AN OVERVIEW OF EUROPEAN ACTIVITIES ON MICROGRAVITY COMBUSTION

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Introduction

The global objective of the European efforts in microgravity combustion is to combine theoretical and experimental work, both under normal and reduced gravity, to progress in the basic understanding of gravity dependent phenomena in various combustion situations.

The first phase of the European activities on microgravity combustion has been summarized in refs. 1, 2 and 3. This overview will summarize the more recent developments. The focus will be on new experimental facilities, new research topics, and new collaborative efforts.

European experimental facilities for microgravity combustion research

Parabolic flights of aircrafts have been and still are the most common reduced gravity means used in Europe for combustion experiments. After the 1986-88 period during which the NASA KC-135 aircraft was used by the European combustion community (ref.2), combustion experiments have been conducted since 1989 in the Centre d'Essais en Vol, at Brétigny-sur-Orge, France during the parabolic flights of the CNES Caravelle, under the auspices of CNES or ESA/ESTEC. The Caravelle aircraft, with modified engines and hydraulics and reinforced structure, provides, during approximately 20 seconds per parabolae, mean reduced gravity levels of 10^{-2} g_0 when the measuring equipment is attached to the aircraft structure, and between 10^{-3} and 10^{-2} g_0 if free floated in the cabin. Some combustion experiments are also taking advantage of the succession of normal-high-low-high gravity levels (ref. 4).

With the construction of the ZARM-Bremen Drop Tower, European combustion community has a new facility providing much lower gravity levels than those obtained during parabolic flights. The ZARM Drop Tower is a 145.5 m high concrete tower which contains the drop tube of diameter 3.5 m and 110 m height. The tower is designed as a vacuum chamber with a residual air presure of 1 Pa. The free fall duration is 4.74 s. In a later development phase, the experiment capsule could be launched from the bottom up to the tower top, almost doubling the flight time up to 9.4 s. The microgravity level is of the order of 10^{-6} g_0. During the free fall period the drop capsule is in constant contact with the command centre via telemetry, remote control and television (ref. 5). A smaller drop tower (height 25 m, free fall time approximately 2 s) is also operated for combustion experiments in Forrejon, Madrid, Spain, by INTA (Instituto Nacional de Tecnica Aerospacial) (ref. 6).

The use of sounding rockets for microgravity combustion research is under preparation by ESA/ESTEC since few years. The combustion experiments module under design aims the use of TEXUS sounding rocket program, which is a proven system, having been flown successfully many times from ESRANGE in Kiruna, Sweden, since 1977. With an experimental payload weight of about 250 kg subdivided into four to six experiment modules, the apogee is typically between 250 and 300 km. This corresponds to a free fall time of 6 to 7 minutes with residual accelerations of less than 10^{-4} g_0. The use of sounding rockets for combustion experiments offers many additional advantages such as direct experiment operation by the scientist using telescience, reduced safety and hazard requirements, short recovery time and the possibility of late access (ref. 7).

Examples of European microgravity combustion research programs

This chapter summarizes briefly some of the European microgravity research programs using the above listed facilities. The emphasis is mainly put on new research topics.

Microgravity combustion experiments with gas phase flames is conducted during the parabolic flights of the Caravelle aircraft by the group at the Laboratoire d'Aerothermique of the CNRS at Meudon. Part of the investigation is devoted to the effects of gravity on polyhedral flames. Propane-air premixed flames are burner stabilized and tests are conducted under normal gravity, reduced gravity and at 1.8 g_0 during the pull-up period of the aircraft. Several theoretical results are verified on cellular flames in the polyhedral configuration and it is shown that gravity does have a stabilizing effect for a downward propagating flame. On average, it is observed that one facet of the polyhedron is lost at reduced gravity in those configurations where the number of facets are between 5 and 8 under normal gravity (ref. 8). Another part of the research program focuses on the influence of gravity on laminar premixed and diffusion gas flames (refs. 9 and 10).

