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MICROGRAVITY NONCONTACT TEMPERATURE REQUIREMENTS AT NASA LEWIS RESEARCH CENTER

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INTRODUCTION

NASA Lewis Research Center is currently supporting 66 microgravity science and applications projects. The projects consist of in-house, grant, and contract activities, or some combination of these activities, and involve the participation by personnel in the Space Experiments Division of the Space Flight Systems Directorate and the Materials Division and the Structures Division of the Aerospace Technology Directorate. The Engineering Directorate sometimes provides assistance in the design and fabrication of the in-house hardware efforts associated with these activities. The management structure is shown in figure 1. The 66 projects are separated into 23 flight projects and 43 ground-based projects.

The part of the NASA Lewis program dealing with flight experiments is divided into six areas: Combustion Science, Materials Science, Fluid Physics, Instrumentation/Equipment, Advanced Technology Development, and Space Station Multi-User Facility studies. Table I lists the flight projects and provides other pertinent information. The Advanced Technology Development, of which Noncontract Temperature Measurements is one such project, and Space Station Multi-User Facility are not science studies and will not be discussed in this presentation. For the flight projects, ground-based work is required to better define the experiment, develop and check out the flight hardware, and to provide a 1-g data base for comparison.

The part of the NASA Lewis program dealing with ground-based experiments is coincidentally also divided into six areas: Electronic Materials, Combustion Science, Fluid Dynamics and Transport Phenomena, Metals and Alloys, Glasses and Ceramics, and Physics and Chemistry Experiments. Several purposes exist for ground-based experimenting. Preliminary information is necessary before a decision can be made for flight status, the short low gravity durations available in ground facilities are adequate for a particular study, or extensive ground-based research must be conducted to define and support the microgravity science endeavors contemplated for space. Knowledge of gravity related effects in the ground-based projects (i.e., in a suborbital setting) is obtained by conducting experiments in drop tower facilities or aircraft. Low gravity durations of up to 20 sec are available using these facilities. Table II lists the ground-based projects.

Not all of the 66 microgravity science and application projects at NASA Lewis have temperature requirements, but most do. Since space allocation does not permit a review of all the pertinent projects, a decision was made to restrict the coverage to the science flight projects, flight projects minus the advanced technology development and multiuser facility efforts. Very little is lost by this decision as the types of temperature requirements for science flight projects can be considered representative of those for the ground-based projects. This paper then will discuss the noncontact temperature needs at NASA Lewis, as represented by the science flight projects, by describing briefly the experiments themselves, by displaying an illustration of each experimental setup, and by specifying their temperature requisites.

FLIGHT PROJECTS

The 12 science flight projects are listed in table I and are separated into three areas: Combustion Science, Materials Science, and Fluid Physics. All of these projects contain temperature requirements, except for Droplet Combustion, and some have comments on desired or future temperature requirements. The Droplet Combustion project is an example where temperature requirements were deleted for lack of a ready technique to make the desired measurements.

Combustion Science

Solid surface combustion. - The overall objective of this project is to determine the mechanism of gas-phase flame spread over solid fuel surfaces in the absence of buoyancy-induced or externally imposed gas-phase flow in order to improve the fire safety aspects of space travel. To achieve this objective, measurements are made of the flame spread rate, solid and gas-phase temperature, and flame shape for steady flames spreading over paper and polymethylmethracrylate in a low gravity environment. Figure 2 illustrates the experimental hardware.

Temperatures are measured by small diameter (5 mils) type R thermocouples placed in both the gas and solid phases. Temperatures ranging from 250 to 1000 K are anticipated with a required accuracy of ± 0.5 percent.

Particle cloud combustion. - The objective of the research in this project is to determine the characteristics of flame propagation and extinction for quiescent, uniform clouds of particles. Particles clouds are of practical interest since they occur in coal mine and grain storage fires. The study of particles equal to or greater than 30 μm in normal gravity is compromised by the inability to provide the necessary stationary experimental conditions prior to combustion initiation. Even if these required experimental conditions were accessible at 1-g, free convection effects would be expected to dominate the underlying flame propagation mechanisms. However, experiments in low gravity will permit uniform, turbulence free clouds of combustible particulates to be established and maintained prior to the initiation of combustion. A low gravity environment will also permit the observation of flame propagation through and extinction by uniform particulate clouds wherein molecular conduction and radiative transport (rather than free convection) will be the dominant heat transfer mechanisms.

Only the pretest temperature will be measured to insure an uniform ambient temperature of 294 ± 6 K through each combustion tube, see figure 3. A typical propagation speed is 50 cm/sec, making temperature measurements after ignition a problem.

Droplet combustion. - The goal of this project is to determine the burning rates, disruption, and extinction mechanisms and chemical reaction rates of liquid fuel droplets burning at various oxygen concentrations and pressures under conditions of negligible buoyancy. These experiments will serve as large scale simulations of microscopic fuel droplets burning in ground based propulsion and power generation systems. The delivery to and ignition of a test droplet at a prescribed test site is required. The droplet must be unconstrained mechanically and nearly motionless to achieve spherical symmetry while the droplet burns. Figure 4 illustrates the experimental hardware.

