1998 Reduced Gravity Student Flight Opportunity: Thin Film Extrusion in Microgravity

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SENIOR HONORS PROJECT

1998 REDUCED GRAVITY STUDENT FLIGHT OPPORTUNITY: THIN FILM EXTRUSION IN MICROGRAVITY

DECEMBER 17, 1997

BY: JASON DUCKWORTH
ADVISOR: DR. DOUGLASS FEIKEMA
ABSTRACT

The purpose of this senior honors project was to develop an idea and propose an experiment to fly on the KC-135 reduced gravity student flights. The first step in this process was to choose a feasible topic and how to research it. Next, the experiment was refined and specific tests, procedures and goals were weighed against one another. Finally, these details about the experiment were arranged in a proposal that was submitted to the Texas Space Grant Consortium for a review and selection process. This proposal was also presented to the Honors Forum at UAH.

PROPOSAL ACTIVITY REPORT

The Texas Space Grant Consortium and NASA sponsored student flights on the KC-135 "vomit comet" aircraft for the first time last year. The KC-135 is an aircraft that flies a parabola shaped trajectory. At the apex of the flight the aircraft begins to start downward in a "free fall." This provides a period of about 20 seconds of a reduced gravity environment to the plane and its passengers. The University of Alabama in Huntsville sponsored a team for this initial year of flights. The team's experiment was titled "Liquid Transfer in Microgravity" and was one of the 24 experiments in the program.

The number of experiments for the 1998 student flight program was increased to 48. The University of Alabama in Huntsville decided to enter two proposals for these flights. One experiment would be an improved version of last year's liquid transfer experiment. The purpose of the senior honors project was to choose a topic, to devise an experiment, and to write and submit a proposal for it.

The first step was to generate ideas for the proposal. One of the limiting factors in choosing a topic was the ability to get the project funded. The first experiment considered was testing a microwave plasma thruster in reduced gravity that was being tested at the UAH Propulsion Research Center lab. Another idea was to test burn rates of solid fuel in reduced gravity. The other experiment was to test ways to make a thin film mirror in reduced gravity.

The microwave plasma thruster was going to be tested in reduced gravity because it has only been tested in a vertical position in a one g environment. The tests would determine if gravity had any effects on its performance. The main setback with this idea was a lack of funding. Since we had little money to give the inventor, a student at another school, he was reluctant to give us very much of his time. Because of this we began to consider the burn rate experiment more seriously. The purpose of the solid fuel burn rate experiment would be to see what effect, if any, a gravitational field has on a solid fuel during combustion. This would tell whether data collected for solid fuel motors on earth would be valid in space. The problem with this experiment was safety. Solid fuel combustion was too dangerous to do on board the KC-135. It would take an enormous effort to guarantee safety during the explosion.
The alternate idea was making a thin film mirror in reduced gravity. There were four known ways used to accomplish this on earth. One idea was to release a liquid in the center of a rotating disk. As the liquid moved away from the center of the disk, it forms a thin, smooth sheet. The problem with this method was safety. After it broke off at the edge, the fluid would be spinning all over at high speeds if it was not properly contained. The second idea was a lasso method. This method takes a lasso with the liquid attached to it and increases the size of the lasso gradually. Surface tension would hold the liquid together and hold it within the lasso. The drawback to this idea was that it probably could not be performed in the short 20-25 second time constraint. The first two ideas create a circular shaped sheet. A third concept was the impinging jet. The impinging jet idea consists of two jets of liquid directed at each other creating a flattened, thin stream when they hit each other. The interesting point to study would be the breakup point of the stream. Some problems with this method were that the equipment size can get bulky, the jets are difficult to adjust, and the pressurized streams were a safety issue. A similar idea was spraying the liquid from a nozzle. These two ideas create a U-shaped sheet with the small end starting at the nozzle and expanded outward.

It was finally decided to try to create a rectangular shaped film. The rotating disk and lasso methods were eliminated since they form a circular film. The impinging jet and nozzle spray methods were not desired because they did not widen out from the source immediately. An extrusion process was proposed to make a rectangular sheet that would be the same width all along. This concept was chosen to be the idea for the proposal.

The next task was the research phase. The goal was to see what had been done previously and to see what existing technologies could be applied to this project. Many sources were found that offered information on the history of thin film mirror technology and on the current materials that were available to make these thin films. A meeting took place with four NASA employees from a development lab. They were able to offer a great deal of pertinent information, but no financial support. These findings can be seen in the background section of the proposal. The entire proposal can be found in appendix A.

Other sections that were required for the proposal include test objectives and test description. The test objectives section discussed the goals and information that was expected to be obtained from the experiment. The test description described the day by day, detailed plan of action for the flight. An equipment description was also required to let NASA know exactly what would be taken on the plane. Other sections dealt with more technical subjects that would document that the project could meet NASA’s specifications. Some of these parts include the structural load analysis, the pressure vessel certification, the test operating limits, and the hazard analysis. For the purpose of having a better chance of getting both of UAH’s proposals accepted, they were submitted in one booklet. The liquid transfer experiment proposal was written by Dr. Douglas Feikema. The proposal was submitted for review on November 14.

To fulfill the senior honors project requirements this project was presented at the Honors Research Symposium on Thursday December 4. The announcement and the
slides from the presentation can be found in appendix B. They provide a basic outline of the discussion. A short question and answer session followed.

The proposal results were announced on Friday December 12. Both of the UAH proposals were accepted and won spots on the student flights scheduled for the spring of 1998. The email announcement is located in appendix C.

PERSONAL THOUGHTS

This senior honors project taught me a great deal about proposal writing for government agencies. For example, I learned that the requested format must be followed. I also learned that specifics are required, especially in the safety and technical areas. With the due date on November 14, a strict schedule had to be followed. My planning and timing skills were improved during the process. I felt very comfortable giving the presentation because I have had opportunities to speak before.

Dr. Feikema, my advisor, was very helpful and supportive through the entire process. He provided guidance and sound advice, but allowed to take the proposal in the direction I wanted to go.

THANKS

I would like to thank Dr. Feikema for his patience and guidance. I would also like to thank Johnathan Jones for his help in the idea generation process, the Honors Program office and the Mechanical Engineering office for their cooperation, and Whit Brantley and his associates for the knowledge they offered. Additional thanks goes to the relatives and friends who offered patience and support.
APPENDIX

APPENDIX A

1. Submitted version of proposal

APPENDIX B

1. Announcement for presentation
2. View graphs from presentation

APPENDIX C

1. Winning email message
APPENDIX A
ABSTRACT

This proposal describes the test data package design and test description for two teams, or eight fliers and two experiments. Both of these experiments are proposed as free floating experiments in order to obtain a precision reduced gravity platform. Two flight qualified accelerometers, including a prototype model from MEMS Optical and another from CMDS, will be operated to record the quality of the reduced gravity environment. The performance of these accelerometers will be compared.

The liquid transfer experiment addresses design issues such as the role of surface tension devices (baffles) in effective liquid transfer, the gas ingestion phenomena, the rate of bubble formation in transition from high to low gravity, the distribution of liquid in reduced gravity environments, and the expulsion efficiency of liquid inside the containers. The features of the design include a liquid transfer device similar to the apparatus flown on Apollo 14.

The thin film extrusion experiment addresses issues concerning the manufacture of components from liquid films in reduced gravity which is of interest for in space production of solar components for spacecraft. This experiment will also be a free floating experiment. Of particular interest is the stability of the liquid films created which is important for optical quality.

