COMBUSTION AND FLAMMABILITY CHARACTERISTICS OF SOLIDS AT MICROGRAVITY IN VERY SMALL VELOCITY FLOWS

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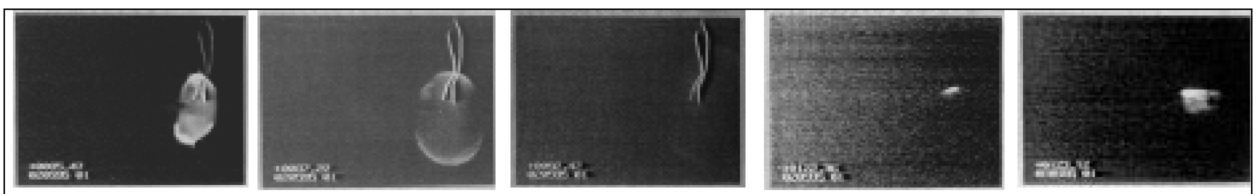
INTRODUCTION

Fires still remain as one of the most important safety risk in manned spacecraft. This problem will become even more important in long endurance non orbital flights in which maintenance will be non existing or very difficult.

The basic process of a fire is the combustion of a solid at microgravity conditions in O_2/N_2 mixtures. Although a large number of research programs have been carried out on this problem, especially on flame spreading, several aspects of these processes are not yet well understood. It may be mentioned, for example, the temperature and characteristic of low emissivity flames in the visual range that take place in some conditions at microgravity; and there exists a lack of knowledge on the influence of key parameters, such as convective flow velocities of the order of magnitude of typical oxygen diffusion velocities.

The "Departamento de Motopropulsión y Termofluidodinámica" of the "Universidad Politécnica de Madrid, Escuela Técnica Superior de Ingenieros Aeronáuticos" is conducting a research program on the combustion of solids at reduced gravity conditions within O_2/N_2 mixtures. The material utilized has been polymethylmethacrylate (PMMA) in the form of rectangular slabs and hollow cylinders. The main parameters of the process have been small convective flow velocities (including velocity angle with the direction of the spreading flame) and oxygen concentration. Some results have also been obtained on the influence of material thickness and gas pressure.

The experimental program has been continuously supported by ESA, including three parabolic flight campaigns in the NASA KC-135 and one in the ESA Caravelle; a MiniTexus sounding rocket launched in 1995 and a Texus launching that would be carried out in November/December of this year.



Flow Vel. $U_\infty = 0$	$U_\infty = 0$	$U_\infty = 0$	$U_\infty = 8$ mm/s	$U_\infty = 12$ mm/s
t = - 36.61 s since flow starts.	t = - 34.77 s since flow starts.	t = - 29.62 s since flow starts.	t = + 0.32 s since flow starts.	t = + 1.08 s since flow starts.

Fig. 1.-MiniTexus tests. PMMA hollow cylinder (ϕ = 6 mm). Wall thick = 2 mm. YO_2 = 40%. Pressure ≈ 100 kPa.

A considerable amount of information of flame spreading and flammability limits have already been obtained, as shown in the references. Some significant findings are also shown in Figs. 1 to 5. In Fig. 1 the ignition and combustion processes of a PMMA cylinder in an O_2/N_2 mixtures (40% O_2) are shown, obtained in the MiniTexus experiments. The premixed and diffusion flames are followed by a long period (30 s) in which the flame becomes non visible. Throughout this period the atmosphere is at rest. Then a forced air flow is started becoming visible the flame at very small velocities and within a very short time.

In Fig. 2 simultaneous video and infrared photographs of the combustion of a similar PMMA cylinder are shown, in a still O_2/N_2 mixtures (23% O_2). They where obtained in a parabolic flight (NASA KC-135). It may be pointed out that at 40% O_2 in the parabolic flight the flame was of a normal visible type, showing the influence of the different gravity level, when comparing these results with those obtained in the MiniTexus.

In Figs. 3 and 4 some results of the influence of forced convection velocities and oxygen mass fraction on flame spreading velocity are shown. Finally, in Fig. 5 it may be seen the influence of the gravity level on the values of the spreading velocity.

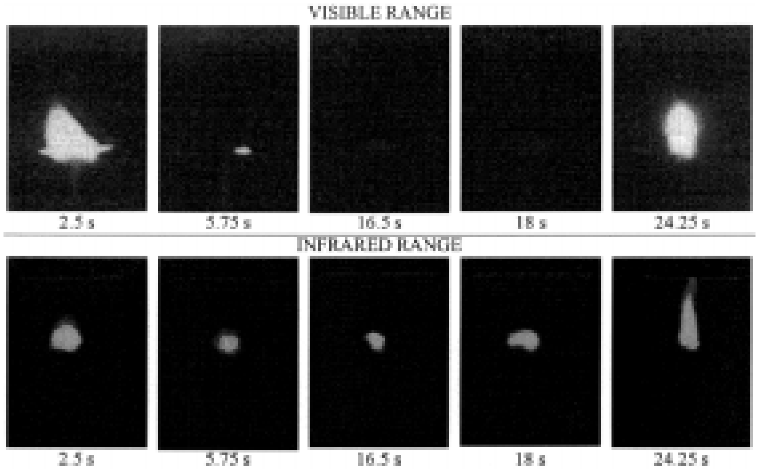


Fig. 2.-Parabolic flight. Simultaneous video and infrared photographs. ϕ = 6 mm. Wall thick. = 2 mm. Pressure 100 kPa. YO_2 = 23%.

Due to the very large number of inter-related parameters of the process: type of material, configuration, thickness, O_2 concentration, pressure, and convective flow velocity; the test matrix is very large and it would require a very long time and it would be very costly to accomplish the program utilizing sounding rockets (parabolic flights provide an insufficient gravity level and in drop towers the testing time is too short).

