Study of Droplet Coalescence Criteria of a Liquid/Liquid Interface in Micro- and Macro-Gravity Conditions

Topic Area: Fluid Dynamics

Team Name:
Zero G and the Funky Bunch

Team Contact:
Nicolas G. Schellpfeffer
sche0435@umn.edu / (612) 730-2723

Supervisor:
Dr. Ellen K. Longmire
ellen@aem.umn.edu / (612) 626-7853

Team Members:

Nicolas G. Schellpfeffer, flight crew
Senior, Aerospace Engineering
sche0435@umn.edu / (612) 730-2723

Maria L. Bigwood, flight crew
Senior, Aerospace Engineering
bigw0002@tc.umn.edu / (612) 378-7886

Richard A. Johnson, flight crew
Senior, Aerospace Engineering
john3528@umn.edu / (952) 210-1826

Nathan T. Koelln, flight crew
Senior, Aerospace Engineering
koel0024@tc.umn.edu / (612) 331-4187

Matthew J. Stegmeir, alt. flight crew
Senior, Aerospace Engineering
steg0044@umn.edu / (612) 623-1129

Kimberly A. Lay, ground crew
Senior, Aerospace Engineering
layx0010@umn.edu / (612) 331-2571
# Table of Contents

1.0 Flight Manifest ................................................................. 3  
2.0 Experiment Background .................................................... 3  
3.0 Experiment Description ...................................................... 6  
4.0 Equipment Description ...................................................... 7  
5.0 Structural Analysis ............................................................ 10  
6.0 Electrical Analysis ............................................................. 17  
7.0 Pressure Vessel Certification .............................................. 20  
8.0 Laser Certification .............................................................. 20  
9.0 Parabola Details and Crew Assistance ............................... 20  
10.0 Free Float Requirements .................................................. 20  
11.0 Institutional Review Board (IRB) ....................................... 20  
12.0 Hazard Analysis ............................................................... 20  
13.0 Tool Requirements ........................................................... 21  
14.0 Photo Requirements ........................................................ 21  
15.0 Aircraft Loading ............................................................... 21  
16.0 Ground Support Requirements ....................................... 21  
17.0 Hazardous Material ........................................................ 21  
18.0 Material Safety Data Sheets (MSDS) .............................. 22  
19.0 Experiment Procedures Documentation .......................... 27  
20.0 Bibliography ................................................................. 28  
21.0 Exceptions ................................................................. 28
Quick Reference Sheet

Principal Investigator: Ellen K. Longmire, Ph.D.
Contact Information: ellen@aem.umn.edu; (612) 626-7853; (612) 626-1558 (fax)

Experiment Title: Study of Droplet Coalescence Criteria of a Liquid/Liquid Interface in Micro- and Macro-Gravity Conditions

Flight Date(s): March 13th - March 22nd, 2003

Overall Assembly Weight (lb): 230 lbs

Assembly Dimensions (L x W x H [in]): 42 x 19 x 29

Equipment Orientation Requests: NONE

Proposed Floor Mounting Strategy (Bolts/Studs or Straps): Straps

Gas Cylinder Requests (Type and Quantity): NONE

Overboard Vent Requests (Yes or No): NO

Power Requirements (Type and Amps Required): 115 V, 60 Hz, 5 Amps

Free-Float Experiment: NO

Flyer Names for Each Proposal Flight Days:

- **Day 1**
  - Nicolas Schellpfeffer
  - Maria Bigwood

- **Day 2**
  - Richard Johnson
  - Nathan Koelln

Camera Pole and/or Support Video: NONE
1.0 Flight Manifest:
Flyer Names for Flight Days:

- Day 1
  - Nicolas Schellpfeffer
  - Maria Bigwood
- Day 2
  - Richard Johnson
  - Nathan Koelln

None of the team members have previously flown aboard the KC-135.

2.0 Experiment Background:
The criteria for coalescence of two droplets colliding in a liquid-liquid interface will be studied in micro- and macro-gravity conditions. Previous experiments in this subject have used droplet sizes with diameters on the order of microns to justify the assumption that buoyancy forces were negligible. For this experiment the ability to perform the collisions in a zero gravity environment creates a unique opportunity to analyze the criteria for coalescence on a macroscopic scale. The zero-gravity environment will establish if coalescence can be determined directly by two dimensionless parameters, the Weber number and impact parameter. With buoyancy forces not present, the properties of droplet collision and coalescence are defined only by their size, relative velocity and position at impact. Variations of these parameters will be studied to determine when coalescence occurs.

The collision of two droplets will result in one of three possible outcomes: shattering, bouncing, and coalescence (See Figure 2.1). Shattering occurs at high relative velocities and will not be a factor in this experiment. Bouncing is a trivial result and will not be analyzed if it occurs. Coalescence is a more intriguing phenomenon and will be the emphasis of our experiment.

![Figure 2.1: Time Sequence of two-drop coalescence experiments](image)

*Figure 2.1: Time Sequence of two-drop coalescence experiments (a) Coalescence does not occur. (b) Coalescence does occur. (Taken from Leal, L.G. – 2000)*
Coalescence is the combination of two discrete fluid particles and occurs in a three-stage process beginning with the approach of the particles toward one another. The approach phase is characterized by constant droplet shapes. The drag on the particles is well known due to the maintained spherical shapes. This allows the trajectories to be easily modeled. The second stage is the ambient liquid film drainage between the droplets as the separation distance becomes small compared to the droplet radii. Gravity affects the drainage rate. The final stage is the rupture of the film between the fluid droplets which causes a combination of the two volumes. Coalescence of the droplets will occur when a critical thickness of the film is reached; if this thickness is not reached the droplets will bounce off one another.

After coalescence the droplets may remain together or separate. The outcome of coalescence is dependant on the ratio of the inertial energy of the droplet to its surface energy, which is quantified by the Weber number (see Figure 2.2). Separation of the droplets can occur by stretching or reflexive separation. Stretching involves the elongation of the new fluid particle after combination, while reflexive separation is passing of the droplets through one another with no significant change in the original droplet properties. If the droplets combine and remain together they will oscillate until slowed by viscous effects. Additional effects that will not be considered in the realm of this experiment are initial droplet oscillations from nozzle detachment and droplet wake interactions in the collision zone.

