Dynamic fluid flow due to capillary forces in microgravity

Topic Areas:

Fluid Physics/Applied Mathematics

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Flight Week Preference

First Choice: Flight Group 5, July 20-29, 2006
Second Choice: Flight Group 6, August 10-19, 2006
Third Choice: Flight Group 4, July 6-15, 2006

Advisor/Mentor Request

No advisor or mentor is requested.

Abstract

In the 23 seconds of microgravity aboard the C-9B we predict that we will be able to image the progression of capillary action in different geometries and later make calculations describing the rate of fluid progression to capillary action as dependent upon geometry in a microgravity setting. Past studies have examined the equilibrium positions of fluid in microgravity under varying geometric constraints, but we will study the dynamic flow induced by capillary action in order to better understand the time dependent fluid location. This research has applications in any area dealing with fluid containment or use in microgravity including fuel location in fuel tanks.

I. Technical

1. Introduction

1.1 What is capillary action?

Capillary action is the natural phenomenon occurring between a fluid and a contact surface in which the fluid acts against gravity and travels upward along the surface due to intermolecular attractions between the surface and fluid molecules. The height attained by the liquid is determined by the physical qualities of the liquid, specifically the cohesion of the liquid to itself and the adhesion to the surface as well as the geometry of the surface. Many of us have seen this occur in basic science courses when different capillary tubes are partially submerged in a liquid and the liquid is drawn upwards along the tube. This phenomenon is also responsible for the formation of menisci in graduated cylinders. Capillary action is enhanced in an inside corner, due to increased proximity of the rigid surface to the liquid. This allows adhesion forces to more strongly draw the fluid's surface upwards along the wedge formed by the corner. The implications of this will be discussed in more detail below. The corner or angle along which the liquid travels is referred to as the angle of incidence. The height to which the fluid surface will rise is also dependent on the force on the fluid due to gravity. All else being equal, lighter fluids or reduced gravity will cause more pronounced effects due to capillary action.

Capillary action has been studied in much detail in the past and mathematical equations are available to calculate the equilibrium position of a free surface, given information about the geometry and properties of the system [1]. Such systems are usually studied by minimizing the sum of the surface and gravitational energies as described by the equation:

$$\nabla \cdot \left(W^{-1}\nabla u\right) = \kappa u + 2H \qquad \textbf{Eq. 1-1} \text{ [1]}$$

where $W = \left(1 + u_x^{\ 2} + u_y^{\ 2}\right)^{1/2}$ and κ and H are constants describing the properties of the system.

A boundary condition of constant contact angle is applied such that

$$\cos\gamma = W^{-1}\nabla u \cdot \mathbf{n} \qquad \textbf{Eq. 1-2} \text{ [1]}$$

where γ is the contact angle.

In the case of zero gravity, these equations give

$$\nabla \cdot \left(W^{-1}\nabla u\right) = 2H \qquad \textbf{Eq. 1-3}$$

$$W^{-1}\mathbf{n} \cdot \nabla u = \cos\gamma \qquad \textbf{Eq. 1-4} \text{ [1]}$$

It can be shown that these equations are solvable only in the case that $\alpha + \gamma \geq \pi / 2$ where α is half the angle of incidence [1]. Concus and Finn have devoted a paper to the development of solutions to this problem which are valid in the case where $\alpha + \gamma \geq \pi / 2$ is not satisfied, but neither this result nor the standard case addresses the time dependence of the surface location [1]. Although it is clear that the time dependent location of the surface will be affected by the viscosity of the fluid as well as the factors influencing the equilibrium position of the fluid, it appears that little is know about its motion towards this final position [1, 2, 3].

1.2 Applications of capillary action in microgravity.

Capillary induced flow may have applications in moving fluid without the use of conventional pumps, especially in microgravity where this phenomenon is usually more pronounced. Using this natural phenomenon, liquid will travel without power from sources such as pumps. This is not an energy free pump because energy must still be used to remove the fluid from the end of the capillary tube, but it presents some interesting possibilities and may be efficient for low volume flows. Also, the unbounded case, which occurs when $\alpha + \gamma \geq \pi / 2$ is not satisfied, may play a role in the delivery of water to the upper leaves of tall trees [1]. However the feasibility of this proposition is unknown since little is known about the volume of fluid capillary action is capable of transporting. Finally, understanding the dynamic portion of capillary flow is crucial to knowing fluid location at all times. Although equations are available to calculate fluid surface equilibrium positions [1, 2], intermediate positions may be equally important, especially for viscous fluids which may take considerable time to reach an equilibrium state [2].

1.3 Role of gravity

As discussed above, gravity plays an important role in how capillary action occurs. In a 1g environment, capillary action is not strongly pronounced except in the case of extremely small contact angles or small angles of incidence on the surface. In the case of microgravity, capillary effects become much more important. Large rises in fluid surface occur due to relatively large angles of incidence in the container surface. This will allow us to study a much more useful and realistic situation for microgravity applications. If the angles of incidence are kept small, as in the 1g case, frictional forces between the fluid and the walls become dominant and slow the fluid motion, changing the nature of the flow. The microgravity aboard the C-9B will allow us to study capillary flows where friction is not as dominant as well as make the capillary effects much more pronounced, improving data recording and later analysis.

The most important difference between our experiment and past research is the focus on the dynamic flow induced by capillary action instead of looking only at the final equilibrium state of a fluid surface. This will allow us to acquire information on how the liquid acts as it reaches its equilibrium state. We will be able to see the fluid's speed and acceleration as it reaches different heights. This will allow us to estimate flow rates for the fluid when subjected to different angles of incidence. We believe this is an important consideration in fully understanding the nature of capillary action in a microgravity environment during all times, not just when equilibrium has been reached.

2. Test Objectives

2.1 Objectives of the Experiment

It is our objective to quantitatively measure how capillary action occurs in a micro-gravity environment when differing angles of incidence are used. We propose that aboard NASA's C-9B Reduced Gravity Laboratory, we will be able to record and measure the dynamic nature of capillary induced flow. We will also attempt to discover and quantitatively describe the functional relationship between angle of incidence and flow velocity.

Goal 1: Allow for the measurement of capillary action using varying angles

By using varying angles and keeping all other possible variables constant (i.e. physical properties of the liquid are unchanging, etc.) we will be able to determine which angle or range of angles allow for the most effective flow of liquid due to capillary action in a microgravity environment. Since the angle of incidence is the variable we wish to investigate, we will to have a range of strict tolerance angles in which the liquid travels. The range to be used is highly dependent on contact angle, γ, and the exact values will be determined once materials have been finalized and contact angle can be determined. However, the angles will be chosen such that $\alpha + \gamma \geq \pi / 2$ so that during the 2g portion of flight, the fluid may fully drain from the surface and allow for multiple trials of this experiment. We will use a nontoxic dye to color the fluid for contrast, a ruler mounted on the fluid tank for scale, and a video camera to record the progression of the fluid surface in zero gravity.

Goal 2: Determination of relationship between angle of incidence and flow velocity

After our flights have concluded we will analyze our data to find average velocities of the fluid surface as dependent on the height of the fluid surface and the angle of incidence. We will look to develop preliminary equations, which describe this specific situation and may lead to further research into other factors involved in determining the velocity of the fluid surface, including viscosity and contact angle.