This project has no temperature requirements but desirable would be nonintrusive temperature determination of the gases surrounding the burning droplet. The profile is estimated to vary typically from 400 K at the droplet surface to perhaps 2300 K at the flame front. For typical droplets of 1 to 3 mm in diameter the corresponding flame front would be 5 to 20 mm in diameter. The droplets move typically from 2 to 10 mm/sec. Both the droplet and its flame front are proportionally diminishing with time by the d^2 law throughout the test. Additionally a soot shell in the region between the droplet and flame may interfere with measurements internal to the shell, yet outside the droplet. If the above temperature measurements were possible, an accuracy of just ± 50 K would suffice.

Gas jet diffusion flames. - The overall objective of this project is to gain a better fundamental understanding of the effect of buoyancy on laminar gas jet diffusion flames which will aid in defining the hazards and control strategies of fires in space environments, as well as improve the understanding of earthbound fires. To achieve this objective, measurements will be obtained from low gravity experiments that will include flame shape development, flame extinction, flame color and luminosity, temperature distributions, species concentrations, radiation, pressure, and acceleration. These measurements will be used to validate a transient numerical model which reflects current understanding of the important phenomena which control gas jet diffusion flames. See figure 5 for an illustration of the experimental arrangement and flame behavior at normal and low gravity.

Temperatures are measured by a rake of nine thermocouples arranged above the flame jet in three layers with three thermocouples per layer. These sensors are 2 cm apart within each layer with 3 cm between layers. The rake height above the flame is adjustable, but no specs were given. All nine thermocouples are 0.01 cm in diameter, and are type K (1523 K), except the one closest to the flame which is type S (1723 K). Flame temperatures are expected to range from 200 to 2000 K. Sampling rates will be 20 Hz or less.

Materials Science

Alloy Undercooling. - Undercooling of liquid metals provides the impetus for solidification. Once started, solidification will proceed with a release of the latent heat of fusion causing recalescence. The extent of undercooling and the cooling rate will influence the microstructure and the properties of a material. Heat removal is easily controlled in earth gravity through the use of mold materials and chills. Deep undercooling in metals, however, is beset with considerable difficulty, because solidification is easily nucleated by inclusions, impurities, contact with container walls and vibration. Nevertheless, it has been possible to effect some deep undercooling in earth gravity in very small droplets or in contact with a rotating chilled surface (melt spinning). In these instances, rapid heat removal has been more often than not the cause of undercooling, because it could, for a very short time interval, suppress nucleation. In microgravity it is possible to segregate the effects of the rate of heat removal and of nucleation on solidification. The desired undercooling will be obtained by levitating droplets of nickel and iron alloys, melting them by induction and then allowing them to cool and solidify while still positioned in an electromagnetic levitator. During this process, temperature measurements and visual observations will be made. Subsequent metallographic examination will compare the microstructure of materials processed and undercooled in microgravity with materials undercooled in earth gravity. See figure 6 for an illustration of the procedure.

Data to be obtained and compared include temperature-time traces for characterization of cooling rates, recalescence and, solidification; surface and cross-sectional microstructures for nucleation sites, grain and dendrite morphologies; and high-speed photography for observation of the recalescence and progression of solidification. The levitated molten specimen will be between 5 and 8 mm in diameter. Temperature will be sensed by two color pyrometry, two spots 90° apart aligned on the center of the specimen. Temperatures will range from 700 to 2000 K and require an accuracy of 3 K.

<u>GaAs crystal growth</u>. - Improving the homogeneity and purity of GaAs are two major goals of current research by the GaAs crystal growth community. It has been shown that buoyancy-driven convection plays a major role in observed dopant segregation and dislocation formation in GaAs crystals. The objective of this study is to define the magnitude of the effects of buoyancy-driven convection on the quality of melt-grown GaAs. This will be accomplished by conducting a comparative study of GaAs crystals grown from melt with differing degrees of convective flow: growth of the crystal in 1-g (maximum convection), in 1-g with an applied magnetic field (damped convection), and in microgravity aboard the Space Shuttle (minimum convection). All the space and ground-based growth experiments will be performed in a specially designed growth ampoule and furnace system with an electronically-controlled gradient, see figure 7. Both doped and undoped GaAs will be grown. Two impurities, silicon dissolved from the silicon dioxide ampoule and deliberately-introduced selenium, will be studied. The important phenomena to be addressed by the characterization include the effect of convection on the nature, concentration, and homogeneity of unintentionally introduced defects and intentionally introduced dopants, as well as the effect of convection on the electrical and optical properties of GaAs. A numerical model of the fluid flow patterns in melts will be constructed.

The space-growth experiment will be flown in a Get-Away-Special canister. Two pregrown boules of selenium-doped GaAs, 1 in. in diameter and 4 in. long, will be regrown during nominal 6 hr, low g periods in the gradient furnaces. Power will be supplied by self-contained alkaline batteries. Temperature will be monitored at six locations outside of each of the growth ampoules. The relationship between these temperatures and the desired temperature gradient of the crystal will be established by trial and error. A 60 K gradient will be established over the 3 in. molten zone of the crystal. The melting point of GaAs is 1511 K. The cooling rate controlling the single crystal growth will be linearized by the microprocessor control system. Temperature, acceleration and selected housekeeping data will be acquired and stored during the growth of each crystal. Nonintrusive determination of the crystal core and radial temperatures would be desirable, but are not part of this project.

