Long Duration Fluorescence Imaging of the Richtmyer-Meshkov Fluid Instability

TOPIC AREAS:

Fluid Physics/Applied Mathematics/Plasma Physics

RM ZERO-G TEAM

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Second Choice: Flight Group 6 July 21 to July 30, 2005
Third Choice: Flight Group 2 March 17 to March 26, 2005

ADVISOR/MENTOR REQUEST

No advisor or mentor is requested.

ABSTRACT

We predict that in the 23 second reduced gravity environment the amplitude of the Richtmyer-Meshkov fluid instabilities will increase into a non-linear growth phase to a point where full turbulence has developed. This has never been imaged successfully for the RM fluid instability between two fluids for longer than 900 milliseconds. By studying these instabilities in a longer Reduced Gravity Environment we will be able to get a clearer picture of how the instabilities grow and develop into a turbulent regime. Better understanding and imaging of the RM fluid instability may lead to a better understanding of physical phenomena like supernovae evolution, hydrogen/helium interactions within the surface of dying stars, burning rates of SCRAM jet fuel and other high performance engines, and inertial confinement fusion target implosions.

I. TECHNICAL

1. INTRODUCTION

1.1 What are Richtmyer-Meshkov Instabilities?

A Richtmyer-Meshkov (RM) instability is one of the most fundamental fluid instabilities, manifesting itself in many fields of study. An RM instability results when a shock wave or impulsive acceleration passes normal to the interface of two fluids with a density gradient. "During the passage of the shock wave, vortices are deposited at the interface due to misalignment of the pressure and density gradients (baroclinic effect)."[1] This acts to disturb the fluid and cause small perturbations which grow in amplitude and eventually transition into turbulent flow. "RM instability is a fundamental hydrodynamic instability which exhibits many nonlinear complexities that transform simple initial conditions into complex turbulent flow." [1] It is closely related to Rayleigh-Taylor Instability, but inhabits a few distinct characteristics. In RM instability, the acceleration of the impulse induces instability regardless of which direction it is applied as long as it is applied normal to the interface. In Rayleigh-Taylor instability, the instability only occurs in the direction of gravity and only in the direction of lighter fluid to heavier fluid. Also because the influential force is impulsive, the progression to turbulence largely occurs with no forces acting on the fluids. However, RM instability does exhibit certain simplicity in that it requires few defining parameters.[1] In addition, it can be generated in a closed container, making it an excellent candidate for studying nonlinear stability theory as well as the transition to turbulence.

1.2 Applications of RM Instability

RM instability is present in a number of scientific applications. It is a fundamental process in supernovae, supersonic combustion, and inertial confinement fusion. RM instability is believed to occur in dying stars, when an outward propagating shock wave encounters stratified layers of helium and hydrogen.[2] RM instability is also very important in the design and performance of supersonic ramjet engines (scramjets). Efficient mixing of the fuel and air is difficult to achieve. Introducing a shock wave through a light fuel and heavy air results in RM instability. This creates faster mixing rates, higher burning rates, and overall better performance. Inertial Confinement Fusion (ICF) research is dependent on understanding RM instability. In an ICF experiment, a spherical shell encloses a deuterium-tritium fuel mixture. Lasers generate energy on the surface until the shell implodes on itself. As the shell implodes, the temperatures and pressures rise rapidly until nuclear fusion occurs. The

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[1] Puranik, Bhalchandra, Oakley, Jason, Anderson, Mark, and Bonazza, Riccardo. "Experiments on the Richtmyer-Meshkov Instability I: Preparation of a Membraneless Interface Using the Rayleigh-Taylor Instability". Fusion Technology Institute. University of Wisconsin. pp 4. 2001.

[2] Niederhaus, C.E. and Jacobs, J.W. "PLIF Flow Visualization of Incompressible Richtmyer-Meshkov Instability." University of Arizona. pp 528.

fuel undergoes RM instabilities as it is being compressed resulting in turbulent flow. This turbulence reduces the energy output significantly. Currently the experimental lasers use more energy than the reaction yields, but reducing the instabilities that occur could change the amount of energy released appreciably.

1.3 Liquids vs. Gases

1.3.1 Gases

Much of the current research in RM instability involves the debate between using liquids or gases. Previous RM instability experiments have been carried out in shock tubes using two gases.[2] The major hindrance in these experiments is in sustaining a well defined, sharp boundary interface between the two gases. One solution has been to initially separate the two gases with a thin membrane. The membrane is then broken by the shock wave. This, however, presents some difficulties. Fragments of the membrane disturb the growth and generate uncontrolled instabilities that instigate interfering turbulence. Other experiments have used solid barriers and remove them immediately before the shock wave passes. The high diffusion coefficients of gases are inconvenient with this technique. The gases mix slightly before the shock wave passes, and the interface is not smooth. This causes the perturbations to be non-uniform and difficult to differentiate and study. This technique severely limits the usefulness of the data.

1.3.2 Liquids

The use of liquids instead of gases has several distinct advantages. Firstly, it eliminates the boundary interface problem. Liquids have low coefficients of diffusion so mixing is not an issue.[3] The low coefficients of diffusion do slow down the speed of the instability development. At these speeds, the earth's gravitational field strongly affects the turbulent flow. Gravity acts to stabilize the instability. Liquid experiments must therefore be conducted in reduced gravity. The low velocity instabilities provide a longer time in which to image the growth rate. Visualization is much easier because the speed is reduced and standard video imaging equipment can be used.

1.3.3 Role of Gravity

Gravity plays such a negative role in RM instability experiments, especially those involving liquids. The only way to achieve good data is to remove the affects of gravity. A few experiments have tried to keep the fluids in freefall while the RM instability is developing.[4] Drop towers are used to accomplish this, but the time frame of these experiments is on the order of milliseconds. The transition to turbulence is not developed in such a short time. The longest imaging of RM

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[3] Cohen, R.H., Dnanevik, W.P., Dimits, A.M., Eliason, D.E., Mirin, A.A, Zhou, Y., Porter, D.H., Woodward, P.R., "Three Dimensional Simulation of a Richtmyer-Meshkov Instability with a Two-Scale Initial Perturbation." pp 3. 2002.

instability is 700 milliseconds.[4] The environment of the C-9 would allow sufficient time for the instability to fully develop and can be imaged with relatively low cost video equipment. There is no other testing environment that would solve the issues associated with studying RM instability like the parabolic flight of the C-9, except for a permanent zero gravity environment like that experienced aboard the International Space Station, but it would be much more difficult and expensive to devise such a system.

[4] Niederhaus, C.E. and Jacob, J.W., "Experimental study of the Richtmyer-Meshkov instability of incompressible fluids," J. Fluid Mech. (2003), vol 458, pp 243-244, Cambridge University Press.

2. TEST OBJECTIVES

2.1 Objectives of the Experiment

Our experiment aims to accomplish two main goals. The microgravity environment produced on the C-9 will allow us to study and record the complete development of Richtmyer-Meshkov instabilities well into the nonlinear phase. We will also attempt to experimentally affirm Richtmyer's linear stability theory through careful analysis of our results and comparison with theoretical values. Please see the following sections for a detailed explanation of these objectives.

2.1.1 Objective Number 1: Observing and recording the development of Richtmyer-Meshkov instabilities into full turbulence

Past experiments that have attempted to study Richtmyer-Meshkov instabilities have encountered significant difficulties in obtaining accurate results. If the fluids used in the experiment are gasses, it is very difficult to obtain a clear interface due to the high diffusion coefficients of gasses. Methods of improving the interface, including barriers that are removed just prior to the impulse and barriers that are destroyed by the impulse, have been shown to influence the development of Richmyer-Meshkov instabilities, especially as the instabilities progress into turbulence. The sensitive dependence on initial conditions demonstrated in the nonlinear phase of the instabilities results in great uncertainty due to inconsistent initial conditions of the experiments. In particular, non-uniformities at the interface caused by removing a barrier or the small fragments from a shattered barrier can change the development of Richtmyer-Meshkov instabilities in unpredictable ways.

Other experiments have been performed using liquids to create the instability. Liquids allow the creation of a very clear, uniform interface because of their low diffusion coefficients. However, when liquids are used, gravity adversely affects the developing instabilities. The relatively high mass of liquids greatly stabilizes the interface when placed in an acceleration field such as Earth's gravitational field. This obstacle was overcome in a novel experiment performed by C.E. Niederhaus and J.W. Jacobs at the University of Arizona.[5] In this experiment micro gravity was simulated by dropping the tank containing the liquids onto a spring. The spring provided the impulse. The developing Richtmyer-Meshkov instabilities were videotaped for analysis as the tank was in freefall after bouncing off the spring. Although this experiment provided very good data during freefall, the instabilities were only allowed to develop freely during a period of about 0.7 seconds, before the tank bounced of the spring a second time and experienced a second impulse.

By performing our experiment in the microgravity environment aboard the C-9, we plan to take advantage of the clear interface provided by using liquids to develop the Richmyer-Meshkov instabilities without the limited time frame imposed by the freefall experiment. The use of liquids will allow us much more precise control over the initial

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[5] 2Lindl, J.D., McCrory, R.L., and Campbell, E.M., "Progress Toward Ignition and Burn Propagation in Inertial Confinement Fusion," *Physics Today,* 45 (9), 32-50 (1992).

conditions of the experiment than gasses can offer, without the drawbacks of creating an artificial boundary at the interface. The 23 seconds of microgravity experienced on the C-9 will provide enough time for the instabilities to develop well into the nonlinear phase, a phase that has not been closely studied. We will record and study the development of turbulence in the Richtmyer-Meshkov instabilities in an effort to understand this aspect of fluid instabilities.

2.1.2 Objective Number 2: Confirming agreement with Richtmyer's linear stability theory

After collecting our data, we hope to analyze the experiment and provide evidence supporting Richtmyer's linear stability theory. Past Richtmyer-Meshkov experiments have provided data showing varying levels of agreement with this theory. By studying the development of instabilities for a longer time period and under more ideal circumstances we hope to show a more certain correlation between theoretical values and actual data. There are many calculations that can be made to compare our data with theoretically expected values, one of the simplest being the rate of advance of the instabilities.

We hope that our data will lead to a more fundamental understanding of Richtmyer-Meshkov instabilities. In the future, computer modeling and simulations may be able to better predict these instabilities and account for their effects on a system. Improved understanding and simulation ability would have a wide reaching effect. Richmyer-Meshkov instabilities are one of the main barriers to creating positive yield inertial containment fusion[5], but are also taken advantage of in combustion at supersonic speeds[6] and explosive welding processes[7]. We feel that a deeper understanding of Richtmyer-Meshkov instabilities may lead to improvement of these current technologies as well as many unforeseen advancements.

2.2 Not a Follow-up Experiment

This experiment is not a follow up from a previous experiment.