2.2 Hypothesis

We hypothesize that liquid undergoing capillary action in a microgravity environment will move at different rates dependent on angle of incidence. We believe that an appropriate choice of angles will allow us to estimate an angle which maximizes flow velocity and volume. We believe that we will to be able to successfully and safely perform this experiment aboard NASA's C-9B. We believe that our measurement techniques will provide ample data to develop preliminary empirical equations describing fluid surface motion in this situation.

3. Test Description

3.1 Description of Phenomena

The contact angle between a solid surface and a liquid is the angle that the liquid makes when in contact with the surface. This is seen in menisci. According to Concus and Finn's research, there is a contact angle intrinsic to a container, γ_0 , called the critical angle. For a container with an interior angle of 2α, the critical angle is equal to $\pi/2-\alpha$.

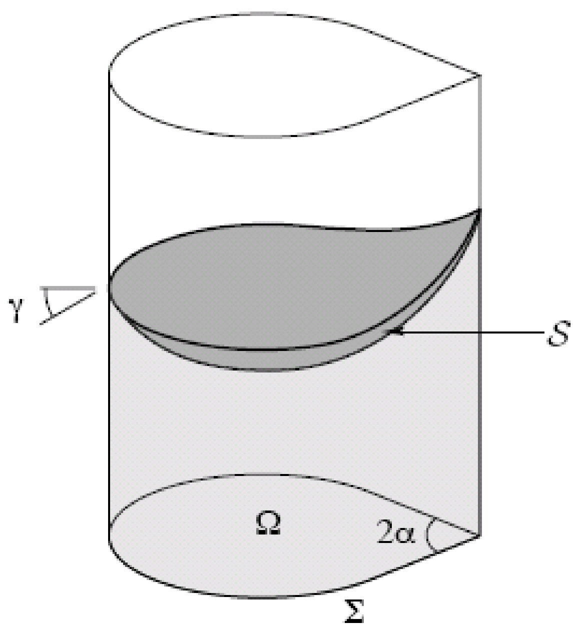


Fig. 3-1 Wedge shaped container with inner angle 2α, contact angle γ, surface area S, horizontal cross sectional area Ω and horizontal perimeter Σ. P. Concus, R. Finn, M. Weislogel, "Measurement of Critical Contact Angle in a Microgravity Space Environment," Preprint for Experiments in Fluids, 28, pp.197-205, (2000).

Another important property of the system is the fluid's contact angle with the container. This is an experimentally determined value which measures the angle at which the fluid contacts a material. A smaller contact angle indicates a stronger attraction between the fluid and the solid and therefore stronger capillary effects.

For a contact angle greater than zero but less than the critical angle, the liquid will move to the walls, rise arbitrarily high and can uncover the base if the walls are high enough. Concus, Finn and M. Weislogel conducted an experiment aboard the United States Microgravity Laboratory Space Shuttle flight STS-73. This experiment showed the rise of a fluid in a double proboscis shaped container near the critical angle. With the proboscis, Concus, Finn and Weislogel found that the liquid rises discontinuously as the critical angle is approached.

Our experiment will focus solely on the effect of changing the container angle on the rate of rise of water for a basic planar wedge. Our experiment will not focus on the height or contact angle as previous studies have, but on the speed with which our fluid flows up the walls.

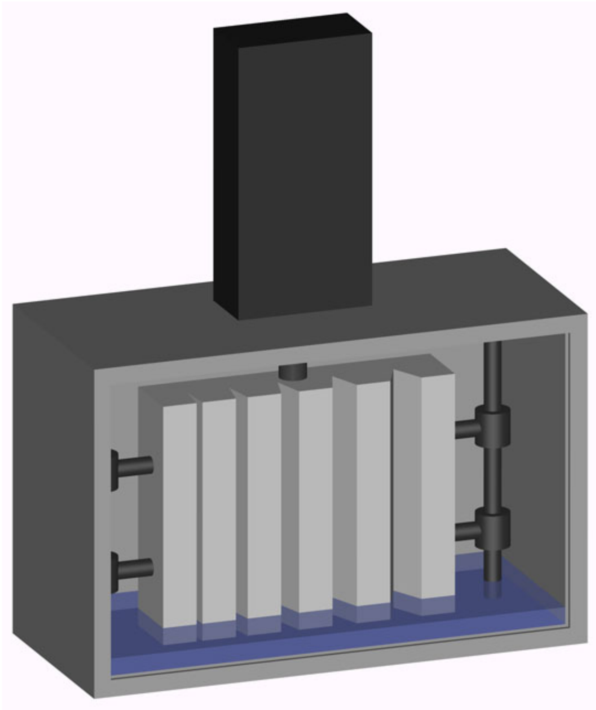


Fig. 3-2 The fluid containment box containing the polycarbonate wedge piece with actuator mounted on top

We will be constructing a polycarbonate piece with wedges of various angles cut out of one side. The base of this piece will be submerged in a fluid. We have chosen water because it is nontoxic, easily obtained in pure quantities, and has a positive contact angle with many materials such as polycarbonate. Next to this block we will set up a measuring stick to record the vertical displacement of our fluid. We will video record the rise and from this obtain the velocity with which our fluid rises when in contact with different angled surfaces.

We believe these phenomena will have applications in zero gravity when pumping a fluid from one spot to another. Research in this field could eventually lead to the ability to move fluids in space without the use of a conventional pump. Instead one may simply change the angle of contact in a tube to transport a fluid. This will also lead to better understanding of the time dependent location of a fluid under varying geometric constraints.

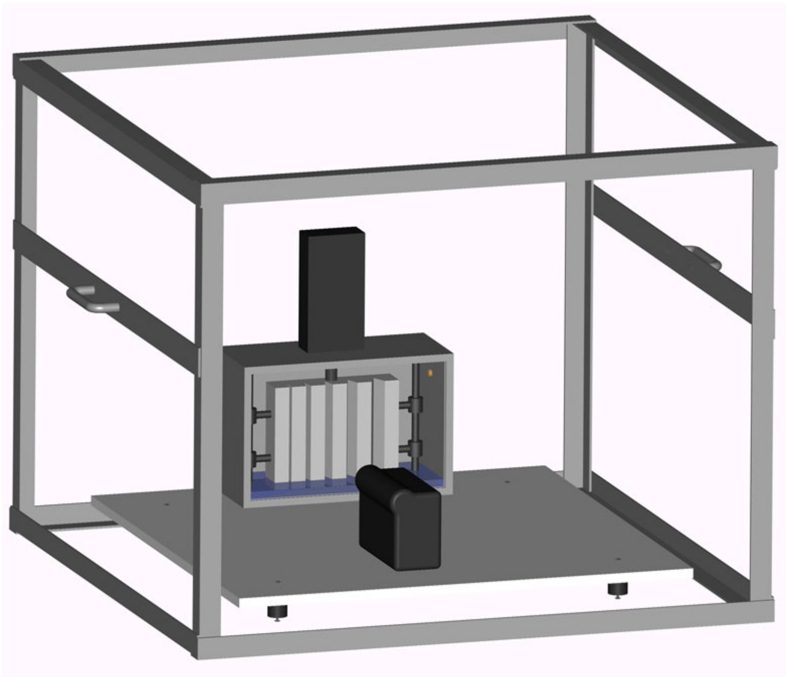
We expect to find that the fluid rises faster against the smaller angled surfaces and slower against the larger angled surfaces. We hope to be able to explain this both qualitatively and quantitatively using the measurements taken from our video.