Another example of microgravity combustion experiment using the parabolic flights of the Caravelle is the research program on high pressure droplet burning conducted at the CNRS-LCSR at Orléans. A High Pressure Droplet Burning Facility has been developed for this purpose. It allows the investigation of burning and vaporizing single droplets up to an ambient pressure of 12 MPa. A powerful image analysis system is added to the facility. N-heptane and methanol droplets undergoing pure vaporization or burning are investigated. Preliminary results show that the pressure effect on the gasification process differs strongly depending on the gasification regime and that the instantaneous gasification rate can be obtained by the techniques developed (refs. 11, 12).

With the availability of the Bremen drop tower, new combustion experiments have started to take advantage of the very low gravity levels provided by this facility. One recent research program is developed by the team of the CNRS-LCPC in Poitiers, in collaboration with the University of California, Berkeley (ref. 13). The global aim of the research is to study the diffusion flame combustion of gaseous, liquid and solid fuels in a non-buoyant, low velocity, flat plate boundary layer established in an oxidizing flow. The research program is planned in progressive stages. The forced flow boundary layer flame combustion produced by a gaseous flame injected through a porous plate is first studied in the Bremen Drop Tower. An experimental apparatus has been developed and the first drops were realized in 1992. Methane flames were ignited under both normal gravity and microgravity and the flame behaviour is recorded by CCD cameras and thermocouples. Several parameters have been varied. Preliminary observations indicate that microgravity flames are wider and more diffuse, and less flickering. The flame temperature is lower in microgravity (ref. 13). In parallel, modelling activities devoted to similar problems are conducted at the Universidad Politecnica de Madrid (ref. 14).

The Bremen Drop Tower allowed also the development of another international collaboration on the topic of high pressure droplet evaporation between German and Japanese teams (ref. 15).

Another example of new microgravity combustion research in Europe is provided by the future use of the Texus sounding rocket program by the team of the Polytechnic University of

Madrid. They developed the conceptual design and expected operational characteristics of a multipurpose Microgravity Combustion Module for sounding rocket experiments. The same team proposed also to carry out one particular experiment on flame spreading with forced convection along the surface of a solid fuel at reduced gravity. It is proposed to use hollow cylinders of PMMA samples of 8 mm external diameter and 4 mm internal diameter. Three series of experiments are proposed including the influence of small flow velocities at constant ambient composition with parallel and cross flow conditions, and the influence of oxygen concentration. In parallel, a theoretical program will be developed and will include the search of an analytical solution for flame spreading under forced convection in all upwind or opposed flow cases and an approximate theory of the downwind flame spreading processes. This program is also conducted in collaboration with CISE, (Milano, Italy) and CNR/CNPM (Milano, Italy) concerning the development of laser diagnostics for microgravity combustion applications.

A new European collaboration program on Gravity Dependent Phenomena in Combustion

In 1990, ESA started to organize Expert Working Groups (EWG) in various domains of fluids and materials sciences in order to structure at the European level the corresponding microgravity relevant research programs, by seeking strong complementarities between (1) ground and space based experimental activities (2) theoretical, numerical and experimental approaches, and (3) basic and technologically relevant research objectives. Another objective of the EWGs is to seek collaboration possibilities between ESA programs and those of the Commission of the European Community (CEC). An EWG in combustion has also been constituted. It is composed of the following individuals: Profs. K.N.C. Bray, N. Peters, A. Linan, A. d'Alessio, Drs. M. Champion and I. Gökalp (chairman). After several preliminary meetings and workshops a research program on "Gravity Dependent Phenomena in Combustion" has been put together and submitted to the Human Capital and Mobility program of the CEC. The global structure of the program constructed along four tasks, and which is currently under evaluation, is as follows:

Task I. Flame spread over liquid or solid surfaces

University of Madrid (A. Linan, S. Tarifa)
University of Naples (C. di Blasi)
CNRS, Poitiers (P. Joulain, J.M. Most)

Task II. Flammability limits in gaseous premixtures

RTWH, Aachen (N. Peters)
University of Cambridge (B. Rogg, K.N.C. Bray)

Task III. Droplet Combustion

CNRS, Orléans (I. Gökalp, C. Chauveau)
University of Naples (P. Massoli, A. D'Alessio)
University of Madrid (A. Linan)

