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FLARE-2/FLARE-3 プロジェクト：低重力環境下における固体材料の火災安全評価手法の開発

FLARE-2/FLARE-3 Projects: Development of Flammability Evaluation Method of Solid Materials for Partial Gravity Environments

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1. Introduction

Fire safety is one of the most important issues in manned space explorations. The flammability of solid materials in the microgravity environment has been studied by FLARE (Flammability Limits At Reduced-g Experiment) project. In the Artemis program, on the other hand, astronauts will be sent to Moon or even Mars in the future. Therefore, the fire safety of bases in partial gravity environments, which are different from the microgravity nor Earth ground environments, should be ensured. However, the flammability of solid materials in partial gravity environments has not been clarified yet. In FLARE-2 and FLARE-3 feasibility studies, the flammability of solid materials in partial gravity environments are studied.

2. Prediction of the limiting oxygen concentration of an electric wire in partial gravity conditions by numerical simulation in FLARE-2 FS

In FLARE-2 feasibility study, the limiting oxygen concentration of an electric wire in partial gravity conditions was predicted by the numerical simulation. In the numerical simulation, two-dimensional axisymmetric coordinate system and two-step global reaction of ethylene, which is major species of decomposed gas from wire insulation made of polyethylene (PE), were employed for its simplicity to reduce a computational cost. The detailed explanation of the numerical simulation is available in references[1-3]. Figure 1 shows the comparison of temperature fields of spreading flame over an electric wire insulation in different

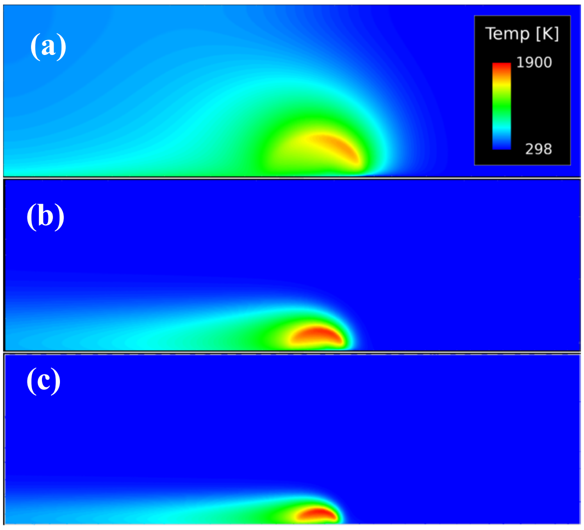

Figure 1. Gas temperature distribution of the flame spreading over a wire insulation in (a) zero gravity, (b) Moon gravity and (c) Earth gravity conditions with an external flow of 5 mm/s at 21% oxygen concentration

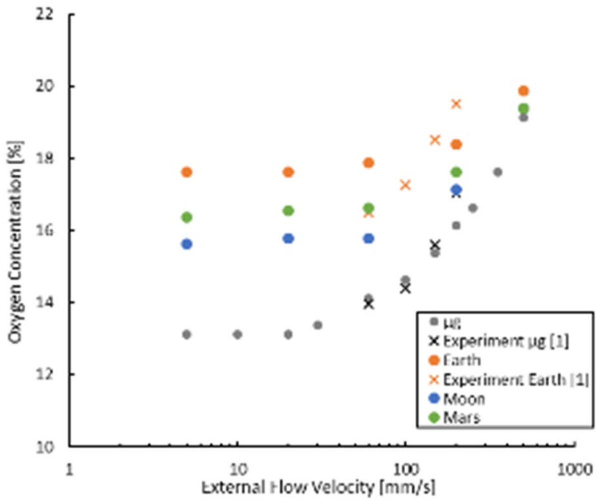

Figure 2. Predicted limiting oxygen concentration (LOC) for various gravity conditions. Plots indicating experimental data are also shown in the graph.

gravity conditions, namely, in (a) zero gravity, (b) Moon gravity, and (c) Earth gravity conditions[3].