3.2 Equipment Design

3.2.1 Overview

Our experiment was designed with safety and usability in mind. Our outer containment box will be strapped to the plane. Our fluid container will have a pressure relief valve attached to it. We will not be using any toxic materials and all of our electronics will have an emergency kill switch. We will only be using a few centimeters of water and this will be doubly contained.

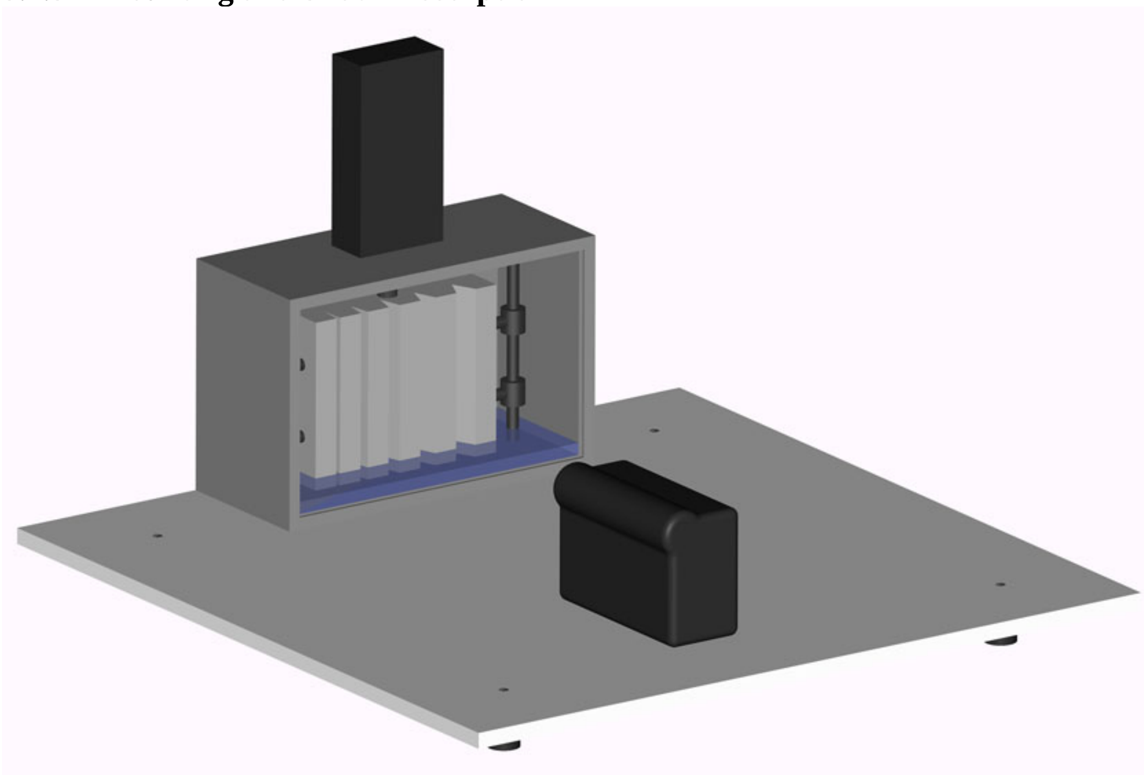
3.2.2 Outer Containment



<u>Fig. 3-3</u> Complete experimental assembly showing outer containment box and inner experiment

Our outer containment layer is a polycarbonate box of dimensions 30”x30”x24”. The ¼” thick polycarbonate sheets are held together by 1 ½” aluminum L-beams and ¼” bolts and nuts. All the inner and outer edges are caulked with silicone to prevent any leaking. There are two handles on opposite sides that are used for carrying and for strapping the box to the plane. This box was approved and flown as an outer containment box for an experiment last year.

3.2.3 Mounting and Shock Absorption



<u>Fig. 3-4</u> The experiment will be bolted to a ¼” thick aluminum plate which will be attached to our outer containment box with vibration damping neoprene sandwich mounts.

Inside the outer containment box we have a 24”x24”x3/8” aluminum platform with five cylindrical neoprene sandwich mounts to attach it to the outer containment box. This platform was used in last year’s experiment to mount the experiment contents. We will be mounting our camera, fluid tank, actuator and an accelerometer to this platform to prevent collision of any part of our experiment with the containment layer. The neoprene sandwich mounts are designed for vibration damping and will help to lessen the effects of high frequency vibrations in the plane.

3.2.4 Electronics

We will be using a video camera with its manufacturer-supplied battery to record data. This camera will be mounted to the aluminum platform and will face the fluid containment box. In past years we have observed that the motion of the plane causes unrestrained fluids to splash along the sides of fluid containers. To prevent this we will have a sponge on the bottom of the inner containment box to contain the water. An actuator on the top of the fluid container box will plunge the polycarbonate wedge piece onto the sponge, exposing the water, after microgravity has been achieved the first time so that we may collect data from a dry surface first. The block will then be raised off of the sponge when the period of zero gravity has ended. The actuator will be controlled by two buttons on a control box, one to lower it and one to raise it. During the recovery part of the flight parabola, the 2g's of gravity will help to drain the water from the polycarbonate test surface. It will drip back onto the sponge and be absorbed until the next period of zero gravity. Following trials will be performed on an already wetted surface which may affect the rate of progression of the fluid. Please see Section 10 for a complete overview of our experiment's electrical system.

3.2.5 Fluid Container

This container will weigh no more than ten pounds and will be made with clear polycarbonate and aluminum. There will be approximately 2 cm of fluid at the bottom of the tank. This fluid will be water with bright food coloring for contrast so that we may distinguish between the polycarbonate test surface and the fluid. Because this container is a sealed box we will consider it a pressure vessel. Although we do not expect the pressure in this box to reach dangerous levels we will install a pressure relief valve that will release any pressure at or above 3 psi. Our polycarbonate wedge piece will be placed inside this tank. This piece will stay at the top of the box until zero gravity is achieved. When we are at the top of the parabolic flight, the block will contact the fluid by sliding down rails under the power of an actuator. This polycarbonate block will have various angles cut out of the face the entire vertical length. We will compare the velocity of fluid rising along these surfaces and be able to compare between small and large angles. See **Fig. 3-2** for a view of the fluid container.