2.3 Hypothesis

We believe that in the microgravity environment created aboard the C-9 we will be able to collect data on the Richmyer-Meshkov instabilities of unprecedented quality over an as of yet unrealized length of time. We believe that the 23 seconds of microgravity experienced during each parabola will allow the instabilities to develop well into the nonlinear phase and demonstrate pure turbulence as created by Richtmyer-Meshkov instabilities from a single impulse. We believe that our high speed camera will allow us to watch the instabilities develop in slow motion and in great detail. The detail and frame rate will provide much more data than previous experiments have collected.

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[6] Markstein, G.H., "A Shock Tube Study of Flame Front-Pressure Wave Interaction," Sixth Symp. (Int) on Combustion, Reinhold, 387-398 (1957).

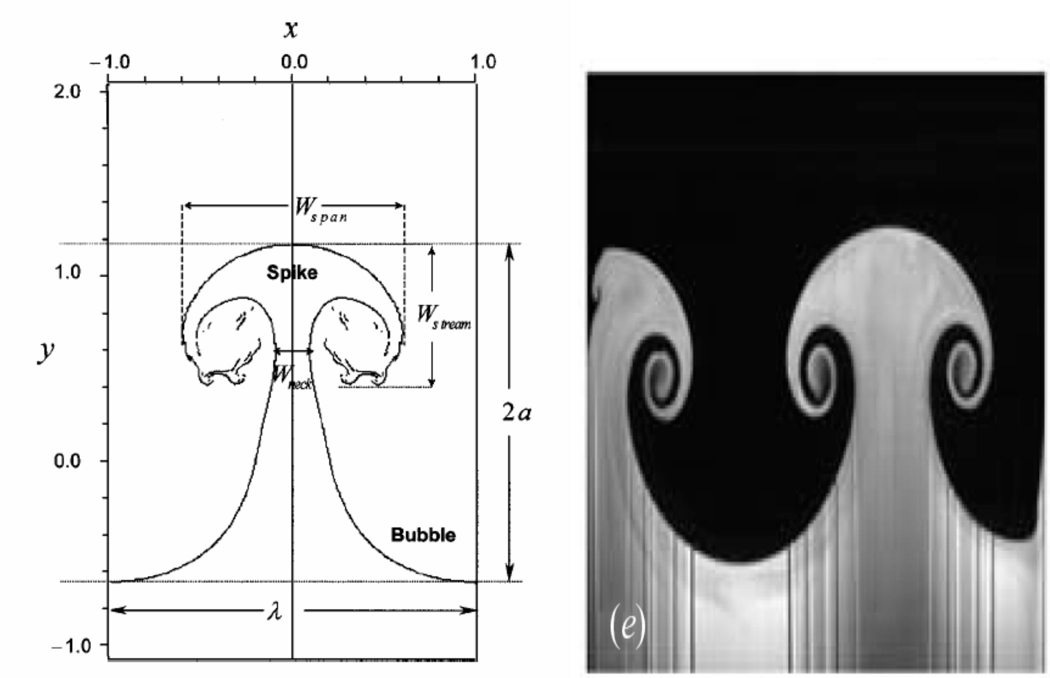
[7] Shaner, J.W., "Pattern Formation by Shock Processes," *Physica D*, 12, 154-162 (1984).

We believe that our data will closely match and affirm Richtmyer's linear stability theory.

3. TEST DESCRIPTION

3.1 DESCRIPTION OF RICHTMYER-MESHKOV INSTABILITIES

Richtmyer-Meshkov instabilities are usually recognizable by their unique mushroom like shape and key characteristics. The main mechanism behind the development of RM instabilities is called baroclinic vorticity generation which is a result of the misalignment of the pressure gradient caused by the shock wave or impulsive acceleration and the density gradient present at the interface between the two liquids. The generation of this baroclinic vorticity leads to the development of counterclockwise vorticity on the right side of a perturbation and clockwise vorticity on the left side. These alternating vorticities eventually develop into the spiral shapes on either side of the classical RM mushroom shape. The other driving force of these instabilities can be found to be a result of the pressure perturbations caused by the transmitted and reflected shock waves at the interface. It is found that localized pressure variations across the interface due to these pressure perturbations tend to increase the penetration of the heavy fluid into the light fluid and the light fluid into the heavy fluid, hence driving the instability forward to a more unstable nonlinear regime.[8] The figure below illustrates the many key characteristics of Richtmyer-Meshkov instabilities that are usually studied. The table below this figure gives a brief description of what these characteristics are.



[8] M. Brouillette, "The Richtmyer-Meshkov Instability," Annu. Rev. Fluid Mech. **34**, pp.445-468, (2002)

Figure 3-1: a) The picture on the left shows a drawing of a typical RM instability with typical measurable characteristics.[8] b) The picture on the right is an actual photograph of an RM instability in the nonlinear stage.[8]

Table 3-1: Measurable Characteristics of RM Instabilities

Characteristic	Description
a_0	Initial amplitude of perturbations at t = 0
a	Current amplitude of the instability at time t
da/dt or a-dot	The growth rate of the instability's amplitude
Wspan	The max width of the instability from side to side
Wstream	The distance from the bottom of the vortex to the top
Wneck	The width of the neck of the instability
Spike	The spike is the part of the heavy fluid that protrudes up into the lighter fluid
Bubble	The part of the lighter fluid that protrudes downward into the heavy fluid
k	The wave number of the perturbation defined as 2p/?
?	The wavelength of the initial perturbation
A	The Atwood's number of the system (?$_2$ – ?$_1$)/(?$_2$ + ?$_1$)
?	The density of a fluid
t	Time

Richtmyer-Meshkov instabilities are usually characterized by three distinct stages of development; the linear stage, the nonlinear stage, and the turbulent stage. The nonlinear stage is also divided into two separate groups, the weakly nonlinear region and the nonlinear region. Most experimental studies to date have provided good experimental data for the linear and weakly nonlinear stages of these instabilities. From this data accurate models of these stages have been developed and refined. However, there is a lack of information about the fully nonlinear and turbulent stages of the Richtmyer-Meshkov instability. This is mainly due to the limited amount of time the instabilities can develop in current experimental setups. In most shock tube experiments the shock wave used to create the initial impulse will eventual get reflected from the ends of the shock tube, this reflected shock wave will again apply a weaker secondary impulsive force on the interface, rapidly causing it to become turbulent and limiting the development time of the instability. This problem also occurs in drop tower setups using liquids, when the experiment eventually hits the ground it will create a secondary impulsive force that will disrupt the instability. We hope to avoid this problem of a limited development time for the instability by doing our experiment in a reduced gravity environment that will allow the instability to fully develop. The three regimes of the RM instability are described in the following paragraphs.

3.1.1 Linear Regime

The linear regime was first studied in depth by Richtmyer in 1960. Richtmyer basically characterized the RM instability as a special case of the Rayleigh-Taylor instability, where an impulsive acceleration is used instead of a constant acceleration field. Richtmyer's analysis of the linear stability states that the amplitude of the perturbations present at the interface between two liquids of different densities follows the following relationship [2]:

$$\ddot{a} = -kAg(t)a(t)$$

Where A is the Atwood number $(?_2 - ?_1)/(?_2 + ?_1)$ ($?_i$ is the density of one of the fluids), k is the wave number of the perturbation(k = (2p/?)), and g(t) is the acceleration present during the development of the instability. From this equation models for the linear stage of both Rayleigh-Taylor and Richtmyer-Meshkov instabilities can be determined. In Rayleigh-Taylor instabilities the gravitational acceleration is constant, and depending on which way the acceleration travels through the interface it can be positive or negative. With a constant positive acceleration the solutions for the amplitudes of Rayleigh-Taylor instabilities are sinusoidal functions, implying that the interface oscillates and is stable. However, if the acceleration is reversed and goes from the heavy fluid to the light, then the solutions are exponential functions, implying the system is unstable and it will eventually lead to Rayleigh-Taylor instabilities. For Rayleigh-Taylor instabilities, however, we assume the acceleration to be an impulsive force given by the function,

$$g(t) = \Delta V d(t)$$

Where ?V is the change in velocity caused by the impulse and d(t) is the dirac-delta function. By substituting this function into the second order differential equation above and integrating you get the following result:

$$\dot{a} = -kAa_0$$

Where a_0 is the initial amplitude of the perturbations at time zero. This result shows us that the amplitudes of the perturbations will grow at a constant rate after the impulsive acceleration. To accurately predict what this constant acceleration will be and compare it to the linear stability theory our team will have to record the profile of our impulsive acceleration profile and compute a_0. We will use a similar approach of analyzing our data of the perturbations in the linear regime as that done by Niederhaus and Jacobs in their study of the Richtmyer-Meshkov instability in incompressible fluids.[2]

3.1.2 NonLinear Regime

The approximations made by Richtmyer and Taylor in their linear stability analysis of these instabilities starts to fail when the amplitudes of the perturbations reach a critical point. This critical point is usually characterized as time when the rate of change in the amplitude begins to decay and the instability first becomes multi-valued. The amplitude at which linear stability diverges and is no longer valid has been found to be a_{max}˜ 0.1?[8] At this point the instabilities enter a weakly nonlinear regime and are best modeled by nonlinear stability theory. The most characteristic aspect of the instability that has been used in many models is the amplitude growth rate $\dot{a}$. Since the growth rates of the bubbles and spikes in the instabilities are not symmetrical for A ? 1 most models look at the individual velocities of each and take the average.[8] Many models predict that the amplitude growth rate will vary inversely proportional to time in this intermediate nonlinear stage. Other more recent models have refined this statement to say that the amplitude growth rate will vary proportional to t^{-p} where p is some number between about 0.4 and 1 depending on the Atwood number of the system.[5] We hope to collect data that helps verify how the amplitude growth rate decays in this nonlinear stage. Since the amplitude growth rate is predicted to decay to zero in some accepted models this implies that there will be an asymptotic bubble velocity, this bubble velocity has been calculated by several models and is predicted to be $v_b(t)$ = C?/t where C = 1/3p.[8] During this nonlinear stage as the amplitude growth rate decreases it is predicted that the bubble shape will flatten out and small oscillations will be seen on the top of the bubble.[7] Other important aspects of the instability that will be looked in this stage are the amplitude differences between the spikes and bubbles of the interface, the width of the neck of the spikes and the velocity or rate at which the vortices turn during the nonlinear stage. All of these characteristics of the instabilities are important and will help build and refine current models and explanations of these instabilities.

