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AUTOMATED DIRECTIONAL SOLIDIFICATION SYSTEM FOR SPACE PROCESSING

FINAL REPORT
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FOREWORD

The Automated Directional Solidification System for the Space Processing program was initiated under the Advanced Applications Flight Experiment (AAFE) series of Engineering Model level of flight instrument and equipment developments, as a result of a response to an Announcement of Opportunity in the spring of 1974. The responsibility for contracting and technical management was transferred from the NASA-Langley AAFE Program Office to the Marshall Space Flight Center as part of their Materials Processing in Space Program under which Contract NAS8-31536 was initiated on June 30, 1975 with the General Electric Company.

Many people in NASA, Grumman and General Electric have participated and aided in the development and flights of this apparatus. While there is a risk in citing some and omitting others, it is appropriate to mention and thank the following as having had a particularly high degree of involvement and to offer the author's apologies to all those who were helpful but not specifically named.

NASA:	Dr. James H. Bredt, Roger Chassay, Lloyd Gardner, Mary Helen Johnson, John Noel, Robert L. Parker and Fred Reeves.
Grumman:	Drs. David J. Larson, Jr. and Ron G. Pirich who were the Investigator's using the apparatus in their work.
General Electric:	Tony Coppa, Arno Gatti, Bob Grosso, Bob Locker, Mike Noone, Howard Semon, and Bud Wagner.

ABSTRACT

A five and a half year program to develop, test and use an Automated Directional Solidification System under low gravity conditions aboard a sounding rocket is summarized in this report. The program was successfully structered and staffed to simultaneously provide an apparatus comparable to the best available terrestrially for research on directional solidification of metals and alloys while meeting the many requirements for the performance of space flight experiments.

While the initial objectives of the program were aimed at developing an engineering model of the proposed system, the final results include the supplying of the following to NASA:

1. Two single furnace prototype units for laboratory use in preparing reference samples and defining the desired operating conditions for the flight test units.
2. Two complete flight qualified units, each of which includes four individually controllable furnaces capable of operation to as high as 1600°C, with operating and control panels, associated cables, tools and some spare supplies.
3. Drawings, Operating Manuals, a User's Computer Program, and reports and papers describing the work and equipment.
4. Subsequent to the initial completion of the above primary aspects of the program in early to mid 1977, several additional smaller tasks were undertaken to adapt the units to the specific needs of the NASA selected and supported Principal Investigators and to support the actual flight test operations. This included providing additional circuitry to handle the extensive data available from these units as well as keeping the instruction manual and main drawings and diagrams updated.

The above items are briefly reviewed in this report but the actual equipment and extensive support documentation appear to serve even better as a final report than any additional document such as this one that would be redundant to them.

INTRODUCTION

Directional solidification of various materials but particularly of eutectic metallic alloys has been under extensive investigation for some 2-3 decades. Most of the work is performed at relatively slow cooling rates which are primarily dictated by the heat transfer conditions which are in turn closely associated with the specimen composition, sizes and properties. During the late 1960's Cline and Livingston of the General Electric Research Laboratory performed high speed solidification of small diameter samples of lead-tin alloys as well as of other materials. Their work served as a basis for thinking that directional solidification of useful sizes of specimens could be performed in as short a time as the few minutes available on a sounding rocket rather than having to wait for the opportunity to perform such experiments in space on vehicles that would offer longer periods of time for undisturbed low gravity experiments.

The desirability for performing directional solidification under low gravity conditions which would reduce the chances of convection related disturbances during the solidification process had been previously expressed. In fact, some preliminary demonstrations and experiments had been identified if not already designed and performed on the Apollo and Apollo - Soyez manned space flight. These led to the desirability of being able to perform more sophisticated, carefully controlled experiments in a manner closely approximating the terrestrial state-of-the-art equipment.

The 1974 Announcement of Opportunity for additional experiments to be developed under the Advanced Applications Flight Experiment (AAFE) program provided the vehicle to propose the design of such equipment. This resulted in the program starting on June 30, 1975 described in this report.

SCOPE OF WORK

The scope of work including the Objectives and Statement of Work are reproduced here to provide an indication of the various aspects of the program which were contemplated, performed and very successfully achieved, including two flights on sounding rockets:

I. OBJECTIVE: The Objectives of this contract are:

1. Design, build and test an engineering model of a furnace system that will provide an operational system with broad and general applicability to a wide range of eutectic, crystal and other systems of interest in the field of directional solidification. The system will incorporate the ability to use modular elements, including furnace units, crucible arrangements, and coolants to cover the entire range of melt compositions and solidification temperatures of practical interest. The basic system is expected to consist of an assembly of four directional solidification units mounted within a common frame. Each unit will be made up of specimen and heating/cooling element module. The specimens will be fixed with respect to the frame. The heating/cooling element will be capable of translating along the length of the specimen.