It is obvious that the flame size is significantly affected by the gravity condition, namely, the flame size decreases with the increase of the gravity level. This is caused by the natural convection flow induced by the gravity. Figure 2 shows the predicted limiting oxygen concentration (LOC) for various gravity levels. Experimental data are also shown in the graph. LOC indicates the flammability limit of materials, and flame will extinct under the oxygen concentration condition below LOC. It is shown in the graph that the gravity level significantly affect the LOC prediction results. As shown in the graph, experimental data are only obtained for microgravity and Earth gravity conditions. To validate the calculated results, the experimental data for partial gravity conditions are necessary.

3. Development of experimental apparatus in ISS for the flame spread of solid materials under partial gravity conditions by FLARE-3

The development of the experimental apparatus for space experiments to clarify the flammability of solid materials in partial gravity conditions has been attempted in the new feasibility study called as FLARE-3. Although the partial gravity experiments for electric wire flammability have been already conducted using parabolic airplane flights[4], it is necessary to develop a new apparatus for ISS for long time partial gravity experiments. Figure 3 shows the basic concept of the experimental apparatus. To obtain the partial gravity environment, centrifugal force by the rotation of chamber is employed. The rotation speed of the chamber will be adjusted so that the centrifugal force acting on a solid sample, which will be placed parallel to the rotation axis with a certain radius position, will be equivalent to the target gravity level. The apparatus will be launched to ISS and installed to the existing Solid Combustion Experiment Module (SCEM) as a new insert.

To investigate the basic flow field in the new apparatus prior to its development, the simplified numerical simulation has been conducted. Figure 4 shows the overview of the computation domain for the numerical

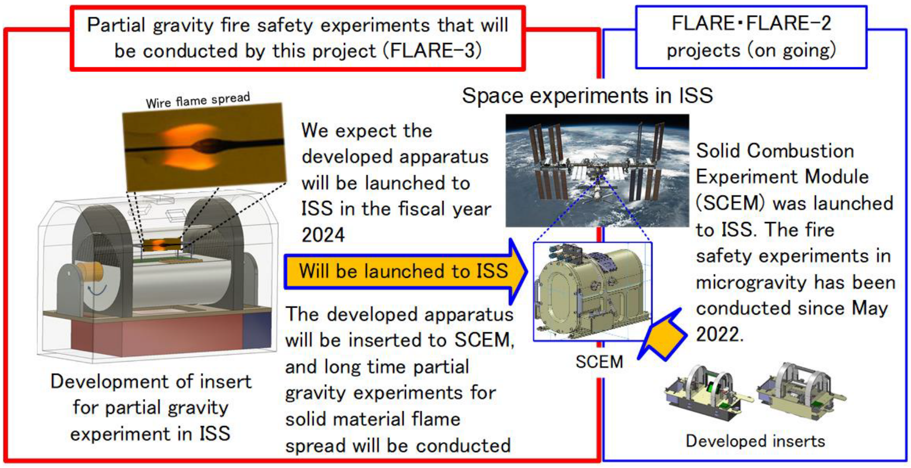

Figure 3. Concept of the development of partial gravity experiment apparatus for ISS.

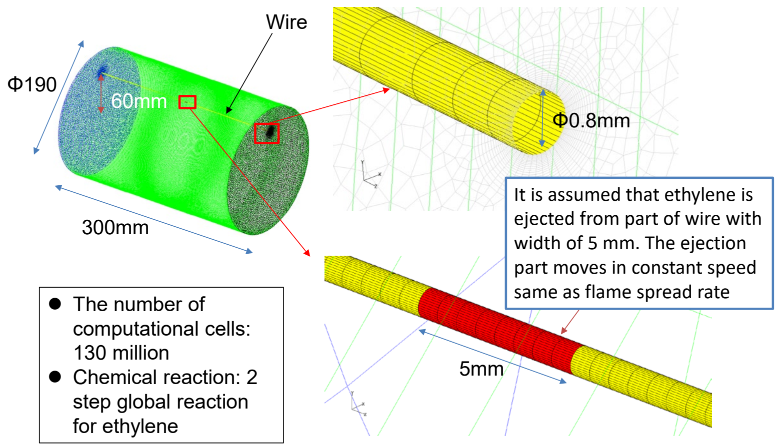

Figure 4. Overview of the computational domain.

simulation. The tentative chamber size for the space experiment is suggested to the dimension with the diameter of 190 mm and length of 300 mm. This size is the maximum size when considering the size of existing SCEM in ISS. Because the purpose of the simulation is to grasp the entire flow field characteristics, the heat balance of solid (or melted) phase of the insulation is ignored. It is assumed that ethylene gas is ejected from a part of wire with width of 5 mm. The ejection part moves in constant speed same as the flame spread rate measured at the ground 1g test condition. The chemical reaction of ethylene is treated as the two-step global reaction model suggested by Westbrook and Dryer[5)].