EDUCATIONAL OUTREACH AND DISSEMINATION

The plan is to offer a course during the winter/spring semester in which the faculty advisor and instructor, Dr. Douglas Feikema, would organize and manage the tasks of the project amongst the students. There are approximately ten students enrolled for the course at the present time. The University of Alabama in Huntsville, Department of Mechanical and Aerospace Engineering, will provide students with 3 credit hours of technical elective for this activity. In addition to the development of the test package students will be required to attend lectures on microgravity research. The lectures will be organized in class on specific topics related to the project which include: accelerometer measurements, lessons learned on aircraft reduced gravity experimentation, frontiers in microgravity research and applications.

Each task in the plan for dissemination information is described below. The outreach coordinator will lead each of these efforts.

- Develop a page or site on the World Wide Web (WWW).
- Publish reports in the local newspapers and the school newspaper. Channel 48 News in Huntsville will provide a reporter to travel to Johnson Space Center. He will publish numerous articles regarding our project and air stories on local television.
• Present a display at UAH's Engineering Open House. This booth will present our project to prospective University students and expose them to microgravity experimentation.

• Visit local schools, including high schools, and present the data to science classes. This effort will begin upon completion of the test flights. The information will be presented to classes ranging from the eighth grade Physical Science classes to senior level Physics classes. The presentations will include a video of our experiment in operation (flight video), portions from the story about the project aired on Channel 48 News, NASA press release footage, and some of the in-flight NASA video footage.

INTRODUCTION AND BACKGROUND: LIQUID TRANSFER

During space operations in reduced gravity the transfer of a liquid from one tank to another is required. One element of propellant management that will be necessary during future space operations will be the transfer of liquid from a tanker vehicle to a receiver vehicle. Examples of such include: 1) transfer of propellants from the shuttle to the space station, 2) transfer of propellants to tanks of vehicles designed for lunar or planetary missions, 3) transfer of vital fluids to the space station, and 4) restart of propulsion systems in space. Also, applications occur in high speed aircraft under high "g" and variable "g" loading where liquid transfer issues are encountered. The fluid management challenges encountered with the transfer process include: 1) Gas free outflow from the supply tank, 2) Spill free inflow into the receiver tank, 3) Control of the liquid-vapor interface during acceleration changes, and 4) Positioning of the fluid at the drain port.

In microgravity liquid behaves dramatically different than on the surface of the earth in 1-g. In environments where gravity is reduced, the body force of gravity no longer dominates. Instead, the effects of surface tension, adhesion, and other applied forces such as rotationality and random accelerations determine the distribution of liquid. On the surface of the earth liquid inside a container will fill the bottom of a container, minimizing liquid/gas interface surface energy. One also observes a meniscus develop as the liquid "climbs-up" the side of a container due to surface tension. In microgravity liquid inside a container in equilibrium will no longer be at the bottom of the vessel. Rather, the liquid will be distributed inside the vessel such that the liquid/gas interfacial surface energy is minimized. This results in a bubble of constant curvature being formed within container.

Much work has been done concerning the transfer of liquid between a supply and receiver tank. Initially, several investigations were completed in the NASA-Lewis drop tower facility which demonstrated various aspects of liquid transfer phenomena. The first comprehensive demonstration of liquid transfer was performed by Apollo 14 astronauts during transearth orbit. The objectives of this experiment were to demonstrate the effectiveness of two surface tension baffle designs during fluid transfer. The un baffled tanks were found to be unsuitable for transfer of liquid in weightlessness. The baffled designs; however, were shown to be effective in transferring liquid in weightlessness.
Liquid motion in microgravity was also investigated on Skylab 3. This research was designed to investigate liquid/gas interface behavior including wave propagation and surface tension effects. The results of this study provided insight into low-g liquid motion, wave propagation, and manipulation.

More recently several shuttle experiments concerning liquid transfer have also been conducted. On the STS-51-G shuttle mission a hemispherical tank filled with fluid was subjected to acceleration inputs and the resulting sloshing forces were measured. The objectives of this STS Get Away Special (GAS) canister included 1) determining the low-gravity, dynamic behavior of a partially filled tank using experimental methods, 2) correlating the experimentally obtained data to mathematical models, and 3) evaluating the outflow of the liquid in the test tank through a tube and solenoid valve and into an evacuated chamber. The study was initiated to examine the coupling between the dynamic response of the fluid in the tanks and the tank design. Another shuttle experiment was conducted to evaluate the effects of liquid sloshing. If propellant tank liquid sloshing should occur in a spin stabilized satellite the energy of the vehicle would be dissipated and wobbling motion about the spacecraft’s axis could occur. The objective of this experiment was to measure slosh forces and observe slosh motion in a model satellite propellant tank.

On shuttle mission STS-017 a Get Away Special (GAS) experiment was conducted to (1) investigate the use of advanced surface-tension, propellant-acquisition concepts in the design of propellant tanks, and (2) demonstrate the bubble-free delivery of fuel from a partially filled propellant tank to the spacecraft engines. More specifically, the experiment was designed to demonstrate an off-load capability for a fuel-tank propellant acquisition system, a capability that did not exist with current fuel-tank surface tension devices such as the Shuttle RCS propellant acquisition system.

Hassan et al. designed a tank pressure control experiment which flew on board the space shuttle (STS-52). On the Orbiter each test generally started with a heating phase to increase the tank pressure and to develop temperature stratification in the liquid followed by a fluid mixing phase for the tank pressure reduction and fluid temperature equilibration. Analysis of data from the flight experiments and their comparison with the results obtained in drop tower experiments suggest that as the Bond number approaches zero the flow pattern produced by an axial jet and the mixing time can be predicted by the Weber number.

The equilibrium configurations of free liquid/gas surfaces in reduced gravity environments are of particular importance for liquid transfer phenomena. These conditions generally yield surfaces of constant curvature meeting the container wall at a particular contact angle. The time required to reach and stabilize about this configuration is not completely understood for sudden changes from elevated to reduced gravity. Therefore, one objective of the proposed research will be to determine the time scale to stabilize an equilibrium liquid/gas interface within a partially filled tank.
The proposed experiment is designed to address a number of the issues raised by previous research in fluid physics and liquid transfer. Among these issues include the effect of microgravity on liquid transfer, the role of surface tension devices (baffles) in effective liquid transfer, the gas ingestion phenomena, and the distribution of liquid in reduced gravity and under changing acceleration environments.

INTRODUCTION AND BACKGROUND: THIN FILM EXTRUSION

The idea of solar power for space applications dates back to about 1650. Since the space race began in 1957, scientists decided to use mirrors to harness the sun's power for spacecraft. The solar collectors used on earth are too bulky to haul into space, so they began making lightweight aluminized Mylar plastic sheets that could be folded until they were ready for use. Another idea, the solar sail, was first investigated by NASA in 1976 when it began to look for more economical ways to power spacecraft. The solar sail would be a very large, but thin sheet of reflective material that would catch small particles of light called photons much like a sail on a boat catches wind. The photons would exert a small force on the sail, but over a large surface (originally designed to be 160 acres and 0.0001 inches thick) this collective force would be enough to move large objects through space. The thin mirror would be folded up, carried up by the space shuttle, and unfolded in space. Since 1984 progress of the solar sail program has been slow due to funding and development problems.