2. Design and build a single furnace unit of the engineering model for laboratory testing at NASA-MSFC.

3. Develop analytically a matrix of possible experiment operating conditions in relation to various potentially interesting directionally solidified materials.

4. Operate the equipment and conduct experimental simulation studies to provide data and experience that will specify the performance of the design when translated to the space environment.

5. Predict the operation in space based upon analysis and experimentation. Identify problem areas that remain unresolved by ground evaluation that must be tested or measured in space.

6. Define flight experiments of varying duration from several minutes to several hours that will demonstrate and prove the performance of the design and apparatus concept for various materials.

II. STATEMENT OF WORK: The statement of work covers an eighteen month period in which the contractor shall accomplish the tasks shown below. In addition the contractor shall deliver to the COR one set of viewgraphs (1 reproducible copy and 1 transparency) used in all presentations.

TASK 1: Design optimization

a) Accumulate a list of materials with scientific and technical interest in the field of directional solidification.

b) Develop the mathematical expressions to describe the inter-relationships between the desired operating requirements (capabilities) e.g. furnace parameters, crucible materials, sample melting point and other physical properties and the system constraints in terms of design criteria, e.g. sample quantities, flight time, thermal gradients, power, weight and volume for a wide range of conditions.

c) Program the mathematical model for computer solution and exercise the model to identify performance limiting situations. Use the model to design and optimize the operation of the experimental equipment.

d) Demonstrate the applicability of the analysis to design and predict the operation of chosen experiments.

TASK II: Design, Fabrication and Testing of Furnace System

a) Provide drawings, sketches, and specifications as required and appropriate, and construct a single furnace element laboratory model and a four furnace element engineering model of an automated directional solidification furnace. The system will incorporate the ability to use modular elements, including furnace units, crucible arrangements, and coolants, to cover the range of materials designated of interest in Task 1.

b) System design and analysis and the development tasks required to design, construct, assemble and checkout the equipment will be performed.

c) Design considerations will include: size (approximately 35-40 cm in diameter by 40-50 cm in length), weight (approximately 20 kg), capability to maintain an inert atmosphere at a partial pressure, telemetry connections, ability to survive leads up to 25 g's, versatility of power requirements (28 volts and/or 110 volts), and maximum operating temperature or 1600°C.

d) The design will consider redundancy, ability to accommodate a variety of specimen sizes and shapes, and innovation designs.

TASK III: Experimental Operation

a) Experimental programs shall be conducted to determine if the furnace thermal conditions are such to produce optimum solidification conditions for the sample materials. This will consider the shape of the solidification interface as well as the eutectic structure as a function of solidification rate and temperature gradient.

b) Experimental programs shall be conducted to assess effects of sample size, crucible materials, quenching rates, etc.

c) Experiments and evaluations shall be conducted upon the equipment used in these ground tests to demonstrate the ability to sustain space flight induced environments:

d) Experiments shall be done under conditions to simulate weightless conditions or to minimize gravity as much as possible.

TASK IV: Design Iteration and Advanced Design

As the Task II design matures, and experimental data becomes available from Task III, the contractor shall update the mathematical model of Task I. The model will be exercised to provide refined and additional design data for updating and finalizing Task II and III efforts. The contractor shall apply the refined and improved model and methods to the generation of design criteria in support of conceptual design of advanced directional solidification systems.

TASK V: Delivery of Single Furnace Prototype Unit

A prototype single furnace laboratory unit with components, controls and drive system will be furnished to NASA-MSFC for their usage and evaluation. This will include all engineering drawings and specifications for the furnace, controls, and drive system.

TASK VI: Space Experiment Planning Task

The contractor will develop the necessary planning documents, drawings, and reports to define a flight test program directed toward demonstrating the performance of the equipment, and the achievement of the objectives of improved solidification structure and properties, and rapid quenching rate.

The program planning will emphasize unmanned short duration rocket flights because of the early opportunity for that type of flight, and its potential cost effectiveness through reusable payloads. The basic planning task will include the conceptual design efforts to translate the engineering ground test model to a flight-type experimental facility of minimal sophistication consistent with the requirements of demonstrating the future performance. The designs and planning shall reflect the constraints presented by vehicle payload weight and volume, power and other services, data acquisition -- transmission and recovery. They shall sustain the environmental conditions created by powered and coasting flight, and satisfy the physical interfaces required by the payload recovery sub-system and its operation and all operational and environmental conditions imposed by the flight test range.

TASK VII: Delivery of Operating Engineering Models to NASA-MSFC

Two (2) complete operating engineering models of the equipment developed in this program including the operating furnace system with all custom designed components, controls, and drive system shall be furnished to NASA-MSFC for their usage and evaluation in preparing directionally solidified materials. This will include all engineering drawings and specifications for the furnace, controls, drive system and configurations which permit adaptability to a variety of specimen sizes and shapes.