Figure 2.2: Analytically obtained regions of coalescence, reflexive separation, and stretching separation for two drops of same size, together with experimental data (Taken from Ashgriz - 1990)
Previous research on droplet coalescence has been studied; however, the effects of micro-gravity on this phenomenon are not completely understood, and it is the intention of this experiment to determine the manner in which the droplets will behave.

The University of Minnesota has participated in the NASA Reduced Gravity Student Flight Opportunities Program (RGSFOP) for the past two years. Our experiment is not an extension of the previous fluid dynamics experiments performed by those teams. The prior experiments specifically studied droplet pinch-off angles at a single nozzle interface. The phenomenon of droplet coalescence occurs in a liquid-liquid interface and pinch-off angles are not applicable. However, we will take advantage of information and data acquired during previous years experience with the NASA-RGSFOP. In addition, we will be using the same frame and tank that was used in previous years, with some modifications. This equipment has been proven to be safe in experiments aboard the KC-135A.

**Technical References:**


3.0 Experiment Description:
Coalescence of liquid drops dispersed in an immiscible liquid has a vast importance in many industrial applications, including liquid-liquid extraction, emulsification, and polymer blending processes. Our aim is to conduct experimentation on the effects of droplet diameter and velocity on the probability of a droplet collision leading to coalescence or separation. More specifically our objectives include:

- Eliminating the effects of buoyancy forces on the droplets through the use of the micro-gravity environment.
- Studying how the critical film thickness is affected as droplet size is varied.
- Observing how the collision outcome is affected by the relative velocity between the two droplets.
- Comparing macroscopic droplet interactions to previously obtained microscopic droplet data.

The experiment is fully defined by seven dimensionless parameters: Weber number (We), impact parameter (x), Reynolds number, density ratio, viscosity ratio, diameter ratio, and a velocity ratio. However, the outcome of droplet collision is primarily influenced by the Weber number and impact parameter. In our experiment we intend to vary the droplet diameter (d) and the droplet velocity (U), which are related to the Weber number through the following equation:

\[ \text{We} = \frac{\rho U^2 d}{\sigma} \]

where \( \rho \) is density of the droplet fluid, and \( \sigma \) is the interfacial surface tension between the droplet and ambient fluids. The density and surface tension will be experimentally determined constants. The other significant dimensionless quantity in this experiment is the impact parameter, defined by:

\[ x = \frac{2X}{d_1 + d_2} \]

where \( X \) is the distance from the center of one drop to the relative velocity vector placed at the center of the other drop (see Figure 4.1), multiplied by two, and divided by the sum of the two drops diameters. The impact parameter varies between 0 and 1, where zero corresponds to a head-on collision and tangential collisions have an impact parameter of one.
Our hypothesis is that collected data will validate previously determined relationships between dimensionless parameters. It is our belief that the direction and magnitude of the droplets’ velocities and sizes can be directly related to coalescence when the buoyancy forces are not present. The main objective of the experiment is to find a relationship between the impact parameter and the Weber number for which coalescence or separation of the colliding droplets occurs. Previous studies have modeled coalescence in three consecutive stages: collision, liquid film drainage, and rupture.

4.0 Equipment Description:
The following are the main elements of our experimental apparatus:

Plexiglas Tank:
The tank is 18” tall x 9” wide x 9” deep, and is constructed of ½” thick Plexiglas with a total fluid capacity of 4.43 gallons. The tank is held together using Weld-On 3, manufactured by the IPS Corporation. A quarter turn valve will be used for filling the tank. The top of the tank will include an accumulator, which will adjust for pressure and volume changes during flight. It is secured to the sides with bolts and an o-ring is used to prevent possible leaks. The tank includes a deflection plate located slightly above the fluid interface to decrease fluid mixing during transitions. The plate is also used as a contrasting background for the top video camera.

Nozzles:
The nozzles, fabricated from stainless steel pipe, are used to insert the water-glycerin mixture into the tank. The nozzle separation distance will be adjustable. Swage lock
seals around the nozzle connections to the tank allow for movement of the nozzles while preventing the fluids from leaking.

**Solenoid Valves:**
Two identical solenoid valves manufactured by J. D. Gould Company, Inc., model number M-3V, will be used to control the flow from the nozzles. The solenoid valves are internal pilot piston operated valves. These will allow us to precisely vary the amount of fluid contained in each set of droplets. A simple electronic controller will be used to control the valves’ duty cycles.

**Pump:**
A centrifugal pump manufactured by the Little Giant Pump Company, model number 1.5-MDI-SC, will be used to provide a constant pressure head at the nozzles. The pump contains a leak-proof, seal-less, magnetic drive. The advantage of using a centrifugal pump is that it is capable of continuously running while the solenoid valves are closed. The pump is connected to a surge protector, which functions as our main kill switch. A voltage regulation attached to the pump allows for the variations of the pressure head.

**Fluids:**
Two fluids will be used in this experiment: mineral oil and a 50:50 water/glycerin mixture (based on volume). The past two University of Minnesota Micro-Gravity teams have used these fluids, which have been proven to provide consistent performance under all gravity conditions encountered aboard the research plane. The interfacial surface tension between the fluids is 14.3 mN/meter.

<table>
<thead>
<tr>
<th>Fluids</th>
<th>Density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Oil</td>
<td>860</td>
</tr>
<tr>
<td>Water/Glycerin</td>
<td>1150</td>
</tr>
</tbody>
</table>

**Tubing:**
Two types of tubing will be used to transfer the fluid from the pump to the valves. Flexible plastic tubing is fastened onto plastic nipples using hose clamps will be used to connect the pump to the tank and the solenoid valves. Stainless steel pipe was used to fabricate the nozzles.

**Timing Circuit:**
A 555 integrated circuit timer regulates the opening and closing of the solenoid valves. The duty cycle is controlled by a 100 kilo-ohm potentiometer. The interval between pulses is set at approximately five seconds. The circuit is powered by a nine-volt battery. Transistors are used to amplify the output signal to the 24 volts necessary to operate the solenoid valves. The timing circuit contains a kill switch.

