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Abstract #
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Title
Study of aluminum droplet ignition in a solid propellant flame

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Abstract
Aluminum is one of the main components of composite solid rocket propellants used for space launchers like those of the Ariane and Vega families. It represents about 18 to 20 % of the propellant mass and provides an important increase in specific impulse due its high calorific value. During the propellant combustion, aluminum droplets are formed, ignited and burnt in a hot-gas flow produced by the combustion of ammonium perchlorate and polybutadiene binder, the other main components of the solid propellant. Aluminum droplets vary in their initial size from tens to hundreds of microns because aluminum particles often form agglomerates on the burning propellant surface. On the other hand, the hot-gas environment near the propellant surface has variable properties in terms of temperature and chemical composition because of the heterogeneous composition of the composite propellant. The variety of physical parameters makes it difficult to characterize the processes of ignition and combustion of aluminum droplets in a solid propellant flame.
Aluminum combustion has been studied at ONERA since many years in collaboration with CNES, DGA, Ariane Group and its predecessors. The proposed paper presents some experimental and numerical results, obtained at ONERA, on the ignition of aluminum droplets. The tested propellant was fabricated at ONERA for research purposes and its main components have similar proportions to those of the solid propellant for the Ariane 5 rocket boosters.
The experimental study in relation with this paper was realized in a test chamber enabling optical access [1, 2]. The test samples of few millimeters in size were burnt in nitrogen at a pressure of 1 to 1.5 MPa. High-resolution images of aluminum droplets near the burning propellant surface were obtained with a high-speed camera. It was possible to observe aluminum droplets during several milliseconds on the propellant surface and in the gas flow. A part of them were ignited on the surface while the others started burning in the flow after detachment from the surface. The experimental observations allow determining the droplet size and ignition delay but it was not possible to characterize the local conditions in the gas flow and hence their effect on the droplet ignition process.
A model of aluminum droplet combustion was previously developed at ONERA and implemented in the CEDRE code. This model includes detailed mechanisms for the gas-phase and surface reactions as well as a precise description of the molecular transport [3]. Numerical simulations of the ignition process of individual aluminum droplets in a hot flow were carried out in the 2D axisymmetric approach. The flow conditions correspond to the experimental pressure. The temperature and chemical composition of the ambient gas were varied to study the effect of the propellant heterogeneities on the ignition delay. It was found that the presence of free oxygen from the zones rich in ammonium perchlorate was the principle factor controlling the ignition delay.

References

[1] Devillers, R., Nugue, M., Tong, A. C. H., Le Besnerais, G., Pichillou, J. Experimental analysis of aluminum-droplet combustion in solid-propellant conditions using deep learning. EUCASS 2019

[2] Chevalier, P. H., Devillers, R., Dorval, N., Vilmart, G., Attal-Trétout, B., Brossard, C., Pichillou, J. Analysis of high-speed Al-PLIF images to study aluminum droplet combustion in solid propellant flames. EUCASS 2019
[3] Muller, M., Davidenko, D., Giovangigli, V. Computational study of Al droplet combustion in a burning solid propellant environment. EUCASS 2019