Ph.D. Proposal 2019

Laboratory : Institut Jean le Rond d'Alembert

University: Sorbonne Université (Paris, France)

Title of the thesis: Detection and mitigation of fire in microgravity for spacecraft safety enhancement

Thesis supervisor: Dr Guillaume Legros (∂'Alembert)

Email contact: guillaume.legros@sorbonne-universite.fr

Co supervisor: Pr Jose L Torero (University College of London, UK)

Co-supervision: Pr Jose L Torero

University: University College of London, UK

Thesis's summary (abstract):

Latest reviews of technological issues that still prohibit long term travel into space, such as the Mission to Mars, clearly identify spacecraft fire safety as a crucial domain that requires more fundamental insights. For several decades, many sound scientific works on fire growth and the movement of smoke and heat have been providing the engineers with the information and tools that are necessary in the design of fire detection and the definition of the subsequent procedures on ground. However, due to the specific conditions encountered in spacecraft, the tools for normal gravity fire detection design needs to be assessed into realistic space conditions and modified according to the discrepancies among detection thresholds in 1g and 0g, that could lead to inappropriate procedures, then disasters, following a misdetection -or a non-detection- in microgravity.

Under the joint supervision of Dr Legros (Sorbonne Univ.) and Pr Torero (Univ. College of London), the student will conduct investigations on flame spread over small samples in microgravity. The experiments will take place onboard the Novespace zeroG airplane. Since 2014, the experimental rig DIAMONDS (Detection of Ignition And Mitigation Onboard for Non-Damaged Spacecrafts) developped at Sorbonne Université[1] has allowed for these experiments. Recent Ph.D. works by Augustin Guibaud[2] have paid a specific attention to the influence of the ambient atmosphere conditions (chemical composition, flow, pressure). These conditions especially deliver means of soot production control. Soot has been shown to play a key role into the radiative heat transfer which significantly contributes to fire hazards in the absence of buoyancy. Following these findings, the student will especially focus on setting and assessing state-of-the-art fire detection systems. The ambition of the Ph.D. works is to design an alternative fire mitigation strategy that could contribute to enhance spacecraft fire safety procedures.

The works will be complemented by numerical studies to further assess the experimental analysis. To do so, the student will collaborate with Jean-Louis Consalvi (IUSTI, Marseille, France) and his co-workers. The numerical code that they developed is properly designed to model soot production and radiative heat transfer in non-buoyant laminar diffusion flames. As a result, the proper numerical simulation of the flame signature detection is expected to be also a potential output of the Ph.D. works.

This Ph.D. is expected to contribute to ongoing international projects, such as SpAcecraFt Fire Safety Demonstration (SAFFIRE) and Flammability Limits At REduced gravity, lead by NASA and JAXA, respectively. The French contribution, lead by Dr Legros, is funded by the French Space Agency (Centre National d'Etudes Spatiales).

[1] http://www.dalembert.upmc.fr/home/legros/index.php/publications
[2] augustin.guibaud@sorbonne-universite.fr

Subject

For several decades, many sound scientific works on fire growth and the movement of smoke and heat have been providing the engineers with the information and tools that are necessary in the design of fire detection and the definition of the subsequent procedures. However, due to the specific conditions encountered in spacecraft, the usual tools for normal gravity fire detection design needs to be at least assessed into realistic space conditions and probably modified according to the discrepancies among detection thresholds in 1g and 0g, that could lead to unappropriate procedures, then disasters, following a misdetection -or a non-detection- in microgravity.

As a result, NASA launched the SAFFIRE (SpAcecraFt FIRe safety Experiment) project eight years ago. This project allows for a close collaboration among American, European, Japanese, and Russian partners gathered in an international topical team. Within the framework of this project, fires are to spread over samples of real length scale (~1m) within real time scale (~20 minutes) into six actual spacecrafts, i.e. Cygnus supply vehicles. These extraordinary experiments are a worldwide première to date into the challenging Mission To Mars. While the results are still processed, the first experiment operated in June 2016 [1] was really successful [2]. Concomitantly, JAXA launched the FLARE (Flammability Limit At REduced gravity) project. This project aims at the definition of the conditions that systematically lead to flame extinction within the context of manned spacecraft [2]. The aforementioned international topical team also takes part in the FLARE project.

