Steady State Two-Phase Flow in a Reduced Gravity Environment 2

Portland State University
Team Contact – Brian O’Neel
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December 23, 2003
Team Number – 2004-456
KC-135 Quick Reference Data Sheet

Principal Investigator: Portland State University

Contact Information: Brian O’Neel (503) 699-5106

Experiment Title: Steady State Flow in a Reduced Gravity Environment

Flight Dates: 03/04 – 03/15

Overall Assembly Weight: 143.97 lb

Assembly Dimensions (L x W x H): 26” x 25” x 17”

Equipment Orientation Requests: Near CG of Plane

Proposed Floor Mounting Strategy: Straps

Gas Cylinder Requests: N/A

Overboard Vent Requirement: No

Power Requirement: 115 VAC

Free Float Experiment: No

Flyer Names for Each Proposed Flight Day: Day 1: Brian O’Neel and Shem Hieple Day 2: Jim Cloer and Jason Mooney

Camera Pole and/or Video Support: Camera Pole Requested
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**Flight Manifest**

**Academic Institution:**

Portland State University  
1719 SW 10th Street  
SBII Rm 118  
Portland, OR  97201

**Flight Dates:**

March 4 – 15, 2004

**Flight Team:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Grade</th>
<th>Major, Department</th>
<th>Experience</th>
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<tbody>
<tr>
<td>Brian O’Neel</td>
<td>Senior</td>
<td>Mechanical Engineering</td>
<td>No Previous Experience</td>
</tr>
<tr>
<td>Jason Mooney</td>
<td>Senior</td>
<td>Mechanical Engineering</td>
<td>No Previous Experience</td>
</tr>
<tr>
<td>Shem Heiple</td>
<td>Senior</td>
<td>Mechanical Engineering</td>
<td>No Previous Experience</td>
</tr>
<tr>
<td>Jim Cloer</td>
<td>Junior</td>
<td>Mechanical Engineering</td>
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Experiment Background

Team Albert’s unique method of studying two-phase slug flow was designed by using a closed circuit circular loop. The most valuable and unique aspect of this design was the partial achievement of steady state, fully developed slug flow during last year’s flight. Despite the problems encountered with the apparatus during their flights, the design proved unique in furthering our understanding of controlling steady state two-phase flow. The flow control was not as simple, reliable, or as accurate as they had anticipated, yet their limited results were shown to be inspirational. We believe that consistent steady state flows can be achieved with alterations to the same apparatus.

The aim of this experiment is exactly the same as before… to gather reliable experimental data that will be used in comparison with theoretical models of steady two-phase flow in a reduced gravity environment. This will again be achieved by rotating a closed circuit circular loop containing a liquid slug. The slug length will be recorded for various viscosities or tube diameters. From this slug length measurement, a film deposition rate will be calculated and the characteristics of the flow will be documented. This test is to be done in a reduced gravity environment to examine the augmentation of the film thickness and slug size.

![Figure 1: Schematic of the closed circuit loop containing a steady slug](image)

Figure 1 illustrates the force balance location of the slug within the old 1-g and 0-g test apparatus and reflects the same principles within the new ones as well. The only difference being that the new closed circuit loop will be band saw shaped, allowing for a linear, wider force balance region to view the moving slug. This new concept was favorably chosen over enlarging the disk and subsequent apparatus size.
Experiment Description

The unique characteristic of this experiment is that it produces a slug flow that is truly *steady* and fully developed. A series of 1g experiments have been developed to compare and predict fluid behavior in a reduced gravity environment. A predetermined volume of .5-10 centistoke silicone oil is injected into each transparent tube and then sealed. The volume of liquid selected coats the tube wall while allowing for a slug of length \( L_s \) to form during a steady rotational velocity. A thin, semi transparent drive belt capable of fitting 4 selected tubes on the face is mounted between two rotating drums. One of the drums is driven by a small motor and in turn, the motor connects to a DC speed controller that enables prompt responsive control of rotational speed. The 1g apparatus consists of this drum assembly mounted to a hinged support. (Figure 2)

Tilting the plate from a vertical to a horizontal position in a 1g environment decreases the effect of the gravitational force in the direction of flow, lowers the rotational velocity needed for steady state conditions and allows for insight predicting low gravity conditions.1

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1 Colin, 533
In reduced gravity, additional modifications are made to the experiment to ensure slug flow. The drums are driven by a geared 90° motor and both are mounted as an integral assembly to the top surface of a rotating, 22-inch aluminum disk, as shown in Figure 3. The centerline of the straight section of the tubes within the drum assembly is aligned radially with the center of the disk as shown in Figure 3. This rotating disk provides an applied centrifugal force to the drum assembly and is used to simply collect the slugs of silicone oil to the outer edge of each tube during the 2g portion of the parabola to remove bubbles. Once the slugs have completely formed and the reduced gravity portion initiates, the disk rotational speed is lowered and the drums are rotated to start the test. Like the 1g experiments, four tubes with various properties are mounted on a drive belt, enabling numerous tests without any other modifications during the flight. A camera is positioned on the disk so that motion capture software can be used and data analyzed later.

Figure 3: Drum assembly used in low-g environment
(motor and drum cover not shown)
The 1g tests provide experimental data that can be compared to theory and previously published results. The result of 1g testing aids in the proper selection of tube radius, fluid viscosity, and rate of rotation in a reduced gravity environment. For comparison, data collected during preliminary tests was plotted against experimental data gathered in Jing-Den Chen’s research on film thickness surrounding a bubble in a capillary and F.P. Bretherton predictions on film thickness (Figure 4).

![Dimensionless Film Thickness vs. Capillary Number](image)

**Figure 4:** $\delta r$ as a function of Ca, (♦) Data for 1 cst silicone oil in our closed circuit loop, (○) Comparative data from Jing-Den Chen’s research on film thickness surrounding a bubble in a capillary and F.P. Bretherton’s predictions (−)

This plot displays a direct correlation between the preliminary data collected using the closed circuit loop and both the experimental results of Chen’s data as well as Bretherton’s theoretical prediction. Despite the failure to collect 0-g deposition rate data, last year’s time averaged steady state flow success in reduced gravity showed that a far greater tube diameter could be tested while maintaining a tube Bond number less than 1.0. Reduced gravity will not only allow us to achieve steady state flows again, but will help obtain the accompanying film thicknesses and contact angle data for varied tube sizes. This data is not attainable in a 1g environment for larger tube diameters, $Bo << 1$ can not be achieved (and the flows stratify). Once the tube Bond number is greater than 1.0, capillary forces no longer dominate the system, and gravity begins to play a complicating role rapidly draining the thin films and eventually destabilizing the liquid slug. This information will provide insights to an area of science where little data has been successfully collected, particularly in regards to a truly steady slug flow.

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2 Chen, 347
Equipment Description

This student class experiment consists of the same fully self-contained, enclosed apparatus that we used last year. (Figure 5) The outer frame is composed of T-slotted aluminum extrusions encompassing a total 26x29x17 (inch) volume. The entire frame is enclosed with Plexiglas surrounding all sides and an outer aluminum shelf covering a 26x8 square inch area of the top. In addition to our experiment, and in keeping with our proposal, we’ve included a ‘piggy-backed’ outreach project within the perimeter of the enclosed apparatus. Designed under the same guidelines as our project, the Portland Blazer Kids Club has created a miniature lego robot they would like to test in low-g before sending it on the Mars mission.

Figure 5: Schematic of outer frame
The inside components include an aluminum rotating disk that supports a camera and drum assembly, utilizing two separate motors and a lower shelf assembly (Figure 6a-6d).