3.3 Procedures

3.3.1 Pre-Flight

We will conduct a pre-flight check before each flight to make certain that our experiment is all set for flight. Here is the checklist:

1) OUTER CONTAINMENT BOX INTEGRITY: Visually examine the box for any cracks or fractures
   REACTION PLAN: Substitute with alternate box that is free of cracks and fractures
2) TANK INTEGRITY: Visually examine the tanks for cracks or fractures that may cause leaks
   REACTION PLAN: Substitute with alternate tanks that are free of cracks and fractures
3) MOTION ALONG POLES: Slide the polycarbonate wedge piece along the poles to make sure that it moves smoothly and does not have any unfamiliar objects interfering the motion
   REACTION PLAN: Remove any unfamiliar objects or dirt from the sliders and poles and if needed, will lubricate poles
4) SPONGE AND WATER CHECK: Verify that the sponge contains the correct amount of water that has food coloring to help see it better
   REACTION PLAN: Replace with alternate sponge and put the correct amount of water in

5) ACCELEROMETER FUNCTIONALITY: Confirm that the accelerometer is functioning correctly and the laptop is receiving data from it
   REACTION PLAN: Inspect all the electrical connections between the accelerometer and laptop
6) ACTUATOR FUNCTIONALITY: Confirm that the actuator is functioning properly
   REACTION PLAN: Inspect all the electrical connections between the actuator and the motor
7) VIDEO CAMERA FUNCTIONALITY: Confirm that the video camera is functioning appropriately and that it has a new tape and batteries and the laptop is receiving data from it
   REACTION PLAN: Inspect all the electrical connections between the video camera and the laptop
8) COMPUTER SOFTWARE: Test that all electrical systems are functioning properly and communicating with the laptop
   REACTION PLAN: Check all connections and restart the laptop

Following the pre-flight checklist, a Test Flight Director will help us fasten the test apparatus to the floor of the plane and finish our pre-flight procedure.

3.3.2 Overview

We will start our experiment when the plane enters microgravity. The experiment will be controlled by switches on the motor. In case of an emergency, there will be a manual power shut off.

3.3.3 In-Flight

1) The computer is fastened to the floor by Velcro and turned on before the parabolas start
2) Once we are in microgravity, one of the researchers will push a button on the control box to activate the actuator which will move the polycarbonate wedge piece down towards the sponge, thus forcing the water to come out and climb up the angles
3) When we enter normal gravity, one of the researchers will push another button to move the actuator up so that the water can soak back into the sponge
4) Repeat steps 2 and 3 for each parabola
5) After completing all the parabolas, the motor, camera, and laptop will be turned off

3.3.4 Data Collection

The video camera will start recording data once the polycarbonate wedge piece touches the sponge. The accelerometer will send data to our laptop. The laptop and camera will store these two sets of data for future analysis.

3.3.5 Post Flight

We will unload our experiment at the end of the flight and replace the video camera batteries and put a new tape in. After each flight, we will repeat the preflight checklist to make sure everything is still ready for the next flight.

3.4 Necessity of Microgravity

In a gravity field, the water would make a contact angle with the Plexiglas because of the molecular attraction between the two substances. However, gravity would stop it from traveling up the walls. Our experiment needs to be done in microgravity because we wish to show how quickly a fluid will rise in a planar wedge without the hindrance of a gravity field.

4. Not a Follow-Up Flight

This is not a follow up flight

5. Bibliography

[1] Concus, Paul and Finn, Robert. “On the Behavior of a Capillary Surface in a Wedge,” Lawrence Radiation Laboratory. (1969).

[2] Concus, P., Finn, R., and Weislogel, M. “Measurement of Critical Contact Angle in a Microgravity Space Experiment.” Preprint for *Experiments in Fluids*. (2000).

[3] Smedly, Gregory Todd. “A Study of Immiscible Liquids, Liquid Behavior at Zero Gravity, and Dynamic Contact Lines and Angles.” (1990).

II. Safety Evaluation

6. Flight Manifest

Flyers
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Mai Lee Chang, Ground Crew July 2005
Andrea Martin, No Previous Experience
Eric Breckenfeld, No Previous Experience

Alternate Flyer
Kevin Jimenez

Ground Crew
Lisa McGill
Pete Penegor
Keith Rein
Meg Reinbold
Josh Shea
Brian Sutherland
Cody Williams

7. Experiment Description/Background

Please see Sections 1 and 2 for complete description and background of our experiment.

8. Equipment Design

Please see Section 3.2 for our experimental design.

9. Structural Design

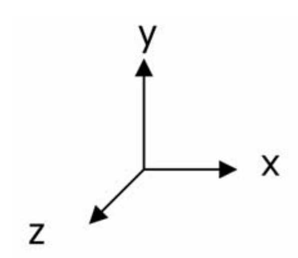
In this section we will explain the calculations made for the structural analysis on the containment box. The box is to be adapted from a previously flown NASA RGSFOP experiment. Since this experiment is different, the inside components will be removed and the new test components will be added. However this will not change the type of calculations for the structural design from years past.

9.1 Overview

Our experiment is designed to pass all G-load requirements required by NASA's Reduced Gravity Flight Program. To begin, the calculations are completed to determine the center of gravity that will be used for later calculations. Next, the calculations will be made for all of the G-load specifications of the Reduced Gravity Flight Program on our experiment. The different G-load forces include 9 G's forward, 3 G's aft, 6 G's down, 2 G's up, and 2 G's lateral. These G-load forces will be used to demonstrate that the force of resistance on the outer containment box will be sufficient in every direction of the box as a whole. After that, structural analysis of the inner box will show that the internal components of the inner box will remain isolated from the fuselage of the aircraft. Finally, the inner components will be analyzed to show that they will be contained inside the outer containment box. Free-body diagrams (FBD's) and G-loads are included for every calculation. The critical factors of safety (FS) that are included demonstrate the safeness of the equipment for all passengers and the aircraft itself. For calculation purposes, the right hand side of the experiment is assumed to be toward the front of the C-9B aircraft.

9.2 Centers of Gravity

For the center of gravity calculations the 3-D right-hand coordinate system's origin will be assumed to be the lower-left-rear corner of the outer containment box's aluminum frame. All of the inner components weights and relative centers of gravity with respect to the origin will be used to find the center of gravity of the entire system as a whole. Every dimension is in inches.



At normal gravity conditions (1 G) the inner components have a weight of 30 lbs. (inner box – 10 lbs, video camera – 5 lbs, plate – 15 lbs). The following table of centers of gravity can be measured due to roughly complete symmetry in all directions.

Table 9-1

Object	X (in)	Y (in)	Z (in)	Weight (lbs)
Inner Box	25.0	7.5	15.25	10
Video Camera	9.5	4.5	13.5	5
Plate	15.25	2.0	15.25	15

The center of gravity of the inner components can be calculated using the data from the **Table 9-1**:

$CG_x = (10*25 + 5*9.5 + 15*15.25) / 30 = 17.54$
$CG_y = (10*7.5 + 5*4.5 + 15*2) / 30 = 4.25$
$CG_z = (10*15.25 + 5*13.5 + 15*15.25) / 30 = 14.96$

Therefore the center of gravity of the inner component is (17.54, 4.25, 14.96)

In order to obtain the center of gravity for the entire apparatus, for the further calculations of the G-load forces, the center of gravity of the inner components needs to be combined with the center of gravity of the entire outer containment box. The outer box has dimensions 30.5 x 30.5 x 24.5. Since the outer box is roughly symmetrical in the x, y, and z directions, the center of gravity can easily be found to be (15.25, 12.25, 15.25). The center of gravity for the entire system can be found by combining the outer container's center of gravity and weight (40 lbs) with the inner container's center of gravity and weight (30 lbs). The calculations for the center of gravity for the whole system are as follows:

$\mathbf{CG_x}$ = (40*15.25 + 30*17.54) / 70 = **16.23 inches**
$\mathbf{CG_y}$ = (40*12.25 + 30*4.25) / 70 = **8.96 inches**
$\mathbf{CG_z}$ = (40*15.25 + 30*14.96) / 70 = **15.13 inches**

Therefore the center of gravity of the entire system is (16.23, 8.96, 15.13)

For all following calculations of the G-force analysis, the weight of the system will be assumed to be concentrated at the center of gravity of the system (16.23, 8.96, 15.13).