<u>Isothermal dendritic growth</u>. - This project will test fundamental assumptions concerning dendritic solidification of molten metals and provide mathematical models describing important aspects of that process. Since virtually all industrial alloys solidify dendritically, correct models could lead to improved

earth-based industrial production of alloys such as steel and aluminum. Specifically, the project will provide precise quantitative data relating dendrite growth velocity, tip radius, and side branch spacing to melt undercooling, to material physical properties, and to acceleration (g levels). To permit direct visualization of dendritic growth, succinonitrile (SCN) will be used in the experiment. SCN is a transparent body-centered cubic crystalline material that solidifies dendritically in a manner similar to iron.

Precise temperature measurements of the isothermal test volume is required, an accuracy of $\pm$0.002 K. Such accuracies dictate the use of thermistors as the sensors.
Figure 8 illustrates the experimental arrangement.

Fluid Physics

EMD flow in metals. - The purpose of the Electromagnetically Driven Flow in Metals project is to develop an improved fundamental understanding of electromagnetic, heat and fluid flow phenomena in levitation melted (positioned) metallic specimens under both normal gravity and microgravity conditions. The principal components of this research are the calculation of the transient heat and fluid flow phenomena in levitation-melted specimens; the calculation and measurement of three-dimensional turbulent recirculating flow phenomena; and the prediction and measurement of pulsed flow phenomena in electromagnetically stirred melts.

Gold alloys and silver have proven to be suitable metals on which to measure electromagnetic flow. The molten spherical specimen will be about 10 mm in diameter. Temperatures in the range of 700 to 1500 K will be measured by an optical pyrometer to an accuracy of 0.5 percent of the reading. The temperature measurement rate will be 1 per second. Figure 9 schematically depicts the experimental layout.

Surface tension driven convection. - Materials processing involving solidification and crystal growth is expected to be dramatically improved in the microgravity of space. However, changes in the nature and extent of thermocapillary flows can cause deleterious fluid oscillations. Thermocapillary flow is fluid motions that are generated by the surface-tractive force induced by surface tension variation due to the temperature gradient along the free surface. Numerical modeling is not adequate to predict oscillations due to an inherent coupling among the imposed thermal signature, surface flow, and surface deformation. Therefore, to complete an understanding of the physical process and to develop an accurate numerical model, experimental data must be obtained in the extended low gravity environment. This project will supply the necessary data. The experiment consists of a container 4 in. in diameter and 2 in. deep filled with silicone fluid, see figure 10. The design can provide both a flat and a curved free surface which can be centrally heated either externally or internally. The cross section is illuminated by a sheet of light that is scattered by micron size alumina particles in the silicone oil allowing the observation of the resulting thermocapillary flows.

The liquid bulk temperature will be measured at six specified points using thermistors. The bulk temperature range will be from 298 to 473 K with a required accuracy of plus or $\pm$0.1 K. A full field surface temperature gradient measurement is specified using infrared thermography. The surface temperature range will be from 298 to 473 K with a required accuracy of $\pm$5 percent of the delta temperature (60 K). A surface temperature resolution of 1 mm^2 is needed. The desired set of temperature specifications include noncontact full field bulk measurements with accuracies comparable to thermistors, higher resolution quantitative thermography with accuracies greater than presently available, and two color full field infrared thermography to eliminate emissivity dependence.

Critical fluid light scattering. - The proposed experiment will measure the decay rates and correlation lengths of density fluctuations in xenon at its critical density as a function of temperature. This will be achieved by using laser light scattering (correlation spectroscopy) and turbidity measurements, see figure 11. The goal of the experiment is to measure the fluctuation decay rate and correlation length at temperatures very near to the critical temperature, which could be as close as 100 μK if the residual gravity level is low enough. Such experiments are severely limited on earth because the gravitational field causes large density gradients in the sample due to the divergence of the compressibility of the gas as the critical temperature is approached.

The experiment concept requires the automatic location, within 20 μK, of the critical temperature of xenon at its critical density. Light transmission and fixed-angle scattering intensities will be measured at controlled temperatures, within 3 μK, in the range 1 K to 100 μK above the critical temperature. The control system will calculate and store the turbidity and correlation functions at each temperature. These data will be used during postflight analysis to determine the density, fluctuation decay rates and correlation lengths near the critical temperature. Temperatures within the liquid and gas phase will be measured with thermistors with lock-in amplifiers. Precision and resolution will be in the vicinity of micro Kelvin. It would be desirable, although not very feasible, to have a noncontact three dimensional point measurement device with the above precision.

Pool boiling. - The goal here is to experimentally determine the effect of heat flux and liquid subcooling on nucleate pool boiling in a long term reduced gravity environment using Freon R-113 as the test fluid. An analytical study will be made of the onset of nucleate boiling, bubble growth and collapse, bubble motion, and heat transfer characteristics. Small thermocouples or thermistors will be located at various positions within the Freon chamber to measure the uniformity of the fluid ($\pm$0.22 K) and variations associated with the boiling process taking place on the heater surface. The test fluid temperature will range from 311 to 339 K and will need to be measured with an accuracy and a resolution of 0.06 K. Figure 12 illustrates the apparatus for this experiment.