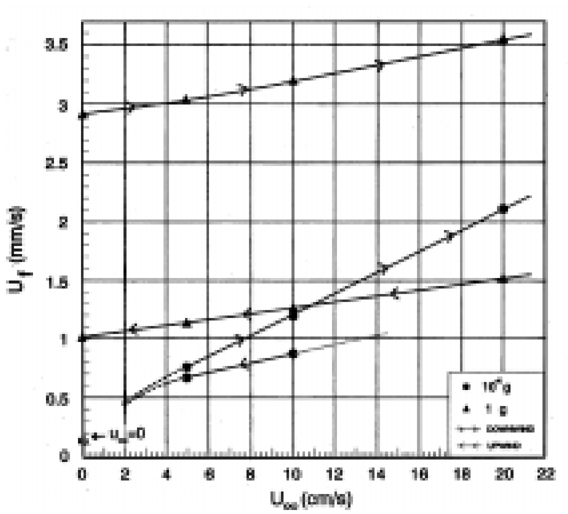


Fig. 3.-Flame spreading vs. forced flow velocity.

MiniTexus results. ϕ = 6 mm. Wall thick. = 2 mm.

P = 100 kPa. YO_2 = 40%. Flow incidence angle 45º

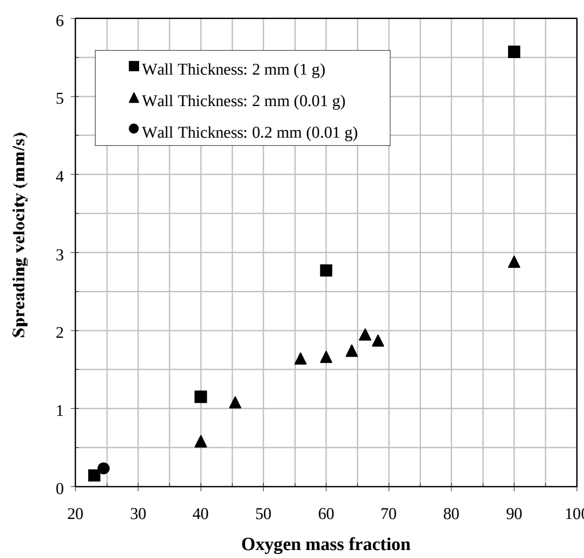


Fig. 4.- Influence of O_2 mass fraction on spreading velocity. Parabolic flight. ϕ = 4 mm. Wall thick. = 2 mm. Pressure 100 kPa.

Accordingly, a Proposal was submitted to NASA in June 1998, as a response to NRA-97-HEDS-01, requesting a research program on combustion of solids in O_2/N_2 mixtures to be carried out in the ISS US combustion module. This proposal has been approved by NASA.

RESEARCH PROGAM

The research program to be carried out in the ISS module would consist, in the first place, of the completion of the tests with PMMA material. In a second phase, materials utilized in manned space stations will be tested.

Specifically, the research program will be as follows:

a) Completion of tests with PMMA samples (hollow cylinder mostly). Flammability limits and flame spreading velocities as function of flow velocity, O_2 concentration, thickness and, possibly, pressure. Determination of flame temperature and characteristics in the non-visible optical range. Ignition tests at low flow velocities.

b) Tests with materials utilized in spacecraft.

Flammability limit tests and flame spreading velocities as function of thickness oxygen concentration and flow velocities. Ignition tests at low flow velocities, and possibly flame extinction limits as function of pressure. Materials tested will be: foams and, in principle, one composite and one insulation blanket.

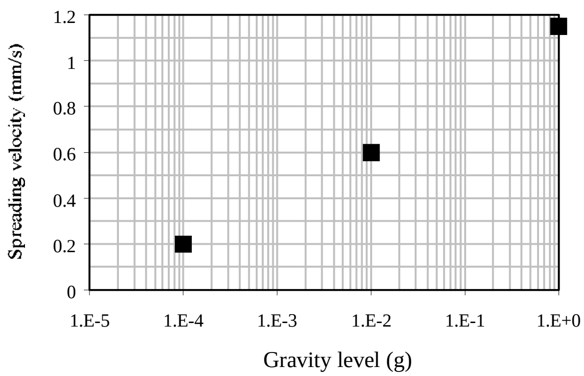


Fig. 5.- Influence of gravity level on flame spreading velocity. ϕ = 4 mm. Wall thick. = 2 mm. YO_2 = 40%. Pressure 100 kPa.

It may be pointed out that, actually, flammability limits will be approximately determined by obtaining extinction limits following the procedure described in the next paragraph.

The number of tests will be limited by the amount of gases available in the ISS module and by crew time. A final selection will have to be made.

An auxiliary test program will be carried out on the ground, parabolic flights and drop towers. These tests will be utilized for initial selection of materials and predetermination of the values of parameters, especially material thickness. Rough estimation of the values of ignition of flammability limits will also be determined. Finally, some fundamental combustion data of materials will be obtained by burning small spherical samples in drop towers.

COMBUSTION AND FLOW SYSTEM

The combustion chamber and flow system will be based, in principle, on the one being designed for the Texus 38 rocket. With this system it would be possible to change continuously, and in a controlled manner, the oxygen concentration from a maximum of 40% down to a value at which the flame extinguishes. Flow velocity would kept constant at a predetermined value at each tests.

This system has to be integrated in the gas supply system of the ISS module. This might possibly require important design changes in the Texus flow system. In addition, it is intended to perform tests with very small flow velocities, below 15 mm/s. This might require additional changes in the flow system which are already being evaluated.

The combustion chamber will be large enough to accommodate several cylinder or slabs to be investigated in each test run.

This combustion and flow system will be offered for utilization by the US and European scientific community.

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