Glass mirrors are very stable, but they are too expensive and heavy to take into space. Polymers on the other hand, have the possibility to help achieve total system cost effectiveness. The main advantages of polymers for space optics are potentially lower costs, simpler manufacturing, lighter weight, and greater design flexibility. The thin film polymer also offers good corrosion protection and improved tear resistance. With all of these things to gain, the only thing lacking is more research, especially on the materials side. The problem is that there are not many experts on polymer optics. Industry is waiting for the right materials to do certain things and the materials researchers are waiting on a large enough demand from industry to improve existing products and to make new ones.

There has been much work done in the study of thin film mirrors to date, although most has been done researching the material properties of the thin films. For instance, Boeing Engineering and Construction has been involved in the study and use of thin films for solar collectors since 1975. NASA has been leading the study of thin film usage in space since its beginning. Some other leaders in this technology are the Jet Propulsion Lab, SRS Technologies, and United Applied Technologies Inc. The most extensive government attempt at the construction of a thin plastic film collector was made at Brookhaven National Laboratory. This extremely light weight, high performance collector consisted of the thin film polymer with two layers of teflon-aluminum foil laminated to it for a reflective coating. The most common line focus collector is the parabolic trough, however, very little work has been done to upgrade its design. A flat sheet of thin film material is used to form a parabolic trough collector. Another type of solar collector made from thin film material is the inflated, cylindrical concentrator.
With all of the new technology available that is waiting on the right material for the job, the materials industry has a chance to capitalize by coming up with new low cost polymer films. The best materials will be the ones that are specifically designed for the application and maintain a low cost. Data about the organic film materials that are available today has been compiled by the Jet Propulsion Laboratory when they were exploring ideas for the solar sail project. Deployable membrane collectors fabricated from thin polymide films are the leading material candidate for construction of solar collector systems. Another name for the polymide film is Kapton. It costs about $7.00 per square meter, and has a thickness of 2 mil. Currently a molding process is being used to produce the thin films. When the surfaces come out of the mold they are finished and ready to be coated with a reflective material. One problem with this method is that the surface quality decreases as the size of the mold increases. A slope-error tolerance as low as one milliradian is needed for certain applications. Glass mirrors can meet this requirement, but as of now metallized polymeric film mirrors can not. Another problem is that a large surface is usually made by taping flat sheets of film together to make a larger sheet. This causes the reflection to be distorted and reduces the performance of the reflector. Also, when the mirrors are folded for transport into space and they unfold with the slightest wrinkle, the reflection gets distorted. The most logical solution to these problems would be to manufacture these thin film mirrors in space.

This experiment would investigate the feasibility of making long sheets of thin films in microgravity by an extrusion method. The study would be conducted to find out how "perfect" the surface of the film could be, or how much oscillation there would be in the sheet. The study would also find out what effect pressure and flow rate would have on the thin sheet being extruded. The experiment would determine if the quality of the thin films would be good enough for applications such as a long parabolic trough mirror or the solar sail. The experiment would also evaluate two different injector patterns.

TEST OBJECTIVES: LIQUID TRANSFER

The test objectives of the experiments proposed are as follows:

1) Demonstrate orderly transfer of liquid from a supply tank to a receiver tank in reduced gravity.

2) Evaluate and measure the expulsion efficiency for baffled and unbaffled tank designs.

3) Evaluate the time scale required to establish a static equilibrium vapor/liquid interface inside a partially filled container during transition from 2-g to a reduced gravity environment.

4) Obtain video of liquid transfer phenomena and the dynamics and damping of oscillations encountered during the transition from 2-g to reduced gravity.

5) Obtain experience with free floating experiments in the KC-135.
TEST OBJECTIVES: THIN FILM EXTRUSION

The test objectives for the proposed experiment are:

1) Demonstrate that a thin flat film can be extruded in a microgravity environment.

2) Evaluate the reaction of the extrusion process to changes in pressure and flow rate of the liquid as it exits the injector.

3) Obtain video data of the extrusion process for the purpose of analyzing the sheet flatness and determining any oscillation patterns in the sheet.

4) Evaluate two different injector patterns.

TEST DESCRIPTION: LIQUID TRANSFER

Ground Tests

Prior to flight a number of tests are to be performed. These tests are as follows:

- Leak test
- Clean interior of containers and lines to ensure surfaces are contamination free
- Pressure test including pressure release valves
- Accelerometer check out
- Systems operation test
- Pressure vessel certification
- Pump Test

Inflight Tests

The inflight tests are proposed to be organized within four sets of ten consecutive parabolas on a given day. The time between the parabola sets will be used to adjust the amount of liquid in the tanks and adjust equipment. A separate test will be conducted for each parabola sequence enabling eight separate tests to be conducted with a repeatability of ten for each test. The test plan for each parabola set is as follows:
Ground Tests

Prior to flight a number of tests are to be performed. These tests are as follows:

- Leak test
- Empty fluid collection container
- Verify electrical power
- Calibrate flow meter
- Check accelerometer
- Systems operation test
- Pump test
- Solenoid valve test
- Computer control verification

### Inflight Tests

During the flights, there will be four sets of ten consecutive parabolas per day. At the beginning of each parabola the pump will be turned to get the proper flow through the injector, and the pump will be turned off at the beginning of the 2-g portion of the parabola. Video and accelerometer data will be recorded continuously throughout the flight. At the end of each parabola set the flow rate will be adjusted and a general inspection of the experiment will be made to ensure that there are no problems. On day one the first injector pattern will be tested and on day two the second one will be tested. The test plan for each parabola set is as follows:

<table>
<thead>
<tr>
<th>DAY</th>
<th>PARABOLA SET</th>
<th>TEST DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Run liquid extrusion experiment at Flow Rate 1. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Run liquid extrusion experiment at Flow Rate 2. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Run liquid extrusion experiment at Flow Rate 3. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Run liquid extrusion experiment at Flow Rate 4. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Run liquid extrusion experiment at Flow Rate 1. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Run liquid extrusion experiment at Flow Rate 2. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Run liquid extrusion experiment at Flow Rate 3. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Run liquid extrusion experiment at Flow Rate 4. Record acceleration data.</td>
</tr>
</tbody>
</table>
EQUIPMENT DESCRIPTION: LIQUID TRANSFER

Figure 1 shows a system integration package including the relative position of each major component. The test package can be bolted or free floated. Each component is securely fastened to the structure.