Figure 5 shows the comparison of gas velocity vector distributions between (a) the case without rotation at the normal gravity condition and (b) the case with rotation at zero gravity condition. The rotation speed of the case (b) was set so that the centrifugal force acting on the wire was same as the earth gravity (1g). It is observed that there is significant difference of flow fields between the two cases. It is observed in Fig. 5(a) that the simple straight buoyancy flow is induced in vertical direction caused by the difference of the densities between the combustion product gas and the surrounding gas. In Fig. 5(b), on the other hand, the flow direction of the combustion product gas is affected by not only the buoyancy but also by the Coriolis force. As a result, the direction of flow is not a simple straight line, but starts at an angle of about 45 degrees to the direction of centrifugal force and then changes direction in a complicated manner. Accordingly, the flow field for the case

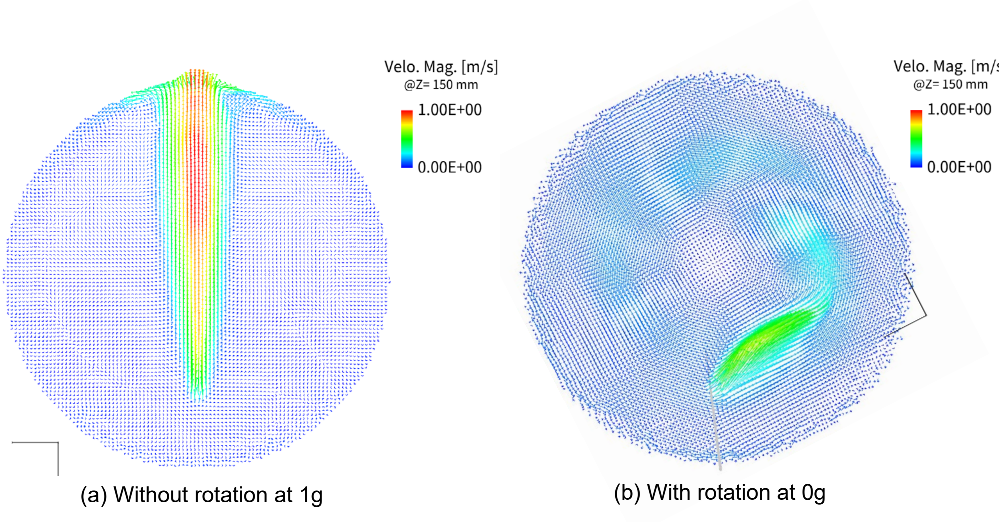

Figure 5. Comparison of gas velocity vector distributions for (a) the case without rotation at 1g condition and (b) the case with rotation at zero gravity condition. The rotation speed for case (b) was set so that the centrifugal force acting on the wire was same as the Earth gravity.

(b) is much more complicated than that for the case (a). This means that the flow field obtained by the experimental apparatus that will be developed in FLARE-3 is different from that in the actual partial gravity environment. Therefore, it is necessary to appropriately model the flow field for the evaluation of the actual flammability of solid material.

4. Summary

In FLARE-2/FLARE-3 feasibility studies, the development of the evaluation method for flammability of solid materials in partial gravity environments. It was predicted by the two-dimensional axisymmetric numerical simulation that the limiting oxygen concentration of electric wire is significantly affected by the natural convection even though the gravity level of Moon is much lower than that of Earth. To validate the predicted simulation results, the experiments for evaluating the flammability of solid materials in partial gravity environments is necessary. To achieve this aim, the concept of the experimental apparatus employing the centrifugal force by rotating the chamber has been examined in FLARE-3 feasibility study. According to the predicted results of the three-dimensional simplified numerical simulation, the flow field inside the chamber will be complicated due to the combination of centrifugal force and Coriolis force. Therefore, it is necessary to appropriately model the complicated flow field to evaluate the results of flammability tests using the experimental apparatus that will be developed.

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