**Accelerometer Circuit:**
An integrated circuit accelerometer, ADXL202, connected to a digital LCD panel, will be used to obtain g-force values while in flight. The circuit is powered by a nine-volt
battery. The analog output of the accelerometer is converted to a digital signal by an A/D converter. A basic stamp controller processes the digital output and controls the LCD.

**Video Cameras:**
Two digital cameras (Canon ZR40) will be positioned orthogonal to each other. This will allow us to obtain multiple continuous video streams of the flow. These cameras are capable of capturing images at 30 frames per second and are equipped with a variable shutter speed. Time will be displayed in every frame to allow us to correlate the images from both cameras. Both cameras will be connected to the surge protector, and are mounted on the external frame.

**Lights:**
Four fluorescent lights with their respective casings will be used to illuminate the testing area. The lights are connected to the frame with Velcro. Each light uses four AA batteries.

**Frame:**
We will support our experiment with a frame made of Unistrut™. This material has been used for the last two years by the University of Minnesota Micro-Gravity Fluids research teams. The cross section of the frame is 1 5/8 in². The outside dimensions of the frame are 42 in. L x 29 in. H x 19 in. W. This structure will support our experiment. All sharp angles and edges will be rounded and padded in accordance with the hazard checklist. Eighth inch plastic sheeting will be attached with Velcro around the outside of the frame as a secondary leak protection barrier.

**Total Assembly:**
The frame and location of the major components are shown in Figure 5.2. The assembly will be discussed extensively in the structural load analysis section.

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Weight (lbs)</th>
<th>Dimensions (in., LxWxH)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera #1</td>
<td>1</td>
<td>5.25x3x4</td>
<td>Aluminum Mounting Plate</td>
</tr>
<tr>
<td>Camera #2</td>
<td>1</td>
<td>5.25x3x4</td>
<td>Aluminum Mounting Plate</td>
</tr>
<tr>
<td>Tank and Fluids</td>
<td>70</td>
<td>9x9x18</td>
<td>Plexiglas and PVC box, Aluminum Mounting Plate, Glycerin-Water, Mineral Oil</td>
</tr>
<tr>
<td>Frame</td>
<td>105</td>
<td>42x19x29</td>
<td>Steel</td>
</tr>
<tr>
<td>Timing Circuit</td>
<td>3</td>
<td>4x7x3</td>
<td>Aluminum</td>
</tr>
<tr>
<td>Accelerometer Circuit</td>
<td>2</td>
<td>2x2x1</td>
<td>Plastic</td>
</tr>
<tr>
<td>Pump</td>
<td>7</td>
<td>7x3.5x4</td>
<td>Aluminum Mounting Plate</td>
</tr>
<tr>
<td>Nozzle (2)</td>
<td>5</td>
<td>1x1x6</td>
<td>Steel</td>
</tr>
<tr>
<td>Tubing, Clamps</td>
<td>10</td>
<td>N/A</td>
<td>Plastic, PVC, Aluminum</td>
</tr>
</tbody>
</table>
### Component Description

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Weight (lbs)</th>
<th>Dimensions (in., LxWxH)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solenoid Valves (2)</td>
<td>10</td>
<td>3x4x6</td>
<td>Brass</td>
</tr>
<tr>
<td>Lights (4)</td>
<td>5</td>
<td>1x1x8</td>
<td>Plastic, Fluorescent Bulbs</td>
</tr>
<tr>
<td>Secondary Plastic Covering</td>
<td>10</td>
<td>Varies</td>
<td>Plastic</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>230</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.0 Structural Analysis

5.1 Free Body Diagram

The centers of gravity (CG) of significant items are listed (Table 5.1) and diagrammed below (Figure 5.1):

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (lbs)</th>
<th>Location (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>105</td>
<td>x = 21.0, y = 9.8, z = 14.5</td>
</tr>
<tr>
<td>Tank</td>
<td>67</td>
<td>x = 15.0, y = 7.0, z = 9.8</td>
</tr>
<tr>
<td>Pump</td>
<td>6</td>
<td>x = 29.5, y = 9.5, z = 4.0</td>
</tr>
<tr>
<td>Shelf</td>
<td>6</td>
<td>x = 32.0, y = 9.5, z = 14.7</td>
</tr>
<tr>
<td>All Other Items</td>
<td>41</td>
<td>x = 19.2, y = 10.6, z = 13.8</td>
</tr>
<tr>
<td><strong>CG</strong></td>
<td><strong>225</strong></td>
<td>x = 19.4, y = 9.1, z = 12.7</td>
</tr>
</tbody>
</table>

Table 5.1: CG
5.2 Listing of Weights and Materials

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetric Frame</td>
<td>95.4</td>
</tr>
<tr>
<td>4 Joints, 8 Nuts&amp;Bolts</td>
<td>9.7</td>
</tr>
<tr>
<td>Tank Support #1</td>
<td>3.3</td>
</tr>
<tr>
<td>Tank Support #2</td>
<td>3.3</td>
</tr>
<tr>
<td>Top Camera Support</td>
<td>3.9</td>
</tr>
<tr>
<td>Shelf Support</td>
<td>3.9</td>
</tr>
<tr>
<td>Empty Tank, Lid, Accumulator</td>
<td>25.0</td>
</tr>
<tr>
<td>Mineral Oil</td>
<td>16.0</td>
</tr>
<tr>
<td>Water/Glycerin</td>
<td>20.0</td>
</tr>
<tr>
<td>Pump</td>
<td>6.0</td>
</tr>
<tr>
<td>Tubing, Wiring, Clamps, ...</td>
<td>10.0</td>
</tr>
<tr>
<td>Power Strip</td>
<td>1.0</td>
</tr>
<tr>
<td>Solenoid #1</td>
<td>3.0</td>
</tr>
<tr>
<td>Solenoid #2</td>
<td>3.0</td>
</tr>
<tr>
<td>Electronics Box</td>
<td>2.0</td>
</tr>
<tr>
<td>Shelf</td>
<td>2.0</td>
</tr>
<tr>
<td>Outer Covering</td>
<td>10.0</td>
</tr>
<tr>
<td>Lighting System</td>
<td>5.0</td>
</tr>
<tr>
<td>Top Camera</td>
<td>1.0</td>
</tr>
<tr>
<td>Side Camera</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>224.5</strong></td>
</tr>
</tbody>
</table>

Figure 5.2 – Experimental Setup (developed using SolidWorks)
5.3 Compliance with Structural Design Requirements

a. Component Attachment Analysis: The components are attached to the frame with ½” P1010 Unistrut bolts.