3.1.3 Turbulent Regime

Very few if any experiments to date have supplied accurate data and visualization of Richtmyer-Meshkov instabilities that have fully developed into their turbulent phase. However a study done by Peng, Zabusky, and Zhang seems to indicate that during the late-intermediate time of the developing instability, a process they call Vortex-Accelerated Vorticity Deposition (VAVD) will cause the amplitude growth rate to approach a constant value and stop decaying.[6] This effect will be witnessed during the late time development of the instability, probably right before the system goes into a turbulent regime. We hope to verify this prediction in our experiment and support this new predicted process of vortex-accelerated vorticity deposition.

3.2 EQUIPMENT DESIGN

3.2.1 Overview

Although our experiment does not make use of any hazardous materials, we acknowledge the additional challenges weightlessness creates in ensuring the stability and safety of a structure. We have taken steps to ensure that the forces created in our experiment will not near the rated strengths of our structure. Safety is a major concern in the design of our equipment and all equipment will be thoroughly tested before it is used in a microgravity environment. We are confident that this experiment, as we have designed it, poses no serious safety hazard even in a microgravity environment.

3.2.2 Tank

We will use two Lexan® tanks to contain the fluids used in our experiment. The inner tank will have internal dimensions of 5cm by 20cm by 25cm and wall thickness determined by the necessary strength of the tank. The outer tank will enclose the inner tank and provide double containment of the fluids used in our experiment. The tanks will contain two liquids of different densities. Although the specific liquids have not yet been chosen, the criteria have been set. The liquids must be inert and nontoxic. Furthermore, a dye that fluoresces under UV light testing must be soluble in one of the liquids. Please see Figure 3-2 for a visual representation of the tank to be used. In this diagram, ½ inch thick tank walls have been used.

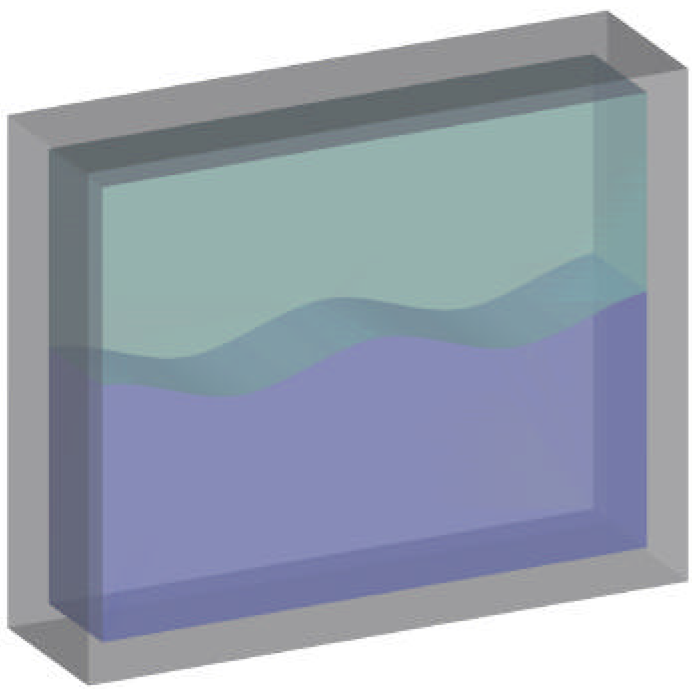


Figure 3-2: Fluid Testing Tank

3.2.3 Support Cage

A "support cage" will be built to hold the tank as well as our data recording equipment during the experiment. The cage will be made out of steel and will be capable of withstanding the forces involved in our experiment. This cage will also provide a place to attach our video camera, ultraviolet light source, and accelerometer. Before the experiment is begun, the cage will serve as an axis for horizontal motion in order to create a sinusoidal wave at the interface between the two liquids.

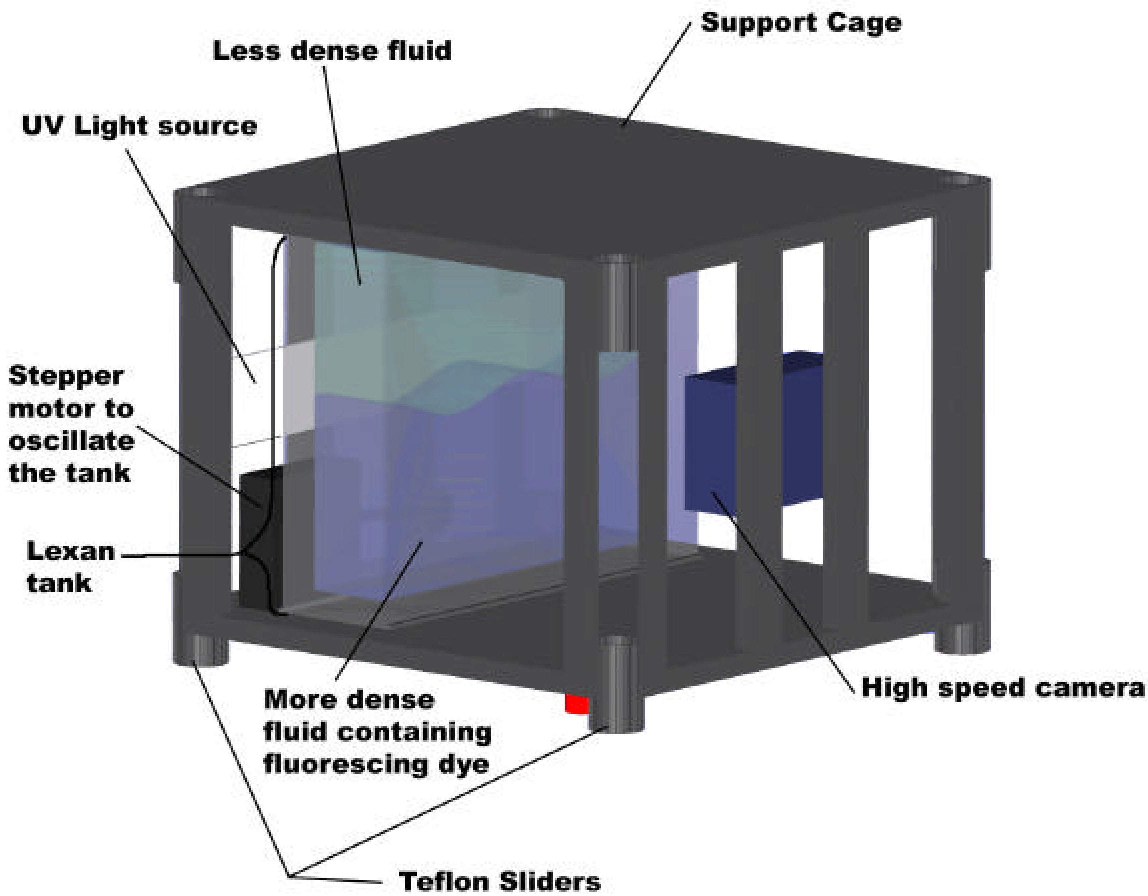


Figure 3-3: Support cage and components

As can be seen in Figure 3-3, the tank will be placed near the back of the support cage. It will be mounted on a horizontal track within the cage. A stepper motor will be attached the back of the tank to oscillate the tank laterally. The speed of the stepper motor, and the corresponding frequency of the oscillations, will be controlled from a laptop computer in order to produce a standing wave along the interface of the two liquids in the tank. This standing wave at the interface will define the most important initial conditions of our experiment.

The support cage will also contain a digital accelerometer which will measure the acceleration experience by the cage and tank and send this information to our computer.

An ultraviolet light source will be placed directly behind the tank at the level of the interface of the fluids. This light source will be used to illuminate the fluorescent dye in one of the liquids. The fluorescence of the dye will make it easy to tell the difference between the two fluids at the interface and greatly aid in recording the results of our experiment with standard video recording equipment.

A high speed video camera will be attached to the front of the cage. This camera will be focused on the interface between the two fluids to record the results of our experiment. Along with the UV light source, the accelerometer, and the stepper motor, the video camera will attached directly to a laptop computer. All wires coming from these electrical components will be bundled together and leave the cage at the same point to minimize the chance of tangling or dislodging the wires. Also, we will use wires that are as thin and flexible as possible, in an attempt to minimize their effects on the motion of the support cage.

Finally, a permanent magnet will be attached to the bottom of the support cage, this magnet will interact with a solenoid on the frame of the test apparatus to produce some small acceleration and provide the initial velocity in our experiment. The solenoid will be discussed further in section 3.2.5.

3.2.4 Rails and Sliders

Our experiment uses a sudden deceleration of vertical motion to generate an impulse which will travel through our tank and across the interface of the fluids within the tank. It is very important that the vertical motion be constant and without vibration to ensure the best results possible. In order to facilitate smooth, consistent motion, we will pay close attention to the track on which our support cage slides.

We will be using 4 rails to guide the motion of the support cage along the track. Eight sliders will be attached to the cage, four on the top and four on the bottom. The sliders will run up and down the rails with the support cage. To reduce friction between the rails and the sliders, all surfaces where these two objects contact one another will be coated with Teflon®. We will also thoroughly measure and test the positions and orientations of the rails and

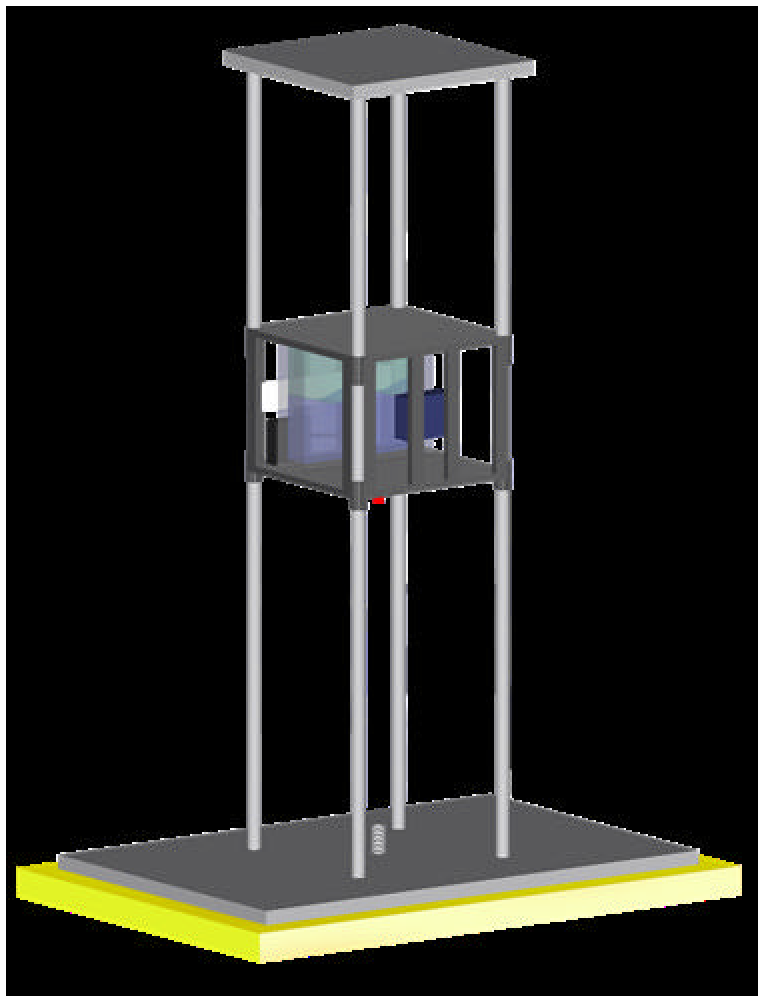


Figure 3-4: Rails and sliders

sliders throughout the construction of the testing apparatus.