COMMENTS ON THE PROGRAM

1. Program Organization and Philosophy. From the start it was the objective of the program management to provide a balance between satisfying the needs or desires of the P.I. and the needs and desires of the spacecraft operators. Furthermore their needs were to be met with a high quality, well instrumented unit which would provide a wide range of operational capability.

2. Conceptual Design

For several reasons the equipment design involved an enclosed design but with means for providing additional chilled coolant, gaseous atmosphere, power and signals from instruments to the telemetry system. Among the reasons for the enclosed design were for (a) the possibility of a launch from Wallops Island with a subsequent recovery from the Atlantic Ocean, (b) the probable need for an inert or reducing atmosphere for the research samples being processed, and (c) safety, EMI, etc. related to the high temperature equipment and specimens both with respect to other experiments and for the eventual possibility of operating the experiment on the Space Shuttle.

Other aspects of the conceptual design approach were then defined and are listed in Table 1.

3. Results of the Program

It is believed that all aspects of the program have been very successfully met as follows:

a) Prototype furnaces (Figure 1) were delivered and are in use at MSFC and Grumman for obtaining ground based data. They also initially served the purpose of providing a confirmation of the design and operating conditions that should be provided to prepare unidirectionally solidified specimens satisfactorily.

b) A computer program was prepared by A. P. Coppa and provided as a supplement to the Interim Summary report in July 1976 to assist the users in selecting suitable operating parameters for their experiments in this apparatus. It was titled "Users Manual for the Steady State Interface (SSI) Computer Program". Arrangements to operate the program on MSFC computers were also supported.

TABLE 1

AAFE OBJECTIVES FOR DEVELOPMENT OF AUTOMATED DIRECTIONAL SOLIDIFICATION SYSTEM

- FULLY AUTOMATED OPERATION
- MAXIMUM OPERATIONAL VERSATILITY
- MULTI SPECIMEN CAPABILITY
- CAPABLE OF ACCOMMODATING A WIDE RANGE OF MATERIALS
- CAPAXBLE OF EMPLOYING SEVERAL CRUCIBLE MATERIALS
- OPERATING TEMPERATURE UP TO 1600^{o}C
- FURNACE DRIVE RATES 0.1 to 5 CM/MIN
- SPECIMEN SIZE 2-5 MM DIAMETER UP TO 10 CM LONG
- OPERATIONAL TIME 3-5 MIN'S "ZERO-G"
- MULTI-FLIGHT CAPABILITY
- AMBIENT ATMOSPHERE CONTROL
- EXTENSIVE INSTRUMENTATION FOR BOTH EXPERIMENT AND EQUIPMENT DATA GATHERING

c) Two complete sets of experimental equipment were provided. One is shown in Figures 2 and 3 in the assembled or stacked mode and in the unstacked mode, respectively. In the latter situation, provisions for setting up the experimental parameters, servicing, and testing the system prior to stacking it for flight are provided through the modular design and use of short connecting cables. The control panel also provides some special features for the P.I.'s usage in setting up and checking out the equipment more rapidly and easily without having to wait for the normal slow carefully controlled traverse of the furnaces up and down, etc.

d) An extensively illustrated and detailed "ADSS, Operating Instruction Manual" prepared by R. J. Locker in May 1977 and Revised in June 1978 was provided (in numerous copies). It contains sections of primary interest to the P.I., to the spacecraft operator and supplementary information on servicing, parts lists, drawings, etc.

e) SPAR-AFT Mounting Plate - In order to interface the extensive data capabilities of the ADSS Unit with the White Sands telemetry system and in preparation for the P.I. experiment, some additional components (primarily commutators for data signals) and circuitry were required. Since there was insufficient space available inside of the experiment container and since these were likely to be needed only on SPAR flights, it was decided to provide a special mounting plate for the ADSS experiment and these components, which is shown on Figure 2.

Flight Tests

One of the units was flown on October 17, 1979 (as Experiment 76-22) of the SPAR VI payload. The results and related supporting work are well described in Grumman Aerospace Corporation Report PE-602 July 1980 by Ron G. Pirich and David J. Larson, Jr.

The other unit is expected to fly on SPAR IX about mid-January 1981 with additional samples furnished by Dr's Pirich and Larson.

Some further flights are being contemplated but are not sufficiently defined to permit listing them here at this time.