(1) Tank: The tank assembly includes a ½” thick aluminum base attached to two 19” beams with six ½” bolts. The beams are attached to the bottom 38” beams with four ½” bolts.

i. 9Gs Forward:
   - Shear Force / Bolt: 146 lbs
   - Max Shear: 1500 lbs
   - Tensile Force / Bolt: 130 lbs
   - Pull-Out Force / Bolt: 2000 lbs
   - Beam Load: 130 lbs
   - Max Beam Load: 5000 lbs

ii. 3Gs Aft:
   - Shear Force / Bolt: 49 lbs
   - Max Shear: 1500 lbs
   - Tensile Force / Bolt: 43 lbs
   - Pull-Out Force / Bolt: 2000 lbs
   - Beam Load: 86 lbs
   - Max Beam Load: 5000 lbs
iii. 6Gs Down:
   Beam Load: 195 lbs
   Max Beam Load: 5000 lbs

iv. 2Gs Lateral:
   Shear Force / Bolt: 33 lbs
   Max Shear: 1500 lbs
   Tensile Force / Bolt: 29 lbs
   Pull-Out Force / Bolt: 2000 lbs
   Beam Load: 58 lbs
   Max Beam Load: 5000 lbs

v. 2Gs Up:
   Tensile Force / Bolt: 33 lbs
   Pull-Out Force / Bolt: 2000 lbs

(2) Pump: The pump is attached to a \( \frac{1}{2} '' \) thick aluminum base. The base is attached to the bottom 38” beams of the frame with two \( \frac{1}{2} '' \) bolts.
   i. 9Gs Forward:
      Shear Force / Bolt: 27 lbs
      Max Shear: 1500 lbs
   ii. 3Gs Aft:
      Shear Force / Bolt: 9 lbs
      Max Shear: 1500 lbs
   iii. 6Gs Down:
      Beam Load: 18 lbs
      Max Beam Load: 5000 lbs
   iv. 2Gs Lateral:
      Shear Force / Bolt: 6 lbs
      Max Shear: 1500 lbs
   v. 2Gs Up:
      Tensile Force / Bolt: 6 lbs
      Pull-Out Force / Bolt: 2000 lbs

(3) Shelf: The shelf is attached to two of the middle 16” beams with four \( \frac{1}{2} '' \) bolts.
   i. 9Gs Forward:
      Shear Force / Bolt: 14 lbs
      Max Shear: 1500 lbs
   ii. 3Gs Aft:
      Shear Force / Bolt: 5 lbs
      Max Shear: 1500 lbs
   iii. 6Gs Down:
      Beam Load: 18 lbs
      Max Beam Load: 5000 lbs
   iv. 2Gs Lateral:
      Shear Force / Bolt: 3 lbs
      Max Shear: 1500 lbs
   v. 2Gs Up:
Tensile Force / Bolt: 3 lbs
Pull-Out Force / Bolt: 2000 lbs

(4) Solenoid Valves: The solenoid valves are attached to ½” thick mounts. Each mount is attached to the middle 38” beam with one ½” bolt.
   i. 9Gs Forward:
      Shear Force / Bolt: 27 lbs
      Max Shear: 1500 lbs
   ii. 3Gs Aft:
      Shear Force / Bolt: 9 lbs
      Max Shear: 1500 lbs
   iv. 6Gs Down:
      Beam Load: 18 lbs
      Pull-Out Force / Bolt: 2000 lbs
   iv. 2Gs Lateral:
      Shear Force / Bolt: 6 lbs
      Max Shear: 1500 lbs
   v. 2Gs Up:
      Tensile Force / Bolt: 6 lbs
      Max Beam Load: 5000 lbs

b. Frame Analysis: Each piece of the frame was analyzed under each loading condition and g-loads were satisfied.
   (1) Members: The members of the frame are 1 5/8” P1000 Unistrut beams made of 12 gauge (.105) in thick steel.
   (2) Joints: P2226 Unistrut joints are used.

c. Floor Attachment: Cargo straps will be used to tie down the experiment to the test cabin floor. Straps will be provided by the Reduced Gravity Office (RGO). Three, 2” wide cargo straps will be used to secure the frame to the aircraft (Figure 5.4 – 5.5). The straps will pass through handles built into the top beams of the frame. Handles will be constructed of ½” steal rods. For the calculations, it is assumed that the straps will support the frame in forward, aft, and lateral loading conditions after the frame has realigned 5” in the direction of the applied force. The yield strain (ε) of the straps is assumed to be greater than 0.01. Static friction coefficients are assumed to be at least 0.1 (straps/frame and frame/floor). Equal tension in each strap is also assumed. The straps in the lateral direction and in the longitudinal direction are 6.7 ft and 9.4 ft in length.
   i. 9Gs Forward:
      29” Column Load: 1413 lbs
      Max Column Load: 3000 lbs
      Shear Force / Handle: 172 lbs
      Max Shear / Handle: 11390 lbs
      16” Beam Load: 821 lbs, 945 lbs
Max Beam Load: 1690 lbs, 1690 lbs  
Tensile Force / Strap: 2145 lbs  
Yield Load / Strap: 5000 lbs

ii. 3Gs Aft:
   29” Column Load: 481 lbs  
   Max Column Load: 3000 lbs  
   Shear Force / Handle: 57 lbs  
   Max Shear / Handle: 11390 lbs  
   16” Beam Load: 315 lbs, 274 lbs  
   Max Beam Load: 1690 lbs, 1690 lbs  
   Tensile Force / Strap: 715 lbs  
   Yield Load / Strap: 5000 lbs

iii. 6Gs Down:
   N/A

iv. 2Gs Lateral:
   29” Column Load: 366 lbs  
   Max Column Load: 3000 lbs  
   Shear Force / Handle: 38 lbs  
   Max Shear / Handle: 11390 lbs  
   16” Beam Load: 222 lbs  
   Max Beam Load: 1690 lbs  
   Tensile Force / Strap: 545 lbs  
   Yield Load / Strap: 5000 lbs

v. 2Gs Up:
   29” Column Load: 113 lbs  
   Max Column Load: 3000 lbs  
   16” Beam Load: 83 lbs  
   Max Beam Load: 1690 lbs  
   Tensile Force / Strap: 205 lbs  
   Yield Load / Strap: 5000 lbs

