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Evolution of aluminum droplets in solid-propellant combustion by image analysis using deep learning

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Abstract

Adding aluminum particles in solid-propellant composition increases propulsion performance by about 10% but can also generate various troublesome phenomena such as thermo-acoustic instabilities (ITHAC) leading to pressure oscillations. Characterization of aluminum combustion burning above the propellant surface is decisive for understanding the stability of a rocket motor propulsion. Numerical simulation is supported to study complex instabilities [4]; however, an accurate aluminum model is essential with realistic input data. But regardless of model precision, accurate characterization of aluminium-droplet size and velocity remains limited in realistic combustion conditions. These data are particularly complicated to obtain experimentally, given the combustion conditions (high pressure, high temperature). ONERA has been using a shadowgraphy [2] set-up to observe small solid-propellant samples in combustion at a high repetition rate. Information-rich images contain multiple objects moving quickly in the gas flow. The complexity of the shadowgraphy images has led this present work to analyze images by deep learning neuronal network, particularly instance segmentation using a convolutional pre-trained network. Instance segmentation combines semantic segmentation (providing detailed object shape) and object detection (giving access to localization and classification) by segmenting images only in areas of interest (determined by the network). It gives access to information on the characteristics of each object (shape, size, etc.), their place in the image, and their relationship to other objects (location, distance to neighbors, etc.). The learning phase is conducted with a restricted base of various annotated shadowgraphy images for different experimental conditions (solid propellant compositions, pressure, acquisition parameters, etc.). Mask R-CNN [3], the most popular network for semantic segmentation, has been selected for this task.
Nevertheless, classical deep learning approaches aim at optimizing global performance indices, combining detection probability and false alarm rate without considering the objects' size distribution, our goal for aluminium characterization. Under these conditions, the networks favor detecting the most straightforward objects (typically the largest droplet) while neglecting their counter-performance on the most challenging objects (tiny droplets), which can bias the estimated granulometric proportions. The learning process has therefore been modified to make it more robust to the size distribution. We called this modified network MRCNN-A, and it is detailed in [1]. The results are analyzed with statistical tools to obtain an accurate droplet size distribution.
The current paper demonstrates the efficiency and performance of the image analysis approach to characterize aluminum droplets in solid-rocket propellants and provides valuable. Moreover, a Kalman filter has been developed as a tracking approach to obtain droplet trajectories and estimate their velocity close to the burning surface. It also reflects the efficiency of instance segmentation, particularly with MRCNN-A.

References

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