Table 1 shows a complete list of components and their respective sizes and weights to be used in the data test package. The total weight of the experiment is estimated to be 112 pounds. The overall dimensions of the test package are 60 inches long, 20 inches wide, and approximately 20 inches tall.
### Table 1: List of Components to be Integrated into the Test Package

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WEIGHT (lb)</th>
<th>LENGTH (in.)</th>
<th>WIDTH (in.)</th>
<th>HEIGHT (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toshiba Laptop computer</td>
<td>15.5</td>
<td>8.25 (deep)</td>
<td>11.63</td>
<td>2.00</td>
</tr>
<tr>
<td>Computer Ribbon Cable</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video Camera</td>
<td>5.00</td>
<td>15.00</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>Pressure Gauge</td>
<td>0.251</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>4.11</td>
<td>21.00</td>
<td>7.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Plumbing Support Board</td>
<td>5.00</td>
<td>19.5</td>
<td>14.5</td>
<td>0.750</td>
</tr>
<tr>
<td>Handles (x4)</td>
<td>6.26</td>
<td>12.69</td>
<td>0.75 (dia.)</td>
<td></td>
</tr>
<tr>
<td>Foam Insulation (x1)</td>
<td>0.06</td>
<td>36.00</td>
<td>1.75 (dia.)</td>
<td></td>
</tr>
<tr>
<td>Base Plate</td>
<td>10.0</td>
<td>60.00</td>
<td>20.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Liquid Transfer Device (weight x2)</td>
<td>25.50</td>
<td>15.00</td>
<td>1.50</td>
<td>5.12</td>
</tr>
<tr>
<td>Masterflex pump control</td>
<td>10.9</td>
<td>9.00</td>
<td>4.06</td>
<td>4.06</td>
</tr>
<tr>
<td>Power Strip</td>
<td>2.00</td>
<td>12.5</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>5.30</td>
<td>5.54</td>
<td>5.54</td>
<td>4.22</td>
</tr>
<tr>
<td>Mounting Brackets</td>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camera Support Blocks (x4) (3 Lg)</td>
<td>2.09</td>
<td>6.50</td>
<td>3.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Fuse Box (x2)</td>
<td>5.00</td>
<td>3.50</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td><strong>Sum of all components-base plate</strong></td>
<td><strong>101.18</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sum of all components + base plate</strong></td>
<td><strong>111.18</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2 shows a schematic of the liquid transfer device. Two such devices will be constructed, one with and one without baffles or surface tension devices. The baffled designs consist of a standliner baffle and a curved-web design. These designs are similar to the Apollo 14 experiment. Each tank is a flat disc or cylinder 4.0 inches in diameter and 0.25 inches thick. These discs permit photographic fluid flow analysis in two dimensions. The sides of the tanks are to be constructed of a clear plastic such as Lexan. The baffles in the tanks are to be constructed of slotted aluminum. The top port of each tank is a vent line which consists of a porous ceramic material to reduce liquid ingestion during sloshing. At the bottom of each tank a drain/fill port will be inserted for liquid transfer. The tank has a volume of $4\pi (12.6)$ in$^3$. 
Ethanol has been selected as the test liquid since the liquid wets the container material. This is important since propellents have a low surface tension and are wetting to surfaces. A dye such as red food coloring is to be added to the solution to improve visibility and contrast between the liquid/vapor interface. The gas will be air.

Liquid transfer will be induced by attaching a small electrically operated compressor between the vent ports of both tanks. This will induce a higher pressure in one tank which will pump the liquid from one tank to the other tank. Pressure relief valves are to be placed on both sides of the compressor on the vent side of each tank to ensure safety in the case of over pressurization. The tubing will be stainless steel with a nominal diameter of 0.25 inches. The tank can be evaluated in 15 seconds with a laminar Reynolds (i.e. less than 2300) in the drain/fill line. The Weber number of the injection jet in this case has been estimated to be less than 1.3, the critical Weber number. A maximum pressure rise of 40 psi can be produced by the compressor. The flow rate produced is estimated to be 1.0 in³/s.

EQUIPMENT DESCRIPTION: THIN FILM EXTRUSION

The equipment needed for the experiment consists of a free float safety container, the liquid extrusion and collection system, the video recording system, and the
accelerometer package. Figure 3 shows a schematic of the liquid extrusion and collection system. The liquid extrusion system begins with a storage tank that will hold the liquid that will be extruded to form the thin film sheets. The variable flow pump will be used to move the fluid from the storage tank into the injector chamber. The injector chamber consists of a slender rectangular box that has two openings. One opening comes from the pump to allow the fluid to enter the chamber. The other opening is a long, thin slot where the liquid is to be extruded to form the sheet. There will be two injector chamber designs, one to test on each day of flight. One will be for a thin flat sheet and the other will be for a parabola shape. The collection container will be made from clear polycarbonate so that the camera can record the thin film sheet as it is extruded.

Figure 3 Schematic of the Test Apparatus for Thin Film Extrusion

Water has been chosen as the fluid to represent the thin film. Water can replace the polymide material as the fluid since the main interest is in the formation of the thin film sheets. The main reason that water was chosen for the experiment is that it is not necessary to study the curing process of the polymide. The water will behave similar to how the polymide behaves before it cures.

The video recording system will consist two video cameras. One camera will be mounted at the end of the collection chamber, and slightly above the sheet, facing the injector port. The other camera will be mounted to the side of the thin film sheet. The accelerometer package includes the actual accelerometer and also the Toshiba laptop computer that will record the data. The clocks on the video cameras will be synchronized with the computer clock. The free float safety container is the package that the whole experiment will come in and it is basically a support frame around the whole experiment. Table 2 contains a list of the components in the test package.
### Table 2: List of Components to be Integrated into the Test Package

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WEIGHT (lb)</th>
<th>LENGTH (in.)</th>
<th>WIDTH (in.)</th>
<th>HEIGHT (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toshiba Laptop computer</td>
<td>15.5</td>
<td>8.25 (deep)</td>
<td>11.63</td>
<td>2.00</td>
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<tr>
<td>Computer Ribbon Cable</td>
<td>2.50</td>
<td></td>
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<td></td>
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<tr>
<td>Video Camera (x2)</td>
<td>10.00</td>
<td>15.00</td>
<td>3.50</td>
<td></td>
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<tr>
<td>Pressure Gauge</td>
<td>0.251</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Light</td>
<td>4.11</td>
<td>21.00</td>
<td>7.50</td>
<td>2.50</td>
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<tr>
<td>Free Float</td>
<td>10.00</td>
<td>19.5</td>
<td>14.5</td>
<td>0.750</td>
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<tr>
<td>Protection Package Handles (x4)</td>
<td>6.26</td>
<td>12.69</td>
<td>0.75 (dia.)</td>
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<td>Foam Insulation (x1)</td>
<td>0.06</td>
<td>36.00</td>
<td>1.75 (dia.)</td>
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</tr>
<tr>
<td>Base Plate</td>
<td>10.0</td>
<td>60.00</td>
<td>20.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Liquid Extrusion Device (weight x2)</td>
<td>10.0</td>
<td>15.00</td>
<td>1.50</td>
<td>5.12</td>
</tr>
<tr>
<td>Masterflex pump</td>
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<td>9.00</td>
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<td>4.06</td>
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<td>Power Strip</td>
<td>2.00</td>
<td>12.5</td>
<td>2.00</td>
<td>2.00</td>
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<tr>
<td>Accelerometer</td>
<td>5.30</td>
<td>5.54</td>
<td>5.54</td>
<td>4.22</td>
</tr>
<tr>
<td>Camera Support</td>
<td>2.0</td>
<td>6.50</td>
<td>3.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Fuse Box (x2)</td>
<td>5.00</td>
<td>3.50</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

| Sum of all components-base plate | 85.591      |               |             |              |
| Sum of all components + base plate | 95.591      |               |             |              |