Figure 6a: Schematic of Drum Assy. mounted on a Disk
### FIGURE 6b Item List

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
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<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>1/4&quot; # 5 SAE Bolts</td>
<td>15</td>
<td>1/8&quot; Neoprene Pad</td>
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<tr>
<td>2</td>
<td>Dayton 4Z138 90° DC Motor</td>
<td>16</td>
<td>1/8&quot; 7075-T6 Camera Mount Angle</td>
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<td>1/4&quot; 6061-T6 Aluminum Cover Plate</td>
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<td>Fafnir S5KDD Bearing</td>
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<td>1/4&quot; 6061-T6 Drum Cap</td>
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<td>7</td>
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<td>1/4 ID x5/8 OD Nylon Spacer</td>
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<td>Belt &amp; Tygon Tube Pack</td>
<td>22</td>
<td>1/4 THK X 4&quot; OD 6061-T6 Drum</td>
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<tr>
<td>9</td>
<td>1/4&quot; 6061-T6 Drum Assy. Base Plate</td>
<td>23</td>
<td>LED Drive Module &amp; Light Pucks</td>
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<td>10</td>
<td>MS21043 Nuts &amp; AN960-416 Washers</td>
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<td>Drum Sub-Assy</td>
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<td>11</td>
<td>1/4&quot; 6061-T6 Aluminum Disk (Ref)</td>
<td>25</td>
<td>1/8&quot; Excelon Tygon Tubing</td>
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<td>12</td>
<td>JackShaft Assy. (Ref)</td>
<td>26</td>
<td>3/16&quot; Excelon Tygon Tubing</td>
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<td>1/4&quot; Excelon Tygon Tubing</td>
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<td>14</td>
<td>Canon Elura 50 Camcorder</td>
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<td>3/8&quot; Excelon Tygon Tubing</td>
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<td>15</td>
<td>.055&quot; Clear-055 Superior Belt</td>
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Figure 6b: Exploded view of Drum and Camera Assy’s mounted on Disk
Figure 6c Item List

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<td>¼&quot; Screws</td>
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<td>2</td>
<td>¼&quot; 6061-T6 Disk</td>
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<td>3</td>
<td>JackShaft</td>
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<td>4</td>
<td>Jackshaft Housing</td>
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<td>5</td>
<td>Jackshaft Nut</td>
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<td>6</td>
<td>Cogged Drive Belt</td>
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<td>7</td>
<td>Cogged Pulleys</td>
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<td>8</td>
<td>Kollmorgen U12M4 Servo motor</td>
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<td>9</td>
<td>.060&quot; 2024-T3 Shim</td>
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<td>10</td>
<td>5/16 Screws</td>
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<tr>
<td>11</td>
<td>Lower Shelf</td>
</tr>
<tr>
<td>12</td>
<td>‘80/20’ Apparatus Frame Cutaway</td>
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</tbody>
</table>

Figure 6c: Exploded view of Lower Shelf Assy. and Disk
(Tach. Sensor and Power Supply not shown)
The drum assembly contains 4 experimental stacked tubes with a total fluid quantity of less than six ounces of silicone oil. This is then affixed above the 22” diameter aluminum disk. A camcorder used to collect images of the experiment, is connected to the disk oriented perpendicular to a straight portion of the tube pack. Two controllers and a tachometer used in monitoring rotational speed will be hard mounted inside the frame to the bottom of the aluminum shelf. Components outside of the enclosure used for data collection will be stowed during take-off and landing. These items include a DV cam and Lego controller (outreach program experiment) which will both be attached to the top aluminum shelf using Velcro. Additionally, two personal cameras will be taken on board.
the KC-135 separate from the experiment. The size and weights of these components and the entire experiment are listed below. (Table 1)

<table>
<thead>
<tr>
<th>Component Weight Breakdown</th>
<th>Weight (lb)</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Frame Components</strong></td>
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<td></td>
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<tr>
<td>Frame</td>
<td>29.45</td>
<td>80/20</td>
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<tr>
<td>Plastic Shielding</td>
<td>18.7</td>
<td>Acrylic</td>
</tr>
<tr>
<td>Instrument Panel</td>
<td>2.4</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Mini-Robot Acrylic Container &amp; Robot</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td><strong>Shelf Components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum Shelf</td>
<td>18.21</td>
<td>6061 T6</td>
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<tr>
<td>Motor 1</td>
<td>8</td>
<td>Kollmorgen U12M4</td>
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<tr>
<td>Controller1</td>
<td>18</td>
<td>Kepco JQE15-6M</td>
</tr>
<tr>
<td>Big Aluminum Disk</td>
<td>9.5</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Hub Assembly for Large Disk</td>
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<td>6061 T6</td>
</tr>
<tr>
<td>Jack Shaft Assembly</td>
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<td>6061 T6</td>
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<td>Motor 2</td>
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<td>Dayton 4Z138</td>
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<td>Drum Assembly</td>
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<td>Balance Mass</td>
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<td>Video Camera</td>
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<td>Camera Bracket</td>
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<td>2 handles</td>
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<td>Surge Protector</td>
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<td>Eclipse Pro</td>
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<td>Lego Controllers/Battery Pack</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>143.97</strong></td>
<td></td>
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Table 1: Individual and overall weights and sizes of experiment
During ground operations, only a few additional components will be necessary. The apparatus will be completely assembled previous to the arrival at Ellington Field. One set of Allen wrenches will be brought to aid in any necessary modifications to the device and a roll of foam for covering any sharp edges of the outer frame with the RGO supplied duct tape.

This flight team requests a location for the experiment near the center of gravity of the KC-135. The experiment is not a free float and requires two RGO supplied restraints. Two handles bolted to the outside of the experiment will be used to wrap the 2.0 inch wide strap through, prohibiting the apparatus from forward, backward, and any lateral movement. (Figure 7) The experiment will remain in the same position for the entire flight including take-off and landing. Two members of the flight crew will be positioned on either side of the experiment and will remain in these positions for the duration of the experimental reduced gravity flight time.

Figure 7: Schematic of the frame being attached to the floor

**Structural Analysis**

The variables used in the analytical analysis of the frame and components follow the standard convention for stress and strain calculations:

- \( \rho \) = Density \[3\]
- \( V \) = Volume
- \( m \) = Mass
- \( I \) = Moment of inertia
- \( E \) = Modulus of Elasticity \[4\]
- \( F \) = Force
- \( R \) = Resultant force
- \( M \) = Moment
- \( r \) = Radius
- \( \omega \) = Rotational velocity
- \( d \) = Diameter
- \( c \) = Distance from centroid to point of interest

\[3\] Norton, 982-988
\[4\] Gere, 897-901
σ = Stress
V = Velocity
W = Weight
g = Gravity
cg = Center of gravity
SF = Safety factor
\( k_{eq} \) = Equivalent spring constant

The frame is analyzed by comparing the total moment that results from 9g loading to the published 80/20 recommended maximum loading.

Figure 8: Schematic of forces acting on one of the T-slot extrusions of the frame.

Figure 9: Schematic of 80/20 recommended maximum loading

The force due to the total frame assembly, \( F_1 = 66.92(9) = 602.3 \text{ lbs} \), acting through the centroid, 8.5 in, creates a moment of 5119.4 in-lbs (\( M_1 \)) summed with the force due to the internal components, \( F_2 = 81.3(9) = 731.7 \text{ lbs} \), acting through the components center, 2.5 in., creates a moment of 1829.3 in-lb (\( M_2 \)), results in a total

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5 Young, 189-192
6 80/20, 36-38, 49
moment of $M_1 + M_2 = 6948.6$ in·lb which is divided equally among eight bolted angle bracket assemblies gives a moment of 868.58 in·lbs. The safety factor for each bolted angle bracket assembly is as follows:

$$SF = \frac{1200in \cdot lb}{868.6in \cdot lb} = 1.38$$

**Floor Attachment Analysis**

Two 2.0 in. wide cargo strap with a 5000 lb yield tensile strength will be sufficient to secure the rig to the aircraft floor. As shown in Figure 10, the straps will be wrapped around a handle mounted in the middle of the frame on both the front and back of the rig. The cargo strap will provide a downward force on the rig to prevent any lateral movement at the specified 2g loading.

