Editorial

Introduction to Special Issue on Spacecraft Fire Safety

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Humankind has progressively increased the duration and extent of missions beyond the surface of the Earth. This journey has not been without risk, and the history of human spaceflight contains a number of catastrophic events [1]. In the history of human spaceflight, of the 10 recorded events that resulted in the loss of crew, two events involved fire. On-orbit, there have been 13 fire or overheat events of which two were grave and represented a clear risk to the crew. Therefore, fire remains a significant risk for spaceflight that merits research for future flights. The fire risk in a spacecraft is more challenging than most terrestrial locations due to inevitable use of polymers and potential ignition sources in cramped quarters, limited resources for fire response, and limited evacuation strategy. One advantage of spaceflight is that the ability to control the materials that are present in the vehicle is very robust; consequently, the control of material and ignition sources for fire prevention should be carefully followed as the primary defense against the establishment of fires [2].

Spacecraft fire safety has been a research topic in combustion and fire safety engineering, since the beginning of the space program in the 1970s, and has expanded to include future long-term manned missions, and establishment of human habits on the moon, Mars, and beyond. Spacecraft fire research is complex and experimentally costly, constrained by limited access to space experiments and brief ground-based experiments [4]. To help limit the cost to individual agencies and to expand the knowledge base, it has become an active area of international collaborations involving numerous countries and space agencies (Fig. 1).

The special issue of Spacecraft Fire Safety includes 18 papers with multidisciplinary contributions from different aspects of fire science and technology. Unique space fire experiments have been conducted in the International Space Station [5, 6], unmanned spacecraft [7], and a satellite [8] to understand the long-term micro-

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Figure 1. International space station and spacewalk, courtesy of NASA (left). The flame spread over the black PMMA rod in microgravity, where the central fire image shows a vapor jet disrupting the blue flame, and surrounding fire images show the opposed flame spread [3] (right) (Color figure online).

gravity combustion and fire phenomena. The fire dynamics small and thin fuels are also explored through ground-based microgravity experiments using drop towers [9] and parabolic flights [10–14]. In addition, combustion and fire experiments under reduced pressures [15–17] and a narrow channel [18] are applied to lower the influence of buoyancy and simulate low-gravity environments on Earth. Numerical simulations also provide essential information on the flame structure, quantify the experimental data, and verify microgravity combustion theory [6, 19].

This special issue covers various aspects of fire dynamics in the spacecraft environment. The changes in *material flammability* resulting from the microgravity environment is a primary fire-safety concern for manned spacecraft. Proper material selection for spaceflight requires a thorough knowledge of fire and flammability behavior in varied gravity. Thus, the critical conditions for flame ignition and extinction in microgravity are extensively explored under different ignition protocols [12], oxygen concentrations [11–13], airflow rates [13] and radiant heat fluxes [11], and for flame retardant materials [13].

Once ignited, the *growth and spread of flames* in microgravity also behave differently from those on Earth, because of the absence of buoyancy flow. Thus, microgravity also provides an ideal environment for fundamental combustion research [4]. Unique phenomena for flame spread in microgravity over thin paper [9], thick plastic plates [7, 10, 18], cylindrical rods [8, 17], spherical fuels [5] and electrical wires of different thicknesses [11, 12, 14, 20] are observed, and the influence of air-flow speed, direction, and oxygen concentration on flame stability are investigated.

The ample literature on wire fires in microgravity and beyond are also reviewed [20].

The role of *radiation heat transfer* becomes more important for the near-limit flame phenomena in microgravity, where flame radiation and surface reradiation dominate the heat loss from the fuel. Important progress has been made in the quantification of the radiation profile and its effects on flame spread via experimental measurements [6, 14] and computational simulations [6, 19]. For the design of firefighting strategies in spacecraft, special *fire-suppression technologies* are required. In addition to the conventional extinguisher, novel technologies such as vacuuming extinguishing systems [21] and inert-gas balloon [22] are proposed.

Today, we still have a relatively limited understanding of the fire dynamics in low-gravity or microgravity, despite fundamental research input over the last a few decades, mainly because of the high cost of long-term space experiments and the limitation of short-term ground experiments. Particularly, real fire behaviors on large and complex fuels in spacecraft are mostly unexplored, and many details remain unknown. For example, what is the flashover behavior under varying gravity levels? What is the standard for a fire-safe material that should be used for space travel? Is there an optimal spacecraft atmospheric condition that balances the fire safety and crew health? How does one design a more reliable fire protection system for the space station and human habitat on Moon and Mars? It is essential that fire scientists fill the knowledge gaps and fire engineers solve the very practical safety concerns for human space exploration activities. This special issue helps shed some light on these critical needs and aims to inspire future work on this important fire research topic.

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