### STRUCTURAL LOAD ANALYSIS

Our test apparatus will comprise a 24” x 30” x 8” rigid frame enclosing all test tanks and supporting equipment. The frame will consist of two 1/4” aluminum plates sandwiching all the test equipment. The experiments will free float, but the base plates will have 3/4” holes drilled on 20” centers to match the nut plates in the floor of the aircraft in case the experiment needs to be bolted down. The following is a list of the test equipment and the associated weights:
<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WEIGHT (lbf)</th>
<th>9g's FORWARD (lbf)</th>
<th>3g's AFT (lbf)</th>
<th>2g's LATERAL (lbf)</th>
<th>2g's UP (lbf)</th>
<th>2g's DOWN (lbf)</th>
<th>6g's (lbf)</th>
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<tbody>
<tr>
<td>Toshiba Laptop computer</td>
<td>15.5</td>
<td>139.50</td>
<td>46.50</td>
<td>31.00</td>
<td>31.00</td>
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<tr>
<td>Computer Ribbon Cable</td>
<td>2.50</td>
<td>22.50</td>
<td>7.50</td>
<td>5.00</td>
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<tr>
<td>Video Camera</td>
<td>5.00</td>
<td>45.00</td>
<td>15.00</td>
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<tr>
<td>Pressure Gauge</td>
<td>0.251</td>
<td>2.26</td>
<td>0.75</td>
<td>0.50</td>
<td>0.50</td>
<td>1.51</td>
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<tr>
<td>Light</td>
<td>4.11</td>
<td>36.99</td>
<td>12.33</td>
<td>8.22</td>
<td>8.22</td>
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<tr>
<td>Plumbing Support Board</td>
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<td>45.00</td>
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<td>10.00</td>
<td>10.00</td>
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<tr>
<td>Free Float Protection Package</td>
<td>10.00</td>
<td>90.00</td>
<td>30.00</td>
<td>20.00</td>
<td>20.00</td>
<td>60.00</td>
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<tr>
<td>Handles (x4)</td>
<td>6.26</td>
<td>56.34</td>
<td>18.78</td>
<td>12.52</td>
<td>12.52</td>
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<td>Foam Insulation (x1)</td>
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<td>0.13</td>
<td>0.13</td>
<td>0.38</td>
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<tr>
<td>Base Plate</td>
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<td>90.00</td>
<td>30.00</td>
<td>20.00</td>
<td>20.00</td>
<td>60.00</td>
<td></td>
</tr>
<tr>
<td>Liquid Extrusion Device</td>
<td>10.00</td>
<td>90.00</td>
<td>30.00</td>
<td>20.00</td>
<td>20.00</td>
<td>60.00</td>
<td></td>
</tr>
<tr>
<td>Liquid Transfer Device (weight x2)</td>
<td>25.5</td>
<td>229.50</td>
<td>76.50</td>
<td>51.00</td>
<td>51.00</td>
<td>153.00</td>
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<tr>
<td>Masterflex pump</td>
<td>10.9</td>
<td>98.10</td>
<td>32.70</td>
<td>21.80</td>
<td>21.80</td>
<td>65.40</td>
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<tr>
<td>Masterflex pump control</td>
<td>1.71</td>
<td>15.39</td>
<td>5.13</td>
<td>3.42</td>
<td>3.42</td>
<td>10.26</td>
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<td>Power Strip</td>
<td>2.00</td>
<td>18.00</td>
<td>6.00</td>
<td>4.00</td>
<td>4.00</td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>Accelerometer</td>
<td>5.30</td>
<td>47.70</td>
<td>15.90</td>
<td>10.60</td>
<td>10.60</td>
<td>31.80</td>
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<tr>
<td>Mounting Brackets</td>
<td>10</td>
<td>90.00</td>
<td>30.00</td>
<td>20.00</td>
<td>20.00</td>
<td>60.00</td>
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<tr>
<td>Camera Support Blocks (x4) (3 Lg)</td>
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<td>18.81</td>
<td>6.27</td>
<td>4.18</td>
<td>4.18</td>
<td>12.54</td>
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<tr>
<td>Fuse Box (x2)</td>
<td>5.00</td>
<td>45.00</td>
<td>15.00</td>
<td>10.00</td>
<td>10.00</td>
<td>30.00</td>
<td></td>
</tr>
<tr>
<td><strong>Sum of all components-base plate for Liquid Transfer</strong></td>
<td>101.18</td>
<td>910.66</td>
<td>303.55</td>
<td>202.37</td>
<td>202.37</td>
<td>607.11</td>
<td></td>
</tr>
<tr>
<td><strong>Sum of all components+ base plate for Liquid Transfer</strong></td>
<td>111.18</td>
<td>1000.66</td>
<td>333.55</td>
<td>222.37</td>
<td>222.37</td>
<td>667.11</td>
<td></td>
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<tr>
<td><strong>Sum of all components-base plate for Thin Film Extrusion</strong></td>
<td>85.591</td>
<td>771.17</td>
<td>257.05</td>
<td>179.37</td>
<td>179.37</td>
<td>514.11</td>
<td></td>
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<tr>
<td><strong>Sum of all components+ base plate for Thin Film Extrusion</strong></td>
<td>95.591</td>
<td>861.17</td>
<td>287.05</td>
<td>191.37</td>
<td>191.37</td>
<td>574.11</td>
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<table>
<thead>
<tr>
<th>Component</th>
<th>9g's Forward Load (lbf)</th>
<th>Failure Shear Load (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Transfer Device, 4 – 1\4&quot; steel bolts</td>
<td>229.50</td>
<td>966.80</td>
</tr>
<tr>
<td>Mounting Brackets, 1\4&quot; bolts</td>
<td>90.00</td>
<td>3419.50</td>
</tr>
<tr>
<td>Handles, 1\4&quot; bolts</td>
<td>56.34</td>
<td>953.49</td>
</tr>
<tr>
<td>Accelerometer, 3\8&quot; Aluminum bolts</td>
<td>47.70</td>
<td>536.97</td>
</tr>
<tr>
<td>Pump, 1\4&quot; Grade 8 bolts</td>
<td>98.10</td>
<td>3496.93</td>
</tr>
<tr>
<td>Computer Support, 1\4&quot; Grade 1 bolt</td>
<td>139.50</td>
<td>1049.40</td>
</tr>
<tr>
<td>Video Camera, 1\4&quot; Grade 1 bolt</td>
<td>45.00</td>
<td>962.03</td>
</tr>
</tbody>
</table>
The entire test apparatus will weigh no more than 70 lb, with the center of gravity being approximately 3" above the floor of the aircraft. In case the experiment as bolted to the floor the following calculations have been made. Considering a vertical acceleration equivalent to 6g's the load that each of the mounting bolts will be required to hold is about 105 lb. This is well below the maximum load carrying capacity of a standard 1/2" bolt and well below the 5000 lb loading capacity of the mounting grid. Considering a horizontal acceleration equivalent to 9g's. And assuming that the test apparatus will rotate about a forward mounting bolt. The maximum load that a single mounting bolt 20" behind the first will have to carry, is a vertical force of 60 lb. This is also below the ultimate loads of the bolts and the mounting grid. In the event that the test apparatus should break free or if it should be recovered on an end or side after free-float maneuvers the maximum shear across the 1/2" through bolts must be calculated. Considering a 9g horizontal acceleration the maximum shear load that any bolt must hold is 158 lb, which is also below the ultimate shear load for a 1/2" bolt. And the apparatus is again within the allowances of the aircraft's mounting grid.

ELECTRICAL LOAD REQUIREMENTS

![Diagram of electrical system]

Figure 4. Schematic of the electrical system.

A preliminary electrical diagram is shown in Figure 4. The power requirements for the test data package as proposed are estimated to require 110 Volt AC 60 Hz, single phase power to operate a computer, accessories and a back light. The accelerometers, compressor, and solenoid valves will require a DC voltage which can be operated with the 28 volt DC source available on board the aircraft.
The current requirements have been estimated to be less than 10 Amps and will be fused for 10 Amps. Access to the 1 V/g output of the aircraft’s accelerometer is also requested as a comparison to the test package accelerometers.