![Figure 10: Schematic of the frame being attached to the floor](image)

The maximum force the assembly and frame will apply to the straps will be the total experiment weight multiplied by the g load. 143.97lb\(\times\)9g=1295.73 lb

This will yield a safety factor of:

$$SF = \frac{Allowable \_ load \times 2 \_ strap}{Loading} = \frac{10000lb}{1295.73lb} = 7.72$$

**Floor Load Analysis**

The overall system has been designed to not exceed the maximum allowable floor load of 200 lb/in². The footprint of the frame is 4.33 ft² and the floor load during the 6g downward acceleration is no more than \((143.97\times6) = 863.82\) pounds. This will provide a 199.5 lb/ft² load which does not exceed the allowable floor loading.
Acrylic Panel Analysis

Acrylic Containment Panel – External Impact

The impact loading on the outer acrylic paneling was examined as a point load on the siding with the largest resulting moment arm. This analysis was determined as the extreme loading on the entire outer frame and would suffice for all external loading analysis.

\[ E = 4 \times 10^5 \text{ psi} \]
\[ l = \frac{bh^3}{12} = \frac{17''(0.25'')^3}{12} = 22.135 \times 10^{-3} \text{ in}^4 \]
\[ k_{eq} = \frac{192EI}{l^3} = \frac{192(4\times10^5 \text{ lb/ in}^2)(22.135\times10^{-3} \text{ in}^4)}{(24\text{in})^3} = 122.975 \text{ lb/in} \]
\[ V = 2 \text{ ft/s} \]
\[ W = 180 \text{ lb} \]

---

\(^7\) Norton, 112


\[ F_c = V \sqrt{\frac{mk_{eq}}{g}} = 2.0 \text{ ft/s} \sqrt{\frac{180 \text{ lb}(122.975 \text{ lb/in})(12 \text{ in/ft})}{32.2 \text{ ft/s}^2}} = 78.5157 \text{ lb} \]

\[ F_1 = F_2 = \frac{1}{2} F_c = \frac{1}{2}(71.5157 \text{ lb}) = 39.258 \text{ lb} \]

\[ M_1 = M_2 = 39.258 \text{ lb}(11 \text{ in}) = 431.837 \text{ in-lb} \]

\[ \sigma = \frac{Mc}{I} = \frac{431.837 \text{ in-lb}(0.25 \text{ in})}{22.135 \times 10^{-3} \text{ in}^4} = 4.877 \text{ ksi} \]

\[ SF = \frac{10 \text{ ksi}}{4.877 \text{ ksi}} = 2.05 \]

\[ V = 17 \text{ in}(24 \text{ in})(.25 \text{ in}) = 102 \text{ in}^3 = 0.059 \text{ ft}^3 \]

\[ \rho = 2.325 \text{ lb-s}^2/\text{ft}^4 \]

\[ m = V \rho = 0.059 \text{ ft}^3(2.325 \text{ lb-s}^2/\text{ft}^4) = 0.1372 \text{ lb-s}^2/\text{ft} \]

\[ R_{og} = 9mg = 9(0.1372 \text{ lb-s}^2/\text{ft}(32.2 \text{ ft/s}^2)) = 39.76 \text{ lb} \]

**Acrylic Containment Panel – Internal Impact**

The impact loading on the acrylic paneling was modeled as a block of mass (m) moving with a velocity (v) hitting the panel in the center where the maximum moment would occur. Using the work energy method and the largest possible kinetic energy that could be attained in the apparatus, the maximum stress in the acrylic panel was determined and ultimately a factor of safety.

Assumptions: The panel is modeled as a prismatic member constrained at both ends. The material does not reach its elastic limit. The maximum kinetic energy is due to the rotation of components contained in the apparatus.

Analysis:

\[ E = \text{Modulus of Elasticity of prismatic member} = 3.5 \times 10^5 \text{ psi} = 2.4 \times 10^9 \text{ Pa} \]

\[ b = \text{Base of prismatic member} = 15.5 \text{ in.} = .3937 \text{ m} \]

\[ h = \text{height of prismatic member} = .25 \text{ in.} = .00635 \text{ m} \]

\[ L = .572m \]

\[ c = .00635 \]

\[ I = \text{Second Moment of Inertia} = \frac{bh^3}{12} = 2.018 \times 10^2 \text{ in}^4 = 8.4 \times 10^{-9} \text{ m}^4 \]

\[ m = \text{mass of block} = 1.33 \text{ kg} \]

\[ r = \text{radius to center of mass of block} = .18415 \text{ m} \]

\[ \omega = \text{Max Rotational velocity of rotating component} = 5.6 \text{ rad/s} \]

\[ v = \text{Velocity of mass m} = r\omega = 1.03 \text{ m/s} \]

\[ \text{KE} = \text{Kinetic Energy of mass m} = \frac{1}{2}mv^2 \]

\[ U_m = \text{Strain Energy of the prismatic member} = \frac{1}{2}\frac{P_m}{\chi_m} \]
\[ x_m = \text{Deflection of the outer fiber of the prismatic member} \]
\[ P_m = \text{Equivalent Static Load corresponding to the deflection } x_m \]

For a prismatic member constrained at both ends loaded in the center,

\[ x_m = \frac{PL^3}{192EI} \]

substituting \( x_m \) into \( U_m \),

\[ U_m = \frac{1}{2} \frac{P_m^2 L^3}{192EI} \]

Equating the strain energy of the member to the kinetic energy of the block prior to impact yields,

\[ P_m = \sqrt{\frac{192IEmv^2}{L^3}} \]

The corresponding maximum stress is,

\[ \sigma = \frac{3P_mLc}{8I} \]

Substituting \( P_m \),

\[ \sigma = 3 \sqrt{\frac{3Emv^2}{L}} = 2538.8 \text{ N/m}^2 = .368 \text{ lb/in}^2 \]

\[ n = \frac{9 \times 10^3 \text{ psi}}{.368 \text{ psi}} = 24.5 \times 10^3 \]
Support Shelf

The aluminum shelf support was examined for the 6g downward loading as a point load in the center of the plate. Supported along two sides with aluminum angle, the shelf contains four 1/4-20 flathead bolts per side. (Figure 12)

![Figure 12: FBD for 6g load on shelf support (aluminum)](image)

The downward loading will be the combined weight of all the “shelf components” (see component weight breakdown) experiencing a 6g load.

\[
F = 82.5 \text{ lb}(6g) = 495 \text{ lb}
\]

\[
M = \frac{495 \text{ lb}}{2}(13\text{ in}) = 3217.5 \text{ in} \cdot \text{lb}
\]

Shape Properties:
\[
A_1 = 3 \text{ in}(0.25 \text{ in}) = 0.75 \text{ in}^2
\]
\[
A_2 = 1.75 \text{ in}(0.25 \text{ in}) = 0.4375 \text{ in}^2
\]
\[
cg_1 = \frac{1.875\text{in}(0.75\text{in}^2) + 0.875\text{in}(0.4375\text{in}^2)}{0.75\text{in}^2 + 0.4375\text{in}^2} = 1.5066 \text{ in}^2
\]
\[
I_1 = \frac{3\text{in}(0.25\text{in})^3}{12} = 3.906 \times 10^4
\]
\[
I_2 = \frac{0.25\text{in}(1.75\text{in})^3}{12} = 0.1117 \text{ in}^4
\]
\[
I_t = 3.906 \times 10^4 \text{ in}^4 + 0.75\text{in}^2(0.3684 \text{ in})^2 + 0.1117 \text{ in}^4 + 0.4375 \text{ in}(0.6316 \text{ in})^2
\]
\[
= 0.3919 \text{ in}^4
\]