Critical fluid viscosity measurement. - The purpose of the project is to produce archival viscosity data on xenon closer to its liquid-vapor fluid critical point than is possible in 1-g due to the strong density gradient arising from the singular compressibility of the fluid near the critical point and the hydrostatic head from gravity. The data will provide complementary results with the Critical Fluid Light Scattering project to test the mode coupling theory of critical phenomena and provide guidance to renormalization group theory development on dynamic critical point fluid behavior.

The apparatus concept (see figure 13) currently centers on a torsional viscometer with a filled 1 mm deep by 10 mm radius cylindrical fluid cavity in a bob suspended by a fine quartz fiber. The bob is excited into torsional motion by capacitance vanes and the viscous damping is recorded through amplitude decay by the same vanes. Magnetic bearings are used to eliminate nontorsional motions and maintain constant tension on the quartz fiber. The task requires a few micro Kelvin temperature controls and vibration isolation sufficient to approach the critical temperature to within 300 μK while measuring viscosities to 0.5 percent precision.

The temperature specifications for this project are the same as with the Critical Fluid Light Scattering project and the noncontact temperature desires are also the same.

SUMMARY OF RESULTS

Although the temperature needs of none of the 43 ground-based projects have been discussed, they cover many of the same discipline areas as the flight projects so that in general the needs of one set of projects can be used to represent those of the other. Many of the temperature requirements of both sets of projects can be completely satisfied with contact devices, thermocouples and thermistors, but a need has been shown for noncontact temperature techniques. As has been shown, the temperatures range from below ambient to those generated by combustion. Accuracies and precisions vary from a few degrees to a few thousandth of a degree. Extremely accurate point measurements are required in some cases while the full field temperature is desired if not actually measured. The spectrum of conditions for temperature in microgravity experiments possesses a challenge to the designers of temperature measuring instruments. Also it has been shown that it is desirable to have noncontact temperature measuring techniques so as not to interrupt the delicately balanced processes encountered when investigating effects of microgravity. The lack of noncontact type instruments for measuring accurate temperature, point and full field, has led investigators to by-pass the problem, but at the expense of more meaningful data.

TABLE I. - FLIGHT PROJECTS

Projects	Principal investigator/ affiliation	Lewis project manager Project scientist	Carrier
	Combustion science		
Solid Surface Combustion (SSCE)	Altenkirch/U Kentucky	Zavesky/Olson	Middeck; Spacelab
Particle Cloud Combustion (PCCE)	Berlad/UCSD	Siegert/Ross	(a)
Droplet Combustion (DCE)	Williams/Princeton	Haggard/Haggard	Middeck; Spacelab
Gas Jet Diffusion Flames (GDF)	Edelman/SAIC	Stocker/Stocker	GroundProgram
	Materials science		
Alloy Undercooling (AUE)	Flemings/MIT	Harf/Harf	(a)
GaAs Crystal Growth (GaAs)	Kafalas/GTE	Lauver/Lauver	GAS
Isothermal Dendritic Growth (IDGE)	Glicksman/RPI	Winsa/Winsa	MSL; Spacelab
	Fluid physics		
EMD Flow in Metals (EMDF)	Szekely/MIT	Harf/Harf	(a)
Surface Tension Driven Convection (STDCE)	Ostrach/CWRU,	Jacobson/Jacobson	Spacelab
Critical Fluid Light Scattering (CFLSE)	Gammon/U Maryland	Lauver/Wilkinson	MSL
Pooling Boiling (PBE)	Merte/U Michigan	Zavesky/ Chiaramonte	GAS
Critical Fluid Viscosity	Moldover/NBS	Lauver/Wilkinson	MSL
	Instrumentation		
Space Acceleration Measurement System (SAMS)	Chase/Lewis	Delombard/Chase	Middeck; Spacelab MSL
	Advanced technology development (ATD)		
Microgravity Fluids and Combustion Diagnostics (MFCD)		Santoro/Greenberg	
High-Temperature Furnace Technology (HTFT)		Rosenthal	
High-Resolution, High-Frame-Rate Video Technology (HHVT)		Metzinger/Butcher	
Reactionless Microgravity Mechanisms and Robotics (RMMR)		Rohn	
Vibration Isolation Technology (VIT)		Lubomski	
Noncontact Temperature Measurement (NCTM)		Santoro	
Laser Light-Scattering Instrument (LLSI)		Meyer	
	Space station multiuser facilities		
Modular Combustion Facility (MCF)		Thompson/Sacksteder	
Fluid Physics and Dynamics Facility (FPDF)		Thompson/Salzman	
Modular Containerless Processing Facility (MCPF)		Glasgow	

[a]To be determined.

