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Materials Processing in Low Gravity

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1.0 Introduction

This report covers the continuation of the Materials Processing in Low Gravity Program in which The University of Alabama in Huntsville worked with scientists and engineers at Marshall Space Flight Center to design, implement and perform low gravity experiments with various scientific investigators in materials processing science through March 15, 1989. The facilities used in these short duration low gravity experiments include the Drop Tube and Drop Tower at MSFC, and the KC-135 aircraft at Ellington Field. The F-104 aircraft at Dryden Air Force Base was not used in this phase of the program.

During this program the utilization of these ground-based low gravity facilites for materials processing has been instrumental in providing the opportunity to determine the feasibilty of either performing a particular experiment in the microgravity of Space or continuing on-going activities which may have been delayed due the absence of shuttle flights during this contractual effort.

2.0 Tasks Accomplished

2.1. In collaboration with scientists from MSFC and industry, UAH has defined, developed, and conducted materials processing experiments in low gravity using the Drop Facilities at MSFC and the KC-135 aircraft at Ellington Field. This effort has included the defining of experimental requirements and equipment, experiment-facility integration requirements, building/assembling the necessary experiment apparatus, and conducting experiments which will contribute to the knowledge base for commercialization of materials processing in low gravity. UAH has also performed the logistical support needed to execute the experimentation, and the necessary sample preparation, metallography analysis/interpretation and physical properties measurements of processed samples. UAH has interfaced with designated MSFC scientists and project representatives who will provide Center policy, programmatic requirements and goals, priorities, and scientific and technical advice.

2.1.1. All ground based facilities have been very productive during the duration of this contract. The Drop Facilities at MSFC are manned daily to perform drop experiments, build up experimental hardware for drops, and provide maintenance on existing instrumentation. Dr. Mike Robinson has provided the most leadership for MSFC in over-seeing this facility. Tom Rathz is currently in charge of UAH activities at the Drop Facilites and works quite closely with Dr. Robinson in meeting scientific objectives of the facilities.

The KC-135 missions have occurred approximately eight times during the year. Scheduling of the aircraft is performed by Dr. Robert Shurney of MSFC and the UAH personnel adhere to that schedule. Slippages due to aircraft down-times are the major reasons for any cancellations in scheduled aircraft experiments.

Current experimental hardware which is being used still includes the following:

DROP TUBE: Electromagnetic Levitation Furnace.
Electron Beam Furnace.

DROP Tower: Critical Point Wetting Experiment
High Temperature Vacuum Furnace

KC-135: Advanced Directional Solidification Furnace (ADSF)
Isothermal Casting Furnace (ICF)

In addition some additional funds were provided under this contract to transport a Tube Welder Experiment provided by Richard Poorman of MSFC (and in the beginning provide assistance in performing low G experiments on the KC-135). UAH has also performed KC-135 support for a liquid nitrogen quench experiment for Dr. Don Frazier of MSFC. The results of this experiment were inconclusive at the time, but does deserve a closer look as a low G experiment which can benefit from KC-135 experimentation. In addition we have assisted in flying a polymer directional solidification experiment on the KC-135 designed and built by Ben Goldberg of MSFC/EH Laboratory.

2.1.2. As an example of the progress made in productivity of the Drop Tube, the chart below lists the number of drop tube experiments made at the facility during FY88.

DROP TUBE PRODUCTIVITY

MONTH	DROPS
10/87	48
11/87	55
1/88	24
2/88	40
5/88	85
6/88	63
8/88	64
9/88	25
TOTAL	404

Having experienced personnel and no long down times as has occurred in previous years, has made a difference in productivity. The months in which no data are shown were months when either equipment break-down or testing occurred or on occasion, testing and installation of new equipment on the facility was necessary.

The total number of drops is also affected by the number of users who want to use the facility. As an example, during the time period above, the users were Vanderbilt, University of Alabama in Birmingham, North Carolina State University, and MSFC. Vanderbilt is the major user of the facility. Their experiments have been both scientific and commercial. In addition several students have received their Ph.D. degrees from Vanderbilt using data from the Drop Tube experiments. The most notable are Dr. Mike Robinson and Dr. William Hofmeister. They are also current users, permitting good interaction between MSFC facility requirements and scientific needs.

All current commercial customers use the facility through the Vanderbilt Consortium. Allied Chemical, Armco, and Lockheed have used the facility during FY88, with Allied by far the major sponsor of research at the facility.