The experiment requires an AC and a DC power source. The AC requirement is 120 volts. The DC needed is twenty-eight volts. The following is a break down of the systems and their requirements.

**Accelerometer**
The accelerometer uses the twenty-eight volt DC source and pulls one and a half amps. A two amp fuse will be installed.

**Video Camera**
The video camera runs off the 120 volt AC source and pulls three amps. A three amp fuse will be installed inline with the power supply.

**Florescent Lighting**
The back light is florescent and requires 120 volts AC. The back light has two ballast that pull 0.75 amps. A two amp fuse will be installed in the ballast housing.

**Laptop Computer**
The computer uses 120 volts AC and pulls less than two amps. The computer has an internal 2 amp fuse.

**Pump**
The pump runs off the 120 volts AC and pulls three amps. The pump has an internal three amp fuse.

**PRESSURE VESSEL CERTIFICATION**

The plumbing system concerned with the pressure vessel certification for both experiments mainly consists of storage tanks, silicone tubing which the fluid is pumped through, and stainless steel tubing and fittings that make up the vent system. The team under the advice of Greg Tyler, an expert who does this type of work for other UAH teams doing NASA projects, will oversee the pressure vessel certification. The maximum allowable working pressure (MAWP) is the maximum pump output pressure of 40 PSIG. The system will be designed to exceed the MAWP by at least a factor of four. Relief valves and a vent box will be included for additional leak control.

The pump used is a Masterflex Peristatic pump Part No. 7553-02 with a maximum output pressure of 40 PSI. The flexible hose between the containers is Masterflex silicone tubing. It has an O.D. of 0.375 inches, an I.D. of 0.25 inches, and is pressure rated at over 40 PSI. Parker-Hannifin Corporation manufactured the plumbing components. They are all stainless steel parts and are rated at 2000 PSI. These parts include 0.25 inch tubing with a wall thickness of 0.032 inches, 0.25 inch union fittings, 0.25 inch NPT inlet
pressure relief valves adjustable from 25-50 PSIG, 0.25 inch tube tee fittings, and 0.25 inch barbed fittings. Two US Gage 100 PSI pressure gages will also be used.

The plumbing system will be tested with a hand pump with a certified pressure gage. The system was pressurized to 1.5 times the MAWP (60 PSI). The pressure relief valves will be set at 40 PSI.

PARABOLA REQUIREMENTS, NUMBER AND SEQUENCING

The KC-135A allows one to experience reduced-g, or weightlessness, by flying a parabolic trajectory. The plane begins its ascent at 24,000 feet and climbs to 33,000 feet. At the beginning of the ascent one experiences a force of 2-g, that is, everything weighs twice as much as it does on Earth. On the ascent of the parabola the pilot cuts back on the engines, reduced-g begins, and lasts for about 25 seconds. The plane then begins to descend rapidly and quickly goes from reduced-g to 2-g. Normally ten parabolas are flown in a row, followed by a brief period of 1-g, and then the parabolas begin again. Forty parabolas are flown on a typical flight.

The experiment will operate in the standard parabolic maneuver with approximately a 20 second pull-up followed by 20 to 25 seconds of reduced gravity time concluded with a 20 second pull-out 2-g maneuver. We are requesting 80 reduced-g parabola's, 40 on day one and 40 on day two for each team or 160 total parabolas. The time between the parabola sets would be used to adjust the equipment, refill the supply tank, adjust the flow rate, reset the camcorder, and type commands into the computer.

DATA ACQUISITION SYSTEM

The data acquisition system consists of: 1) visual information recorded by the video system, and 2) the accelerometer data recorded and stored to the computer. This data is planned to be operated by a PC compatible computer which is to be securely mounted to the test stand. A clock will be synchronized between the video/camcorder system and the computer.

TEST OPERATING LIMITS OR RESTRICTIONS

Perturbations in reduced-g induced by the aircraft for mounted experiments will impart instability to the liquid. For this reason the proposed experiments will be free floating. Restriction and operating limits are defined by space requirements on the aircraft. The test packages will be approximately 60 inches long, 20 inches wide, and 15 inches tall. Space will be required for experimentors on both sides of the experiment during flight.

PHOTOGRAPHIC REQUIREMENTS

The standard NASA provided photographs are requested of preflight and in-flight operations. A camcorder will provide the visual data required for the analysis of the liquid transfer between the tanks and stability of liquid sheets.
HAZARD ANALYSIS

Hazard Number: 1
Hazard Title: Flammable/Combustible Material
Equipment Name: Ethanol
Description of Hazard: Ethanol can start a flame or induce an explosion
Hazard Causes: Leak, Pressurization fails, Overpressurization of LTD, Venting of Ethanol
Hazard Controls: Compression fittings in design, o-rings designed into system, strong tubing
Verification Method: Pressure Vessel Certification, Leak test after static load test

Hazard Number: 2
Hazard Title: Toxic/Noxious/Corrosive Material
Equipment Name: Ethanol
Description of Hazard: Ethanol vapor is toxic if inhaled and if swallowed as a liquid
Hazard Causes: Leak, Pressurization fails, Overpressurization of LTD, Venting of Ethanol
Hazard Controls: LTD pressure vessel is qualified to 1.5 MAWP, if pressure relief valve is opened, vapor is deposited into vent box
Verification Method: Pressure Vessel Certification, Leak test, Vent box designed & implemented

Hazard Number: 3
Hazard Title: High Pressure System
Equipment Name: LTD
Description of Hazard: Pressure inside LTD becomes high and it explodes
Hazard Causes: Overpressurization of LTD
Hazard Controls: Pressure Relief Valves set below MAWP, Pressure Vessel Certification Test
Verification Method: Pressure Relief Valve test - to ensure their setting; LTD Pressure tested to 2 times the MAWP

Hazard Number: 4
Hazard Title: Frangible Material
Equipment Name: Bulb of Light
Description of Hazard: Bulb breaks/sharp glass in cabin
Hazard Causes: Object/Flyer bumping into the light; Light becoming free floating (leaving its support structure)
Hazard Controls: Two layers of protection between bulb and cabin environment (plexiglass cover & light cover); solder pins on bulb to the light socket; bolts on plexiglass are torqued to specified level
Verification Method: Inspection to see that the covers are in place and fastened accordingly

Hazard Number: 5
Hazard Title: Frangible Material
Equipment Name: Computer
Description of Hazard: Computer screen is broken & fragments enter the cabin
Hazard Causes: Object/Flyer bumping into the computer; Computer becoming free floating (leaving its support structure)
Hazard Controls: Computer screen already qualified for use on the space shuttle and secured with bolts torqued to a pre-defined specification
Verification Method: Inspection to ensure bolts are securely fastened

Hazard Number: 6
Hazard Title: Frangible Material
Equipment Name: Camcorder
Description of Hazard: Camera lens breaks and glass is in the cabin
Hazard Causes: Object/Flyer bumping into the camera; Camera becoming free floating (leaving its support structure)
Hazard Controls: Plexiglass sheet installed in front of lens to protect lens from an impact; Bolts are torqued to pre-defined specs
Verification Method: Inspection to ensure plexiglass sheet installed and bolts are torqued