TABLE II. - GROUND-BASED PROJECTS

Projects	Principal investigator/ institution	Lewis project manager/ project scientist
	Electronic materials	
CVD Silicon Deposition	Stinespring/Aerodyne	Glasgow/Santoro
Opto-Electronic Materials	Hopkins/Westinghouse	Glasgow/Duval
Crystal Growth	Duval/Lewis	Glasgow/Duval
	Combustion science	
Pool Fires: Modeling	Sirignano/UC Irvine	Salzman/Ross
Pool Fires: Preignition Process	Ross/Lewis	Salzman/Ross
Smoldering Combustion	Fernandez-Pello, Pagni/UC Berk.	Salzman/Olson
Particle Cloud Combustion	Berlad/UC San Diego	Salzman/Ross
Computational Studies of Flames	Oran/NRL, ONR	Salzman/Ross
Fuel Droplet Vaporization	Farrell, Peters/Wisc., GM	Salzman/Stocker
Flame Spreading Over Solids in Forced Flows	Olson/Lewis	Salzman/Olson
Flame Spreading in Liquid Pools	Ross/Lewis	Salzman/Ross
Complementary Activities	Lewis	Salzman/Olson, Ross Salzman/Sacksteder, Stocker
Radiative Ignition	Kashiwagi/NIST	Salzman/Friedman
	Fluid dynamics and transport phenomena	
Transport Processes In-House	Kassemi, Wilkinson/Lewis; Wang/NRC	Salzman/Wilkinson
No-Slip Boundary Condition	Pettit/Los Alamos	Salzman/Wilkinson
Thermodifffusocapillary Phenomena In-House	Chai, McQuillen/Lewis; Balasubramaniam/CWRU	Salzman/Chai
EM Driven Flow in Salts	Szekely/MIT	Salzman/Harf
Thermocapillary Convection	Neitzel, Jankowski/ U Arizona	Salzman/Chai
Pool Boiling	Merte/U Michigan	Salzman/Chiaramonte
Capillary Containment	Steen/Cornell	Salzman/Chai
Suppression of Marangoni Convection	Dressler/GWU	Salzman/Salzman
Capillary Convection	Yang/U Michigan	Salzman/Chai
Benard Stability	Koschmieder/U Texas	Salzman/Salzman
	Metals and alloys	
Bulk Undercooling Studies	Laxmanan/Lewis, CWRU; deGroh/Lewis	Glasgow/Glasgow
Metal Undercooling	Perepezko/U Wiconsin	Glasgow/deGroh
Channel Segregation	Hellawell/MTU	Glasgow/Chait
Macrosegregation of Alloys	Poirier/U Arizona	Glasgow/Chait
Liquid-Phase Sintering	German/RPI	Glasgrow/Santoro
Theory of Solidification	Davis/Northwestern	Glasgow/Chait
Microsegregation of Alloys	Tewari, Chopra/CSU	Glasgow/Glasgow
Whisker Growth	Hobbs/GWU	Glasgow/Westfall
Float Zone Modeling	Young/Akron	Glasgow/Chait
Mg-Alloy Composites	Cornie, Szekely/MIT	Glasgow/Harf
Process Modeling	Chait/Lewis	Glasgow/Chait
	Glasses and ceramics	
Slip Casting Colloidal Suspensions	Debenedetti, Russel/Princeton	Levine/Fiser
Combustion Synthesis	Behrens/LANL, Hurst/Lewis	Levine/Hurst
Foaming in Glass	Hrma/CWRU	Levine/Jaskowiak
Powder Agglomeration	Cawley/OSU	Levine/Fox
Phase Separation	Hyatt/Lewis	Levine/Levine
Single-Crystal Fiber Growth	Levine/Lewis	Levine/Levine
	Physics and chemistry experiments (PACE)	
Electrohydrodynamics	Saville/Princeton	Salzman/Chai
Critical Point Viscosity Measurement	Moldover/NIST	Salzman/Wilkinson
Mass Transport	Dewitt/U Toledo	Salzman/Chai

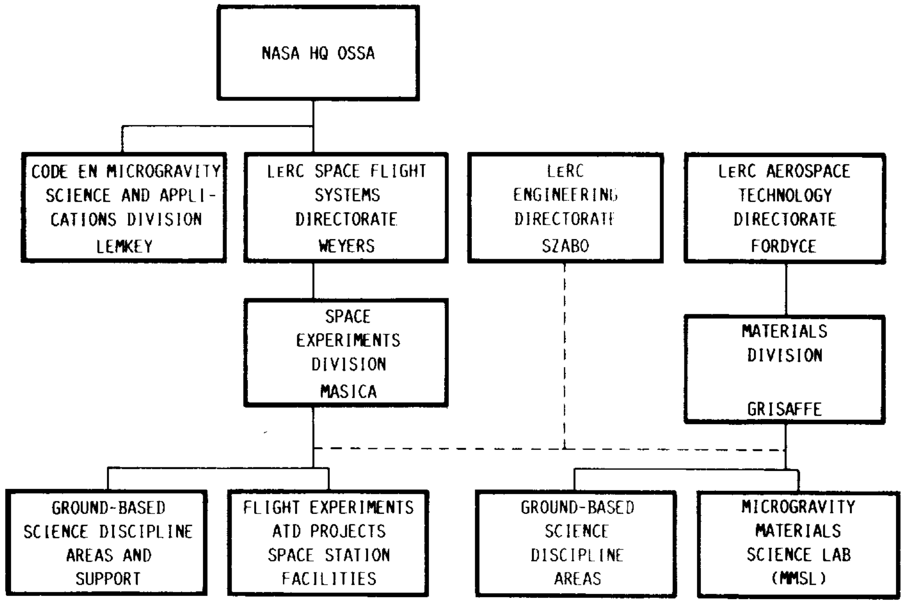

FIGURE 1. - LeRC MICROGRAVITY SCIENCE APPLICATIONS PROJECT MANAGEMENT STRUCTURE.