3.2.5 Solenoid

We will be using a solenoid and a permanent magnet to produce the initial vertical motion for our experiment. The solenoid will be located in the center of the base of the test apparatus as can be seen in Figure 3-4. The permanent magnet will be attached to the bottom of the support cage as described in Section 3.1.3 so that when the support cage is resting on the base of the test apparatus, the magnet is inside the solenoid. The current in the solenoid will be variable in order to provide the desired acceleration and easily make adjustments if necessary. A variable current regulator controlled by our laptop computer will manage the current supplied to the solenoid.

3.2.6 Shock Absorption

We will employ shock absorption in three distinct ways in our experiment. The impulse used to create the Richtmyer-Meshkov instabilities will be generated by a sudden deceleration caused when the support cage and tank impact the top of the test apparatus. The choice of the shock absorbing material used to soften this collision will directly affect the properties of the impulse delivered to the fluids. A softer cushion will provide a longer impulse of less intensity while a firmer shock absorber will provide a short, strong impulse. We need an impulse of about 50 G's so we will choose the shock absorber to produce a short impulse of this magnitude. The impulse strength is also affected by the velocity given to the tank and support cage. We will take this into consideration when choosing the shock absorber and setting the initial velocity.

We will use another form of shock absorption to isolate our test apparatus from vibrations. We will place a two inch thick piece of viscoelastic foam between the base of our test apparatus and the floor of the plane. This will help us to ensure that the instabilities developed at our fluid interface are due entirely to Richtmyer-Meshkov instabilities, and not random vibration caused by the DC-9.

Finally, we will pad the area on top of the base of our test apparatus around the base of each rail. Please see Figure 3-4 for a visual representation of this padding. This will prevent the support cage from accelerating directly into the base of the apparatus or the solenoid when we come out of microgravity. Without this padding, our test apparatus could be damaged by the force of a collision between the support cage and the solenoid.

3.2.7 Stability of the Test Apparatus

We will attach the test apparatus to the floor of the plane using four straps coming from the top of the apparatus. The length and tension in the straps will be adjustable. The base of our test apparatus will be 36 inches by 24 inches aid in stabilizing the tower. Please see Figure 3-5 for a diagram of the stabilizing straps as well as a view of the complete test apparatus.

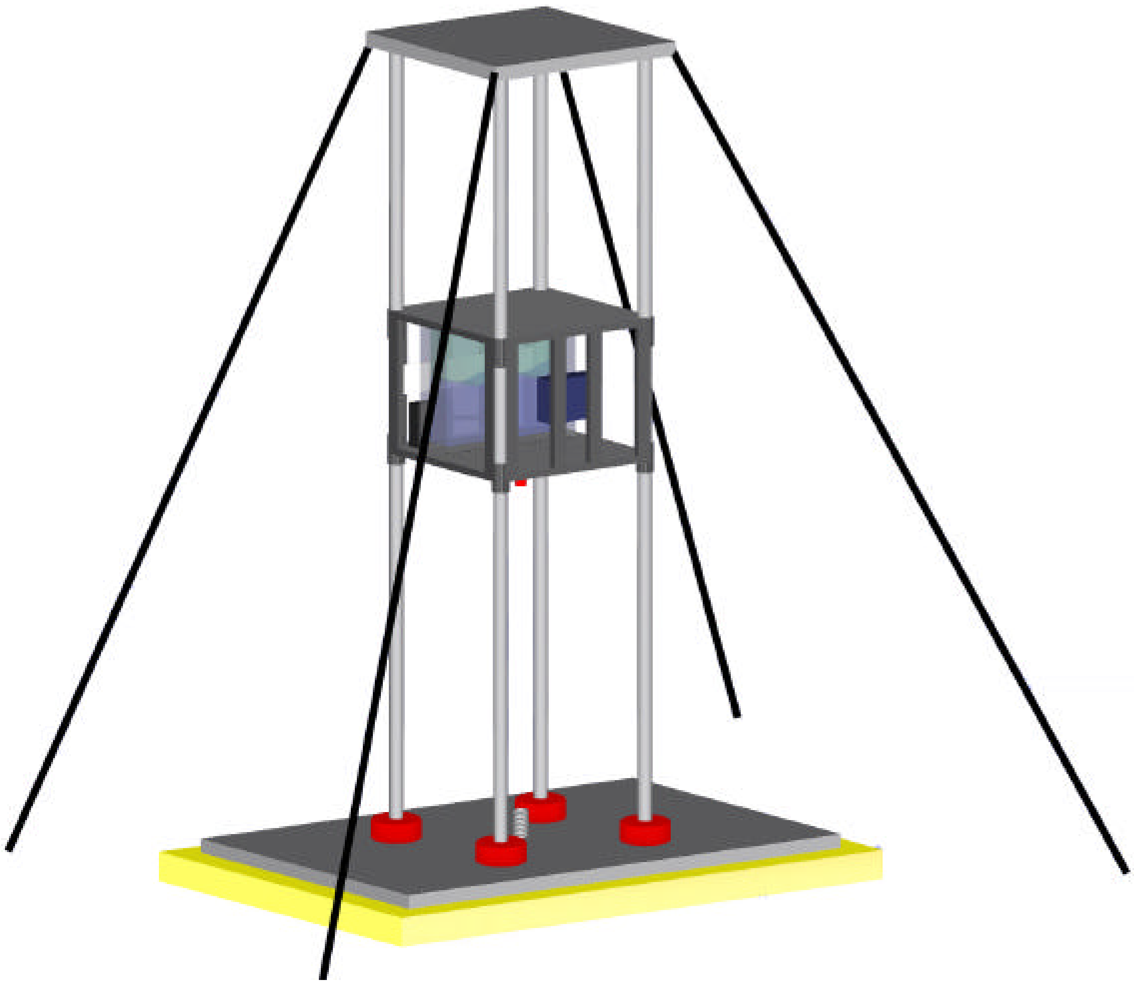


Figure 3-5: The test apparatus with stabilizing straps and all padding

3.2.8 Computer Software

Our team will develop and test computer software to control our experiment. The software will control the current in our solenoid, record measurements from our accelerometer, turn the ultraviolet light source on and off, and save the data recorded by our video camera. This software will be run from a laptop computer connected to the test apparatus. All software will be thoroughly tested before use during flight and a manual power switch will be able to turn off all power to the test apparatus in the case of an emergency.

3.3 PROCEDURES

3.3.1 Pre-flight

Before each flight we will complete a pre-flight check list to ensure that our experiment is ready for flight and is in good working condition. The checklist is as follows:

1) TANK INTEGRITY: Visually inspect the tanks to ensure that there are no cracks or fractures that may develop into leaks.
   REACTION PLAN: Use alternate tanks that have no cracks or fractures
2) MOTION ALONG TRACK: Move the support cage up and down along the track, ensuring that the motion is smooth and unimpeded by any foreign objects.
   REACTION PLAN: Clear any foreign objects or dirt from the track and sliders. Lubricate rails if necessary.
3) UV LIGHT SOURCE: Check the ultraviolet light source for functionality.
   REACTION PLAN: Verify that all electrical connections are intact. If necessary, replace the UV source.
4) ACCELEROMETER FUNCTIONALITY: Verify that the accelerometer is working properly and the computer is receiving data from the accelerometer.
   REACTION PLAN: Check all electrical connections between the accelerometer and the computer.
5) VIDEO CAMERA FUNCTIONALITY: Verify that the video camera is working properly and the computer is receiving data from the video camera.
   REACTION PLAN: Check all electrical connections between the video camera and the computer.
6) STRUCTURAL INTEGRITY: Check the supporting structure for cracks or fractures. Carefully check all joints for cracks
   REACTION PLAN: Evaluate any structural damage with a Test Flight Director. If necessary, do not fly the experiment.
7) WIRING: Check the insulation on all wiring.
   REACTION PLAN: If frayed wiring is found, replace the wiring or repair the insulation with electrical tape.
8) COMPUTER SOFTWARE: Test that all electrical systems are functioning properly and communicating with the computer.
   REACTION PLAN: Restart the computer. Check all connections.

After the pre-flight checklist is complete, we will attach the test apparatus to the floor of the plane with the aid of a Test Flight Director to complete our pre-flight procedure.

3.3.2 Overview

Once the plane enters microgravity we will begin the experiment. The entire experiment will be automatically controlled from our laptop computer. A manual power shut off will be available in case of an emergency, otherwise the operator will just need to initiate the program on the computer and allow the experiment to progress as intended.

3.3.3 Development of Initial Conditions

We will develop the initial conditions for our experiment before the DC-9 enters microgravity. We will first allow the two liquids to settle and form a clear interface. Once the fluids have completely settled, we will use our computer program to begin the horizontal oscillating motion created by the stepper motor attached to our tank. This motion will be of a pre-calculated frequency in order to develop a standing sinusoidal wave along the interface of the two liquids. The oscillating motion will continue until we enter microgravity and begin to accelerate the support cage upward.

3.3.4 Initial Acceleration

Before flight, our computer software will be give the values for the mass of the support cage and all items attached to it, the required velocity of the support cage and the properties of the solenoid. Our computer program will then calculate the necessary current through the solenoid to produce the desired velocity for the support cage. When a current is run through the solenoid, it will apply a force to the permanent magnet attached to the bottom of the support cage. This force will produce an upward acceleration of the support cage and the cage will begin to slide up the vertical track.

3.3.5 Impulse

When the support cage reaches the top of the vertical track it will hit the deceleration bumper and suddenly decelerate to a stop. This sudden downward force and the accompanying downward acceleration will create a shockwave that travels downward through the fluids in a direction normal to the interface. When this shockwave crosses the fluid interface, Richtmyer-Meshkov instabilities will begin to develop.

3.3.6 Data Collection

Our video camera will begin recording data as soon as the solenoid is activated. The camera will send the video directly to our laptop computer for storage and future analysis. Also, our accelerometer will begin sending data to our laptop computer as soon as the solenoid is activated. This data will be stored along with the video for future analysis.

3.3.7 Post flight

After the flight is complete we will unload our test apparatus and back up all data that was collected during the flight. We will repeat the preflight checklist at the end of each flight in order to spot possible problems before the next flight.