A major concern exists in how to really attract a good balance of users. In anticipation of potential small business participation from commercial interests, I gave a presentation at a SBIR focused seminar in Mobile, Alabama on opportunities in materials processing in low gravity. The audience was so diverse that I am not sure what impact these types of presentation can have in generating interest in the use of the facilities. I believe that the workshop or seminar is a good format, but a more focused audience would certainly be more productive.

2.1.3 The Drop Tower has begun to become more productive during the latter part of this contractual period. Mr. Jeff Sinex has been placed in charge of the facility and although he is new to this type of operation, he has performed well.

Over the last two years, several major repairs to the tracks have been performed to eliminate any accelerations during the drop and the nose section of the drag shield was reinforced. Some attempts were made to modify the catch tube's air flow pattern to ameliorate the maximum G's at the end of the drop; however, either the drag shield hit with a thump or it bounced several times. Either occurrence was undesirable, therefore we ended up with partial air flow to be in the middle. As addressed later on, we have made progress in data acquisition for Drop Tower experiments.

As listed above the two experimental packages currently being used at the Drop Tower are the Critical Point Wetting (CPW) and the High Temperature Vacuum Furnace (HTVF). Dr. William Kaukler is the principal investigator for the CPW and Dr. M. K. Wu and Dr. Mohri are the P.I.'s for some solidification experiments for the HTVF. During this period we have brought the Drop Tower production up to around 20 official drops, which is the most in one year for quite some time. This does not include several test drops for checking out particular components of an experiment package or the drag shield itself. We do not make any more drops than necessary due to several factors: the facilities are worn and personnel safety procedures for the drop preparation and re-lifting the drag-shield. This takes several hours and up to 4 or 5 people are tied up during various portions of the drop. Also due to vibration within the building during the drop, the drop tube experiments cannot function. Consequently we do utilize some staff for both experimental facilities. Tom Rathz, as primary supervisor for the facilities, maintains the scheduling of personnel for these occasions.

2.1.4. The KC-135 activities have also been quite active during this contract period. For this task we have been primarily concerned with experiments that have been performed with the ADSF and the ICF furnaces. Scientific investigators for these furnaces include many collaborations that Dr. Pete Curreri has established with the University of Alabama in Tuscaloosa, Rockwell

International, and UAH. In collaboration with Mr. Jimmy Lee at MSFC/M&P Laboratory we have processed a number of superalloy samples in conjunction with his collaborators from Pratt & Whitney and Cleveland State University.

The Vanderbilt Consortium has flown only two missions on the KC-135, using the ADSF in both cases. Guy Smith worked with Dr. Tony Overfelt and his collegues in a number of ground-based studies to prepare for the parameters needed in flight. We have not heard from them since the last flight in terms of results or future interests. This suggests that results from these types of experiments may not be as easily understood in terms of what goals are set for KC-135 experiments. For instance if an experimenter anticipated the type of data obtained is a space-based experiment or if he under-estimates the work required to interpret the directional solidification results properly, then the utility of the KC-135 as an experimental platform may be received negatively. Perhaps this indicates that the program should provide a better understanding of what experimental results can be achieved in the KC-135 environment.

2.2. UAH has developed procedures delineating the objectives, test sequence, operational timeline, etc., prior to each experiment or experiment series, This includes performing ground-based checkouts of experiment apparatus and support systems, both for pre-experiment/flight and ground control. UAH has also installed and tested suitable apparatus in the facilities in order to provide the appropriate processing conditions required for the experimental work, recorded and analyzed experiment apparatus operation parameters and thermal profiles as appropriate to interpret results of the experiments. For this work UAH used existing equipment such as the E-beam furnace and the electromagnetic levitation furnace at the Drop Tube.

2.2.1. UAH personnel have continued work on performing tests and check-outs on all facilities as part of the facilities requirements. The Drop Facilities need extensive mechanical and electrical preventative maintenance, which UAH is not authorized to perform. SSL does provide technician support for this activity. This arrangement works well, since he can interface more easily with MSFC facilities and supply personnel.

2.3. Where required UAH has formulated written scientific and/or engineering reports for each experiment and/or experiment series. These reports were augmented with metallurgical reports where appropriate and were provided on a timely basis for internal program use. No reports or publications intended for distributions to other organizations or individuals included data furnished to NASA with restrictive legends by third parties.