Shelf Composite:
\[
A_3 = 21 \text{ in}(0.25 \text{ in}) = 5.25 \text{ in}^2
\]
\[
I_3 = \frac{21\text{in}(0.25\text{in})^3}{12} = 27.34 \times 10^{-3} \text{ in}^4
\]
\[ c_{g2} = \frac{2.125in(5.25in^2) + 2(1.5066in(1.1875in^2))}{5.25in^2 + 2(1.1875in^2)} = 1.932\text{ in} \]

\[ I_3 = 2(0.3919in^4 + 1.1875in^2(0.4254in)^2) + 27.34 \times 10^{-3}in^4 + 5.25in^2(0.193in)^2 \]
\[ = 1.436in^4 \]

\[ \sigma = \frac{Mc}{I} = \frac{3217.5in \cdot lb(1.932in)}{1.436in^4} = 4328.8\text{ psi} \]

\[ SF = \frac{35.0ksi}{4.329ksi} = 8.08 \]

**Power Supply Bracket and Servo Motor analysis**

The adjustable DC power supply that will power the disk servo motor will be mounted under the aluminum shelf that the main disk is mounted to. It will be hung from the shelf via two 9/16" thick 6061 T6 aluminum brackets. Each bracket contains two 1/4-20 grade 8 bolts.

Given a weight of 18 lbs for the power supply and specified load values the bolts that hold the power supply to the shelf will experience the following forces:

![Diagram](image)

In calculating the loads we will assume the load is uniformly distributed across all 4 bolts evenly.
Forward Load : \( 18 \text{ lbf (9g)} = 162 \text{ lbf / 4 bolts} = 40.5 \text{ lbf (per bolt)} \)

Aft Load : \( 18 \text{ lbf (3g)} = 54 \text{ lbf / 4 bolts} = 13.5 \text{ lbf (per bolt)} \)

Downward Load: \( 18 \text{ lbf (6g)} = 108 \text{ lbf / 4 bolts} = 27 \text{ lbf (per bolt)} \)

Upward Load : \( 18 \text{ lbf (2g)} = 36 \text{ lbf / 4 bolts} = 9 \text{ lbf (per bolt)} \)

Lateral Load : \( 18 \text{ lbf (2g)} = 36 \text{ lbf / 4 bolts} = 9 \text{ lbf (per bolt)} \)

Since all bolts in the brackets are loaded equally we will analyze only one bolt static failure using mean shear stress theory.

We consider the worst case scenarios

- **Worst case shear load:** \( F_s := 40.5 \text{ lbf} \)
- **Worst case tensile load:** \( F_t := 27.0 \text{ lbf} \)

The shear stress is

\[
\tau_{\text{max}} := \frac{F_s}{A_t}
\]

where \( A_t := 0.0318 \text{ in}^2 \) (Tensile stress area of 1/4-20 bolt)

\( S_y := 130 \cdot 10^3 \text{ psi} \) (yield strength of grade 8 bolt)

\( \tau_{\text{max}} = 1.274 \times 10^3 \text{ psi} \)

Our factor of safety against shear failure is

\[
S_{F,\text{shear}} := \frac{1}{2} \frac{S_y}{\tau_{\text{max}}}
\]

\( S_{F,\text{shear}} = 51.037 \)

We now consider tensile failure

\[
\sigma_{\text{max}} := \frac{F_t}{A_t}
\]

\( \sigma_{\text{max}} = 849.057 \text{ psi} \)

Our factor of safety against tensile failure is

\[
S_{F,\text{tensile}} := \frac{S_y}{\sigma_{\text{max}}}
\]

\( S_{F,\text{tensile}} = 153.111 \)

The safety factors for the power supply bracket bolts failing in either tension or she are much greater than 2.
We proceed in a similar fashion with the analysis of the servo motor mounting scheme. The DC servo motor that turns the main disk is mounted under the same shelf that the power supply is mounted. The servo motor is held in place by four 10-32 grade 8 bolts that screw through the shelf plate and into the motor body.

Given a weight of 8 lbs for the servo motor and specified load values the bolts that hold the servo motor to the shelf will experience the following forces:

<table>
<thead>
<tr>
<th>Description</th>
<th>Load Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Load</td>
<td>8 lbf (9g) = 72 lbf / 4 bolts = 18 lbf (per bolt)</td>
</tr>
<tr>
<td>Aft Load</td>
<td>8 lbf (3g) = 24 lbf / 4 bolts = 6 lbf (per bolt)</td>
</tr>
<tr>
<td>Downward Load</td>
<td>8 lbf (6g) = 48 lbf / 4 bolts = 12 lbf (per bolt)</td>
</tr>
<tr>
<td>Upward Load</td>
<td>8 lbf (2g) = 16 lbf / 4 bolts = 4 lbf (per bolt)</td>
</tr>
<tr>
<td>Lateral Load</td>
<td>8 lbf (2g) = 16 lbf / 4 bolts = 4 lbf (per bolt)</td>
</tr>
</tbody>
</table>

Since all bolts in the brackets are loaded equally we will analyze only one bolt static failure using mean shear stress theory.

**Bolt Strength for Components on Rotating Disk**

This analysis was done to verify the integrity of the bolts used to secure the 3 components inside the test apparatus to the rotating disk during a 9g forward configuration. Three masses contained in the apparatus are used for this analysis.

Assumptions: Maximum Shear Stress Analysis was used, The extreme case in which the acceleration due to rotation and the 9g acceleration vectors are in the same direction.

Analysis:

Motor/Drums Assembly

\[
\begin{align*}
  m &= \text{Mass of Motor/Drums Assembly} = 9.078 \text{ kg} \\
  r &= \text{Radius to Center of Gravity} = .0302 \text{ m} \\
  \omega &= \text{rpm}_{\text{max}} = 53.5 \text{rpm} = 5.6025 \frac{\text{rad}}{\text{s}} \\
  a_\omega &= r \omega^2 = .9487 \frac{m}{s^2} \\
  9g &= 88.29 \frac{m}{s^2} \\
  a_{\text{total}} &= 89.24 \frac{m}{s^2} \\
  F &= ma_{\text{total}} = 810.12 \text{N}
\end{align*}
\]
For a bolt group of 8, \( \frac{1}{4} \) in #5 SAE bolts, yield strength \( S_y = 92 \) kpsi,

\[
\tau_{all} = .50S_y = 46\text{ksi}
\]

\[
A_b = \pi d^2 / 4 = 3.167 \times 10^{-4} m^2
\]

\[
A_{total} = 2.534 \times 10^{-4} m^2
\]

\[
\tau = \frac{F}{A_{total}} = 3.2 \times 10^6 \frac{N}{m^2} = 464 \frac{lb}{in^2}
\]

\[
n = \frac{46\text{ksi}}{464\text{ksi}} = 99.1
\]

Camera/Mounting Bracket

\[
m = \text{Camera/Mounting Bracket} = .5 \text{ kg}
\]

\[
r = .2215 \text{ m}
\]

\[
\omega = \text{rpm}_{\text{max}} = 53.5 \text{rpm} = 5.6025 \frac{\text{rad}}{s}
\]

\[
a_\omega = r\omega^2 = 6.95 \frac{m}{s^2}
\]

\[
9g = 88.29 \frac{m}{s^2}
\]

\[
a_{total} = 95.24 \frac{m}{s^2}
\]

\[
F = ma_{total} = 47.62N
\]