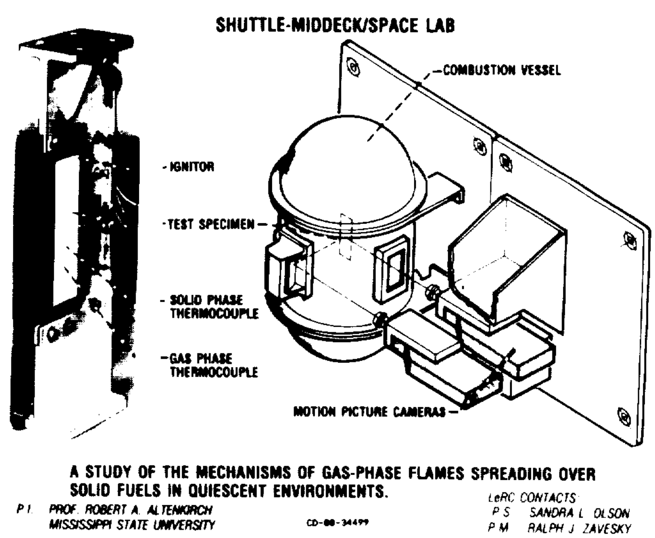

FIGURE 2. - SOLID SURFACE COMBUSTION EXPERIMENT.

A STUDY OF FLAME PROPAGATION AND EXTINCTION LIMITS FOR UNIFORM AND QUIESCENT MIXTURES OF PARTICULATE FUELS IN AIR

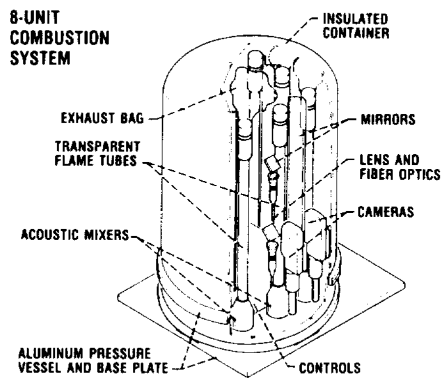

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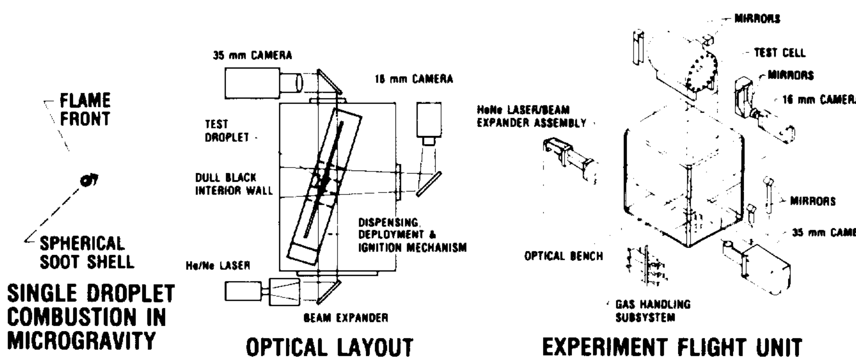
FIGURE 3. - PARTICLE CLOUD COMBUSTION EXPERIMENT - SPACE SHUTTLE-BAY.



DEVELOPMENT AND VERIFICATION OF A MATHEMATICAL MODEL FOR DROPLET BURNING RATES AND CRITICAL DROPLET EXTINCTION DIAMETERS

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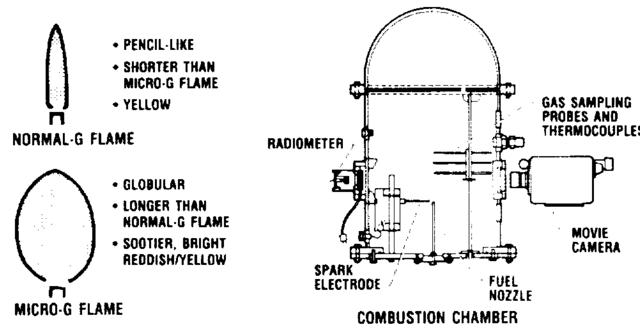
FIGURE 4. - DROPLET COMBUSTION EXPERIMENT - SPACE SHUTTLE-MIDDECK, SPACELAB.