2.3.1. After the experiments are performed, each scientific investigator for each facility or experiment receives their samples, the data derived from each experiment, and any additional comments which might assist in the interpretation of the experiment. For the Drop Tube this data set include pyrometric data, pressure measurements, and electrical parameters effecting the molten droplet. For the Drop Tower this data include acceleration profiles, temperatures, and other pertinent parameters. For the KC-135 experiments the data includes strip charts and computer data files with temperature, acceleration, and position of sample.

2.4. UAH has provided consultation, expert interpretation of experiment results of metallurgical and chemical processes, expert analysis and interpretation of optical records taken during low gravity experiments, and recommendations for research tasks being conducted under this contract.

2.4.1. This activity has in general been performed upon request from other groups using or wishing to use the ground-based facilities. Both Guy Smith for the KC-135 operations and Tom Rathz for the Drop Facilities have responded to numerous requests about particular features of performing experiments in those facilities. Dr William Kaukler has also assisted in responding to outside requests for information about use of the facilities or general information about experimentation in low gravity. In addition, we have received many visiting groups at the Drop Facilities which have been escorted through by Public Affairs Office at MSFC.

Guy Smith has provided some expert advise in the fabrication of furnace cores to a number of groups who are building furnaces. This includes groups like Wyle Labs in building their Video Furnace and the Rapid Melt/Rapid Quench Furnace. His expertise has developed over the years and it continues to be beneficial to the NASA MPLG program in a number of different ways. He has also been able to train student workers in the art of winding the furnace cores such that we are able to provide assistance when needed. A three-zone DC furnace controller using a microprocessor controller has been designed and implemented. Unfortunately the system uses Hexfets for optimal control and only works up to 30 volts DC. Hence our intended application using 110 VDC was not workable; however, it is being submitted as a new technology item to the NASA Technology Utilization Office.

2.4.2. In general other than tour groups visiting the Drop Facilities, we have not been requested by too many outside groups to provide expertise on low gravity materials processing. Due to the nature and the diversity of the many experiments we perform at the various facilities, we feel that we should be more beneficial to the program than we currently are. An accumulation of knowledge from building many experimental packages at the various facilities is certainly useful in designing a scientific experiment for space, that would benefit from preliminary experiments at any of the ground-based facilities. It would appear from our perspective that the many programs initiated by NASA for new hardware do not seem to follow a master plan. If such a plan existed it would certainly make it easier for groups such as ours to make inputs into the role that the ground-based facilities can play in the various materials processing programs.

2.4.3 Task 2.5, as stated below actually prohibits us from making presentations at technical conferences concerning any scientific work being performed at the facilities, without the scientific investigator being involved. In order not to show any indication of bias by being part of some experiments that we run at the facilities, we have not made a substantial effort to become part of a particular research team. Therefore we are basically open with everyone.

However; as part of a university research organization, we are often requested to attain more refereed publications. Consequently we are frequently encouraged to find ways to publish without violating the philosophy of Task 2.5. We are currently working on idesa to fulfil these needs. They would certainly be beneficial to the overall objectives of the program.

2.5. UAH has maintained procedures to protect proprietary and trade secret data provided by an industrial organization from unauthorized disclosure.

2.5.1. UAH has performed this task accordingly by not publishing or sending anyone's data to anyone other than the scientific investigator himself. The TCOR, in this case Dr. Robinson, is always consulted before sending out any information which is not already in the public domain. I have made general presentations about Materials Processing in Low Gravity, but only used information currently open to the public or already published. Dr. Pete Curreri for KC-135 experiments and Dr. Mike Robinson for the Drop Facilites serve as the officials who determine what information can be transmitted.

A concern of mine, of which the philosophy of this task basically helps to propagate, is that officially we are authorized only to transmit the data and the samples to the scientific investigators. We have no mechanism for the investigators to share with us the results of the experiments. Unfortunately this information would be useful for the purpose of maintaining optimal control of the experimental parameters and hardware. Since we do not in general get feedback from the scientific investigators about their scientific results, we are quite limited in determining if our experiments are really what the investigator wanted. Thus this feedback could be used to determine any future modifications or experimental changes required to optimize upon particular experiments.

2.6. UAH has conducted various experimental drops, as directed, associated with operational readiness demonstrations of the drop tube facility and scientific investigations.