For a bolt group of 2, \( \frac{1}{4} \) in #5 SAE bolts, yield strength \( S_y = 92 \) kpsi,

\[
\tau_{all} = .50S_y = 46\text{ksi}
\]

\[
A_b = \pi d^2 / 4 = 3.167 \times 10^{-4} m^2
\]

\[
A_{total} = 6.3334 \times 10^{-5} m^2
\]

\[
\tau = \frac{F}{A_{total}} = .75 \times 10^6 \frac{N}{m^2} = 109 \frac{lb}{in^2}
\]
\[ n = \frac{46 \text{kpsi}}{0.109 \text{psi}} = 422 \]

Counter Balance

\[ m = \text{Counter Balance} = 1.33 \text{ kg} \]
\[ r = 0.18415 \text{ m} \]
\[ \omega = \text{rpm}_{\text{max}} = 53.5 \text{rpm} = 5.6025 \frac{\text{rad}}{s} \]
\[ a_\omega = r \omega^2 = 5.78 \frac{m}{s^2} \]
\[ 9g = 88.29 \frac{m}{s^2} \]
\[ a_{\text{total}} = 94.05 \frac{m}{s^2} \]
\[ F = ma_{\text{total}} = 125.02N \]

For a bolt group of 2, \( \frac{1}{4} \) in \#5 SAE bolts, yield strength \( S_y = 92 \text{ kpsi} \),

\[ \tau_{\text{all}} = 0.50S_y = 46 \text{kpsi} \]
\[ A_b = \pi d^2 / 4 = 3.167 \times 10^{-4} \text{ m}^2 \]
\[ A_{\text{total}} = 6.3334 \times 10^{-5} \text{ m}^2 \]
\[ \tau = \frac{F}{A_{\text{total}}} = 2.0 \times 10^6 \frac{N}{m^2} = 286.4 \frac{lb}{in^2} \]
\[ n = \frac{46 \text{kpsi}}{0.2864 \text{kpsi}} = 160 \]
Large Plate Analysis

The large plate (6061-T6 aluminum) is analyzed for both the 9g forward loading, Figure 13, and the 6g downward loading, Figure 14, to ensure no failure will occur.

Figure 13: FBD for 9g loading on the Large disk (aluminum)

A balance weight is used on the aluminum disk so that the sum of all moments about point A, caused by the 6g downward forces, are zero. $m_1$: The total mass of components attached to the top side of the aluminum disk (motor 2, drum assembly, balance mass, video camera, camera bracket and back lighting).

$m_1 = .825 \text{ lb}\cdot\text{s}^2/\text{ft}$
$R_1 = m_1(9g) = .825 \text{ lb}\cdot\text{s}^2/\text{ft} \cdot (9(32.2 \text{ ft/s}^2)) = 244.17 \text{ lb}$
$V = \pi r^2 t = \pi (0.9167 \text{ ft})^2 (0.02083 \text{ in}) = 0.0550 \text{ ft}^3$
$\rho = 5.366 \text{ lb}\cdot\text{s}^2/\text{ft}^4$
$m_2 = \rho V = 5.366 \text{ lb}\cdot\text{s}^2/\text{ft}^4 \cdot 0.0550 \text{ ft}^3 = 0.2951 \text{ lb}\cdot\text{s}^2/\text{ft}$
$F_B = m_29g = 0.2951 \text{ lb}\cdot\text{s}^2/\text{ft} \cdot (9(32.2 \text{ ft/s}^2)) = 85.52 \text{ lb}$
$M_1 = R_1 (0.25 \text{ in}) + F_2 (0.125 \text{ in})$
$= 244.17\text{lb} (0.02083 \text{ ft}) + 85.52 \text{lb} (0.01042 \text{ ft}) = 5.98 \text{ft\cdot lb}$
$R_2 = R_1 + F_B = 244.17 \text{ lb} + 85.52 \text{ lb} = 229.69 \text{ lb}$

The large disk is mounted to a 1/2 in. diameter 1020 cold rolled steel jack shaft to support the calculated loading, see Jack Shaft Analysis following.

Figure 14: FBD for 6g loading on the large disk (aluminum)

$I = \frac{bh^3}{12} = \frac{22"(0.25")^3}{12} = 28.65 \times 10^{-3} \text{ in}^4 = 1.381 \times 10^{-6} \text{ ft}^4$
$6g = 6(32.2 \text{ ft/s}^2) = 193.2 \text{ ft/s}^2$
$\rho = 5.432 \text{ lb}\cdot\text{s}^2/\text{ft}^4$
$m_2 = \pi r^2 \rho = \pi (11.0 \text{ in})^2 (0.25 \text{ in}) 5.432 \text{ lb}\cdot\text{s}^2/\text{ft}^4 = 0.2951 \text{ lb}\cdot\text{s}^2/\text{ft}$
\[ \bar{y} = \frac{4r}{3\pi} = \frac{4(1\text{ in})}{3\pi} = 4.669 \text{ in} = 0.3892 \text{ ft} \]

\[ F_1 = m_1g = 0.842 \text{ lb-s}^2/\text{ft lb}(193.2 \text{ ft/s}^2) = 162.8 \text{ lb} \]

\[ F_2 = m_2g = 0.2951 \text{ lb-s}^2/\text{ft lb}(193.2 \text{ ft/s}^2) = 57.01 \text{ lb} \]

\[ R = F_1 + F_2 = 162.8 \text{ lb} + 57.01 \text{ lb} = 219.81 \text{ lb} \]

\[ M_A = 5.98 \text{ ft-lb} + 0.388 \text{ ft} (57.01 \text{ lb}) + 0.604 \text{ ft} (162.8 \text{ lb}) = 126.43 \text{ ft-lb} \]

\[ \sigma = \frac{M_A c}{I} = \frac{126.43 \text{ ft} \cdot \text{lb} \cdot (0.0104 \text{ ft})}{1.381 \times 10^{-6} \text{ ft}^4} = 1.278 \text{ ksf} = 6.62 \text{ ksi} \]

\[ SF = \frac{35 \text{ksi}}{6.62 \text{ksi}} = 5.29 \]

**Jack Shaft Analysis**

![Figure 15: Schematic of jack shaft housing](image)
Figure 16: FBD for 9g loading on the Jack Shaft (1020 cold rolled steel)

\[ R_2 = 229.69 \text{ lb} \]
\[ M_1 = 5.98 \text{ ft*lb} \]
\[ \sum M_A = R_2 (1.0") + M_1 - R_4 (2.0") = 0 \]
\[ R_4 = \frac{229.69 \text{ lb}(0.0833 \text{ ft}) + 5.98 \text{ ft*lb}}{0.1667 \text{ ft}} = 150.65 \text{ lb} \]
\[ \sum F_x = R_3 - R_2 - R_4 = 0 \]
\[ R_3 = 229.69 \text{ lb} + 150.65 \text{ lb} = 380.34 \text{ lb} \]

Stress at section a-a:
\[ I = \frac{\pi d^4}{64} = \frac{\pi (0.5 \text{ in})^4}{64} = 3.068 \times 10^{-3} \text{ in}^4 \]
\[ \sigma = \frac{Mc}{I} = \frac{71.76 \text{ in*lb}(0.25 \text{ in})}{3.068 \times 10^{-3} \text{ in}^4} = 24.55 \text{ ksi} \]
\[ SF = \frac{57 \text{ ksi}}{24.55 \text{ ksi}} = 2.32 \]

The individual and overall component weights and sizes are listed in Table 2 and Table 3 includes all fasteners types used in this experiment.
### Component Weight Breakdown

<table>
<thead>
<tr>
<th>Component Weight Breakdown</th>
<th>Weight (lb)</th>
<th>Description</th>
</tr>
</thead>
</table>