3.4 EXPECTED RESULTS AND MEASUREMENTS

3.4.1 Similar 1G Experiments

Similar experiments at earth's gravity have demonstrated that Richtmyer-Meshkov instabilities will develop under conditions similar to those present in our experiment. An experiment by C.E. Niederhaus and J.W. Jacobs from the University of Arizona used an apparatus that created conditions that were almost identical to our experiment. Their experiment used a tank with two liquids in freefall to study Richtmyer-Meshkov instabilities. They achieved "extremely well visualized results", but the experiment had a very limited run time of about 0.9 seconds.

Our experiment is a tank in freefall on a larger scale. While Niederhaus and Jacobs were limited to a 0.9 second runtime by the size and physics of their apparatus, we will have a 23 second period of microgravity in which to perform our experiment. Our data will be of similar quality to that obtained by Niederhaus and Jacobs, but the run time of our experiment will allow the instabilities to progress well into turbulence.

3.4.2 Expected Results

We expect to record data on the development of Richtmyer-Meshkov fluid instabilities beyond the initial stages and into full turbulence. We expect to record high quality images of the different stages of developing Richtmyer-Meshkov instabilities. This data will allow us to closely study the turbulent stages of Richtmyer-Meshkov instabilities, an area that has not been thoroughly studied and is not yet well understood. This data will meet our first objective of observing the development of Richtmyer-Meshkov instabilities into full turbulence. We expect that the instability will first enter an early time linear stage that will be accurately modeled by current linear stability theory. We will measure the amplitude growth rate during this linear regime an expect it to be a relatively constant value. The instability will then form into a weakly nonlinear stage where it will become multi-valued and vortices will be observable at the bubble/spike interfaces. We hope to again measure the amplitude growth rate along with the bubble and spike amplitudes, the neck width of the instabilities and the rate of rotation of the developing vortices. In this weakly nonlinear regime we expect from previous experimental data and models that the amplitude growth rate will be governed by an inverse power law with time as the independent variable. Several models predict the power of this power law to be between 0.4 and 1 depending on the Atwood number of the system. We hope to verify this predicted value of the power law. Finally, as the instability enters a longer nonlinear stage we hope to see secondary instabilities present at the vortices. We are

also looking to verify if vortex-accelerated vorticity deposition processes do occur and if the bubble velocities conform to a asymptotic velocity equation.
Our experiments will also involve studying RM instabilities with several different initial perturbations. We will study single mode and multimode perturbations and see what affect varying the dimensionless constant a_0k has on the development of these instabilities. We expect that for higher values of a_0k (a_0 is the initial perturbation amplitude and k is the wave number of the perturbation) the instabilities will develop quicker and be in a less agreement to current models. We also predict that multimode interfaces will at first develop linearly and each mode will be independent of the other, however as the instabilities progress into a nonlinear regime the instabilities will no longer be independent. We hope that the data collected on these multimode instabilities especially in the nonlinear stages will be helpful in predicting how these modes interact, because most natural occurrences of RM instabilities are composed of multiple modes.

3.4.3 Analysis of Data

By the conclusion of the experimental phase of this project, we will have gathered a large amount of data about on Richtmyer-Meshkov instabilities. In the following weeks, we will analyze the data, making calculations of theoretical values according to Richtmyer's linear stability theory as well as calculating the actual values from our observations. We will also focus on the transition of the instabilities from linear flows to turbulence. We will look for trends and patterns in the transition and try to predict the onset of turbulence based on initial conditions. We hope that this analysis will meet our second objective of affirming Richtmyer's linear stability theory.

3.5 NECESSITY OF MICROGRAVITY

This experiment requires microgravity to obtain the clearest results possible and allow the Richtmyer-Meshkov instabilities to develop into full turbulence. Similar experiments have been performed at 1 G but all have shown difficulties in obtaining good results. In Richtmyer-Meshkov experiments performed using gasses it has been very difficult to form a clear, stable interface between the fluids. If no physical membrane is used to separate the gasses, the interface is generally not very clear due to the high diffusion coefficients of gasses. If a solid membrane is used to separate the gasses other problems are encountered. If the membrane is removed just before application of the impulse, some turbulence is created at the interface which disrupts the natural progression of the Richtmyer-Meshkov instabilities. Another technique involves using a membrane only microns thick to separate the fluids. The membrane is destroyed by the passing impulse. However, the minute remaining particles of the membrane upset the development of Richtmyer-Meshkov instabilities by creating additional turbulence.

The problems involving in creating a clear interface are easily solved by using liquids instead of gasses. However, using liquids creates other problems. The relatively high densities of liquids allow gravity to stabilize the system before Richtmyer-Meshkov instabilities can fully develop. This can be overcome by performing the experiment at zero gravity or in freefall. Ground based freefall has proven ineffective for these experiments because of the limited run time of the experiment. The additional mass of the liquids in comparison to using gasses for the fluids greatly slows the development of Richtmyer-Meshkov instabilities. Due to the slower advancement of these instabilities, a longer run time is required to see the same amount of development in the instabilities. A similar experimental setup as the one we have proposed has been used by Charles Niederhaus and J.W. Jacobs, in the conclusion to there paper titled "PLIF Flow Visualization of Incompressible Richtmyer-Meshkov Instability" they are quoted as stating the following observation, "The low gravity environment of space allows a unique opportunity to develop an experiment of this type which could be carried out in earth orbit. If achievable, this would provide effectively unlimited run times, and as a result yield valuable information about this fundamental and important fluid instability.[2]"

We believe that the best way to gain additional understanding of Richtmyer-Meshkov instabilities is to study their development in an interface between two liquids over a long time interval. We have concluded that the best way to accomplish this is in a microgravity environment such as that provided aboard the DC-9.

4. NOT A FOLLOW-UP FLIGHT

This is not a follow-up flight to a previous experiment.

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II. SAFETY EVALUATION

6. FLIGHT MANIFEST

Flyers
Mark Schneider, Flyer July 2004, Flyer March 2003, Ground Crew April 2002
Emily Prewett, Flyer July 2004, Alternate Flyer March 2003
Tim Swenson, Alternate Flyer July 2004
Doug Lipinski, No Previous Experience
Karen Rivedal , Wisconsin State Journal, Journalist

Alternate Flyers
Mai Lee Chang, No Previous Experience
Andrea Martin, No Previous Experience

Ground Crew
Benjamin Longmier, Flyer 2004
Brad Wilson, No Previous Experience
Nick Hanson, Ground Crew July 2004
Justin Peltzer, No prior experience
Justin Anderson , No Prior Experience
Cory Peltzer, No prior Experience

Riccardo Bonazza , Ph.D., Faculty Advisor

7. EXPERIMENT DESCRIPTION/BACKGROUND

Please see Sections 1 and 2 for Experiment Description and Background.

8. EQUIPMENT DESCRIPTION

Please see Section 3 for Equipment Description.

9. STRUCTURAL DESIGN

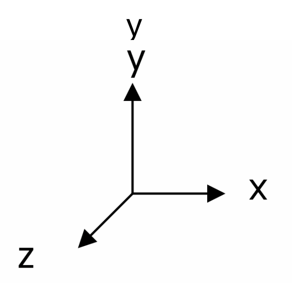
This section is based on our calculations made for the containment box adapted from a previous experiment. The interior of the box will change with installation of the new experiment, but the structural design calculations should stay the same.

9.1 OVERVIEW

The experiment equipment has been designed and built to withstand all G-load specifications required by NASA's Reduced Gravity Student Flight Opportunities Program. First, calculations are performed to show that the apparatus is securely fastened to the floor of the C-9. This portion also contains a floor load analysis showing that the equipment will not exceed the allowable load in flight. Then, a structural analysis of the tank indicates that it will withstand all possible conditions and not leak. For purposes of G-load calculations, it will be assumed that the right-hand side of the equipment will face towards the front of the aircraft. Free-body diagrams (FBD's) and induced G-loads are included for all calculations. Critical factors of safety (FS) show that the equipment is safe for all persons and aircraft components aboard the C-9.

9.2 CENTERS OF GRAVITY

Center of gravity calculations use a 3-D right-handed coordinate system with the "origin" located at the bottom-left-rear corner of the steel base. Individual weights and positions relative to the origin are used to calculate the center of gravity for the system. All dimensions are shown in inches.



The total weight (at 1 G) of the system is 115 lbs. The base has dimensions 40 x 32 x 0.25 (width, depth, height). The top is 15 x 15 x 1/8 (width, depth, height). The four rods supporting the top have a length of 58 inches and a diameter of 0.75 inches. And finally, the tank has dimensions of 8 x 2 x 8 inches and will be centered between the four rods. After considering left-right and front-back symmetry, it can be seen that the CG_x and CG_z of the system with the tank are located at 20 (40/2) and 16 (32/2) inches, respectively. CG_y is a slightly more complicated, as it depends on the height of the tank. It can be seen that the maximum stresses will occur when the tank is at the top, so all calculations will deal with this case. Calculating this, it can be seen that CGy is located at 12.2 inches.

Below are the calculations of the CG for the system:

CG_x = [20*78 + 20*25 + 20*7 + 20*5] / 115 = **20 inches**
CG_y = [0.125*78 + 29*25 * 58*7 + 54*4.5] / 115 = **12.2 inches**
CG_z = [16*78 + 18*25 + 18*7 + 18*5] / 115 = 16 **inches**

Here it can be seen that the center of gravity for the entire system is located at (20, 12.2, 16).

The weight of the equipment will be assumed to be concentrated at the center of gravity for all moment and factor of safety calculations.

9.2.1 9 G's Forward

Under an induced gravity of 9 G's forward, the entire system will experience a weight of 1,035 lbs. (115*9). The reaction force to this weight in the horizontal direction will be provided by two 2-inch wide cargo straps wrapped over the top of the system (bolted to the aircraft with 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 518 lbs. in the negative x-direction. Each strap is capable of supplying 5,000*cos (74°) = 1,378 lbs. This results in a factor of safety of 2.66 for the apparatus in 9 G's forward in the horizontal direction. Taking the moments about the point (0, 0, 16) it can be seen that the reaction moment for each strap will need to be (1,035*12.2 / 2) + (5000*sin(74°)*12.5) = 66,390 in-lbs. The straps are each capable of providing a moment of 5,000*cos (72°)*8 = 80,000 in-lbs. This results in a factor of safety of 1.2. Thus, the equipment will remain static under 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 345 lbs. (115*3). The reaction force to this weight will be provided by two 2-inch wide cargo straps wrapped over the top of the system (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 need to provide a reaction force of 210 lbs. each in the positive x-direction. Each strap is capable of supplying 5,000*cos (74°) = 1378 lbs. This results in a factor of safety of 8.00 in the horizontal direction for the entire apparatus in 3-G's aft. Taking moments about the position (40, 0, 16) it can be seen that each strap will need to provide a reaction moment of (345*12.2 / 2) + (5000*sin(74°)*12.5) = 62,180 in-lbs. Each strap is capable of supplying a 5,000*cos (74°)*58 = 80,000 in-lbs. This results in a factor of safety of 1.29.