2.7. Since the recording of droplet temperatures as a function of drop time in the Drop Tube is such an important part of most Drop Tube experiments, it is necessary to continue to search for and evaluate for the most cost effective method for determining transit droplet temperature along the length of the Drop Tube in order to make recommendations for implementation of such a method or methods. Upon specific direction procure, install and verify equipment and/or instrument required to implement the preferred method.

2.7.1. This problem has a long standing thrust in materials processing experiments in low gravity. Non-contact temperature measurement is required to understand solidification phenomena, fluid behavior, etc in containerless environments. The most progress has occurred since Tom Rathz has taken charge of the facility and Boyd Shelton was hired to respond to electronic instrumentation requirements at the Drop Facilities. Indium Antimonide detectors were purchased under this contract and several attempts were made to determine their effectiveness in measuring the temperature of a falling drop down to about 800 degrees Centigrade. One sub-contract was let to design and build a suitable link between the detectors and the computer data acquisition along the length of the Tube. In general, the low sensitivity of Indium Antimonide and the excessive background temperature of the walls of the tube have thus far made InSb ineffective for the purpose.

2.7.2. Additional work and analysis have been performed by Tom Rathz and Dr. William Kaukler. Several alternatives presented by them and Dr. William Hofmeister of Vanderbilt included high gain Si detectors, temperature stabilized Si detector, and logarithmic amplifiers. Dr. Robinson has basicly decided that logarithm amplication using silicon detectors was the optimal choice. Hence Boyd Shelton has continued to work with that system, performing experiments in parallel with other activities at the Drop Facilities. We currently believe that this method will perform adequately for the tasks at hand when fully optimized. Tom Rathz has also experimented with quartz light-pipes to increase the quantity of radiance collected by the detector. We see noticeable improvements in the S/N level of these signals.

2.8. Upgrade Drop Tube and Drop Tower experiment apparatus capability through continual evaluation of experiment and operational requirements.

2.8.1. In addition to the detectors required for temperature measurement of falling drops, UAH personnel have made a number of improvements to increase the productivity of the Tube and improve upon the data collection process for the facilities. A Soltec High Speed Data Acquisition system was purchased and interfaced to both the optical pyrometer, used to determine the temperature of the levitating droplet, and the silicon detectors measuring the radiant energy of the falling drops. In addition the video capability can also be used for observing samples during the sample heating and melting periods in the belljar. We have also now implemented an optical disk for archiving drop facilities data, replacing all the floppy disks we've used in the past.

After many months of getting the facilities personnel to install a water chiller for the Lepel, it was finally accomplished. During the summer FY88, we had problems performing electromagnetic levitation drops due to over-heating of the Lepel. We have also installed a transformer providing power to the Lepel and improved upon the pressure range allowed for levitaion experiments. A number of modifications have been made to improve upon the ease of sample changing in both the belljar and the catch tube. These modifications have been instrumental in improving control of samples during processing and quicker turn-around time in running experiments.

2.8.2 With the assistance of Dr. William Kaukler, an infra-red laser transmitter-receiver has been installed at the Drop Tower for real-time data acquisition purposes. The band-width of the system also allows video transmission. After a lot of problems in the original equipment as received, we have succeeded in making the system functional. After some more experimentation and a better understanding of the geometries involved in the Drop Tower facility, we should be optimized in the near future.

2.9. Upgrade, as required, the drop tube and drop tower experiment packages associated with MSFC approved experiments and conduct drops necessary to support the investigation.

Continuous improvement in the operational characteristics of both facilities has occurred. For instance the Drop Tube has improved the vacuum attainable by increasing the number of pumps, improvement in temperature measurements with both a new optical pyrometer and new detectors, and evolving redesigns in sample holders and retrieval systems. Also notable in terms of determining recalescence in undercooled samples is the addition of a video camera looking up the tube from the bottom. If recalescence does occur, it is captured on the video tape for comparison with the data from the Si detectors. Some discussion has occurred with respect to using this data for temperature determinations during the drop; however, the complexity of the task makes it less desirable than using the Si detectors at this time. With improvements in CCD's and imaging systems in the future, we may reconsider this capability again.

A subcontract was let to improve the signals obtained by the data acquisition system over the 100 meter length of the Drop Tube. It works fine; unfortunately the contractor was not knowledgeable about InSb detectors, so that the original intent of having the system optimized for InSb did not happen. Since it does have a high band-width required for any signals, it works also for silicon detectors and has been used primarily with them.