A STUDY OF FLAME-LIMITING MOLECULAR DIFFUSION PROCESSES IN THE ABSENCE OF BUOYANCY DRIVEN CONVECTION

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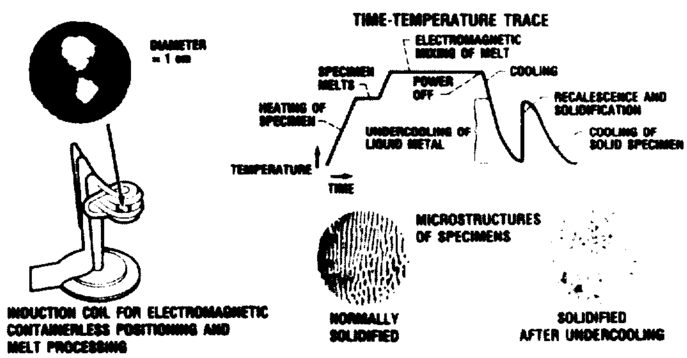
FIGURE 5. - GAS JET DIFFUSION FLAMES EXPERIMENT.



A STUDY OF THE EFFECTS OF PROCESSING IN THE ABSENCE OF A CONTAINER AND CONVECTION ON THE STRUCTURE AND PROPERITES OF METAL ALLOYS
(FIRST FLIGHT JANUARY 12-18, 1986; MSL-2, STS 61-C)

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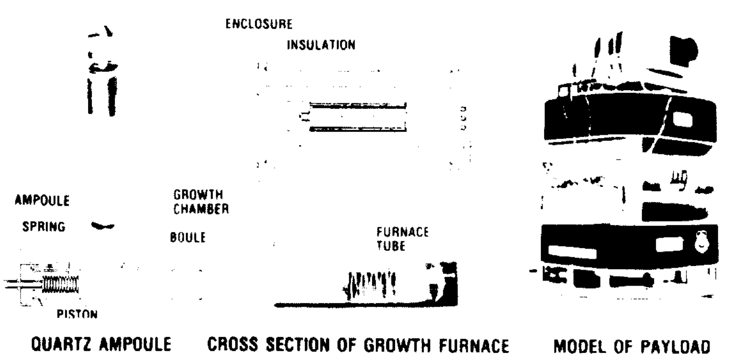
FIGURE 6. - ALLOY UNDERCOOLING EXPERIMENT - SPACE SHUTTLE-SPACE STATION.



A COMPARATIVE STUDY OF THE INFLUENCE OF BUOYANCY DRIVEN FLUID FLOW ON GaAs CRYSTAL GROWTH IN LOW-G AND SELECTED NORMAL GRAVITY ENVIRONMENTS

JOINTLY FUNDED: GTE, AFML, NASA

P.I. JAMES A. KAFALAS
GTE LABORATORIES, INC.

CD-86-30632

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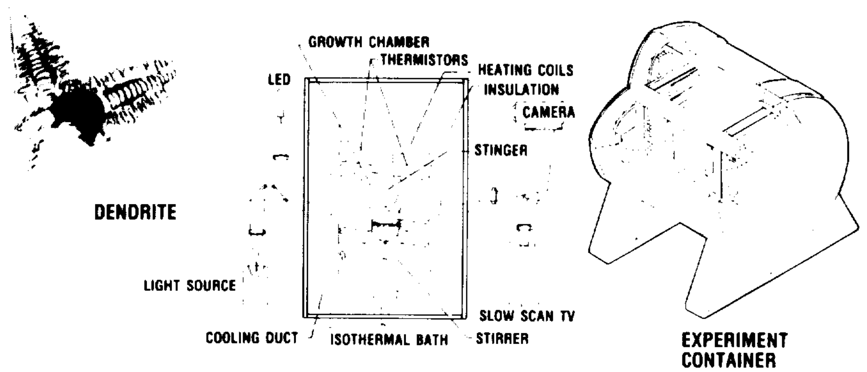
FIGURE 7. - GaAs CRYSTAL GROWTH EXPERIMENT - GET AWAY SPECIAL PAYLOAD.



DEVELOPMENT AND VERIFICATION OF A MATHEMATICAL MODEL RELATING DENDRITE GROWTH RATES AND TIP RADII TO TIP UNDERCOOLING

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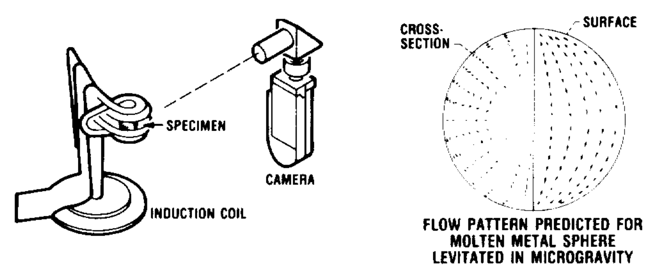
FIGURE 8. - ISOTHERMAL DENDRITIC GROWTH EXPERIMENT - SPACE SHUTTLE, MSL.



