IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM (A2)
Microgravity Experiments from Sub-Orbital to Orbital Platforms (3)

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AN INVESTIGATION OF THE LABORATORY-BASED AND MICROGRAVITY CENTRIFUGAL CASTING OF PARAFFIN WAX

Abstract

This paper presents results from the latter efforts of a comprehensive experimental investigation which comprises (1) a qualitative and quantitative assessment of the solidification of paraffin wax in the simulated 10 cm square wall of a 1U CubeSat in the laboratory, (2) the miniaturization of the centrifugal casting process of paraffin wax and determination of optimal casting times and rotational speeds, (3) a microgravity flight experiment (October 4, 2018) comprising a liquid water-filled centrifuge of similar dimensions to that required for paraffin wax in order to elucidate some of the fluid mechanical considerations at play, (4) and a second microgravity flight (March 20, 2019) comprising a liquid-paraffin-simulant-filled centrifuge to better match properties to paraffin. Qualitative and quantitative results from the microgravity flights as well as ground-based research will be presented. In particular, smooth annuli were achieved at rotation rates on the order of 300 RPM in microgravity.

The discovery of paraffin wax (common candlewax) as a high-performing hybrid rocket fuel at Stanford University in the late 1990's has catalyzed a wide array of research and development at both domestic and foreign academic, government, and private organizations over the last two decades, including NASA and ESA. The technology readiness level of paraffin-based propulsion systems has progressed sufficiently to allow for the upcoming launch of a paraffin-based sounding rocket to 100 km altitude in spring of 2019 – the Peregrine hybrid rocket developed at NASA Ames Research Center – as well as the consideration of paraffin for use in the Mars Sample Return mission operated by the NASA Jet Propulsion Laboratory targeted for launch in the mid-2020's. Despite extensive ground-based investigations of paraffin-based propulsion systems and the upcoming launch of Peregrine, paraffin is yet to have been leveraged for in-

space propulsion. Furthermore, the formation process of paraffin wax into useful geometries for propulsion applications is frequently conducted ad hoc, and comprises a process of melting paraffin, loading into a centrifuge, and spinning at high rotation rate while heat is lost to the surroundings and solidification of the paraffin occurs, yielding an annulus of fuel. This research project has two objectives in particular: (1) advance applied knowledge related to the centrifugal casting of paraffin wax fuel grains in the 1g and microgravity environments and (2) gain insight into the fundamental fluid mechanic and heat transfer mechanisms leveraged in the centrifugal casting process in order to improve Earth-based casting efforts.