2.10. Design, develop and install a drop tower drag shield on-board data acquistion system capable of recording temperature, accelerations, and other parametric data with provisions for transferring information into the existing drop facility computer for analysis.

2.10.1 A Geotek data acquisition unit had been purchased for this purpose early on in our Drop Tower operations. At the time of purchase, very little commercial instrumentation was available which was compatible with the requirements of the Drop Tower. During this contract we have designed a concept and requested funding for an IBM PC clone based system manufactured by Texas Microsystems. The funding was received and purchases were made. Due to the time element involved in contractual transactions we did not not receive the components in time to assemble them under this contact. In additon, some experimentation will be required to get the system to work optimally. That will occur under the following contract for this effort.

2.11. Upon specific direction, develop a new experiment package for processing material samples on the F-104 aircraft. Prepare samples, participate in conducting tests on the aircraft, and analyze the results obtained and prepare reports summarizing results.

2.11.1 Due to the lack of experiments utilizing the F-104 furnace, the experimental package was modified for operation on the KC-135. The quality of the acceleration data for the F-104 are not as good over a sixty second parabolic manuever as the thirty second manuever on the KC-135. Consequently the furnace was reconfigured for KC-135 experiments for a series of experiments on immiscibles for Dr. Barry Andrews and Allison Sandlin of the University of Alabama in Birmingham.

2.12. Modify existing experiment packages for use on the KC-135 aircraft and develop new packages as necessary, prepare material samples, conduct ground tests using the experiment packages, and operate experiments on the aircraft. Analyze results and prepare reports.

2.12.1. The major activity which fits into this category includes the modification of what used to be the F-104 furnace into the Isothermal Casting Furnace (ICF). A number of experimenters have used the ICF since the modifications. The major activity has been with the immiscibles research performed by Allison Sandlin and her Ph.D. advisor Dr. Barry Andrews at the

University of Alabama in Birmingham in their study of copper-lead alloys. Ms. Sandlin will be receiving her Ph.D. this summer based upon the research performed with this work. Additional experiments with the University of Alabama in Tuscaloosa and Rockwell International have been performed with the ICF.

The conversion of the F-104 Furnace to a KC-135 furnace has certainly been instrumental in making the furnace more accessible to the research community. Although only three groups have used it as such, there will be more in the future.

2.12.2 Several new features have been added to the ADSF to make it easier to operate. Incorporation of the Peltier Heater from MIT for marking absolute positions on the samples, a hand-held control for rapid translation after quench, and a new, more stable translation mechanism have made the ADSF an easier operation during the parabolic manuevers.

We have not been able to upgrade the computers performing the data acquisition for the KC-135 experiments. However, it is recommende that it be done sometime in the future. The current computers are from 1985 vintage and are a little slow, particularly in writing to the hard disks. We have attempted to install accelerator boards to speed things up; howver, none have worked very well, if at all.

2.12.3 Guy Smith and his staff have also continued to work on the construction of a three-zone ADSF for the KC-135 experiments in parallel with all the other activities being performed for KC-135 experiments. It also will probably be ready for flight during the next contract period. The major problem facing KC-135 furnace activity is that we certainly will not be able to fly all of them at the same time. After the Video Furnace and the Rapid Melt/Rapid Quench are made flight ready and the three-zone ADSF is operational, there will have to be some scheduling worked out to optimize the use of all the furnace capability for the aircraft. Due to power limitations and the problem of long soak times affecting the number of parabolas obtained during a mission, only one or two furnaces can really ever fly at the same time. In addition, there is the problem of the new hardware being transported to Ellington getting larger and heavier; thereby making transportation more difficult. With sufficient planning there would be more optimal control for implementation of all the furnaces.

As mentioned earlier, a microprocessor controller was designed and a prototype built to power this furnace off DC power on the KC-135 using an 8085 CPU and hexfet controllers. The original software was developed by a graduate student in Electrical and Computer Engineering. Guy Smith and Sue Kosten continued to work with it and built a prototype which works for DC voltages up to 32 volts. Since our original approach was to develop a controller that did not need the 110 VAC on the aircraft, that goal was accomplished. However, to get the watts for three heater zones, 28 volts did not heat the furnace up fast enough for running several samples on KC-135 flights. Consequently we have developed a new concept, but it does not function accordingly for our needs at this time. We are submitting the prototype as new technology.