The experiments conducted at ∂'Alembert contribute to these international projects [1-4]. A rig called DIAMONDS (Detection of Ignition and Adaptive Mitigation Onboard for Non-Damaged Spacecrafts) has been custom-designed at ∂'Alembert to enable the study of flame spreading over the coating of cylindrical wires in microgravity obtained through parabolic flights.[2] This configuration of flame spread is one of those that the FLARE project investigates more specifically. Figure 1 displays a sequence of frames recorded by a camera capturing the backlight provided by a LEDs screen. Every flame captured spreads at a steady rate in an opposed flow in microgravity along a 22s long parabola inside DIAMONDS. As the pressure is increased, a local quenching reveals at the flame trailing edge, which leads to soot release through the flame tip. As a result, the flame spatial extension is limited. Among others, this local quenching might then represent a control potential of flame spread in such conditions. The expertise developed at ∂'Alembert on this kind of fine optical measurements in flames [5,6] supports the ambition of the present Ph.D. proposal towards the design of alternative fire mitigation strategies that could contribute to enhance spacecraft fire safety procedures.

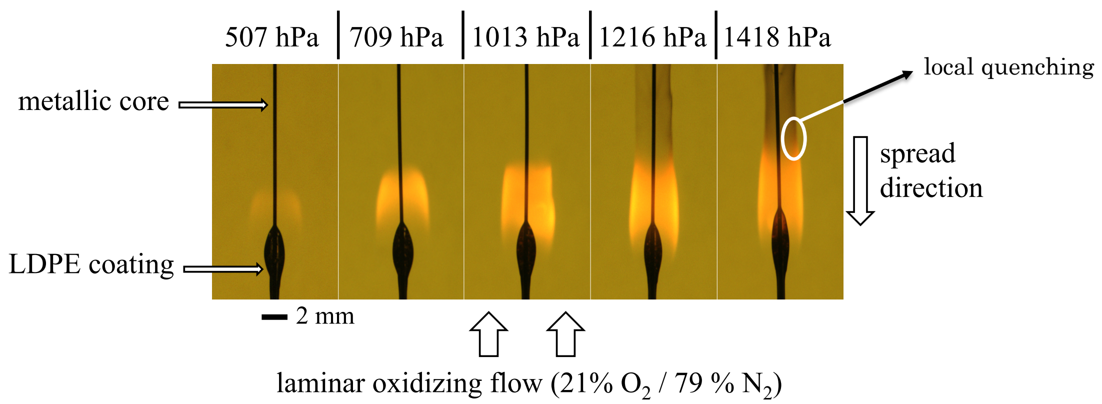

Figure 1: Effect of pressure on the structure of the flame spreading over the LDPE coating of an electrical wire in microgravity (extracted from Augustin Guibaud's Ph.D. works).

The 2D axisymmetric configuration shown in Fig.1 and investigated on DIAMONDS up to now delivered significant insights into the understanding of such a propagation and the ways to control it. Nevertheless, the theoretical basis remains tricky. In contrast, the 2D plane configuration leads to a more established theoretical approach, known as the Emmons' solution [7,8]. Within the context of the present Ph.D. works, the student will have to design a setup to allow for the burning of flat plate samples on DIAMONDS. Thus, the potential parameters to mitigate the flame spread rate will be directed by theoretical considerations. This will be especially by supervised by Pr José Torero.

The works will be complemented by numerical studies to further assess both theoretical and experimental approaches. To do so, an ongoing collaboration with Jean-Louis Consalvi (IUSTI, Marseille, France) and his co-workers will be sustained. The numerical code that these scientists developed is properly designed to model soot production and radiative heat transfer in non-buoyant laminar diffusion flames. As a result, the proper numerical simulation of the flame signature detection is expected to be also a potential output of the Ph.D. works.

To achieve "real-time" computations that drive "real-time" responses of fire mitigation devices, a reduced model will have to be considered. This approach will rely on assumptions, therefore limitations that induce a level of uncertainties. The ultimate ambition of the Ph.D. works is to imagine an experimental configuration on DIAMONDS that would allow such a "real-time" response to be driven by "real-time" computations and experimentally assessed.

[1] https://www.nasa.gov/feature/nasa-ignites-fire-experiment-aboard-space-cargo-ship
[2] Documentaire réalisé par France 3: https://www.youtube.com/watch?v=Vh7rBj4PBnQ

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