Figure 5.4 – Top View of Straps (Not to Scale)
d. Floor Loading: The frame will rest on the floor padding instead of spacers. The floor loading for the in-flight load case of 1.8 Gs is calculated to be 73.1 lbs/ft$^2$. This is below the maximum allowable floor loading of 200 lbs/ft$^2$ with a safety factor of 2.7.

### 5.4 Safety Factors

Safety factors derived from the above analysis are presented in Table 5.2:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
<th>Load</th>
<th>Allowed</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>9Gs Forward</td>
<td>29&quot; Columns</td>
<td>1413</td>
<td>3000</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Handles</td>
<td>172</td>
<td>11390</td>
<td>66.2</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>821</td>
<td>1690</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>945</td>
<td>1690</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Straps</td>
<td>2145</td>
<td>5000</td>
<td>2.3</td>
</tr>
<tr>
<td>3Gs Aft</td>
<td>29&quot; Columns</td>
<td>481</td>
<td>3000</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Handles</td>
<td>57</td>
<td>11390</td>
<td>199.8</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>315</td>
<td>1690</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>274</td>
<td>1690</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Straps</td>
<td>715</td>
<td>5000</td>
<td>7.0</td>
</tr>
<tr>
<td>6Gs Down</td>
<td>29&quot; Columns</td>
<td>338</td>
<td>3000</td>
<td>8.9</td>
</tr>
<tr>
<td>2Gs Lateral</td>
<td>29&quot; Columns</td>
<td>366</td>
<td>3000</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Handles</td>
<td>38</td>
<td>11390</td>
<td>299.7</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>222</td>
<td>1690</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Straps</td>
<td>545</td>
<td>5000</td>
<td>9.2</td>
</tr>
<tr>
<td>2Gs Up</td>
<td>29&quot; Columns</td>
<td>113</td>
<td>3000</td>
<td>26.5</td>
</tr>
<tr>
<td></td>
<td>16&quot; Beam</td>
<td>83</td>
<td>1690</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Table 5.2: Safety Factors
6.0 Electrical Analysis

Our experiment includes six electrical circuits. These include a main 115VAC circuit which will be powered from a single 115 VAC outlet on the aircraft, a 24VDC circuit powered by a power supply connected to the 115 VAC source, and 4 battery-powered circuits. These are a 9V timing circuit which controls the 24V solenoid circuit, a 9V accelerometer circuit, and two digital cameras with onboard 7.4V batteries. The cameras will normally be operated in AC mode via the included 9.6 VDC power supplies. All exposed metal surfaces will be attached to our metal frame. The frame will be constructed with metal surfaces flush against each other. The frame will be grounded to the aircraft. Figure 6.1 shows a schematic of our electrical setup.

Figure 6.1 – Schematic of Major Electrical Components
Load Tables:

<table>
<thead>
<tr>
<th>Power Source Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>115 VAC from Aircraft</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>115 VAC</td>
</tr>
<tr>
<td>Wire Gauge</td>
<td>14 AWG</td>
</tr>
<tr>
<td>Rated Output Current</td>
<td>15 Amp</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Nominal Current Draw</td>
</tr>
<tr>
<td>Pump</td>
<td>1.1 Amp</td>
</tr>
<tr>
<td>Power Supply</td>
<td>0.5 Amp</td>
</tr>
<tr>
<td>Camera1</td>
<td>&lt;100mA</td>
</tr>
<tr>
<td>Camera2</td>
<td>&lt;100mA</td>
</tr>
<tr>
<td>Total Load</td>
<td>2.7 Amp</td>
</tr>
</tbody>
</table>

The highest power electrical circuit used will be the 115 VAC circuit. This will directly power our pump, 24V power supply, and the cameras used for data acquisition (via their included DC supplies). A single power cord will connect the 115 VAC circuit to the aircraft power. The power strip is equipped with a 15A circuit breaker and a switch. The breaker will provide current limiting for the circuit and the switch will serve as the master “kill switch” for the 115 VAC and 24 VDC circuits.

<table>
<thead>
<tr>
<th>Power Source Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Valve Power Supply</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>24VDC</td>
</tr>
<tr>
<td>Wire Gauge</td>
<td>18 AWG</td>
</tr>
<tr>
<td>Rated Output Current</td>
<td>6.25A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Nominal Current Draw</td>
</tr>
<tr>
<td>Main Valve #1</td>
<td>0 Amp</td>
</tr>
<tr>
<td>Main Valve #2</td>
<td>0 Amp</td>
</tr>
<tr>
<td>Total Load</td>
<td>2 Amp</td>
</tr>
</tbody>
</table>

The 24 VDC circuit will be powered by an Astrodyn MKS150-24 power supply. This supply is rated to supply 6.25 A at 24 VDC. We expect to see a maximum draw of no more than 2 A from this supply. Kill switch functionality will be provided by the power strip, as mentioned above. The supply may also be independently switched off if desired. This supply has the capability to self-limit current. 3A fuses will also be installed inline with the valves to guard against short-circuit conditions. The power supply is also self current-limiting.

<table>
<thead>
<tr>
<th>Power Source Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Accelerometer Power</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>9VDC</td>
</tr>
</tbody>
</table>
The accelerometer used to measure accelerations in flight will be powered by a dedicated 9V battery. It will be electrically isolated from the remainder of the experiment. A separate power switch is used to disable this circuit. The timing circuit is also powered via an independent battery source. It also is equipped with a kill switch.

