N90-17895

NON-CONTACT TEMPERATURE MEASUREMENT REQUIREMENTS OF GROUND-BASED RESEARCH AND FLIGHT PROGRAMS AT JPL

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INTRODUCTION

The Modular Containerless Processing Facility project at the Jet Propulsion Laboratory is responsible for the development of flight equipment and of the accompanying scientific and technological research necessary to carry out containerless investigations in the low gravity of Earth orbit. The requirement for sample temperature measurement is just one of the many physical properties determination needs that must be satisfied before the useful exploitation of low gravity and containerless experimentation techniques can be achieved. The specific implementation of temperature measurement for the ground-based research program is different from that of the flight hardware development project. The needs of the latter must also be differentiated according to the chronological order of the relevant space flight missions. Immediate demands of Spacelab instruments must be addressed by the adaptation of existing reliable technology to the special and restrictive on-orbit environment, while more advanced and yet unperfected techniques will be assigned to enterprises further in the future. The wide range of application of the containerless methods to the study of phenomena involving different states of matter and environmental conditions requires the satisfaction of a variety of boundary conditions through different approaches. An important issue to be resolved will be whether an integrated program dedicated to solve the problems of all the Microgravity experimental effort will allow the solution of specific demands of existing as well as future flight equipment.

1. CONTAINERLESS PROCESSING TECHNIQUES AND INVESTIGATIONS

The access to near-Earth orbit and the opportunity of performing investigations sensitive to, or enabled by the drastic reduction the gravitational level has justified the development of containerless positioning and manipulation technology for interdisciplinary scientific and technological studies in microgravity. Existing techniques under consideration for space applications have been adapted from existing Earth-based methods, or have been specifically developed for the low gravity environment. Electromagnetic, acoustic or ultrasonic, and electrostatic or electrophoretic approaches are the current areas of concentration in the Microgravity Science and Applications program. The European effort also involves the development of a version of high temperature aerodynamic positioning. Very preliminary work is being initiated at the Jet Propulsion Laboratory on microwave applications to containerless sample positioning and heating.

Electromagnetic levitation has been in use for many years in the investigation of the high temperature behavior of liquid metals and alloys. The environment around the specimen under investigation may be a gas or a high vacuum. Progress has been made in terms of the control of sample stability (rotational and vibrational), and in the decoupling of the heating and positioning functions for operation in low gravity, but the sample manipulation capabilities remain fairly limited. Only fairly conductive solids or melts are appropriate, and all the ground-based applications have been at higher temperatures (at least 1000 ^{o}C). Space Shuttle flight equipment exists, and improved versions are also under development. Potential flight opportunities exist in the near future.

Acoustic or ultrasonic levitation techniques have also been first developed for use in Earth-based laboratories, and have been adopted for applications in microgravity. Sample manipulation and control capabilities are extensive, and all types of materials are appropriate. The working environment must be a fluid to support the propagation of the sound waves. Flight equipment exists and improved devices are also under development. Previous devices have already flown in space, and future flights are scheduled beginning in 1992.

Electrodynamic levitation of micron-size samples has been extensively used in ground-based laboratories for various experimental investigations. Electrostatic levitation techniques have been mainly developed for space applications using larger samples (on the order of a centimeter), but have also been used on Earth for room temperature experiments. Permanent electric charges are required in order to provide a significant force on the sample in the case of electrostatic positioning, but the electrophoretic technique can rely on induced charges if the force magnitude can be reduced. The working environment can be high vacuum or a fluid at ambient or higher temperature. Limited sample manipulation capabilities exist, but are under current development. No flight equipment exists, and no space flight is yet scheduled for the future.

In summary, the general characteristics of these containerless positioning techniques are multi-disciplinary applications using a wide range of materials properties and environments. Some of the methods can be productively used on Earth, but all are still experimental and yet untested for space operation, and all also require the development of accompanying diagnostic techniques for the non-contact and non-perturbing measurement of the specimen physical properties. One of the more fundamental of these properties is the true thermodynamic temperature.

2. EXPERIMENT REQUIREMENTS

Specific requirements for identified experiments using containerless processing techniques may be obtained by examining past or ongoing projects. More generic requirements will be listed in this paper in order to gain an overall view of the magnitude of the problem. In general, the requirements for any given experiment will not include all the conditions listed below at the same time, but the basic requirement for observing the sample in an optically inhomogeneous medium is invariably present.

An arbitrary division of the potential investigations requiring containerless positioning and manipulation can be made to distinguish experiments carried out at moderate and ambient temperatures from those performed at high and ultra-high temperatures.