A STUDY OF THE CHARACTERISTICS OF ELECTROMAGNETICALLY DRIVEN FLOW GENERATED IN MOLTEN METALS IN THE ABSENCE OF GRAVITY INDUCED CONVECTION

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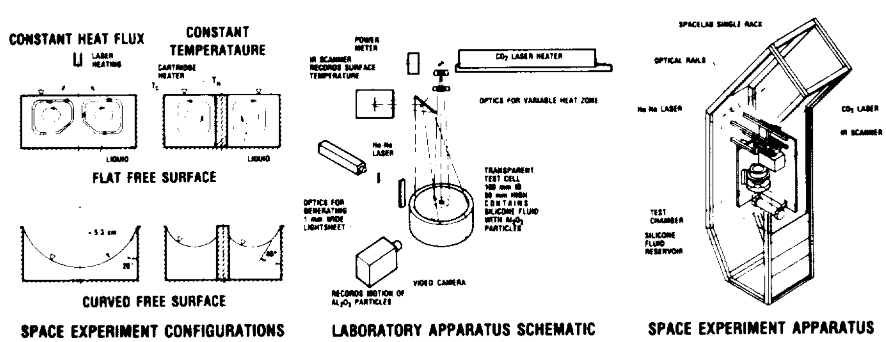
FIGURE 9. - ELECTROMAGNETICALLY DRIVEN FLOW EXPERIMENT - SHUTTLE OR SOUNDING ROCKET.



NUMERICAL DEVELOPMENT AND EXPERIMENTAL VERIFICATION OF THERMOCAPILLARY FLOW IN REDUCED GRAVITY

P.I.: PROF. SIMON OSTRACH
PROF. YASUHIRO KAMOTANI
CASE WESTERN RESERVE UNIVERSITY

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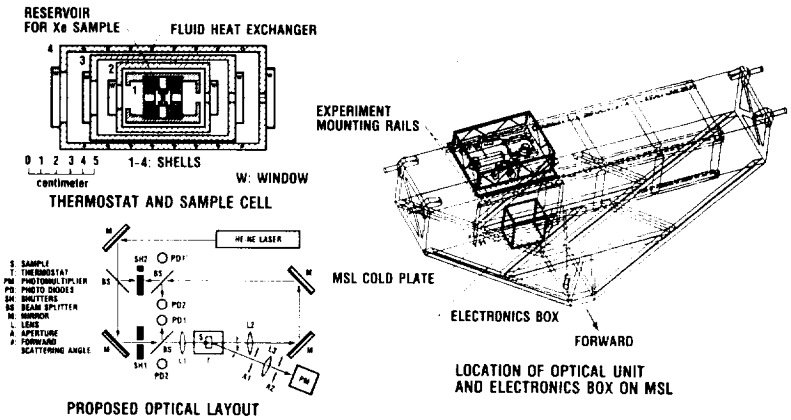
THOMAS P. JACOBSON

FIGURE 10. - SURFACE TENSION DRIVEN CONVECTION EXPERIMENT - SPACELAB.



EXTEND LIGHT SCATTERING MEASUREMENTS OF XENON TO TEMPERATURES CLOSER TO THE CRITICAL POINT BY REDUCING DENSITY STRATIFICATION IN THE SAMPLE

P.I.: PROF. ROBERT W. GAMMON
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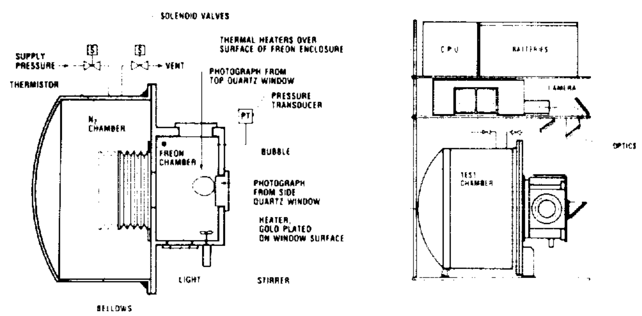
FIGURE 11. - CRITICAL FLUID LIGHT SCATTERING EXPERIMENT - SHUTTLE-MSL.



TEST CHAMBER SCHEMATIC **SET-UP OF EXPERIMENT IN CONTAINER**

STUDY OF HEAT FLUX AND LIQUID SUBCOOLING EFFECTS ON THE ONSET OF NUCLEATE POOL BOILING IN REDUCED GRAVITY

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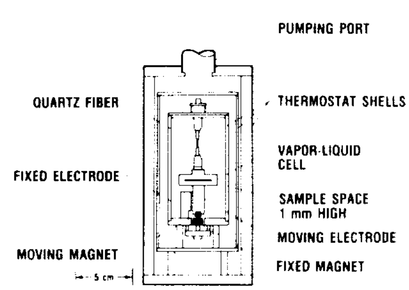
P.M.: RALPH J. ZAVESKY

FIGURE 12. - POOL BOILING EXPERIMENT - GET AWAY SPECIAL PAYLOAD.



VAPOR-LIQUID VISCOMETER

MEASUREMENT OF A PURE FLUID'S VISCOSITY AT 2 ORDERS OF MAGNITUDE CLOSER TO THE LIQUID-VAPOR CRITICAL POINT THAN IS POSSIBLE ON EARTH. THE DATA WILL VERIFY THE MODE-COUPLING THEORY AND GUIDE THE DEVELOPMENT OF THE RENORMALIZATION GROUP THEORY OF DYNAMIC CRITICAL PHENOMENA.

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FIGURE 13. - CRITICAL FLUID VISCOSITY MEASUREMENT EXPERIMENT.