<table>
<thead>
<tr>
<th>Power Source Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Control Circuit Power</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>9VDC</td>
</tr>
<tr>
<td>Wire Gauge</td>
<td>24 AWG</td>
</tr>
<tr>
<td>Rated Output Current</td>
<td>1 A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Nominal Current Draw</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>200 mA</td>
</tr>
<tr>
<td><strong>Total Load</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Stored Energy:**
We will not be using any devices to store or create large electrical charges other than those included within our power supply.

**Electrical Kill Switch:**
The main experiment power is all routed through a single power switch. Turning this switch off disables the experiment and cuts it off from all high voltage sources. Our emergency shutdown procedure is to turn off the main power at this switch. If necessary, we will then proceed to disable our timer and accelerometer electronics and our data acquisition cameras using their power switches after waiting for the power indicator LED on our power supply to go out.

**Loss of Electrical Power:**
Upon loss of power, the experiment will cease operation. The pump will stop, removing the pressure head which drives our droplet generators. The solenoid valves will remain in their closed positions. If left on, the timing circuit and the accelerometer circuit will continue to operate normally without affecting the rest of the experiment. If turned off they will simply cease operating. Our experiment is designed to be in a safe state regardless of power conditions.

**7.0 Pressure Vessel Certification:**
A pressure head, of 5-10 psig, will exist between the pump and the solenoid valves. All components fit the Category E requirements.

8.0 Laser Certification:
Not Applicable to this Experiment.

9.0 Parabola Details and Crew Assistance:
For each individual parabola we desire a zero-g condition. No additional crew assistance is needed for in-flight procedures. A maximum number of parabolas are desired as well as the standard two minute break between parabola sets for readjustment of our parameters.

10.0 Free Float Requirements:
Not Applicable to this Experiment.

11.0 Institutional Review Board:
Not Applicable to this Experiment.

12.0 Hazard Analysis

<table>
<thead>
<tr>
<th>HAZARD</th>
<th>Description</th>
<th>Cause(s)</th>
<th>Prevention and Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammable / Combustible fluid</td>
<td>Fire</td>
<td>Flammable Chemical: Glycerin</td>
<td>We will maintain our fluids well below their flash points and will not be using open flames or heaters in our experiment</td>
</tr>
<tr>
<td>Flammable / Combustible fluid</td>
<td>Fire</td>
<td>Flammable Chemical: Mineral Oil</td>
<td>We will maintain our fluids well below their flash points and will not be using open flames or heaters in our experiment</td>
</tr>
<tr>
<td>Chemical Leak</td>
<td>Exposure to Chemical via leak</td>
<td>Chemicals: Glycerin/Water Mineral Oil</td>
<td>Our glycerin will be diluted with water prior to flight and our tank will be designed to minimize the possibility of leakage.</td>
</tr>
<tr>
<td>Sharp corners/edges</td>
<td>Injuries due to abrupt contact with corners</td>
<td>Sharp corners on frame/tank apparatus</td>
<td>Exposure to sharp corners/edges will be minimized through the use of foam rubber padding</td>
</tr>
<tr>
<td>Ignition source in conjunction with flammable materials</td>
<td>Fire</td>
<td>Electrical short circuit</td>
<td>We will make use of a surge protector for the connection of our electrical equipment. The protector will be located away from chemicals minimizing spark risk</td>
</tr>
<tr>
<td>Fluid spill</td>
<td>Tank rupture</td>
<td>Failure of tank to contain liquid</td>
<td>Our fluid containing tank will be located inside of a protective rack/frame minimizing the possibility of a tank rupture due to impact. A secondary casing of Plexiglas will enclose our tank minimizing the impact of a large spill</td>
</tr>
</tbody>
</table>
13.0 Tool Requirements
We do not anticipate the need to use any tools to conduct the experiment in flight. However, as our experiment will be shipped from Minnesota it will require some assembly for mounting cameras, lights, and loading the fluids. We will bring our own wrenches and screwdrivers. All tools will be stored in a small toolbox and will be labeled with appropriate University information.

14.0 Photo Requirements
We will not need additional photo requirements.

15.0 Aircraft Loading
15.1 To load the experiment aboard the KC-135 we will require a lifting palate and a forklift.

15.2 Six handles are included for ground transportation.

15.3 The total weight loaded onto the aircraft will be 264 lbs, and the total base plate area is 5.4 ft\(^2\). This gives a loading value of 50 lb/ ft\(^2\). The structure will be secured to the floor using straps.

16.0 Ground Support Requirements
16.1 A standard 115 V 60 Hz electrical supply will be needed for ground testing purposes.

16.2 No pressurized gas will be needed for ground operations.

16.3 Non-toxic mineral oil and a glycerin/water mixture will be stored in a separate sealed containers. No venting requirements are needed.

16.4 No access to building 993 will be requested for any hours outside the regular business hours.

16.5 We will not require any general tools or special ground handling.

17.0 Hazardous Materials
Not Applicable to this Experiment.
18.0 MSDS Sheets:

Material Safety Data Sheet - Glycerin
SECTION 1: Chemical Product and Company Identification
Manufacturer: Cumberland Swan
One Swan Drive Date: November 1999
Smyrna, TN 37167
Product: Glycerin, U.S.P.
Telephone: (615) 459-8900
24hr. Emergency: (615) 459-8900 ext. 5270

SECTION 2: Composition / Information in Ingredients
Name: Glycerin CAS#: 56-81-5

SECTION 3: Hazards Identification
Colorless, odorless liquid that is slightly acidic. Hydrogen peroxide in this concentration is a mild oxidizer, prolonged exposure to elevated concentrations of vapors may result in irritation of the eyes, nose, and throat. Prolonged dermal exposure can result in mild skin irritation.