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 690 lbs. The area of the steel plate at the bottom is 8.9 ft^2. This maximum in-flight stress on the fuselage would be 78 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 2.58.

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 230 lbs. in the lateral direction. To avoid any translational motion in the z direction, the equipment will need to be ratcheted down with enough force so that the frictional force generated against the aircraft foam is significantly greater than the 280 lbs. of induced force. If the case were to rotate, the cargo straps would need to counter the moment induced about the position (20, 0, 0). The moment that needs to be countered would be 230*20 = 4,600 in-lbs. The tether strap going over the top of the outer frame would need to provide a force of 4,600 / 15 = 307 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 16.3.

9.2.5 2 G's Up

Under an induced gravity of 2 G's up, the weight of the equipment will be 230 lbs. This weight will be countered by reaction forces provided by the straps over the top of the frame. Each strap is capable of providing up to 5,000*sin (74°) = 4,806 lbs. of force when in tension. This results in a factor of safety of 4,755*2 / 230 = 41.8.

9.3 SUMMARY OF APPARATUS ATTACHMENT TO FUSELAGE OF C-9

Factor of safety calculations for the system shows that the equipment will remain in static equilibrium for all G-load specifications. The use of two cargo straps will provide sufficient reaction forces to secure the apparatus to the fuselage of the C-9.

Table 9-1: 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	518	**2.66**	66,390	**1.20**
3 G's aft	173	**8.00**	62,180	**1.29**
6 G's down	345	**2.58**	N/A	**N/A**
2 G's lateral	Need more info (see text)		4,600	**41.8**
2 G's up	115	**41.8**	N/A	**N/A**

9.4 STRUCTURAL INTEGRITY OF THE TANK

The tank will be made of 2 layers of ½ inch lexan and will be glued in such a way that it can be considered one rigid piece. It will have dimensions of 8 x 8 x 2 inches. It will contain approximately 5 lbs. of water. With this in mind, the maximum shear stresses can be calculated. By figuring out the maximum velocity that the tank will reach, which could occur if it accelerated from top to bottom at 9 G's, and then having this velocity go to zero in a distance of 2 inches (due to foam on the bottom), we can calculate the maximum force exerted by the water. The maximum possible velocity reached by the tank is 1,210 ft./sec. With this dropping to zero over a span of 2 inches, it can be seen that the acceleration is 7,245 ft./sec^2, and the force exerted is 1,125 lbs. Now, dividing this by the cross-sectional area of the bottom piece of lexan, which is (0.5*2) = 1 in, we obtain a shear stress of 1,125 psi. The lexan has a maximum shear stress of 9,200 psi. This results in a factor of safety of 8.18.

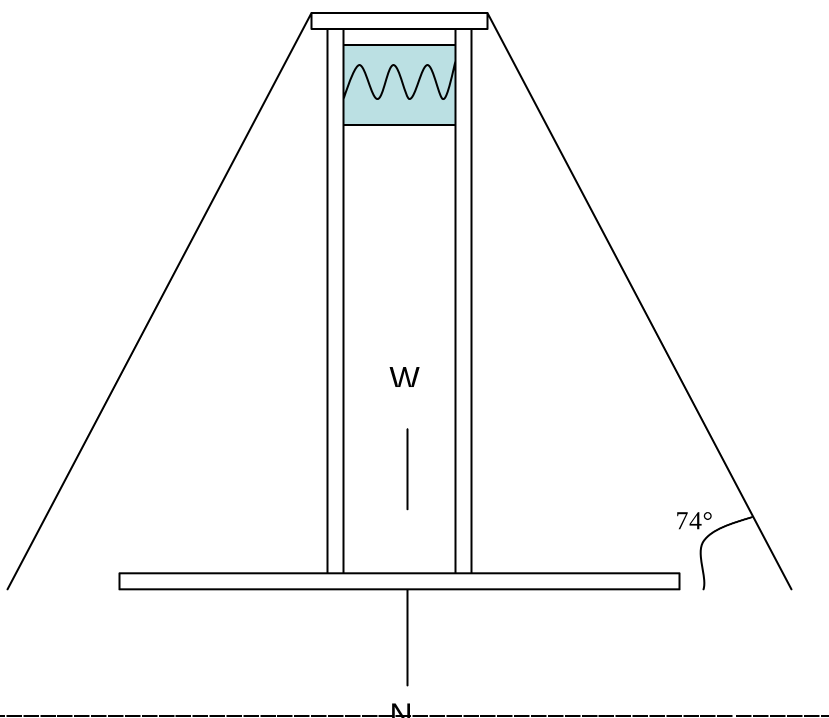


Figure 9-1: The test apparatus with stabilizing straps

10. ELECTRICAL SYSTEM

The experiment will be automated by the use of a laptop computer to control the release of the tank and record the high speed digital images sent to it by the digital camera. The computer will be integrated with an Analog to Digital Converter (ADC) which will allow the computer to monitor and record the values of acceleration sent to it by the four dedicated accelerometers. One accelerometer will be used to determine when the system has entered reduced gravity. Another accelerometer will be used to record the acceleration profile of the tank. The third and fourth accelerometers will be mounted on the tank and used to record the vibrations in the x and y directions of the tank. Solenoids located at the bottom of the track system will be used to release the tank in zero-g and provide an initial velocity upward. These solenoids will be controlled by the computer and can be adjusted in flight to provide a suitable initial velocity. Finally the computer will also control a linear stepper motor which will impart the sinusoidal perturbations at the interface by oscillating the tank to the left and right.

One power strip will be used to connect the one 120VAC outlet on the C-9 Power Distribution Panel. This will provide sufficient power to run our experiment without risk of drawing too much current. The breaker switch present on our power strip will be used as an emergency master kill switch to remove power from the system in case of an electrical malfunction. There will also be fuses present on the stepper motor and solenoids to prevent these items from drawing more than their allowed rated currents.

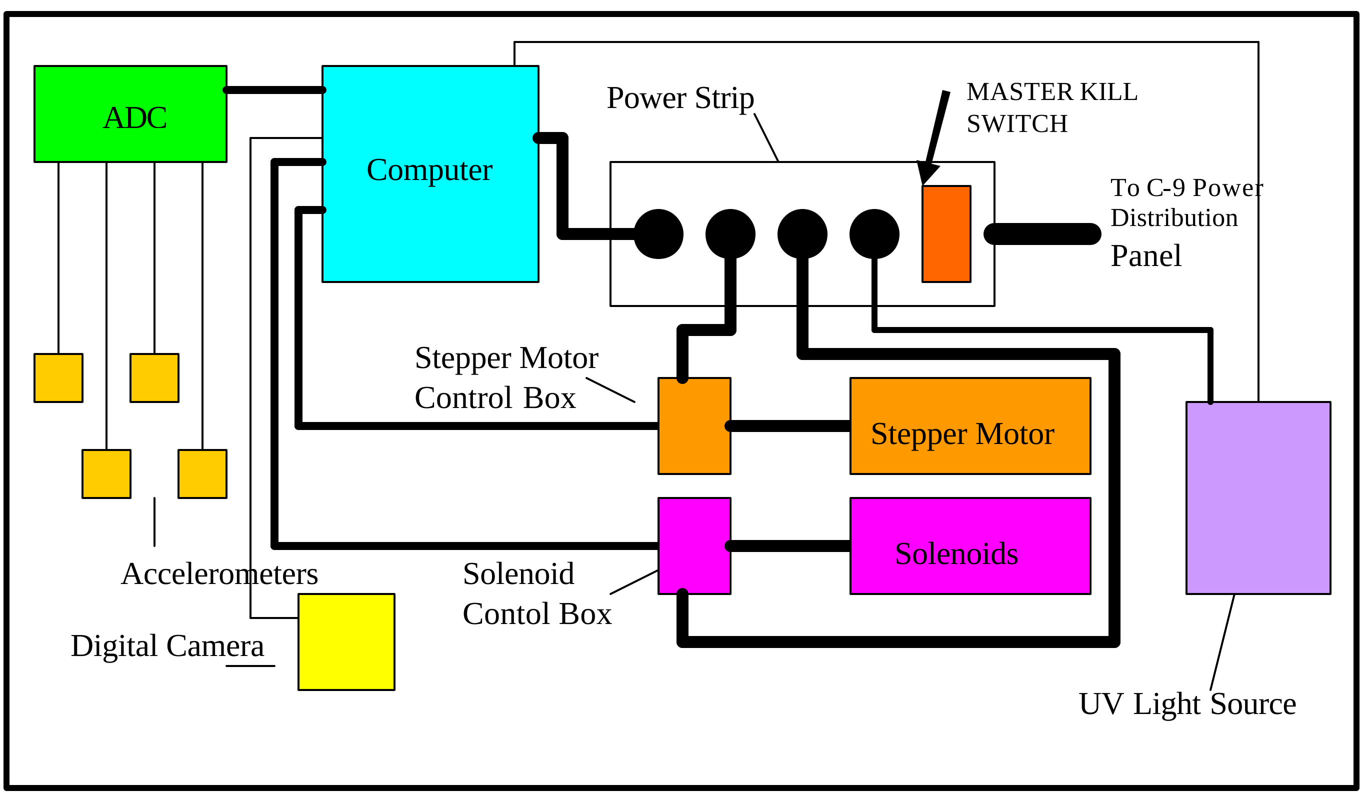


Table 10-1: Electrical Components

Name	Voltage	Max Current	Function
Computer	12VDC	2.0 Amps	Control/data collection
Stepper motor	12VDC	2.0 Amps	Controls oscillation of tank
Accelerometer 1	5VDC	100 mA	Measures general acceleration field
Accelerometer 2	5VDC	100 mA	Measures acceleration profile of the tank
Accelerometer 3	5VDC	100 mA	Measures acceleration of tank in x direction
Accelerometer 4	5VDC	100 mA	Measures acceleration of tank in y direction
Solenoids	12VDC	2.0 Amps	Controls initial vertical motion of the tank
High Speed Camera	5VDC	500 mA	Records visual images of instabilities
Stepper Motor Control	5VDC	200 mA	Provides correct input sequence to stepper motor
Solenoid Control	5VDC	200 mA	Used to interface computer to Solenoids
Analog to Digital Conv.	5VDC	200 mA	Allows analog signals to be measured by the PC
UV Light Source	5VDC	100mA	Provides UV light source for dye illumination.