A. GENERIC MODERATE TEMPERATURE EXPERIMENT REQUIREMENTS

- Low or moderate temperature radiative background
- Slower time variations of the temperature (0.1 to 10°C/sec)
- Larger samples (0.1 to 2.5 cm)
- Temperature range: 30 to 500°C
- Absolute accuracy for temperature measurement: +/-0.1 to 1°C
- Spatial temperature distribution or gradient (1 to 50°C/cm)
- Spatial resolution to 0.1 cm
- Single-phase or multi-phase samples
- Single-or multi-component samples
- Environment temperature distribution measurement required
- Temperature control to 0.01°C
- Temperature generally not the crucial element of the experiment
- Temperature data acquisition rate < 10/sec

- Liquid and solid samples: organic, inorganic, metallic, polymeric.

- Optical properties: Mainly transparent and semi-transparent materials, some opaque materials (specular and diffuse surfaces)

- Internal temperature distribution also desired for samples

- Sample completely stationary, slowly rotating or oscillating

- Sample spot heated from broadband or monochromatic radiant sources

- Fluid environment gas or liquid

- Optical light paths include windows and thermally non-uniform (refractive) environments

- Sample emissive properties generally known or measureable. In situ emittance measurement desired

- Single or small number of samples

B. GENERIC HIGH TEMPERATURE EXPERIMENT REQUIREMENTS

- High, moderate, or low temperature radiative background

- Faster time variation of the temperature (10^{-1} to 10^{6} C/sec)

- Smaller sample (0.05 to 1 cm)

- Temperature range 500 to 2000^{o}C

- Absolute accuracy +/-1 to 10^{o}C

- Sample temperature distribution / gradient (1 to 100^{o}C/cm)

- Spatial resolution to 0.05 cm

- Single-and multi-phase samples

- Single-and multi-component samples

- Environmental temperature distribution

- Temperature control to 1^{o}C

- Temperature is generally a crucial element of the experiment

- Temperature acquisition data rate between 10 to 10^{6}/sec

- Liquid and solid samples: Pure metals and alloys, glasses, ceramics, refractories, polymers, minerals

- Optical properties: transparent, semi-transparent, opaque (specular, diffuse, or both)

- Internal temperature distribution

- Sample stationary, oscillating, rotating, or both

- Temperature measurement of spot heated samples from broadband and monochromatic radiant sources

- Sample environment: vacuum, gas, or high temperature slag or glass

- Optical paths highly inhomogeneous

- Sample emissive properties generally unknown, and in-situ measurement required

- Sample generally outgassing

- High temperature reaction kinetics measurement required

- Significant free charge present. High electric, magnetic and sonic fields present

- Single, small and large number of samples

The above list is a compilation of general projected requirements which could be included in future specific experiments. They are based on a variety of existing ground-based as well as flight investigations.

3. JPL GROUND-BASED RESEARCH: ADVANCED TECHNOLOGY AND SCIENCE

Earth-based experimental facilities used for containerless experiments include electromagnetic, electrostatic, ultrasonic, and aerodynamic levitation devices. Other techniques make use of drop tubes as well as drop towers together with some vertical wind tunnels. The non-contact temperature measurement characteristics used are mostly based on radiometric methods, and are typically commercially available or are experimental and one-of-a-kind devices specially developed by the experimenter. These apparatuses could be elaborate and bulky, and are capable of accommodating high data acquisition rate and storage. They could be operated with complicated procedures, and a high failure rate is probably acceptable. Advanced concepts and development programs are also generally acceptable for use in Earth-based laboratories.

The present research program at JPL involves high temperature acoustic and ultrasonic levitation in isothermal or quasi-isothermal furnaces (30 -1500°C), or with the use of radiant beam heaters. Electrostatic levitation in isothermal furnaces or in vacuum chambers with the use of radiant beam heaters is also under current investigation. Preliminary research is also carried out in acoustic levitation in combination with microwave heating.

Research topics in both materials science and fluid dynamics involve the dynamics of acoustically levitated melts in 1 g and in low gravity, the undercooling and nucleation studies of levitated melts as well as solidification phenomena, the measurement of the thermophysical properties of levitated materials, crystal growth from electrostatically and acoustically levitated solutions, and finally the dynamics of levitated charged liquid samples.

4. FLIGHT HARDWARE PROGRAM AT JPL

Containerless experiments will be carried out during the USML-1 Spacelab flight in 1992 using the Drop Physics Module, an experimental facility precursor to Space Station hardware. JPL is responsible for the design and fabrication of the apparatus which will fit within a Spacelab double rack. Ambient as well as moderately high temperature experiments will be carried out in this instrument, and a non-contact temperature measurement capability is required. The current approach to satisfying this requirement will be to use available thermal imaging technology adapted to the low gravity and Spacelab environments.

The characteristics associated with flight equipment are quite different from those acceptable for ground-based experimentation: High reliability, automation, and low power consumption are prominent requirements. Constraints on available time for flights scheduled in the near future limit the candidate devices to current technology and perhaps even to commercially available units. Advanced technology development aiming to develop the NCTM capability for flight facilities to be scheduled in the future space station will probably be required to provide prototype units for precursor flights in this coming decade.