Potential Routes of Exposure: Ingestion, inhalation, dermal contact, eye contact
Target Organs: Eyes, respiratory system
Symptoms of Overexposure:
Inhalation: In the form of a mist, this product can act as an irritant.
Ingestion: While its oral toxicity in rodents is very low, large oral or parenteral doses in man may produce hemolysis, hemoglobinuria, renal failure, convulsions, and paralysis.
It may cause an increase in blood sugar levels.
Dermal Contact: No known hazards
Acute Effects: Considered to be slightly irritating on an acute local basis.
Chronic Effects: Side effects from oral doses include headache, dizziness, insomnia, nausea, vomiting, diarrhea, and fever.
HMIS: H=1, F=1, R=0 See Section 8 for PPE information

SECTION 4: First Aid Measures
Eye: Flush eyes with copious amount of water for at least 15 minutes
Skin: Flush with water.
Ingestion: May induce vomiting. Consult medical personnel.
Inhalation: Remove victim to fresh air

SECTION 5: Fire Fighting Measures
Extinguishing Media Use water fog, alcohol foam, dry chemical or CO2
Unusual Fire or Explosion Hazards: Caution: Contact with strong oxidizing agents such as chromium trioxide, potassium chlorate, or potassium permanganate may produce an explosion.
Recommendations: Can react violently with powerful oxidizers. This product will become dangerous when exposed to heat, flame, or powerful oxidizers.

SECTION 6: Accidental Release Measures
Large Spills: Evacuate the area of unprotected personnel. Utilize appropriate level of
personal protective equipment. Contain source if it is safe to do so. Dike or otherwise confine spilled product. Keep away from open flame. Small Spills: Dilute with large amounts of water. Dispose of in accordance with applicable local and federal regulations.

**SECTION 7: Handling and Storage**

Storage Requirements: Store in tightly closed containers in a cool, dry area away from heat and other possible ignition source. Handling Precautions: Maintain appropriate class of fire extinguishers nearby in case of fire.

**SECTION 8: Exposure Controls / Personal Protection**

OSHA PEL=10 mg/m 3 (TWA)

**Recommended Engineering Controls:** Use ventilation equipment as necessary.

**Recommended Admin Controls:** Train employees on hazards of glycerin.

**PPE:** Wear chemical goggles where the threat of exposure exists. Gloves should be worn if the user has sensitive skin or frequently use the product. Eye wash fountains should be provided for personnel in areas where eye exposure is possible.

**Recommended Hygiene Practices:** Clean PPE and work clothing contaminated with glycerin prior to reuse.

**SECTION 9: Physical and Chemical Properties**

**Appearance:** Water/white liquid  
**Freezing Point:** No data  
**Autoignition:** N/A  
**Odor:** Odorless  
**Water Solubility:** Miscible  
**LEL:** N/A  
**Odor Threshold:** No Data  
**Molecular Weight:** No data  
**Vapor Pressure:** Negligible  
**Specific Gravity:** 1.251  
**Vapor Density:** N/A  
**Boiling Point:** 550 0 F  
**Flash Point:** 349 0 F

**SECTION 10: Stability and Reactivity**

**Stability:** Slightly unstable  
**Polymerization:** Will not occur  
**Conditions to avoid:** Heat, sparks, and open flame, contact with incompatible materials. Avoid strong oxidizers.  
**Hazardous Products:** Decomposition releases oxygen which may intensify fire. of Decomposition

**SECTION 11: Toxicological Information**

**LD50:** >10,000 mg/kg (dermal rabbit)  
**LD50:** 17,000-27,200mg/m3 (ingestion, rat)  
**LC50:** >.57 mg/l (inhalation- rat)  
**Carcinogenicity:** Not identified as a carcinogen by OSHA, IARC, or NTP  
**Mutagenicity:** Not Indicated  
**Reproductive Effects:** Not Indicated

**SECTION 12: Ecological Information**

**Ecotoxicity:** N/A  
**Environmental Fate:** N/A  
**Soil Absorption/Mobility:** Highly Mobile  
**Environmental Degradation:** Should be removed readily from soils and water by remediation.

**SECTION 13: Disposal Considerations**

Disposal: Contact your supplier or a licensed contractor for detailed recommendations. Disposal Regulatory Requirements: Follow applicable federal, state and local
SECTION 14: Transport Information
Shipping Name: Glycerin, U.S.P. (Non Hazardous)

SECTION 15: Regulatory Information
RCRA Hazardous Waste Number/Classification: N/A
CERCLA Substance: N/A
CERCLA Reportable Quantity: 10,000 lbs (Default)
SARA 311/312 Codes: N/A
SARA Toxic Chemical: N/A

SECTION 16: Other Information
Prepared by: Cumberland Swan
Source of Information: 29CFR1910.1000; NIOSH Pocket Guide to Chemical Hazards (1993);
Disclaimer: While reasonable care has been taken to ensure the accuracy and completeness
of the information regarding the material described herein, it is the purchaser’s responsibility to ensure the suitability of such information as it applies to the purchaser’s intended use of the material.

Material Safety Data Sheet – Mineral Oil

SECTION 1: Chemical Product and Company Identification
Manufacturer: Cumberland Swan
One Swan Drive Date: November 1999
Smyrna, TN 37167

Product: Mineral Oil
Telephone: (615) 459-8900
24hr Emergency: (615) 459-8900 ext. 527

SECTION 2: Composition / Information on Ingredients
Name: Mineral Oil, USP

SECTION 3: Hazards Identification
Potential Routes of Exposure: Ingestion, inhalation, dermal contact, eye contact
Target Organs: None identified
Symptoms of Overexposure:
Inhalation: Not identified
Ingestion: This product is relatively non-toxic unless aspiration occurs. This product has laxative properties and may result in abdominal cramping and diarrhea.
Dermal Contact: Not expected to create any skin irritation upon direct single or repeated and prolonged contact.
Acute Effects: Shortness of breath and coughing.
Chronic Effects: On rare occasions, prolonged exposure to oil mist poses a risk of pulmonary disease such as chronic inflammation. Aspiration may lead to chemical pneumonitis.
**HMIS:** H=0, F=1, R=0 See Section 8 for PPE information

**SECTION 4: First Aid Measures**
- **Eye:** Flush eyes with copious amount of water for at least 15 minutes.
- **Skin:** If hot, submerge clothing/skin in cold water. Seek medical attention if irritation persists.
- **Ingestion:** Seek medical attention or contact the poison control center.
- **Inhalation:** Do not induce vomiting. If vomiting occurs, lower head below knees to avoid aspiration.