#### Frame Components

<table>
<thead>
<tr>
<th>Frame Components</th>
<th>Weight (lb)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>29.45</td>
<td>80/20</td>
</tr>
<tr>
<td>Plastic Shielding</td>
<td>18.7</td>
<td>Acrylic</td>
</tr>
<tr>
<td>Instrument Panel</td>
<td>2.4</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Mini-Robot Acrylic Container &amp; Robot</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

#### Shelf Components

<table>
<thead>
<tr>
<th>Shelf Components</th>
<th>Weight (lb)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Shelf</td>
<td>18.21</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Motor 1</td>
<td>8</td>
<td>Kollmorgen U12M4</td>
</tr>
<tr>
<td>Controller1</td>
<td>18</td>
<td>Kepco JQE15-6M</td>
</tr>
<tr>
<td>Big Aluminum Disk</td>
<td>9.5</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Hub Assembly for Large Disk</td>
<td>0.46</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Jack Shaft Assembly</td>
<td>1.2</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Motor 2</td>
<td>13</td>
<td>Dayton 4Z138</td>
</tr>
<tr>
<td>Drum Assembly</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Balance Mass</td>
<td>2.94</td>
<td></td>
</tr>
<tr>
<td>Video Camera</td>
<td>1</td>
<td>Cannon Elura 50</td>
</tr>
<tr>
<td>Camera Bracket</td>
<td>0.09</td>
<td>6061 T6</td>
</tr>
<tr>
<td>Back light</td>
<td>0.1</td>
<td>Luxeon Star</td>
</tr>
</tbody>
</table>

#### Top Components

<table>
<thead>
<tr>
<th>Top Components</th>
<th>Weight (lb)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini DV Player</td>
<td>2.14</td>
<td></td>
</tr>
<tr>
<td>Controller 2</td>
<td>0.33</td>
<td>Dayton 6A191</td>
</tr>
<tr>
<td>Tachometer</td>
<td>0.82</td>
<td>Dart DM4004</td>
</tr>
<tr>
<td>12 VDC Battery</td>
<td>3.0</td>
<td>Panasonic 12V7.2P1</td>
</tr>
<tr>
<td>2 handles</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Surge Protector</td>
<td>0.5</td>
<td>Eclipse Pro</td>
</tr>
<tr>
<td>Lego Controllers/Battery Pack</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Total 143.97

Table 2: Individual and overall weights and sizes
<table>
<thead>
<tr>
<th>Fasteners Breakdown</th>
<th>Fastener Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame/Handle T-nuts and Bolts</td>
<td>5/16&quot;-18 Button head Bolts and T-nuts</td>
</tr>
<tr>
<td>Top Shelf</td>
<td>5/16&quot;-18 Button head Bolts and T-nuts</td>
</tr>
<tr>
<td>Mini-Robot Acrylic Container</td>
<td>5/16&quot;-18 Button head Bolts and T-nuts</td>
</tr>
<tr>
<td>Drum Geared Motor</td>
<td>¼ in #5 SAE bolts</td>
</tr>
<tr>
<td>Disk Servo Motor</td>
<td>10-32 Allen head cap screws</td>
</tr>
<tr>
<td>Drum &amp; Camera Assemblies</td>
<td>¼ in #5 SAE bolts (various lengths)</td>
</tr>
<tr>
<td>Disk Counterweight</td>
<td>¼ in #5 SAE bolts</td>
</tr>
<tr>
<td>JackShaft &amp; Large Disk</td>
<td>5/16&quot; CS Screws</td>
</tr>
<tr>
<td>Frame Straps</td>
<td>1.5’ Wide Cargo Strap</td>
</tr>
<tr>
<td>Tachometer/Controllers</td>
<td>832 Bolts</td>
</tr>
<tr>
<td>Power Supply</td>
<td>¼ in #5 SAE bolts</td>
</tr>
<tr>
<td>Power Strip</td>
<td>5/16&quot;-18 Button head Bolts and T-nuts</td>
</tr>
<tr>
<td>Drum Sub-Assy</td>
<td>MS20470AD4 Rivets &amp; 10-32 CS Screws</td>
</tr>
<tr>
<td>DV CAM</td>
<td>DV Cam Mount</td>
</tr>
</tbody>
</table>

Table 3: Fasteners
**Electrical Analysis**

**Schematic:**
The experiment will use one main circuit. A single 115VAC 20Amp outlet on the aircraft will power this main circuit.

The main circuit will power three devices (tachometer, video camera and video viewer) and two DC power supplies, which will then in turn power 2 DC motors.

Beyond the main circuit we will use one 12VDC 8Ah battery to backlight LED array.

Load tables have been done for the main circuit (*Power Source #1*) and for each DC power supply (*Power Source #2 and #3*) also a load table has been done for the battery (*Battery Source*)
Since the frame and all components are metal and not a single part is insulated, the grounding method is to connect a ground wire to the frame of the apparatus.

A master kill switch is available on the power surge that will be located on the inside of the apparatus and will be easily accessible.

Controllers and power surge strip have a current limiting device.

<table>
<thead>
<tr>
<th>Wire</th>
<th>Description</th>
<th>Size</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire A</td>
<td>Power strip</td>
<td>12 gauge</td>
<td>6.2 Amps</td>
</tr>
<tr>
<td>Wire B</td>
<td>DC Power Supply</td>
<td>14 gauge</td>
<td>2.1 Amps</td>
</tr>
<tr>
<td>Wire C</td>
<td>DC Power Supply</td>
<td>14 gauge</td>
<td>2.0 Amps</td>
</tr>
<tr>
<td>Wire D</td>
<td>Tachometer</td>
<td>22 gauge</td>
<td>0.3 Amps</td>
</tr>
<tr>
<td>Wire E</td>
<td>Video Camera</td>
<td>18 gauge</td>
<td>0.2 Amps</td>
</tr>
<tr>
<td>Wire F</td>
<td>Video Viewer (miniDV)</td>
<td>18 gauge</td>
<td>1.6 Amps</td>
</tr>
<tr>
<td>Wire G</td>
<td>Kollmorgen DC motor</td>
<td>12 gauge</td>
<td>4.5 Amps</td>
</tr>
<tr>
<td>Wire H</td>
<td>Dayton DC motor</td>
<td>14 gauge</td>
<td>1.5 Amps</td>
</tr>
<tr>
<td>Wire I</td>
<td>LED backlight</td>
<td>18 gauge</td>
<td>725 milliamps</td>
</tr>
</tbody>
</table>

Load Tables:

<table>
<thead>
<tr>
<th>Name: Power Source #1 (power strip)</th>
<th>Power Source #2</th>
<th>Power Source #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage: 115 VAC 60 Hz</td>
<td>Power Source #2</td>
<td>Power Source #3</td>
</tr>
<tr>
<td>Wire gauge : 12</td>
<td>Voltage: 20 VDC</td>
<td>Voltage: 90 VDC</td>
</tr>
<tr>
<td>Maximum Current : 20 Amps</td>
<td>Wire gauge : 14</td>
<td>Wire gauge : 14</td>
</tr>
<tr>
<td>Total Current Draw : 6.2 Amps</td>
<td>Maximum Current : Motor A : 6 Amps</td>
<td>Total Current Draw : 4.5 Amps</td>
</tr>
<tr>
<td></td>
<td>Voltage: 12 VDC</td>
<td>Voltage: 90 VDC</td>
</tr>
<tr>
<td></td>
<td>Wire gauge : 18</td>
<td>Wire gauge : 18</td>
</tr>
<tr>
<td></td>
<td>Maximum Current : Motor B : 2 Amps</td>
<td>Total Current Draw : 1.5 Amps</td>
</tr>
<tr>
<td></td>
<td>Voltage: 12 VDC</td>
<td>Voltage: 12 VDC</td>
</tr>
<tr>
<td></td>
<td>Wire gauge : 18</td>
<td>Wire gauge : 18</td>
</tr>
<tr>
<td></td>
<td>Maximum Current : Battery Source : 4.5 Amps</td>
<td>Total Current Draw : 725 mA</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Power Source #1</td>
<td>Power Surge strip w/ kill switch</td>
<td></td>
</tr>
<tr>
<td>Power Source #2</td>
<td>Kepco adjustable DC power supply (model JQE15-6M)</td>
<td></td>
</tr>
<tr>
<td>Power Source #3</td>
<td>Dayton DC speed controller (model 6A191)</td>
<td></td>
</tr>
<tr>
<td>Tachometer</td>
<td>Dart Controls (model DM4004)</td>
<td></td>
</tr>
<tr>
<td>Video Camera</td>
<td>Cannon Elura 50 digital video camera</td>
<td></td>
</tr>
<tr>
<td>Video Viewer</td>
<td>Mini DV player and viewer</td>
<td></td>
</tr>
<tr>
<td>Motor A</td>
<td>Kollmorgen DC servo disk motor (model U12M4)</td>
<td></td>
</tr>
<tr>
<td>Motor B</td>
<td>Dayton 90VDC right angle gear motor (model 4Z138)</td>
<td></td>
</tr>
<tr>
<td>Battery Source</td>
<td>ELK-12V sealed lead acid battery</td>
<td></td>
</tr>
<tr>
<td>LED’s</td>
<td>4- Luxeon Star 1W White LED’s</td>
<td></td>
</tr>
</tbody>
</table>