9.2.1 9 G's Forward

With the entire system under an induced gravity of 9 G's in the forward direction the weight can easily be calculated by multiplying the weight at 1 G by a factor of 9 (70*9), which gives a force of 630 lbs. In order to counter this forward force on the system, two 2-inch wide cargo straps will be implemented by strapping them through the handles, over the outer box, and bolting them to the floor of the aircraft with 3/8-inch steel bolts. In order to counter this force of 630 lbs, each individual strap will need to supply a force of 315 lbs in the negative x-direction. Each strap can supply a maximum force of $5{,}000*\cos(72^o) = 1{,}545$ lbs. The safety factor can then be calculated to be 1545/315 = 4.90 for the system in 9 G's in the forward horizontal direction. Taking the moments about the point (0, 0, 15.25) it can be seen that the reaction moment for each strap will need to be 630*15.13 / 2 = 4,766 in-lbs. The straps are each capable of providing a moment of $5{,}000*\sin(72^o) * 5 = 23{,}780$ in-lbs. This results in a factor of safety of 23,780/4,766 = 4.99. Therefore, the two straps will be sufficient to keep the system static during 9 G's forward.

9.2.2 3 G's Aft

Under an induced gravity of 3 G's aft, the entire system will experience a weight of 210 lbs. (70*3). The reaction force to this weight will be provided by two 2-inch wide cargo straps attached to the handles of the outer frame (bolted to the aircraft by 3/8-inch steel bolts). Summing the forces in the x-direction it can be seen that the straps will each need to provide a reaction force of 105 lbs. in the positive x-direction. Each strap is capable of supplying 5,000*cos (72^o) = 1545 lbs. This results in a factor of safety of 14.71 in the horizontal direction for the entire apparatus in 3-G's aft. Taking moments about the position (30.5, 0, 15.25) it can be seen that each strap will need to provide a reaction moment of 210*15.13 / 2 = 3177 in-lbs. Each strap is capable of supplying a 5,000*sin (72^o)*5 = 23,780 in-lbs. This results in a factor of safety of (23,780/3177) = 7.48. Thus, the two straps will be sufficient to keep the system static during 3 G's backwards.

9.2.3 6 G's Down

While experiencing an induced gravity of 6 G's down, the equipment will experience an induced weight of 420 lbs. The area of the bottom of the equipment is 30.5 in x 30.5 in or 6.46 ft^2. This maximum in-flight stress on the fuselage would be 65 lbs./ft^2. This is well below the maximum allowable in-flight floor loading specification of 200 lbs./ft^2. This is a factor of safety of 3.08.

Therefore, our experiment does not need to be provided floor shoring to satisfy the g-load specifications in the 6 G's down situation.

9.2.4 2 G's Lateral

The equipment will experience an induced weight of 140 lbs. in the lateral direction. To avoid translational motion in the z direction, the outer frame will need to be ratcheted down with enough force that the frictional force generated against the aircraft foam is significantly greater than the 140 lbs. of induced force. If the case were to rotate, the cargo straps would need to counter the moment induced about the position (15.25, 0, 0). The moment that needs to be countered would be 140*16.23 = 2272 in-lbs. The tether strap going over the top of the outer frame would need to provide a force of 2272 / 30.5 = 74.49 lbs. Since the strap is capable of providing a force of up to 5,000 lbs., the factor of safety for 2 G's in the lateral direction is 67.12. Therefore, the two straps will be sufficient to keep the system static during 2 G's in the lateral directions.

9.2.5 2 G's Up

Under an induced gravity of 2 G's up, the weight of the equipment will be 140 lbs. This weight will be countered by reaction forces provided by the straps over the top of the outer frame. Each strap is capable of providing up to 5,000*sin (72^o) = 4,755 lbs. of force when in tension. This results in a factor of safety of 4,755*2 / 140 = 68. Thus, the two straps will be sufficient to keep the system in place during 2 G's up.

9.3 Summary of Apparatus Attachment to Fuselage of C-9B

The previous calculations prove that the system of the containment box and inner components (video camera, inner box, and the plate) will remain at static equilibrium for all G-load cases. Two cargo straps around the outer containment box will be sufficient in securing the experiment to the floor of the C-9B aircraft.

Table 9-2 Summary of FS calculations for fastening the equipment under all G-load specifications. Forces and moments shown are the reactions that need to be provided by one cargo strap.

Case	Force (lbs.)	Force FS	Moment (in-lbs.)	Moment FS
9 G's forward	315	**4.90**	4,766	**4.99**
3 G's aft	105	**14.71**	3,177	**7.48**
6 G's down	210	**3.08**	N/A	**N/A**
2 G's lateral	70	**need more info**	2,272	**67.12**
2 G's up	70	**68**	N/A	**N/A**

10. Electrical System

The electrical components of this experiment will be minimal and very simple. We will use one accelerometer mounted inside our outer containment box and wired to a laptop computer with an analog to digital (ADC) converter. The laptop will record the g force on the plane and allow the experimenters to know when to start the experiment.

We will also use an electrically controlled actuator wired to a control box to move the sliding polycarbonate wedge piece up and down. The actuator will be wired with appropriate fuses. A standard video camcorder will be used to videotape the experiment.

The ADC, actuator and control box will be wired to a power strip. The breaker switch on the power strip will be used as a master kill switch in the case of a malfunction. The camcorder and laptop will run on battery power.

Fig. 10-1

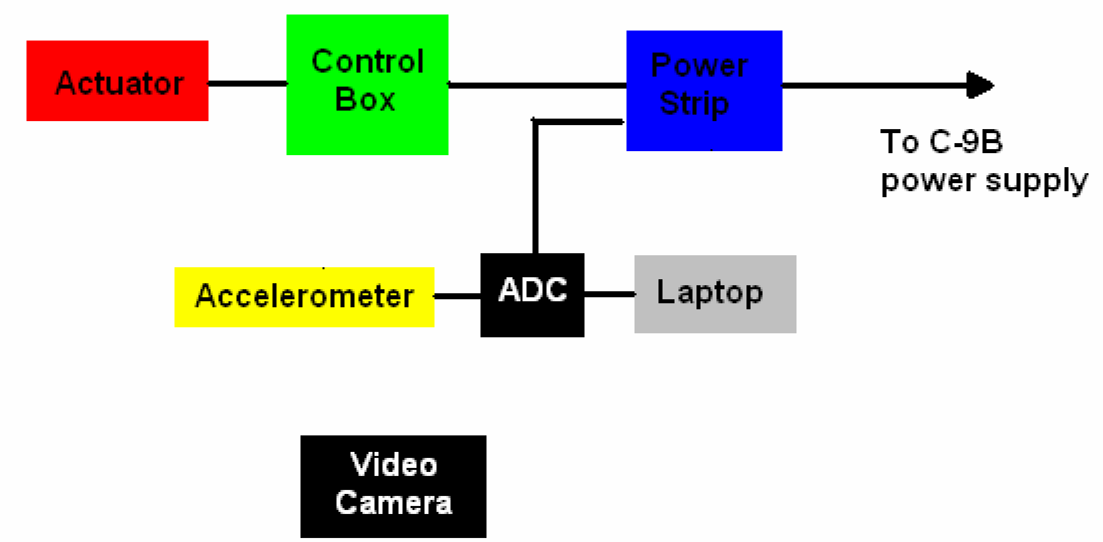


Table 10-1 Electrical Components

Name	**Voltage**	**Max Current**	**Function**
Laptop	12 VDC	2.0 A	Data collection
Accelerometer	5 VDC	100 mA	Measure acceleration
ADC	5 VDC	200 mA	PC-accelerometer interface