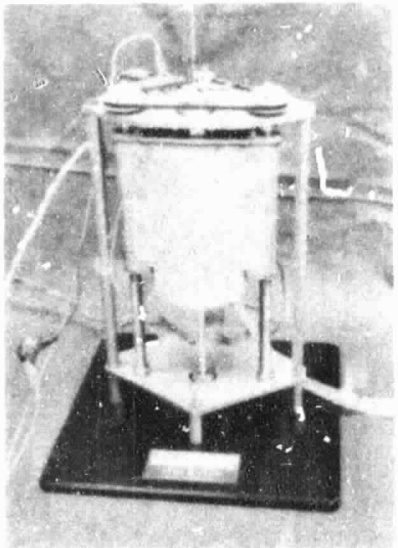

Figure 1. ADSS Prototype Furnace

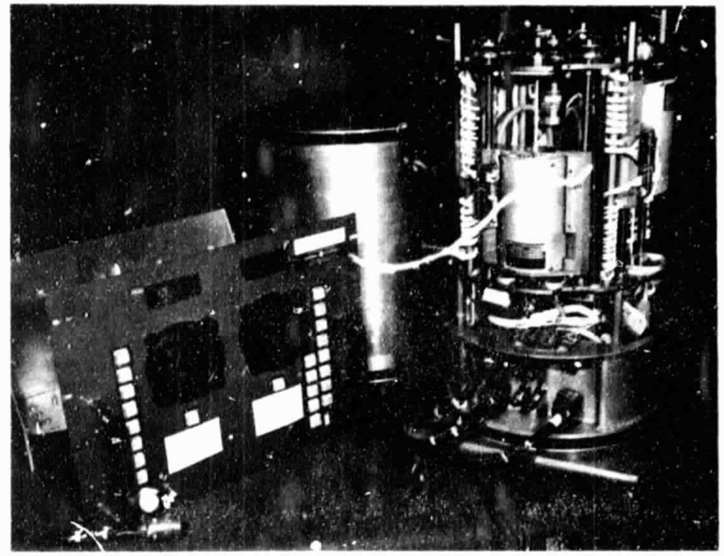

Figure 2. ADSS in Stacked Configuration. The flight unit is approximately 15" dia. x 24" high and weighs about 100 pounds.

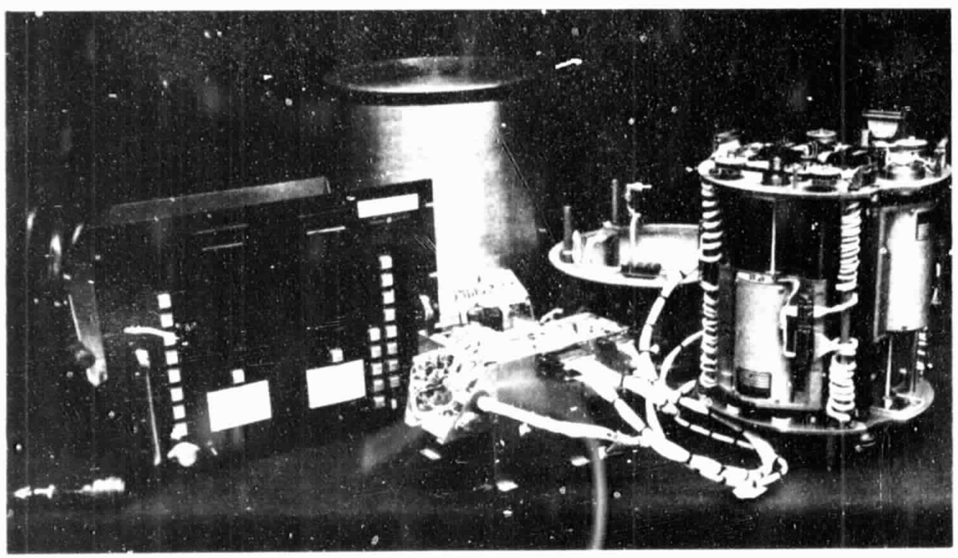

Figure 3. ADSS in Unstacked Condition for Setting Experiment Conditions

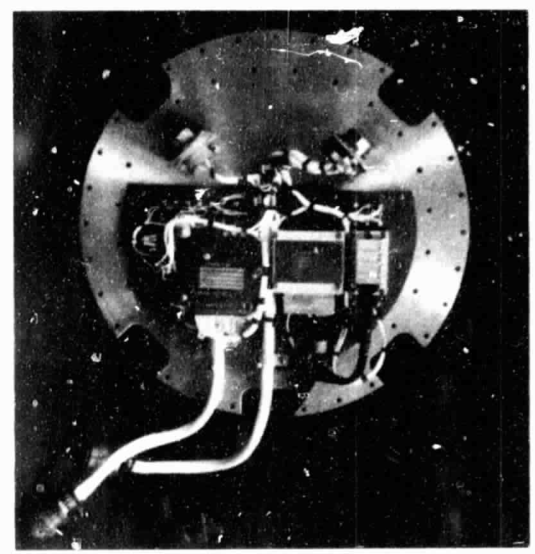

Figure 4. Adapter Plate for Use with SPAR Flight