2.12.4 Additional activities which have supported other experiments flying on the KC-135 include assistance with the Polymer Directional Solidification experiments of Dr. Ben Goldberg/MSFC and instrumenting the Orbital Tube Welder of Richard Poorman/MSFC for temperature measurements. Both of these activities partially supported our involvement with them as modifications to the contract.

2.13. Conduct special studies to define new expeiments to be performed on the F-104 and KC-135 and establish the requirements for the equipment to be used to carry out the experiments.

2.13.1. A number of activities have occurred with respect to implementation of new experiments on the KC-135. The most noteworthy are:

1. Liquid Nitrogen Quench.
2. Miniature Color Video Camera.
3. Robotic Dynamics in Low Gravity

2.13.2 Principally with the assistance of Ms. Teresa Plaster, we helped set up the flight hardware, performed ground-based testing and operated on the KC-135 a series of experiments for Dr. Don Frazier on the solidification of a water-succinonitrile mixture with liquid nitrogen during the low gravity period of the KC-135. A number of experimental problems had to be worked out in getting this experiment to work. Most of which were worked out; however, the difficulty in getting the frozen samples back to MSFC without any thawing was a major problem. We hope that this experiment may be rejuvenated in the future with some modifications as it appears to be a useful experiment for the the KC-135 environment.

2.13.3 As a adjunct to experiments requiring optical observations, Dr. William Kaukler and myself participated in defining the experimental requirements and potential hardware requirements for a miniature color video camera for space. Originally our concept involved KC-135 verification of system performance. Unfortunately funds for the program, originally sponsored by new technology funding, were not sufficient for building up the prototype proposed or carrying out any useful experiments. Several major expenditures were made in video camera equipment and all were turned over to the MSFC contact Mr. Darrell Craig in EB Laboratory. We are planning on providing a more complete description of this activity later on for the benefit of the parties interested in miniature color video applications.

2.13.4 The activity in Robotic Dynamics in Low Gravity was initiated with Ms. Elaine Hinman, also in MSFC/EB Laboratory at MSFC. The major goal was to evaluate a small robot system for materials processing applications in low gravity and determine the characteristics of a robot arm in a space environment, particularly with respect to accelerations which might impact materials grown in space.

A UMI RTX robot was the most affordable robot for this task and subsequently was purchased. Carlos Rondon, a graduate student in Electrical and Computer Engineering assembled a materials transfer workcell simulating sample ampoules as might occur aboard a space laboratory. An accelerometer package was included for determining G levels of the workcell. Several flights were taken with the workcell, improving some data capabilities each time. Ms. Hinman flew the first mission and was able to train the robot to perform a materials transfer function within the 20 seconds desired. The computer used in that experiment did not allow both the control of the robot and reading of the accerometer package at the same time. I flew the second mission and had a number of problems trying to run the robot experiment and tkae care of other experimental requirements on the same flight.

Consequently Ms. Cindy Coker of MSFC/EB Laboratory participated in the ensuing KC-135 experiments. Using a 386 based computer, Carlos was able to do some improvements on the data acquisition process, but the multi-tasking software still did not permit the I/O commands to the robot to operate properly. Consequently we never did get to control the robot and take acceleration data simultaneously.

Ms. Tolli Grisham, an undergraduate student at UAH, has programmed a simulation of the RTX workcell on a Silicon Graphics Workstation using the off-line programming language and simulation tool by Deneb. The simulation works quite well within the capability of the version of Deneb that we have at UAH. No off-line programming is actually available at the moment; however, it would certainly be ideal tool for the space-based activities.

A number of lessons were learned with this series of experiments. The RTX robot uses plastic belts for actuation of the links and optical encoders for position and velocity control. The control system is PID and appeared to work well whether the task was learned in 1 G and performed in low G or vice-versa. It was tedious to teach the robot during parabolas, mainly because we had few visual aids to assist in the correct orientation of the end effector particularly for inserting the sample ampoule into its holder. A borrowed fiber-optic borescope provided no depth perception and was not useful for this study. We believe that the belt-driven actuation would not be acceptable for experiments such as the protein crystal growth studies due to the lack of control of accelerations at the end-effector.