11. Pressure/Vacuum System

Although our experiment does not contain any components intended to operate at an altered pressure, it does contain a rigid, fully sealed fluid containment tank that could be considered a pressure vessel if the plane were to lose cabin pressure. Our inner most layer of containment will have an airtight seal. To account for possible pressurization of the tank, we will construct and test it to withstand a pressure of up to 5 psi. We will also attach a dual directional relief valve set to release at a pressure of 3 psi. This will allow the tank pressure to equalize well before its rated strength. The valve will be located at the top of the tank so that liquid cannot leak out. Furthermore, the tank will contain only air and deionized water, neither of which is toxic or corrosive, and the water will be confined to the bottom of the tank in a sponge.

12. Laser System

Our experiment does not involve the use of lasers.

13. Crew Assistance Requirements

Crew assistance is requested only for loading the experiment onto the plane and proper attachment of straps. No in flight crew assistance is required.

14. Institutional Review Board

Our experiment does not involve human or animal test subjects or biological material.

15. Hazard Analysis

Hazard Number: 1
Hazard Description: Tank leaks
Hazard Causes:

1) Crack/fracture develops as a result of stresses from the experiment
2) Tank dislocates and hits another object thus creating a crack/fracture

Hazard Controls:

1) The two sides, top, and bottom are made of ¼" thick aluminum and the front and back are made of very strong Plexiglas
2) During preflight, the tank will be visually examined for cracks/fractures
3) Only water with a food coloring dye will be used in the tank
4) Tank will be firmly bolted to the aluminum platform

Hazard Number: 2
Hazard Description: Actuator comes in contact with the water
Hazard Causes:

1) Top of the tank breaks due to stresses during the experiment

Hazard Controls:

1) Actuator is splash resistant
2) Will have fuses and a master kill switch to shut off the power
3) Top of tank is made of ¼" thick aluminum
4) The actuator will provide a force of only 25 lbs. which is insufficient to damage any of the experiment's components
5) During preflight, tank will be carefully visually inspected

Hazard Number: 3
Hazard Description: Sliders are jammed
Hazard Causes:

1) Dirt or foreign objects are on the poles
2) Actuator fails to work properly
3) Control box fails to work properly

Hazard Controls:

1) Power will be cut via the master kill switch
2) During preflight, we will test the motion of the sliders to make sure that it works properly and visually examine the poles to make sure that they are free of dirt and foreign objects
3) We will also verify that the actuator works correctly during preflight check

Hazard Number: 4
Hazard Description: Too much current is run through the actuator
Hazard Causes:

1) Current regulator for actuator functions improperly
2) Wires' insulation is worn
3) Malfunction of control box

Hazard Controls:

1) Actuator will only use a small amount of current
2) Will have a fuse to shut off the power incase of a current overdraw
3) Will have a master switch to shut off all power
4) During preflight check, we will verify that all wires and connections function correctly

Hazard Number: 5
Hazard Description: Malfunction of control box
Hazard Causes:
1) Sliders are jammed causing the actuator to work improperly
2) Wires are damaged or worn
3) Electrical malfunction or shortage

Hazard Controls:
1) If the control box does not function properly which causes the actuator to function improperly as well, no damage will occur to the experiment or operator
2) The actuator is contained properly
3) A master kill switch will be available
4) See Hazard Control Number 3: "Sliders are jammed"
5) Prior to flight, the box will be tested to make sure it functions properly and the wires will be carefully examined to make certain they are not damaged or worn

Hazard Number: 6
Hazard Description: Malfunction of camera
Hazard Causes:
1) Camera is connected improperly
2) Camera is damaged
3) Electrical malfunction or shortage

Hazard Controls:
1) We will test electrical parts
2) Before take-off, we will verify that camera functions properly

Hazard Number: 7
Hazard Description: Damage to experiment equipment
Hazard Causes:
1) Experiment becomes detached from the platform
2) Fluids come in contact with electronics

Hazard Controls:
1) Components will be firmly bolted to the aluminum platform
2) Outer containment box will control any free floating parts
3) All sides and corners of outer containment box will be padded with closed cell foam
4) A master kill switch will be available for all electronics
5) See Hazard Number 2: "Actuator comes in contact with the water"

Hazard Number: 8
Hazard Description: Electrical shock of operator

Hazard Causes:

1) Worn or damaged wire
2) Overload of current

Hazard Controls:

1) Before take-off, all wires will be checked
2) A master kill switch will be available
3) See Hazard Number 4: "Too much current is run through the actuator"

Hazard Number: 9

Hazard Description: Damage to DC-9

Hazard Causes:

1) Detachment of experiment from the floor of the plane due to failure of stowage restraint which possibly could cause damage to the cabin and crew

Hazard Controls:

1) Outer containment box will be made from polycarbonate with aluminum on the edges
2) All edges and corners of the outer containment box will be padded with closed cell foam
3) Outer containment box will be restrained with a maximum tensile strength of 5,000 lb

16. Tool Requirements

No specialized tools will be required during our stay in Houston. We will need only standard sized wrenches, screw drivers, scissors, Velcro and duct tape which will be borrowed from the tool chest at Ellington Field. This will minimize the risk of a misplaced tool.

17. Ground Support Requirements

Power Requirements:

Standard 120 VAC, 60 Hz power is required for testing equipment.

Hazardous Material Storage:

No hazardous materials storage is requested.

There are no special ground support requests for our time at Ellington Field.

18. Hazardous Materials

No hazardous materials will be used during this experiment. De-ionized water is the only fluid being used. All other materials will be nontoxic and non-corrosive. Materials Safety Data Sheets (MSDS) will be provided with the TEDP.

