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Fire safety in space – Investigating flame spread interaction over wires

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ABSTRACT

A new rig for microgravity experiments was used for the study flame spread of parallel polyethylene-coated wires in concurrent and opposed airflow. The parabolic flight experiments were conducted at small length- and time scales, i.e. typically over 10 cm long samples for up to 20 s. For the first time, the influence of neighboring spread on the mass burning rate was assessed in microgravity. The observations are contrasted with the influence characterized in normal gravity. The experimental results are expected to deliver meaningful guidelines for future, planned experiments at a larger scale.

Arising from the current results, the issue of the potential interaction among spreading flames also needs to be carefully investigated as this interaction plays a major role in realistic fire scenarios, and therefore on the design of the strategies that would allow the control of such a fire. Once buoyancy has been removed, the characteristic length and time scales of the different modes of heat and mass transfer are modified. For this reason, interaction among spreading flames may be revealed in microgravity, while it would not at normal gravity, or vice versa. Furthermore, the interaction may lead to an enhanced spread rate when mutual preheating dominates or, conversely, a reduced spread rate when oxidizer flow vitiation is predominant.

In more general terms, the current study supports both the SAFFIRE and the FLARE projects, which are large projects with international scientific teams. First, material samples will be tested in a series of flight experiments (SAFFIRE 1-3) conducted in Cygnus vehicles after they have undocked from the ISS. These experiments will allow the study of ignition and possible flame spread in real spacecraft conditions, i.e. over real length scale samples within real time scales. Second, concomitant research conducted within the FLARE project is dedicated to the assessment of new standard tests for materials that a spacecraft can be composed of. Finally, these tests aim to define the ambient conditions that will mitigate and potentially prohibit the flame spread in microgravity over the material studied.

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1. Introduction

Long life power supplies are required for long term missions, such as the mission to Mars, therefore, hazards associated with short circuiting are enhanced. As a result, the control of potential flame spread over electrical wires is crucial to space vehicle fire safety. Managing this hazard requires the capacity to understand and predict the potential growth of a fire initiated by a short circuit. Only then, mitigation strategies can be implemented.

Following the pioneering work by Greenberg et al. [1], the characterization of flame spread over the coating of a single wire in microgravity has been studied extensively in recent years [2–9]. Thus, some governing processes have been identified [10], and it has been found that the "wire-driven mode" controls the spread rate over the coating of a high conductivity metallic core (Fe), while the spread rate follows a "flame-driven mode" for a low conductivity metallic core (Ni/Cr).

Due to the actual arrangements in spacecrafts, some further issues arise, of which the most critical seem to be scale and interaction between burning wires. While the scale influence on fire spread is a topic extensively covered for both normal gravity and microgravity environments [11–13] it still remains unresolved. In a similar manner, the interaction among spreading flames has been the subject of several studies [13,14] but still merits further scientific investigation, in particular, for microgravity and low characteristic forced velocities conditions. The absence of natural convection allows a significant increase of the time scales associated with transport and combustion processes, increasing both soot concentration [15] and radiative emissions, especially from the soot continuum [16]. Transport thus changes the nature of the combustion processes and the interaction between the flame and the solid fuels in a manner that is still not fully understood. In microgravity, radiation from soot can then be the predominant mode of heat transfer involved in flame spread, even for small diffusion flames [17]. In a recent study, Olson [14] showed that the spread rates exhibited by two flames established in microgravity over parallel flat samples facing each other can be accelerated due to radiative heat transfer from every flame towards the opposite sample in spite of the oxidizer vitiation produced by the release of combustion products. However, for such a geometrical configuration, the optical access was restricted, and therefore it did not allow the sample mass burning rate to be quantified. Without the mass burning rate it is difficult to establish the interactions between the flame and the solid fuel.

This study follows the aforementioned studies by Fujita and coworkers [5–10,12] and focuses on the cable to cable interactions. While the main objective of understanding the influence of cable to cable interactions on flame spread rates remains, the present paper documents a new experimental rig that has been custom-designed to conduct experiments in parabolic flights. The inner combustion chamber's aerodynamics was carefully characterized. Thus, flames spreading concomitantly over the polyethylene coatings of three parallel electrical wires were established in a uniform laminar oxidizer flow. A backlighting technique allowed the coating regression rates, therefore the mass burning rates to be quantified along the length of spread. The interaction among spreading flames was established by means of time histories of the mass burning rates in microgravity and normal gravity. This study therefore fills, for the first time in microgravity, a gap of information essential to the understanding of the interaction of spreading flames over adjacent cables.

2. Experimental design

The experimental setup has been custom-designed to enable the study of flame spread over the coating of cylindrical wires in microgravity obtained through parabolic flights.

2.1. Configuration – flame spread

Fig. 1 shows a schematic of a flame established over the coating of an electrical wire. For the present study, the 0.5 mm diameter metallic core was made of NiCr. The coating (outer diameter of 1.1 mm) was composed of polyethylene. Upon ignition of the coating, the flame may propagate over it, provided that the heat feedback from the flame to the coating enables the polyethylene pyrolysis. The mass transfer of this fuel pyrolyzate to the flame allows in turn the heat of combustion to be released at the flame location where the fuel meets the oxidizer. As indicated in Fig. 1, different modes of heat and mass transfers may play significant roles in this coupling.

In the absence of buoyancy, the oxidizer will mainly be conveyed to the flame by advection. In a spacecraft, the forced flow advection is produced by a HVAC system, typically generating flows at velocities ranging from 1 to 10 cm/s. The corresponding range of Reynolds numbers typically leads to laminar oxidizer flows, as represented by the streamline shown in Fig. 1. Although Fig. 1 is schematic in nature, this streamline is in qualitative agreement with the computed streamlines in a similar configuration

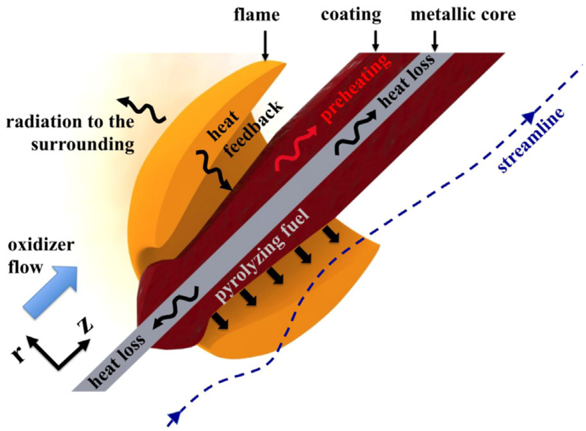

Fig. 1. Schematic of the concurrent spread of a flame established over the polyethylene coating of a wire. The main heat and mass transfers are included.