm diameter droplet. The integration of the vaporized mass flow rate shows that the regression follows a d^2 law in a first step and the obtained burning time is found to be correctly correlated with the Widener-Beckstead law.

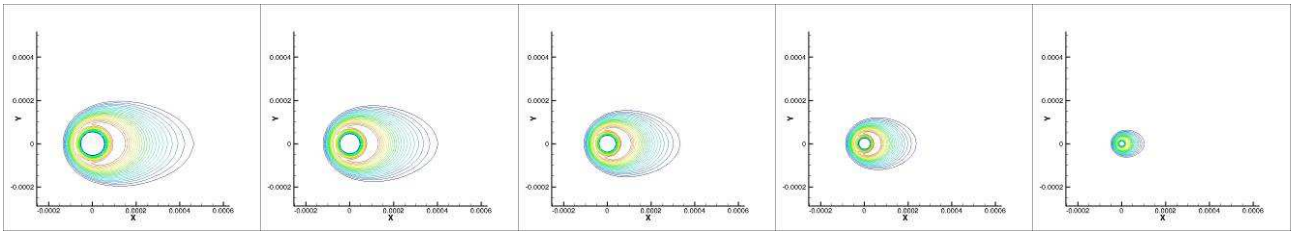

Figure 3- Sketch of AlO concentrations for the combustion of an aluminium droplet in propellant gas

Visualizations of a single burning aluminum droplet show the formation of an alumina cap that breaks the spherical symmetry. In order to improve the model, a cap is added at the front surface of the droplet. The geometry is assumed by considering the equilibrium of the two non miscible liquids. The non vaporizing surface due to the presence of the oxide cap induces a larger combustion time compared with results in a spherical droplet. Repartition of species is also modified.

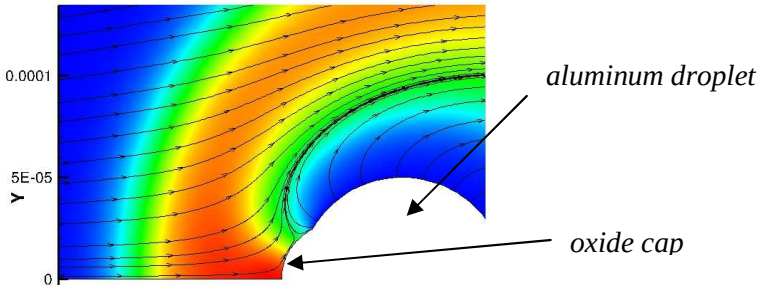

Figure 4- Al2O3 concentration (zoom on cap zone)

This study provides tendencies on the behaviour of a single aluminium droplet burning in a propellant gas environment at 1bar. The obtained results suggest that the correction of Ranz-Marshall is to be modified in this case and the combustion times are well approximated by the Widener-Beckstead, even if a correction should be considered to account for the convective effect.

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[1] *Combustion response of an aluminium droplet burning in air*, S. Gallier, F. Sibe et O. Orlandi, Proceedings of the Combustion Institute, vol. 33, The Combustion Institute, Pittsburgh, PA, ed. Elsevier, 2011, pp.1948-1956.