Total Max Current Required 7.6 Amps

11. UV LIGHT EMITTING DIODE SHEET

An Ultraviolet emitting diode will be used for proper illumination of our fluid instabilities. The device will be a sheet approximately 15cm X 5cm X 2mm and will be situated on the opposite side of the fluid container from the high speed camera. The UV source will be completely shielded by a black film of polycarbonate on the side that does not produce illumination and will be shielded by the clear polycarbonate and fluid within our tank at all times. The UV source is low power <0.5mW and would give a similar does of UV radiation as a typical 10W black light.

12. CREW ASSISTANCE REQUIREMENTS

Crew assistance is requested for proper connections of tie down straps from the floor of the aircraft, through connecting rods and back into the floor of the aircraft.

13. INSTITUTIONAL REVIEW BOARD (IRB)

The experiment does not require approval by an institutional review board.

14. HAZARD ANALYSIS

Hazard Number: 1

Hazard Description: Fluids escape the tank

Hazard Causes:

1) A crack develops in the tank from stresses involved in the experiment
2) The tank dislodges and impacts another object, forming a crack or leak in the tank

Hazard Controls:

1) Very strong Lexan® or plexiglass tank will be used
2) The tank will be impact tested prior to flight
3) The tank will be visually inspected for cracks or possible leaks prior to each flight
4) Inert, non-toxic fluids will be used
5) The tank will be double layered with ½" Lexan
6) The bottom of the track will be padded to soften the tanks landing upon returning to normal gravity

Hazard Number: 2

Hazard Description: Ultraviolet light exposure

Hazard Causes:

1) Ultraviolet light source used in the experiment emits ambient light, exposing nearby persons to ultraviolet radiation

Hazard Controls:

1) A very low intensity UV source will be used; the light will not be strong enough to cause harm

Hazard Number: 3

Hazard Description: Moving parts on the test apparatus

Hazard Causes:

1) A crew member or operator inadvertently sticks his/her hand in the way of the moving tank

2) A part of the testing apparatus becomes dislodged and begins to float about the cabin

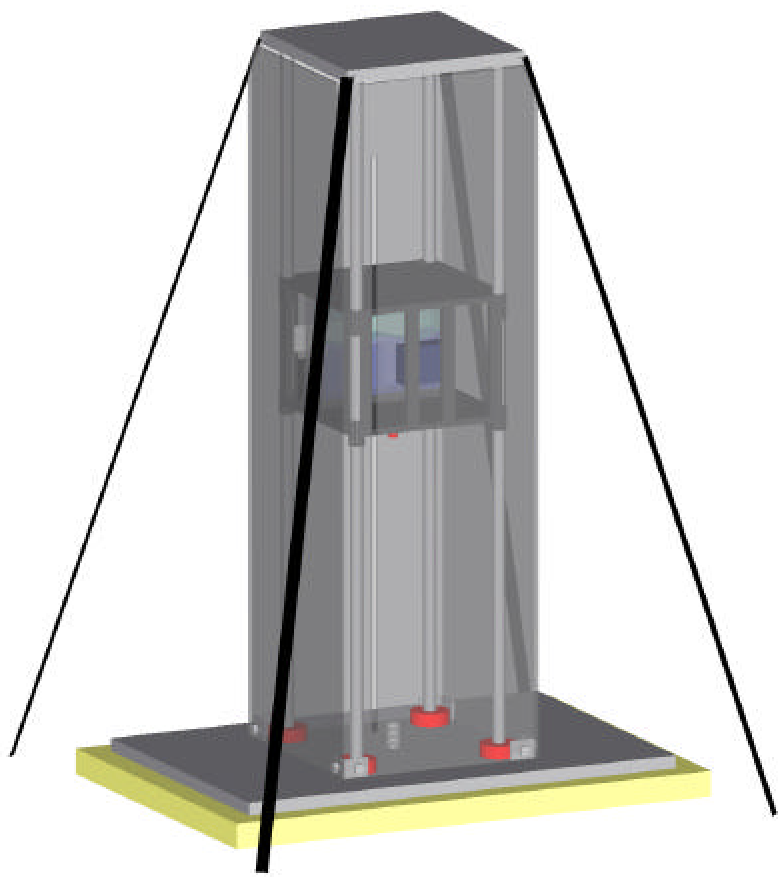
Hazard Repercussions:

1) Failure of the experiment
2) Damage to the test apparatus
3) Personal injury

Hazard Controls:

1) The velocity of the tank will be kept as low as possible
2) All joints and structural supports will be welded for strength
3) Welds and key structural areas will be checked before take off
4) A barrier or shield will be installed around the track to guarantee that no foreign objects enter the path of motion
5) All moving parts are secured inside of the Lexan box.

Figure 14: Protective Lexan shielding around moving parts of test chamber.



Hazard Number: 4

Hazard Description: Collapse of structure or tipping of structure

Hazard Causes:

1) The test apparatus develops a fracture in a structurally important feature
2) The test apparatus is insufficiently stable to withstand the lateral forces experienced during flight
3) A person or other object impacts the test apparatus

Hazard Repercussions:

1) Severe damage to test apparatus
2) See Hazard Number 3, “Moving parts on the test apparatus”

Hazard Controls:

1) All necessary force and center of gravity requirements will be met
2) The apparatus will be anchored to the floor of the plane using four attachment points
3) All force bearing joints and supports will be inspected prior to flight
4) All joints and structurally important elements will be welded for strength
5) All materials used are rated to withstand forces well above those expected in our experiment

Hazard Number: 5

Hazard Description: Overheating of the electrical system

Hazard Causes:

1) Current regulator for the solenoid fails
2) Insulation on wires is worn, exposing wires and creating a short circuit
3) Computer malfunction causes solenoid to draw too much current

Hazard Repercussions:

1) Overheating wires start on fire
2) Large current creates sparks starting a fire
3) Operator may be electrocuted

Hazard Controls:

1) Only small currents will be required in this experiment, minimizing the chance of overheating and electrical shock
2) All wires, insulation and connections will be inspected and thoroughly tested before take off
3) The proper gauge wiring will be used in all parts of the test apparatus
4) A circuit breaker will be installed to shut off the power if a large current is being drawn
5) Any wires in areas susceptible to wear or near moving parts will be protected with extra insulation
6) Power may be manually shut off by a master power switch

Hazard Number: 6

Hazard Description: Too much current is run through the solenoid

Hazard Causes:

1) Malfunction of current regulator for the solenoid
2) Malfunction of the computer software controlling the current regulator for the solenoid

Hazard Repercussions:

1) The tank is accelerated too quickly
2) Poor data
3) Failure of the experiment

Hazard Controls:

1) Computer software will be thoroughly error tested before flight
2) Current regulator for the solenoid will be tested before take off
3) Extra velocity caused by the solenoid will not cause structural damage because the tank and test apparatus will be constructed to withstand forces much larger than those anticipated in the experiment
4) Also see Hazard Number 3 “Moving parts on the test apparatus” and Hazard Number 4 “Collapse of structure or tipping of structure”

Hazard Number: 7

Hazard Description: Malfunction of sensors or camera

Hazard Causes:

1) Sensors or camera improperly connected
2) Malfunction of software controlling the experiment
3) Electrical short or malfunction

4) Interference from outside sources
5) Damage to the camera or sensors

Hazard Repercussions:

1) Inaccurate or unusable data is collected
2) Improperly operated experiment resulting in unusable data
3) An improper current is delivered to the solenoid (see Hazard Number 6 “Too much current is run through the solenoid”)

Hazard Controls:

1) All sensors and electrical connections will be inspected and tested before take off
2) Electrical systems will be tested and inspected before take off (see Hazard Number 5 “Overheating of the electrical system”)

15. TOOL REQUIREMENTS

All tools that we will need will be borrowed from the Ellington field tool chest. This will minimize the risk of any FODD due to a foreign tool.

Tools we may need at Ellington field:
Standard Crescent wrenches
Drill
Drill bits
Duct Tape
Velcro
Screw Drivers
Wire Cutters
Wire Strippers

16. GROUND SUPPORT REQUIREMENTS

Power Requirements:

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

Access to Building 993 During Non-Business Hours:

No access to Building 993 during non-business hours is requested.

General Tools Requests:

No general tools requests.

17. HAZARDOUS MATERIALS

Material safety data sheets (MSDS) will be provided with the TEDP.

No Hazardous Materials will be used during this experiment.

18. PROCEDURES

18.1 Shipping Equipment to Ellington Field

Our experiment will be transported to Ellington Field by van.

18.2 Ground Operations

The equipment will be set up and tested as it would be run on the C-9. This will require a Standard electrical 120v 60Hz outlet. Approximately 1-2 amps will be used at the peak amount of electric demand. Electronics and solenoids will be tested thoroughly.

18.3 Loading

The containment unit containing the experimental apparatus will be loaded onto the C-9 by forklift.

18.4 Pre-Flight

The box will be strapped to the floor of the KC with help from a Test Flight Director. Aircraft Tie straps similar to those used on the C-9 in previous years are requested. We will need 2 straps of approximately 12 feet in length each.

18.5 In-Flight

1) The fluid testing tank is locked in place during take off
2) Fluid testing tank lock is released and tank is left on the bottom of the sliding rails
3) Laptop is hooked up and test programs are initialized
4) Bottom Solenoid is powered up and holds testing tank in place
5) Once in Zero-G, the bottom solenoid is turnoff and then is reversed, providing a slow acceleration of the test tank upwards toward the top of the testing rack.
6) The testing tank impacts the top bumper plate, providing an impulse
7) The testing tank slowly drifts in zero-g for 20 seconds along a rigid, 4 pole track.
8) The testing tank is lowered back into position by the increasing G-load of the plane and stopped by a shock absorbing assembly.
9) The bottom solenoid is activated and holds the testing tank in place until the next duration of zero-gravity.
10) This procedure is repeated roughly 20-28 times for data comparison and repeatability.

18.6 Post-Flight

Our experiment will be ready to offload once on the ground. All data will have been collected by a laptop that will be stowed during take off and landing.

18.7 Offloading

The experimental assembly will easily be unstraped from the floor of the aircraft and removed from the plane by forklift. All equipment will be brought back to Wisconsin by van.

III. OUTREACH

19. OUTREACH PLANS

19.1 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 RM fluid instabilities, why they are 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 outreach initiatives to attain our goals:

19.2 Hmong Population Outreach Initiative

19.2.1 Background

During the Vietnam War, the Hmong fought along side the Americans, rescuing downed pilots and disrupting the communist supply line. Since the late 1970s, thousands have fled to the refugee camps in Thailand and then to the United States. Over 130,000 Hmong have been resettled in the U.S. Wisconsin ranks third in the nation for Hmong population size. This summer the U.S. began accepting a new wave of Hmong refugees because the Thai government is threatening to close the remaining camp. About 2,500 Hmong will settle in Wisconsin, the majority of whom are under 18 years old. The name *Hmong* is synonymous with family and hard work.