19. Procedures

19.1 Pre-Flight

We will conduct a preflight check before each flight to make certain that our experiment is all set for flight. Here is the checklist:

1) OUTER CONTAINMENT BOX INTEGRITY: Visually examine the box for any cracks or fractures
   REACTION PLAN: Substitute with alternate box that is free of cracks and fractures
2) TANK INTEGRITY: Visually examine the tanks for cracks or fractures that may cause leaks
   REACTION PLAN: Substitute with alternate tanks that are free of cracks and fractures
3) MOTION ALONG POLES: Slide the polycarbonate wedge piece along the poles to make sure that it moves smoothly and does not have any unfamiliar objects interfering the motion
   REACTION PLAN: Remove any unfamiliar objects or dirt from the sliders and poles and if needed, will lubricate poles
4) SPONGE AND WATER CHECK: Verify to make sure that the sponge contains the correct amount of water that has food coloring to help see it better
   REACTION PLAN: Replace with alternate sponge and put the correct amount of water in
5) ACCELEROMETER FUNCTIONALITY: Confirm that the accelerometer is functioning correctly and the laptop is receiving data from it
   REACTION PLAN: Inspect all the electrical connections between the accelerometer and laptop
6) ACTUATOR FUNCTIONALITY: Confirm that the actuator is functioning properly
   REACTION PLAN: Inspect all the electrical connections between the actuator and the motor
7) VIDEO CAMERA FUNCTIONALITY: Confirm that the video camera is functioning appropriately and that it has a new tape and batteries and the laptop is receiving data from it
   REACTION PLAN: Inspect all the electrical connections between the video camera and the laptop
8) COMPUTER SOFTWARE: Test that all electrical systems are functioning properly and communicating with the laptop
   REACTION PLAN: Check all connections and restart the laptop

Following the preflight checklist, a Test Flight Director will help us fasten the test apparatus to the floor of the plane and finish our preflight procedure.

19.2 Overview

We will start our experiment when the plane enters microgravity. The experiment will be controlled by switches on the motor. In case of an emergency, there will be a manual power shut off.

19.3 In-Flight

1) The computer is fastened to the floor by Velcro and turned on before the parabolas start
2) Once we are in microgravity, one of the researchers will push a button on the control box to activate the actuator which will move the polycarbonate wedge piece down towards the sponge, thus forcing the water to come out and climb up the angles
3) When we enter normal gravity, one of the researchers will push another button to move the actuator up so that the water can soak back into the sponge
4) Repeat steps 2 and 3 for each parabola
5) After completing all the parabolas, the motor, camera, and laptop will be turned off

19.4 Data Collection

The video camera will start recording data once the polycarbonate wedge piece touches the sponge. The accelerometer will send data to our laptop also. The laptop and camera will store these two sets of data for future analysis.

19.5 Post Flight

We will unload our experiment at the end of the flight and replace the video camera batteries and put a new tape in. After each flight, we will repeat the preflight checklist to make sure everything is ready for the next flight.

III. Outreach Plan

20 Outreach Plans

20.1 Outreach Goals

- Inspire elementary, middle, and high school students, especially those from underrepresented backgrounds, to attend college and to get involved in engineering and science.
- Show the exciting opportunities provided by the University of Wisconsin and NASA to young students and community members
- Excite students and the public about science and engineering that is going on in their state and at their university
- Inform students and the public about capillary action, why it is studied and why NASA is an integral part of this research
- Target groups previously unreachable by similar initiatives so that they too will know about the science and opportunities at the university

We have chosen the following initiatives to obtain our goals:

20.2 Minorities in Science and Engineering Outreach Initiative

20.2.1 Oshkosh Ch.10 News
Wisconsin possesses the third largest Hmong population in the nation. The Oshkosh Channel WI Local Channel 10 presents general and local news on Thursday nights to the Hmong community throughout central Wisconsin. One of our members, Mai Lee Chang, is a native Hmong speaker from the Oshkosh area and has contacted the station with intentions of running an educational segment on zero gravity capillary action as well general science and engineering opportunities available to the Hmong community. By describing her experience in zero gravity in Hmong, we hope that Mai Lee Chang will be able to inspire young Hmong to find careers in science and engineering.

20.2.2 FutureHmong Magazine
FutureHmong Magazine is published monthly and distributed throughout the nation. One of its main goals is to inform and educate the Hmong population about educational opportunities. One of our members, Mai Lee Chang, has been in contact with the editor and has been developing a plan to outline our research to the Hmong community.

20.2.3 Hmong American Student Association (HASA)
HASA represents the Hmong students on campus. They are very active both on campus and in the community, thus allowing us to reach out to younger Hmong students as well. Mai Lee Chang shared with them about our experiment of RM Instabilities that we conducted in July 2005 and sparked interest in space science and engineering. After this year's experiment, we plan to present to the group again.

20.2.3 Association of Asian Engineers (AAE)

AAE is a new organization that provides a support group for Asian students in engineering as well as a place to network. Mai Lee Chang is one of the founders of the organization. She plans to give a presentation after our experiment to the group. We anticipate that this will encourage more students of color to know and take advantage of opportunities open to undergraduates such as NASA's microgravity program.

20.2.4 Society of Hispanic Professional Engineers (SHPE)

The Society of Hispanic Professional Engineers is a national organization dedicated to increasing the number of Hispanic student engineers and scientists in the United States. We will contact the University of Wisconsin chapter with the intentions of presenting our findings on zero gravity capillary action at one of their meetings. We hope that this will attract Hispanic engineering students to future zero gravity teams.

20.2.5 WI Black Engineering Society (WBES)

WBES is a student organization that is also a part of the Region IV National Society of Black Engineers. They are very active in the community such as volunteering at the Young Women's Christian Association shelter and are currently working on a pre-college initiative project to reach out to K-12 students to increase their interest in math, science, technical, and engineering fields. After finishing our experiment, we will share with them our experience of zero gravity and explain the significance of research in specialized environments.

20.2.6 Filipino American Student Organization (FASO)

FASO represents the Filipino American students at the University of Wisconsin-Madison. Their goal is to provide a sense of belonging to Filipino American students at UW-Madison and to spread knowledge of Filipino heritage to the rest of the community. Kevin Jimenez, one of the members of Zero-G, is part of this organization and will present at a FASO meeting to publicize NASA's RGSFOP and make people aware of the exciting opportunities available in science and engineering.

20.3 Youth Science and Engineering Outreach Initiative

20.3.1 Expand Your Horizons

Expand Your Horizons is a program sponsored by the University of Wisconsin to encourage young women to enroll in engineering. We will be giving a presentation at this program about our research with emphasis on showing the exciting opportunities the University of Wisconsin and NASA have for young women.

20.3.2 Engineering Saturday for Tomorrow's Engineers at Madison (ESTEEM)

The ESTEEM program gives high-ability high school students the opportunity to spend a Saturday learning about engineering at the University of Wisconsin-Madison. On October 15, 2005, we talked to four different groups of approximately 15 high school juniors and seniors who were interested in engineering at the University of Wisconsin. In our discussion, we explained the zero gravity experiments that we had performed in previous years and then talked about what we plan to find in the experiment that we are proposing this year. In addition, we answered questions about the different engineering majors offered at the University of Wisconsin and provided some insight as to what the students could expect once they entered the College of Engineering.

20.3.3 Science Alliance

Science Alliance is an event that takes place annually on campus to let the public know about students' and faculties' work/research here. It is a very popular event here so it attracts many students of all ages and adults to the campus. Last year, in April 2005, we had a table with hands-on activities and a computer to show video footages of our past experiments and visits to JSC. This year, the event will take place on April 1, 2006, and we plan to participate again.