Hazard Number: 7
Hazard Title: Stress Corrosion Material
Equipment Name: Bolts
Description of Hazard: Bolt Failure
Hazard Causes: After repeated g-loading cycles caused by parabolic curves, bolts become stressed and break
Hazard Controls: Bolt calculation indicated high factor of safety; Bolts are not over torqued
Verification Method: Bolt calculation; Inspection to ensure specified torque on bolts

Hazard Number: 8
Hazard Title: Extendible/Deployable/Experiment Element
Equipment Name: Computer
Description of Hazard: Computer screen shatters
Hazard Causes: Free-floating objects impact computer screen causing it to shatter
Hazard Controls: Computer verified for flight on shuttle; screen made of plexiglass material
Verification Method: N/A
Hazard Number: 9
Hazard Title: Stowage Restraint Failure
Equipment Name: Bolts
Description of Hazard: Free-floating objects are induced into the cabin environment
Hazard Causes: Bolts fail
Hazard Controls: More than adequate number of bolts used to stow each piece of equipment; bolt selection gives high FOS; Bolts torqued to pre-defined specs
Verification Method: Bolt calculation; Inspection to ensure specified torque on bolts

Hazard Number: 10
Hazard Title: Stored Energy Device
Equipment Name: Pressure Relief Valve
Description of Hazard: Projectile flying through the cabin
Hazard Causes: Spring in pressure relief valve releasing enough stored energy to pop the cap of the valve off
Hazard Controls: Pressure relief valve is set at a value of less than MAWP
Verification Method: Inspection to ensure controls; Pressure relief valve test

Hazard Number: 11
Hazard Title: Propulsion System (Pressurized Gas)
Equipment Name: LTD with Ethanol
Description of Hazard: LTD explodes
Hazard Causes: Overpressurization of system
Hazard Controls: System designed to a 1.5 MAWP; Pressure vessel certified
Verification Method: Pressure test to verify design at 1.5 MAWP; Pressure Vessel certification

Hazard Number: 12
Hazard Title: Propulsion System (Liquid/Propellant)
Equipment Name: LTD with Ethanol
Description of Hazard: Explosion
Hazard Causes: Ethanol ignited when spark is induced
Hazard Controls: Electrical connectors are protected from sparking; fluid is contained
Verification Method: Pressure Vessel Certification; Inspection: Leak Test

Hazard Number: 13
Hazard Title: Toxic off-gassing material
Equipment Name: Ethanol
Description of Hazard: Ethanol vapor is toxic if inhaled
Hazard Causes: Pressure relief valve allows vapor to escape the LTD; leaks in LTD system
Hazard Controls: Vent box & Pressure Relief Valves at below MAWP; LTD pressure vessel certified to 1.5 MAWP
Verification Method: Leak test; Pressure Vessel Certification; Vent box designed and implemented

Hazard Number: 14
Hazard Title: Sharp corner/edge
Equipment Name: Edges of LTM experiment
Description of Hazard: Flyer cut by sharp edge
Hazard Causes: Sharp edge exists on hardware
Hazard Controls: Edges are beveled, rounded, or padded
Verification Method: Visual inspection to ensure controls

Hazard Number: 15
Hazard Title: Flammable/Combustible Material
Equipment Name: Ethanol and Electrical Connectors
Description of Hazard: Fire in cabin
Hazard Causes: Ethanol in contact with spark from electrical connection; Ethanol creating a short circuit between electrical connections
Hazard Controls: All electrical connections covered; each piece of electrical equipment has its own in-line fuse
Verification Method: Visual Inspection; Electrical Load Analysis

Hazard Number: 16
Hazard Title: High Voltage (Electrical Shock)
Equipment Name: Power Strip, Pump
Description of Hazard: Electrical shock from 110V
Hazard Causes: Voltage source not shielded or protected from contact with flyers
Hazard Controls: Electrical connector covers; heavy-duty wire
Verification Method: Inspection to ensure covers

COST SHARING

The Alabama Space Grant Consortium will provide $5000 for the project.

The University of Alabama in Huntsville will be cost share a portion of Dr. Feikema’s time during the Spring 1998 semester.

The University of Alabama in Huntsville Research Office will be waiving indirect costs associated with the project.
The Consortium for Materials for Materials Development in Space of the University of Alabama in Huntsville will be cost sharing the use of an accelerometer, associated equipment, and time required to integrate the equipment into the test package.

MEMS Optical Inc. will be cost sharing the use of equipment.

REFERENCES: LIQUID TRANSFER


REFERENCES: THIN FILM EXTRUSION


INDEPENDENT STUDY/TECHNICAL ELECTIVE
MAE 496-01 (THREE CREDIT HOURS)
REDUCED GRAVITY STUDENT FLIGHT EXPERIMENT:
LIQUID TRANSFER IN MICROGRAVITY
SYLLABUS AND COURSE INFORMATION
SPRING 1998

Instructor: Dr. Douglas A. Feikema
Office: R1 E-31, Propulsion Research Center
Office Hours: 2 hours per week to be arranged or by appointment
Telephone: (205) 890-7206

Textbook: Handouts

Homework: Each week each student will be required to give a five 
/Project: minute progress report on his/her activities.

Course Objectives: 1) Introduce students to Microgravity fluids research.
2) Provide students with hands on design and testing experience and team effort
3) Design, develop, and fly KC-135 flight experiment
4) Report on the results

Prerequisite: Junior or Senior Status

Grading: Weekly Reports: 20%
Participation and Teamwork: 10%
Project: 40%
Contribution to Final Report: 30%

We will also be having invited lectures come into the class two or three times a month to inform us of various aspects of Microgravity science and technology.
The weekly progress reports should be typed and contain atleast the following information: 1) Your name, 2) Report number, 3) Date and period of performance, 4) Activities Performed, 5) Problems encountered, 6) Activities planned for next week. One page in length is sufficient.
TASKS AND RESPONSIBILITIES:

I. Machine, Assemble, and Test Components
- Obtain materials
- Refine drawings
- Machine components
- Assemble
- Measure surface tension and contact angle with ethanol and water
- Develop detailed AutoCAD drawings
- Write up description of device for final report

II. Mechanical System Integration, Data Test Package
- Obtain materials
- Develop final drawings in AutoCAD
- Review structural analysis
- Review test requirements
- Assemble
- Fix components to apparatus
- Camcorder operation

III. Electrical System Integration, Data Test Package
- Review electrical load requirements
- Design requirements for operation of Liquid Transfer Device in flight
- Manual or Computer operation?
- Obtain materials and parts
- Integrate and assemble system
- Lead system checkout for ground testing

IV. Computer System, Accelerometers
- Accelerometers
- Programming in C++
- Work with CMDS
- Interface hardware with analog and digital converters
- Data acquisition

V. System Assembly and Ground Test System Checkout
- Integrate all systems into data test package
- Develop operational procedures in writing
- Checkout each system
- Conduct hazard tests
- Begin analysis of data

VI. Flight Testing

VII. Reduce Data and Prepare Final Report
APPENDIX B
Honors Research Symposium

University Center
Room 126

4 December 1997

11:15 a.m. - 12:20 p.m.
REDUCED GRAVITY
STUDENT FLIGHT OPPORTUNITY:
THIN FILM EXTRUSION
IN MICROGRAVITY

BY: JASON DUCKWORTH

ADVISOR: DR. DOUGLAS FEIKEMA

DECEMBER 4, 1997
1997 UAH Student Flights on KC-135
TOPICS

1. BACKGROUND

2. EXPERIMENTAL SETUP

3. GOALS
LITERATURE REVIEW AND BACKGROUND

• WHERE DID THIN FILM MIRRORS COME FROM?