A major concept which might be important in terms of promoting telescience experiments using the KC-135 would be to implement the above experiments using remote manipulation from the ground. JSC has indicated interest in these types of experiments using the TDRS satellite for transmission purposes. Teaching the robot to perform a task and then performing the task from the ground would be an ideal application to simulate some telescience parameters in many different ways.

A more complete description of this work will be provided in a separate document later on.

2.14. Upon specific direction, define and develop optical analysis procedures and conduct optical analysis of images reconstructed in the Holographic Ground Station (HGS). Work with the experiment Principal Investigators (PI) to optimize images and generate optical data needed to interpret results of low-g experiments. By specific direction procure, install and verify equipment and/or instruments in the HGS required to meet new PI requirements.

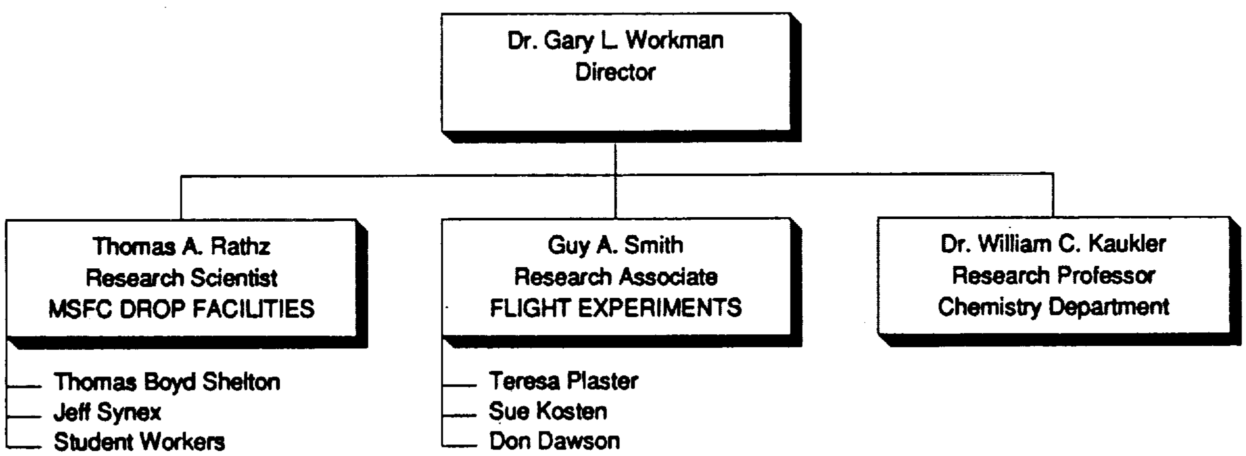
2.14.1 The ground-based research on studying the crystal growth of triglysine sulfate is located in Building 4708 at MSFC. During the duration of this contract, we have provided optical systems expertise through the utilization of both graduate students and undergraduates at the HGS. The relationship enabled optics students at UAH to better understand spome of low gravity experimentation being performed at MSFC and also allowed MSFC personnel at the HGS to have access to optics personnel. The principal investigators for the NASA funded experiment are Dr. Robbie Lau at Alabama A & M University and Dr. James Trolliger at MetroLaser, Inc. Most of the technical direction for this activity obviously came from the P.I.'s and the MSFC personnel.

2.14.2 The assistance of UAH optics personnel was quite beneficial to the HGS program. Maintaining optical alignment on the ground-based FES experimental arrangement is fairly sophisticated, hence the optics students from UAH have been instrumental in helping MSFC personnel to maintain optical alignment, as well as in running some of the long ground-based experiments in determining system sensitivity for both the schlieran and holographic aspects of the experiment.

3.0 Personnel

The following chart shows the organization chart for the Materials Processing Labaratory in the Johnson Research Center. This Laboratory has basically evolved during this contract period to meet the needs of this program and to better respond to future needs of microgravity materials processing programs.

JOHNSON RESEARCH CENTER
MATERIALS PROCESSING LABORATORY



4.0 Acknowledgements

The work performed on this contract was successful due to the fact that many people were able to provide help and assistance in meeting the above goals. This includes Dr. Robert Shurney, NASA/MSFC and Mr. Robert Williams, NASA/JSC in the KC-135 program, Dr. Mike Robinson and Kevin Vellacott-Ford at the Drop Facilities, and of course, the many UAH personnel who have worked with each of the facilities reported here.