Task IV. Laser Diagnostics

University of Naples (P. Massoli, A. D'Alessio)
CNPM, Milan (G. Zizak, F. Cignoli)
CNRS, Orléans (I. Gökalp, C. Chauveau)
CISE, Milan (I. Gianinoni)

The construction of this collaborative program is based on the understanding that analysis of gravity dependent phenomena in combustion necessitates both ground based studies and space (or reduced gravity) experiments. Theoretical studies are also an important part in this conducted with the aid of ESA and National Space Agencies. The reduced gravity experiments will use parabolic flights of the Caravelle aircraft of CNES, the Bremen drop tower, and the Texus sounding rockets. Theoretical and numerical work will be performed in order to analyze and predict gravity effects on combustion.

In building this programme, the basic research relevance and the technological relevance of the proposed studies are taken into account. The elucidation of gravity effects on combustion phenomena has important general basic consequences as combustion induced buoyancy is always present on ground. The technological relevance of the programme appears through its interest i) on flammability limits of essentially hydrogen/air mixtures **(Task II)** which is the fuel selected for the future high speed civil transport (the so called scramjet technology based on supersonic combustion); ii) on droplet combustion **(Task III)** as liquid fuels such as liquid oxygen will power the next generation rocket motors (such as the Vulcain engine of the launcher Ariane V) and iii) on flame spread over solid and liquid surfaces **(Task I)** which constitutes the basic mechanisms of flame propagation during fires. Finally, **Task IV** is of importance for all combustion work as the development of laser diagnostics is today an essential companion of combustion studies. The adaptation of laser diagnostics to space conditions will benefit other applications (for example in medical sciences) through their miniaturization and enhanced stability or user friendliness.

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COMMENTS

Question (Howard D. Ross, NASA Lewis Research Center): (1) What types of laser diagnostics are being provided in ESA's microgravity combustion program?

(2) You showed a photograph of flame spread over a liquid pool. Could you please describe the ESA research in this area in a little more detail?

Answer:

(1) Several groups in Europe are developing laser diagnostics relevant for microgravity combustion. Previous studies at the Istitute Motori - CNR in Naples, Italy, have shown that the velocity, diameter and temperature of homogeneous droplets can be obtained by measuring the light scattered at two timely angles. These techniques are presently extended to non-homogeneous droplets by developing a theoretical model for the light-scattering by droplets with a radial gradient of the refractive index to determine the temperature and species profiles inside multicomponent droplets.

In parallel, a differential interferometer to determine the temperature distribution around a burning droplet is being developed at ZARM, University of Bremen, Germany.

The Research Institute on Propulsion and Energetics of CNR in collaboration with CISE, both in Milan, Italy, are developing a planar laser induced fluorescence system for combustion diagnostics in microgravity. A multi-purpose PLIF system based on a 2-D solid state array sensor is under development. The objective is to investigate the structure of diffusion flames by measuring molecular distributions. The simultaneous detection of the resonant scattering will give indication of the presence of particulate matter such as soot and/or liquid droplets. Also, temperature measurements will be obtained by exploiting the anomalous fluorescence of pyrene. A PLIF system is also under development at ZARM, University of Bremen, with the support of the German space agency. The system is based on a tunable narrow band excimer laser, a sheet-forming optical device and an intensified digital high-speed CCD camera.

(2) An experimental program on the simulation of pool fires with a gas flame stabilized above a porous burner of 7-cm in diameter is in progress at the LCPC-CNRS in Poiters in collaboration with Laboratoire d'Aerothermique in Meudon. The ZARM drop tower and the parabolic flights of the Caravelle are used for this purpose. The influence of macrogravity on the structure of simulated pool fires is also investigated in a centrifuge; LDA measurements have already been performed in this last case. In parallel, a numerical modeling study of flame spread over liquid fuels is being conducted at the University of Naples. The objectives of this study are: (a) the simulation and analysis, by means of a constant property model, of the effects of gravity level on flame spread over sub-flash liquid fuels; (b) the development of variable property gas-phase models (full Navier-Stokes equations) and simulation of the effects of hot-gas expansions; and (c) the simulation and analysis of the effects of slow forced-flow conditions on the pulsating flame spread and extinction mechanisms.