• ADVANTAGES AND DISADVANTAGES

• WHAT LEAD TO OUR IDEA?
WHERE DID THIN FILM MIRRORS COME FROM?

• CONCEPT OF USING MIRRORS FOR SPACE TRAVEL DATES BACK TO 1650

• REALIZED THE NEED FOR LIGHTWEIGHT MIRRORS FOR SPACE TRAVEL AROUND 1957

• IN 1976 NASA BEGAN INVESTIGATING THE USE OF A LARGE THIN FILM REFLECTOR AS A SOLAR SAIL

• FUNDING AND DEVELOPMENT HAS BEEN SLOW SINCE 1984
ADVANTAGES AND DRAWBACKS

• LOWER COSTS, SIMPLER MANUFACTURING, LIGHTER WEIGHT, AND GREATER DESIGN FLEXIBILITY

• GOOD CORROSION PROTECTION AND IMPROVED TEAR RESISTANCE

• LACK OF MATERIALS RESEARCH-NOT ENOUGH EXPERTS

• MOLDING IS CURRENT METHOD OF PRODUCTION, BUT QUALITY DECREASES AS MOLD SIZE INCREASES

• CURRENTLY, LARGE SHEETS CAN NOT BE PRODUCED IN ONE PIECE
WHAT LEAD TO OUR IDEA?

• THIN FILM MIRRORS ARE USED AS SOLAR COLLECTORS FOR POWERING MANY OF THE SATELLITES PLACED IN ORBIT TODAY

• TODAY THE MIRRORS ARE ALL PRODUCED ON EARTH

• DUE TO GRAVITY, SLIGHT OSCILATIONS THAT REDUCE OPTICAL QUALITY ARE FOUND IN THE MIRRORS PRODUCED ON EARTH

• LARGE MIRRORS ARE MADE BY TAPING SHEETS TOGETHER, LOWERING OPTICAL QUALITY

• FLAT MIRRORS ARE FOLDED FOR TRANSPORT INTO SPACE AND UNFOLDED FOR USE, LEAVING SLIGHT CREASES IN THE SURFACE OF THE MIRROR
EXPERIMENTAL SETUP

• PRELIMINARY DESIGN
• HARDWARE
• TEST OBJECTIVES
• TEST DESCRIPTION
Schematic of the Test Apparatus for Thin Film Extrusion
## List of Components to be Integrated into the Test Package

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WEIGHT (lb)</th>
<th>LENGTH (in.)</th>
<th>WIDTH (in.)</th>
<th>HEIGHT (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toshiba Laptop computer</td>
<td>15.5</td>
<td>8.25 (deep)</td>
<td>11.63</td>
<td>2.00</td>
</tr>
<tr>
<td>Computer Ribbon Cable</td>
<td>2.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video Camera (x2)</td>
<td>10.00</td>
<td>15.00</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>Pressure Gauge</td>
<td>0.251</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>4.11</td>
<td>21.00</td>
<td>7.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Free Float</td>
<td>10.00</td>
<td>19.5</td>
<td>14.5</td>
<td>0.750</td>
</tr>
<tr>
<td>Protection Package Handles (x4)</td>
<td>6.26</td>
<td>12.69</td>
<td>0.75 (dia.)</td>
<td></td>
</tr>
<tr>
<td>Foam Insulation (x1)</td>
<td>0.06</td>
<td>36.00</td>
<td>1.75 (dia.)</td>
<td></td>
</tr>
<tr>
<td>Base Plate</td>
<td>10.0</td>
<td>60.00</td>
<td>20.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Liquid Extrusion Device (weight x2)</td>
<td>10.0</td>
<td>15.00</td>
<td>1.50</td>
<td>4.00</td>
</tr>
<tr>
<td>Masterflex pump</td>
<td>10.9</td>
<td>9.00</td>
<td>4.06</td>
<td>4.08</td>
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<tr>
<td>Masterflex pump control</td>
<td>1.71</td>
<td>7.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Power Strip</td>
<td>2.00</td>
<td>12.5</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>5.30</td>
<td>5.54</td>
<td>5.54</td>
<td>4.22</td>
</tr>
<tr>
<td>Camera Support Blocks (x4) (3 Lg)</td>
<td>2.0</td>
<td>6.50</td>
<td>3.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Fuse Box (x2)</td>
<td>5.00</td>
<td>3.50</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

| Sum of all components-base plate | 85.591 |
| Sum of all components + base plate | 95.591 |
TEST OBJECTIVES

1. DEMONSTRATE THAT A THIN, FLAT FILM CAN BE EXTRUDED IN A REDUCED GRAVITY ENVIRONMENT

2. EVALUATE THE REACTION OF THE EXTRUSION PROCESS TO CHANGES IN FLOW RATE OF THE LIQUID SHEET AS IT EXITS THE INJECTOR

3. OBTAIN VIDEO DATA OF THE EXTRUSION PROCESS FOR THE PURPOSE OF ANALYZING THE SHEET FLATNESS AND DETERMINING ANY OSCILLATIONS

4. EVALUATE TWO DIFFERENT INJECTOR PATTERNS
## IN FLIGHT TEST DESCRIPTION

<table>
<thead>
<tr>
<th>DAY</th>
<th>PARABOLA SET</th>
<th>TEST DESCRIPTION (FIRST INJECTOR TYPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Run liquid extrusion experiment at Flow Rate 1. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Run liquid extrusion experiment at Flow Rate 2. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Run liquid extrusion experiment at Flow Rate 3. Record acceleration data.</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Run liquid extrusion experiment at Flow Rate 4. Record acceleration data.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DAY</th>
<th>PARABOLA SET</th>
<th>TEST DESCRIPTION (SECOND INJECTOR TYPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>Run liquid extrusion experiment at Flow Rate 1. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Run liquid extrusion experiment at Flow Rate 2. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Run liquid extrusion experiment at Flow Rate 3. Record acceleration data.</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Run liquid extrusion experiment at Flow Rate 4. Record acceleration data.</td>
</tr>
</tbody>
</table>
GOALS

• CREATE A THIN FILM OF OPTICAL QUALITY BY EXTRUSION IN A REDUCED GRAVITY ENVIRONMENT

• COLLECT AND ANALYZE DATA THAT WILL LEAD TO IMPROVEMENTS ON THE QUALITY OF THE PROCESS
It is my pleasure to convey a well-deserved "Congratulations!" to you and your colleagues for being TWO of the 48 teams selected to participate in the 1998 NASA Reduced Gravity Student Flight Opportunities program.

Yes, BOTH of your proposed experiments were selected.

As you begin to prepare for the flights this Spring, please keep in mind that whether your team actually flies depends on your adherence to the requirements set forth in the Competition Guidelines and elsewhere. Also, I will be contacting you early in January to discuss what additional information, if any, the Peer Review Committee requests that you provide to round out your proposal.

IMPORTANT: Please note that NASA has decided to change the medical examination requirements from those set forth in the Reduced Gravity Users Guide. I will send you the new (substantially less expensive) requirements in early January ... please DO NOT start obtaining medical exams for your flyers until you have the new requirements and form!

I personally look forward to working with you and flying with your team. "Good Luck", and again, "Congratulations!"

Burke Fort
Project Director
1998 NASA Reduced Gravity Student Flight Opportunities