**Overall System Electrical Schematic**
Stored Energy

No Devices are used to store or build large electrical charges in experiment.

Electrical Kill Switch

Since this experiment only uses one input from the aircraft’s panel, the kill switch will be the on/off button on the power surge. The power surge that is used for this experiment will have a built-in current limiting device also. The kill switch will have a LED that is visible for the flight crew in case of emergency. This kill switch will be located at inside of the apparatus.

Loss of Electrical Power

The Loss of electrical power will not cause an unsafe configuration in the experiment nor will it affect the procedure or data collection. The only minor set back is to wait for the liquid to drain from the wall of the tube before the same tube can be used again.

Pressure Vessel Certification

There is no pressure vessel used in this experiment. All fluids are at ambient pressure in flight and on the ground.

Laser Certification

There are no lasers of any kind used in this experiment.

Parabola Details and Crew Assistance

This experiment does not require any crew assistance during the flight. Additionally, the experiment does not require any partial g levels nor extra time between parabola sets.

Free Float Requirements

This experiment will not be free floating and will be securely attached to the floor of the airplane.
Institutional Review Board (IRB)

No Institutional Review board will be required for this experiment.

Hazard Analysis

Hazard Number One:
Title: Silicone Oil Leak
Hazard Description:
A total of less than six ounces of silicone oil is injected inside sealed Tygon tubing. Although the one centistoke silicone oil is a non-hazardous material, the possibility of exposure to electrical components and a leak into the main cabin is considered.
Hazard Cause:
The only causes for a leak would result from improper sealing of the tube or an unidentified puncture of the tube wall.
Hazard Control:
A Loctite Class VI adhesive (shear strength of 1900 psi) is used in sealing the open edges of all tubing prior to being glued to the drive belt. The belt provides an additional 9400 psi tensile strength for the four tubes. Finally, all tubing is further contained within the apparatus acrylic enclosure.

Hazard Number Two:
Title: Rotating Components
Hazard Description:
The experiment includes a large rotating disk and two rotating drums. The large disk is a 22 inch diameter, 6061-T6 aluminum plate rotating at rates less than 55 rpm. The two 4 inch drums are mounted on the large rotating disk and will rotate at rates less than 37 rpm. There are several hazards for these rotating components including:
1. Entanglement of electrical wires
2. Clothing, hands, etc. snagged in rotating components.
3. Shaft structural failure
4. Rotating components becoming dislodged
Hazard Cause:
1. Wiring not protected from rotating components
2. High torque/rotational speed from motors allowing for difficulty in stopping operation
3. Under-designed shafts for specified weights and rotational rates
4. Poor design of securing devices
Hazard Control:
1. All electric wiring passes through conduit mounted from the large disk to the top of the frame through a rotary contact. Wiring is numbered and bundled as described in the Electronic Analysis section of this TDEP. This configuration ensures that there is no entanglement.
2. The rotating components of this apparatus are enclosed in a frame assembly with ¼ inch plexiglass panels. As stated in the Electronic Analysis there is a kill switch that will be turned off when access to the internal rotating components is desired.
3. The analysis of the Jack Shaft provided dimensions sufficient to ensure integrity and a reasonable factor of safety.
4. The analysis of the Bolt Strength for Components on the Rotating Disk leads to acceptable factors of safety. The analysis of the Impact of Acrylic Panel due to Rotating Components leads to acceptable factors of safety should components become dislodged inside the test apparatus.

**Hazard Number Three:**
**Title:** Sharp Corners on the Outer Frame
**Hazard Description:**
The outer frame is the only exposed component of this experiment to any of the flight members. The four corners of the rectangular frame contain the only sharp components exposed.
**Hazard Cause:**
An unexpected collision to the outer frame of the experiment remains the single potential hazard.
**Hazard Control:**
All corners will be padded with foam and attached with RGO supplied duct tape.

**Hazard Number Four:**
**Title:** Structural Failure
**Hazard Description:**
Due to structural failure of either internal components or the outer frame, the possibility of pieces separating from the structure must be considered.
**Hazard Cause:**
Unusually high gravity loads during the KC-135 flight or a collision of either flight crew or free-floating experiments.
**Hazard Control:**
As stated in the structural analysis segment of the TEDP, all individual components and the outer frame have been designed to fit the loading criteria specified by the “Experiment Design Requirements and Guidelines.” Additionally, the experiment is enclosed with ¼-inch Plexiglas to remove any possibility of components leaving the frame. All stress analysis on the Plexiglas and frame is also included in the structural analysis segment of the TEDP. Two components will rest outside the enclosed frame including a 6x5x2 cubic inch digital display and lego controller. These will be mounted with Velcro in flight and stowed during take off and landings.
HAZARD SOURCE CHECKLIST

| N/A | Flammable/combustible material, fluid (liquid, vapor, or gas) |
| N/A | Toxic/noxious/corrosive/hot/cold material, fluid (liquid, vapor, or gas) |
| N/A | High pressure system (static or dynamic) |
| N/A | Evacuated container (implosion) |
| N/A | Frangible material |
| N/A | Stress corrosion susceptible material |
| N/A | Inadequate structural design (i.e., low safety factor) |
| N/A | High intensity light source (including laser) |
| N/A | Ionizing/electromagnetic radiation |
| Yes | Rotating device |
| N/A | Extendible/deployable/articulating experiment element (collision) |
| N/A | Stowage restraint failure |
| N/A | Stored energy device (i.e., mechanical spring under compression) |
| N/A | Vacuum vent failure (i.e., loss of pressure/atmosphere) |
| N/A | Heat transfer (habitable area over-temperature) |
| N/A | Over-temperature explosive rupture (including electrical battery) |
| N/A | High/Low touch temperature |
| N/A | Hardware cooling/heating loss (i.e., loss of thermal control) |
| N/A | Pyrotechnic/explosive device |
| N/A | Propulsion system (pressurized gas or liquid/solid propellant) |
| N/A | High acoustic noise level |
| N/A | Toxic off-gassing material |
| N/A | Mercury/mercury compound |
| N/A | Other JSC 11123, Section 3.8 hazardous material |
| N/A | Organic/microbiological (pathogenic) contamination source |
| N/A | Sharp corner/edge/protrusion/protruberance |
| N/A | Flammable/combustible material, fluid ignition source (i.e., short circuit; |
| N/A | High voltage (electrical shock) |
| N/A | High static electrical discharge producer |
| N/A | Software error or compute fault |
| N/A | Carcinogenic material |
| N/A | Other: |

Table 5: Hazard source checklist

Tool Requirements

Minimal tools will be needed for this experiment since the entire apparatus will be previously assembled before arrival at Ellington Field. Tools brought to Ellington Field will include one contained Allen wrench set labeled with the team name and stored with the device at all times. Tools will not be required on the aircraft.
Photo Requirements

A still photographer, videographer, or S-band downlink will not be requested during this experiment. All camera and video image collection will be supplied by the flight crew and is documented in the Equipment Description section of the TEDP. One camera pole supplied by the RGO is requested per flight for mounting a video camera documenting fluctuations in the accelerometer.