19.2.2 FutureHmong Magazine

FutureHmong Magazine is based in Appleton, WI and publishes monthly, distributing across the nation. One of their goals is to provide information and education to the Hmong people. We have contacted FutureHmong Magazine to see if they will run a story about our RM instability and zero gravity project with an interview with team member Mai Lee Chang.

19.2.3 Oshkosh, WI Local Channel 10

This news station has a segment every Thursday night that presents community and general news to the Hmong community. One goal of this channel is to present educational materials and opportunities to the Hmong children in the community, and we plan to present a piece on RM instabilities and college science and engineering opportunities. Mai Lee Chang speaks Hmong and will be able to explain our research to the entire Hmong community, while specifically reaching out to the children to inspire them to consider careers in science.

19.2.4 Hmong American Student Association

The Hmong American Students Association is an active organization on UW-Madison's campus that contains about 40 members. Our member, Mai Lee Chang, is also a member of HASA and after completing our NASA project, we will share our results with the HASA members and together with other members, will present the research experience to school-aged Hmong groups.

19.3 Other Targeted Population Outreach Plans

19.3.1 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 run a science activity day in the spring with both of these troops, beginning with a discussion about the college experience for science majors and the different opportunities available to students, including the zero gravity research program, and finish the day with a fun science experiment that demonstrates fluid instabilities. We hope to inspire these girls to attend college and show them that science and space are both within their reach as future engineers.

19.3.2 Expand Your Horizons

Expand Your Horizons is a one-day career conference where up to 220 6th, 7th and 8th grade girls from Southern Wisconsin come to the UW-Madison campus to experience a variety of math and science related careers. This year, a team member, Andrea Martin, is volunteering as a science activity leader at the October 30th Expand Your Horizons Conference and will discuss the concept of zero-g and reduced gravity research. Next year she will return to the program to present our RM instabilities project and results and how the zero-g program fits into a career in science.

19.3.3 BBBS Big Brothers and Big Sisters Zero-G Initiative

This initiative is a half-day science workshop and university campus for children participating in the Madison-area Big Brother Big Sisters Program. This program, a branch of the national BBBS program, pairs at-risk children, who are typically from single-parent households with economic troubles and often have academic and social difficulties, with adults in the community. The "Littles" come from all racial backgrounds and range in age from 5-14. Their parents chose to have then matched with a "Big" to enrich their lives through positive interactions and experiences that will hopeful improve the future of the child. Through this initiative, Littles will "go to college" for a half-day with their Bigs and see what a wonderful and important experience college is. We will excite them with the different buildings, classes, and most importantly, the zero-g project that they too can become involved with in college. Through hands-on projects, demonstrations and video, we will explain how gravity and zero-g work, what RM instabilites are and the importance of conducting research in specialized environments such as in the C-9 or ISS.

19.3.4 2005 UW-Madison Engineering Expo

On April 14, 15 and 16, 2005 the University of Wisconsin-Madison College of Engineering will be hosting a technology exposition and festival. This expo is designed to present the exhibits of students, faculty and staff to K-12 students and the general public. Thousands of people attend this exposition, especially students from around Wisconsin, and for many, it is their only experience with college engineering. We will be there with an exhibit of our zero gravity research, explaining why and how we are studying RM instabilities. We will also show pictures and video of our past experiences with weightlessness and visits to NASA in Houston, TX to get the students excited about what they can do in college. In addition to the exhibit, team members will guide small groups of underrepresented students through the exhibits and around the campus to be their mentors for the day and give them a more personal learning experience.

19.4 Additional Classroom and Club Presentations

19.4.1 Madison Memorial High School

In the past, we have given classroom presentations to Madison Memorial High School. This year we will be presenting our new topic to Memorial High School's Aerospace class and Astronomy class. This school is nationally recognized for academic excellence and many of its students go on to impressive careers in the sciences.

19.4.2 East High School

East High School, a school with a large number of underrepresented and economically diverse students, will also receive presentations this year, to its freshman integrated science class and the advanced physics class. East High school has many excellent student but many do not continue their educations past high school, and we hope to encourage them to continue.

19.4.3 Orchard Ridge Elementary

This year we will be planning fun science activities to do with Orchard Ridge Elementary's kindergarten and fifth grade classes. Our discussions will focus on RM instabilities, weightlessness, scientific research and NASA and use hands on projects and questions times to involve the kids.

19.4.4 Solar System Ambassador Program

NASA's own Jet Propulsion Laboratory in Pasadena, CA, sponsors a Solar System Ambassador Program. Solar System Ambassadors conduct four community-based events per year, and we hope to have the Wisconsin ambassadors use our experience as part of one of their outreach initiatives.

19.4.5 Contemporary Issues in Engineering 101

Most freshmen at the University of Wisconsin-Madison who are considering an engineering degree take this course. Its purposes are to introduce the students to the various fields of engineering, show what it is to be an engineer and talk about the different opportunities available both in school and afterwards for an engineering student. The course routinely uses students and alumni as speakers to represent these opportunities, and zero-g projects have been presented here in the past. We will present to the class both semesters as both a way to illustrate the diverse engineering opportunities on campus and as a way to recruit more students to join or start their own zero gravity research team.

19.4.6 American Institute of Aeronautics and Astronautics Presentation

Many of our team members belong to the student chapter of the AIAA. At a monthly meeting we will present our research topic and its applications at a higher level than for previous talks, and give the members a chance to ask technical questions. After the research has been completed, the team will present again with results and stories from the experience.

19.4.7 Hmong American Student Association

The presentation to the HASA and subsequent presentations to school-aged Hmong groups was described in section 19.2.4

19.4.8 Additional Presentations

Additional school and group presentations will be added as requested through our web site (19.5) and to team members directly. Presentations will be tailored to the needs, interests and scientific level of the audience, and will be conducted in English, Hmong, Spanish or French, as desired.

19.5 Website for RM Zero-G Science and Outreach

www.cae.wisc.edu/~rmzerog

We have designed a website explaining how RM instabilities work and how our experiment will add to the field of RM instability research, and this content will be presented in French, Spanish and Hmong. Additional pages will explain outreach initiatives and allow groups or schools to contact us to schedule presentations, and we will have downloadable and printable posters of the C-9, RM instability pictures and explaining how zero-g flights work.

19.6 Community Outreach through the Media

19.6.1 NBC-15 Madison Local News

The morning segment of NBC-15 reaches tens of thousands of people in and around the Madison area and often invites student organizations to discuss their activities. We will contact them this spring to do a segment on our project and the nature of research aboard the C-9.

19.6.2 Oshkosh, WI Local Channel 10

As described in section 19.2.3.

19.6.3 Wisconsin Public Radio Talk Show

Norman Gilliland, author and WPR on air personality, will interview our team on the radio to allow us to explain not only our research, but how NASA is positively affecting our education and the community. Mr. Gilliland is also our alternate journalist-flyer.

19.6.4 The Wisconsin State Journal

The Wisconsin State Journal is the state's official newspaper. Columnist George Hesselberg has already written an article about our 2003-2004 zero gravity team which ran with a large photograph on the front page of the Local section. The feedback we received from the article showed us that the WSJ is an excellent medium for reaching people across the state who might not otherwise be aware of the NASA opportunities available to university students. This year we have invited Karen Rivedal, another journalist for this paper, to fly with us as our reporter. She will be writing an article about our research, the zero gravity experience, and the local students that make up the team.

19.6.5 The Milwaukee Journal Sentinel

The Milwaukee Journal Sentinel is Wisconsin's most widely read newspaper and reaches a different demographic than the WSJ. We will contact them with our story as well.

19.6.6 The Badger Herald

The Badger Herald is one of the University of Wisconsin's most popular student newspapers and is widely read on campus. We will give an interview and explain the nature of our project and our experience after we return from Houston.

19.6.7 The Wisconsin Engineer

The Wisconsin Engineer is a quarterly magazine published and written by and for students. We will write an article for the magazine after completion of our research project and use it as a format to encourage more student and faculty involvement, as well as to generate funding for next year's project.

19.6.8 North Star Newspaper of Oshkosh North High School

North Star, the newspaper of Oshkosh North High School, is a blue ribbon winner of the Northeastern Wisconsin Scholastic Press Association's competition and thus has the opportunity to share their newspaper with other high schools across the nation. We will contact them to have our story run in this newspaper, which will include how they too could get involved in the zero gravity program as freshmen in college. As this newspaper reaches more than Wisconsin high schoolers, it will be a way for us to reach students in states without zero-g outreach, and show them the opportunities of which they might otherwise not be aware.

19.6.9 FutureHmong Magazine

As described in section 19.2.2

IV. ADMINISTRATIVE REQUIREMENTS

20. NASA/JSC HUMAN RESEARCH CONSENT FORM

This experiment does not involve human research.

21. IUCAC

This experiment does not involve any animal research.

22. FUNDING/BUDGET STATEMENT

22.1 Itemized Budget

Zero-G RM Team 2004-2005 Budget
Revised 10/20/2004

Materials			
Aluminum L and channels	\$10/ea	7	\$70
Bolts and connectors	\$5/ea	5	\$25
Vibration damping Foam	\$20/ea	2	\$40
Lexan tank	\$40/ea	1	\$40
Rollerblade wheels	\$5/ea	5	\$25
Tie Down Straps	\$10/ea	2	\$20
Springs and bungee	\$20/ea	2	\$40
Total			**\$260**
Chemicals			
Surfactants	\$10/100 g	1 x 100 g	\$10
Fluorescing dyes	\$20/oz	5x1oz	\$100
Total			**\$110**
Travel			
UW Fleet Vehicle Rental	\$25/day	10 days	\$250
Hotel in Houston	\$125/night	10 nights	\$950
Total			**\$1,500**
Electronics			
Web video camera	\$70/ea	2	\$140
Solenoid switch	\$50/ea	1	\$50
Control and data acquisition	\$50/ea	1	\$50
Accelerometer	\$500/ea	2	\$1000
Laptop and ADC data collection	\$1300/ea	1	\$1300

Total	**$2540**

Project Total	**$4,410**

22.2 Current Sources of Funding

Outreach Funds from UW College of Engineering		$2,500
Wisconsin Space Grant Consortium	Travel Costs	$2,000
Space Science and Engineering Center		$2,000
University of Wisconsin Chemistry Department		$1,000
Earthtech corporate sponsor		$250
University of Wisconsin Electrical Engineering funding		$500
University of Wisconsin Engineering Physics funding		$500
University of Wisconsin Mechanical Engineering funding		$500
University of Wisconsin Polygon Chapter		$500
IBM	(may donate a laptop)	

Total	**$9,750**

23. PARENTAL CONSENT FORMS

All team members are over 18.