**5: Fire Fighting Measures**
- **Extinguishing Media:** Use water fog, alcohol foam, dry chemical or CO2
- **Unusual Fire or Containers exposed to intense heat from fires should be cooled**
- **Explosion Hazards:** with large amounts of water to prevent buildup of internal pressure due to vapor generation which could result in container rupture.

**Recommendations:** Clear area of unprotected personnel. Wear complete turnout gear. Cool containers exposed to fire with water. **Use of water directly could cause frothing**

**SECTION 6: Accidental Release Measures**
- **Large Spills:** Eliminate all ignition sources. Contain source of spill. Dike or otherwise confine spilled product. Uncontrolled releases to air, land, or water may be reportable to the National Response Center (1-800-424-8802).
- **Small Spills:** Wash with water or absorb spill and dispose of absorbent material properly.

**SECTION 7: Handling and Storage**
- **Storage Requirements:** Store in tightly closed containers in a cool, dry area away from heat and other possible ignition sources.
- **Handling precautions:** Maintain appropriate class of fire extinguishers (B) nearby in case of fire.

**SECTION 8: Exposure Controls / Personal Protection**
- **OSHA PEL:** 5 mg/m3 OSHA STEL= 10mg/m3 (oil mist)
- **Recommended Engineering Controls:** Use ventilation equipment to maintain the PEL
- **Recommended Admin Controls:** Train employees on the hazards of oils
- **PPE:** Goggles, gloves when handling large amounts
- **Recommended Hygiene Practices:** Clean PPE and work clothing contaminated with mineral oil prior to reuse. After working with this product, be sure to wash before eating, smoking, drinking, or applying cosmetics.

**SECTION 9: Physical and Chemical Properties**
- **Appearance:** Clear oily liquid
- **Freezing Point:** No Data
- **Autoignition:** N/A
- **Odor:** “Oily”
- **Water Solubility:** Negligible
- **Odor Threshold:** Not Available
- **Molecular Weight:** N/A
- **UEL:** N/A
- **Vapor Pressure:** <1 mmHg @ 70 0 F
- **Specific Gravity:** 0.875
- **Boiling Point:** 650 0 F
- **Flash Point:** 435 0 F

**SECTION 10: Stability and Reactivity**
- **Stability:** Stable
- **Polymerization:** Will not occur
Conditions to avoid: Heat, sparks, and open flame
Hazardous Products: CO and unidentified organic compounds may be formed of Decomposition

SECTION 11: Toxicological Information
LD50: >5 g/kg LC50: N/A LDLO: N/A
Carcinogenicity: Not identified as a carcinogen by OSHA, IARC, or NTP
Mutagenicity: Not Indicated
Reproductive Effects: Not Indicated

SECTION 12: Ecological Information
Ecotoxicity: N/A Environmental Fate: N/A Soil Absorption/Mobility: Mildly Mobile
Environmental Degradation: No Data

SECTION 13: Disposal Considerations
Disposal: Contact your supplier or a licensed contractor for detailed recommendations.
Disposal Regulatory Requirements: Follow applicable Federal, state and local regulations

SECTION 14: Transport Information
Shipping Name: Mineral Oil, Non Hazardous

SECTION 15: Regulatory Information
RCRA Hazardous Waste Number/Classification: N/A
CERCLA Substance: N/A
CERCLA Reportable Quantity: 10,000 lbs (Default)
SARA 311/312 Codes: N/A
SARA Toxic Chemical: Contains Materials listed on TSCA inventory

SECTION 16: Other Information
Prepared by: Cumberland Swan
Sources of Information: 29CFR1910.1000; NIOSH Pocket Guide to Chemical Hazards (1993);
Disclaimer: While reasonable care has been taken to ensure the accuracy and completeness of the information regarding the material described herein, it is the purchaser’s responsibility to ensure the suitability of such information as it applies to the purchaser’s intended use of the material.
19.0 Experiment Procedure Documentation

19.1 Equipment Shipping to Ellington Field
The experiment will be shipped directly to Ellington Field building 993. The experiment will be enclosed in a wood crate, and shipped one day prior to our arrival (March 12, noon). The shipping company is Independent Packing Services, Inc. This company has been used by prior University of Minnesota Micro-Gravity Teams.

19.2 Ground Operations
After unloading the experiment, small parts will be assembled into place and the fluids will be added to the tank. Ground testing will be performed to ensure that the experiment runs properly and that there are no leaks. We request the use of a work table with an available 115 V, 60Hz electrical outlet.

19.3 Loading
To load the experiment aboard the KC-135 we will require a lifting palate and a forklift. The experiment will be strapped down to the floor using the 20 inch separation of the floor connection points in the aircraft. The straps will be secured by guides on the cage of our experiment.

19.4 Pre-Flight
Pre-flight procedures will include plugging in the electrical equipment and ensuring the frame is properly fastened to the floor. The surge protector will remain off until proper altitude is reached. There are no preflight requirements other than the 115V, 60Hz electrical outlet.

19.5 Take-off/Landing
No power is required during take-off or landing and all electrical systems will remain off during these time periods.

19.6 In-Flight
With our proposed flight conditions of three sets of ten zero-gravity parabolas our in flight procedures are as follows. During the transition between sets the nozzle separation distance will be adjusted to the desired distance. During each individual set, droplet size and velocity will be adjusted using the external control knobs of the duty cycle and the pump speed for each individual parabola. The final settings of each parabola will be determined in the coming months to obtain all desired conditions.

19.7 Post-Flight
The first day flight team will inform the remainder of the team of difficulties experienced in flight, if they occurred, and determine means of correction for the following flight day.

19.8 Off-Loading
The experiment will be off-loaded from the aircraft with a forklift and lifting palate. Returning shipping will be provided by the same shipping company, Independent
Packing Services, Inc. The return will be arranged for the first business day after the completion of our flights, tentatively scheduled for Monday, March 24.

20.0 Bibliography


21.0 Exceptions
Not Applicable.