20.3.4 Science Olympiad

Created in 1983, the Science Olympiad aims to spark interest in science in K-12 students by showing them that science can be fun, exciting, and challenging. In the Science Olympiad, students compete in a variety of tournaments covering the science disciplines of biology, earth science, chemistry, physics, computers and technology. Students prepare for these events throughout the year and then participate in a number of competitions that follow the format of popular board games, TV shows and athletic games.

This year we plan on working with the Madison Public Schools to help facilitate youth interest in engineering and the sciences. Several of our members will be matched with a student team at a Madison school and will meet with the team several times throughout the school year to help the team prepare for the different events. On April 22, we will help conduct the Science Olympiad for the Madison area by judging the different events and coaching the student teams.

20.3.5 Madison Memorial High School

Madison Memorial High School is a local school known for its academic excellence. We have given classroom presentations to Memorial High School's Aerospace class and Astronomy classes on our RM Instability experiment that we performed in July 2005. Due to the high number of students who are interested in science and engineering at this school, we plan to return this year to discuss capillary action with the students and encourage them to pursue opportunities in science and engineering.

20.3.6 Madison East High School

Madison East High School has a very diverse student body, including many low income and minority students. We will give presentations to the freshman integrated science class and advanced physics class. Through hands-on activities, video footages, and demonstrations, they will have a better conceptual understanding of how gravity and microgravity work. We will also discuss different opportunities available to them in science and will encourage them to enter college after graduation.

20.3.7 Solar System Ambassadors

The Solar Systems Ambassadors Program is a public outreach program sponsored by NASA's Jet Propulsion Laboratory in Pasadena, CA. One of our members, Andrea Martin, contacted Bill Hensley, a WI Solar Systems Ambassador, and sent him a DVD containing photos and video from the experiment that we conducted in July 2005. We hope to continue having them use our team's experiments in the future.

20.3.8 Birch Trails Girl Scout Council and Black Hawk Girl Scout Council

Birch Trails and Black Hawk Council are two socially diverse Girl Scout troops in Madison, WI. These troops aspire to provide young girls with new opportunities and teach them about the world. We will give a presentation to these troops later this fall. We hope to inspire these girls to attend college and show them that science and space are both within their reach as future engineers. Below we have included an email of our initial correspondence with one of the troop leaders.

> From: Juli <julis@girlscoutsofblackhawk.org>
> To: ANDREA JOYCE MARTIN <ajmartin1@wisc.edu>
> Date: Sun, 16 Oct 2005 18:20:31 -0500
> Subject: RE: NASA zero gravity program presentation
> That would be fabulous. Where would you like to hold it? We could do
> it here at our office or somewhere on campus. When would you like?
> We're pretty open.
>
> -----Original Message-----
> From: ANDREA JOYCE MARTIN [mailto:ajmartin1@wisc.edu]
> Sent: Sunday, October 16, 2005 5:55 PM
> To: Juli
> Subject: NASA zero gravity program presentation
>
> Dear Ms. Speck,
> Last year during the Expand Your Horizons Conference I was a
> volunteer. I talked to you about a team at the University of Wisconsin
> that I was a part of that performs research for NASA's microgravity
> program. We fly in NASA's DC-9 plane and experience weightlessness and
> do research. We'd love to make a presentation to your girlscouts about
> the program, experience and how they can get involved in college.
> Please let me know if you'd still be interested in this presentation
> and when would be a good time to do it. Information about our program
> can be found at http://homepages.cae.wisc.edu/~rmzerog/
> Thanks,
> Andrea Martin

20.4 Other Outreach Activities

20.4.1 AIAA

Most of our team members are also members of the local student chapter of AIAA. At our monthly meetings, we will give updates as to the status of our research project and provide the opportunity for our members to discuss the implications of our research in great detail.

19.4.2 Team Website

In past years, we have maintained a website that explains our research to the general public. This year we plan to build new website that provides educational material as to how capillary action works and its behavior in zero gravity. There will also be additional material explaining our outreach initiatives as well as photo documentation of our experiment this year as well as in years past. The web address is http://homepages.cae.wisc.edu/~rmzerog

20.5 Community Outreach through the Media

20.5.1 WI Engineer Magazine

The WI Engineer Magazine is a student run magazine that is a part of the Engineering College Magazines Associated. It is published four times throughout the academic school year. After the completion of our research, one of our members will write an article that will outline our experiment and explain our results in hope that it will facilitate student and faculty interest in zero gravity research.

20.5.2 Badger Herald

The Badger Herald is the largest independent daily newspaper in the nation. Because it is published and distributed daily on campus, this newspaper provides us with the opportunity to reach a vast majority of the University of Wisconsin student population. We intend to write an article for publication in *The Badger Herald* following our experiment in the hopes of increasing participation in zero gravity research by students not specifically enrolled in the engineering curriculum on campus.

20.5.3 The Daily Cardinal

The Daily Cardinal is an award winning student newspaper that is also produced on campus. Following the completion of our experiment, we will submit our findings to the paper in hopes of once again sparking interest in zero gravity research among non-engineering science majors.

20.5.4 FutureHmong Magazine

As described in section 19.2.2.

20.5.5 Madison Observer

The Madison Observer distributes about 5,000 copies on a weekly basis in the Madison-area to both the student body and Madison residents. Madison residents historically have a strong interest in science and academia. We plan to contact *The Madison Observer* in the hopes of submitting an article for publication. Doing so will allow us to reach a more diverse audience and facilitate community involvement in our research.

20.5.6 Oshkosh Ch.10 News

As described in section 19.2.1

20.5.7 The Wisconsin State Journal

The Wisconsin State Journal is a Wisconsin's official state newspaper and is distributed throughout Wisconsin. In the past, we have had reporters from the paper accompany us to Johnson Space Center. The feedback from the resulting articles has shown us that *The Wisconsin State Journal* is an excellent medium for reaching people across the state that might not otherwise be aware of the opportunities available at NASA for students. We plan to work closely with *The Wisconsin State Journal* this year to bring the results of our research to the public.

IV. Administrative Requirements

Letter of endorsement and **Statement of Supervising Faculty** to be included in mailed hard copy

21. Funding/Budget Statement

<u>Itemized Budget</u> <u>Table 21-1</u>

Materials			
Inner containment tank materials	$100/ea	1	$100
Bolts, connectors, etc.	$0.50/ea	30	$15
Total			**$115**
Chemicals			
De-ionized water	$10/liter	1	$10
Dyes	$5/oz	1	$5
Total			**$15**
Electronics			
Resistors, breakers, etc.	$2/ea	10	$20
Actuator	$200/ea	1	$200
Actuator controls and connectors	$100/ea	1	$100
Total			**$320**
Travel			
UW Fleet Vehicle	$27/day +$0.16/mile	10	$650
Hotel in Houston	$125/night	10	$1250
Total			**$1900**
Project Total			**$2350**

Current Sources of Funding

Wisconsin Space Grant Consortium (travel costs)	$2000
UW Space Science and Engineering Center	$2000
UW Engineering Physics Department	$500
UW Mechanical Engineering Department	$500
Total	**$5000**

22. Experiments Involving Animals
Our experiment does not involve animal test subjects.

23. Parental Consent Forms
All team members are over the age of 18 at the time of proposal.