Aircraft Loading

There are two easily accessible lifting handles that require approximately 70 pounds per handle to manipulate the apparatus into position aboard the plane. The full experiment weight of 144 pounds covers a base plate area of 4.3 square feet with a resulting load of 33.49 pounds per square foot on the floor of the aircraft. Once in position, the experiment will be strapped to the floor using the provided securing straps and readied for flight.

Ground Support Requirements

The experiment will require a standard 115 VAC and 15 amp power supply for minimal ground testing. There are no toxic/corrosive chemicals or pressurized gases neither used in this experiment nor are any special requests needed for ground support.

Hazardous Material

There are no hazardous materials used in this experiment.

Material Safety Data Sheet

Material Safety Data Sheets are included in the Appendix for the silicone oil used in this experiment.

Experiment Procedures Documentation

Experiment Shipment to Ellington Field

All equipment will be flown to Ellington Field with the flight crew. Due to the compact size and weight, all the components of the experiment, including the outer frame, will be packaged and checked as baggage with the flight crew. Any necessary assembly operations will be performed on the day the team arrives in Houston (Wednesday, March 3) and the entire experiment will be transported by the flight crew to Ellington Field the following day. Following its arrival, the experiment will require minimal indoor storage facilities. The experiment is completely self-contained and will require no more than a 30x30x20 inch, clean, dry storage location.
**Ground Operations**

The entire apparatus will be previously assembled and unpackaged before arrival at Ellington Field. The only necessary additions to the experiment will include attaching foam with the RGO supplied duct tape to all sharp edges and corners of the outer frame. The experiment will not require any specialized ground facilities or equipment. The only additional ground operations will include brief testing of the self-contained experiment.

**Loading**

The entire experiment can be lifted onto KC-135 and positioned with the attached handles. The experiment will be strapped to the floor of the aircraft with a RGO supplied straps. It is desirable to place the experiment near the center of gravity of the aircraft.

**Pre-Flight**

During the pre-flight, the flight crew will check that all parts of the apparatus are installed and working properly. A brief test run may be required just to double check condition of the experiment and data acquisition system. This testing will only require a 115 AC power supply for a short duration of approximately five minutes.

**Take-off/Landing**

The only necessary procedures for take-off and landing will include the stowage of two data collection devices that will be attached to the outer frame during experimentation. These small devices (largest component volume less than one quarter of a square foot) will be fastened with Velcro once removed from stowage.

**In-Flight**

During the flight, one flight crew member will start the disk rotating before the aircraft hits reduced gravity. Once the aircraft enters reduced gravity, the disk velocity is slowed, the drum assembly is to be started and data acquisition will commence. The disk and drum assembly speed requirements will be varied per selected tube radius at different parabolas.

In case of errors, the same radius could be tested again depending on the condition of the previously tested tube. Approximately 30-40 parabolas should be used for experiments. After the last parabola, the apparatus will be turned off.

In case of emergency, the apparatus can be turned off using the “kill switch” located on the power surge panel inside the rig of the apparatus.

**Post-Flight**

After the aircraft lands, the crew needs to unplug the power cord from the aircraft’s panel and secure the tape and any other valuable data. The crew can unplug and uninstall the equipment of the apparatus rig, after flight crew is done.
Off-Loading

All equipments and the entire rig will be unloaded off the aircraft with the attached handles and stored in a clean, dry area. The entire experiment and all components will be removed from Ellington Field with the flight crew on the final flight day. (Friday, March 13) The crew will again transport all components on the return flight leaving Houston.
Bibliography


NAME USED ON LABEL: POLYDIMETHYLSILOXANE - DMS-T01
CHEMICAL NAME: POLYDIMETHYLSILOXANE
SYNONYMS: OCTAMETHYLTRISILOXANE; MDM
CHEMICAL FAMILY: SILICONE
HMIS CODES  HEALTH: 1  FLAMMABILITY: 2  REACTIVITY: 0

INGREDIENTS

<table>
<thead>
<tr>
<th>IDENTITY</th>
<th>CAS NO.</th>
<th>% TLV</th>
<th>OSHA PEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCTAMETHYLTRISILOXANE</td>
<td>107-51-7</td>
<td>&gt;85</td>
<td>not established</td>
</tr>
<tr>
<td>DECAMETHYLTETRASILOXANE</td>
<td>141-62-8</td>
<td>&lt;15</td>
<td>not established</td>
</tr>
</tbody>
</table>

PHYSICAL DATA

Boiling Point: 152-3°C  Freezing Point: (-86°C)
Specific Gravity: 0.820  Vapor Pressure, 25°: 4mm
Vapor Density, air = 1: >1  Solubility in water: 34 parts per billion
% volatiles: 100  Evaporation rate: N/A
Molecular Weight: 236.53  Viscosity: 1.0 cSt
Appearance & Color: Clear, nearly odorless liquid
FIRE & EXPLOSION DATA

Flash Point, TCC: 29°C (85°F) Autoignition Temp.: 418°C (784°F)
Flammability Limits-  LEL: N/A    UEL: N/A

Extinguishing Media: Water spray, foam, carbon dioxide, dry chemical.
Special Fire Fighting Procedures: Avoid eye and skin contact. Do not breathe fumes or inhale vapors.
Unusual Fire and Explosion Hazards: Irritating fumes and organic acid vapors may develop when material is exposed to elevated temperatures or open flame. Liquid generates strong static charge when poured.

ENVIRONMENTAL INFORMATION

Spill response: May be hazardous to aquatic life if released to open waters. Cover spill with absorbent material. Transfer to a suitable container for disposal.

Recommended Disposal: May be incinerated. Alternately, absorb onto clay or vermiculite and dispose of absorbent material as solid waste. Follow all chemical pollution control regulations.

HEALTH HAZARD DATA

Eye Contact: Vapors may cause immediate or delayed severe eye irritation.

Skin contact: May produce irritation or contact dermatitis which may be delayed several hours. Prompt and thorough washing with soap and water will reduce or eliminate potential dermal effects.

Inhalation: Inhalation of vapors or particulates will irritate the respiratory tract. Overexposure may produce coughing, headache and nausea.

Oral Toxicity- rat, LD50: >5000mg/kg
Chronic Toxicity: There are no known chronic effects related to this compound.
SUGGESTED FIRST AID

EYES: In case of contact, immediately flush eyes with flowing water for at least 15 minutes. Get medical attention.
SKIN: Flush with water, then wash with soap and water.
INHALATION: Move exposed individual to fresh air. Call a physician.
INGESTION: Never give fluids or induce vomiting if patient is unconscious or having convulsions. Get medical attention.

REACTIVITY DATA

Stability: Stable in sealed containers in a cool place.
Conditions to avoid: Combustible; avoid contact with heat, sparks or open flame.
Incompatibility (materials to avoid): Avoid contact with peroxides, oxidizing agents.
Hazardous decomposition products: Organic Acid Vapors.

-2-(DMS-T01)

SPECIAL PROTECTION INFORMATION

Ventilation: Local exhaust is recommended. Mechanical is recommended.
Respiratory Protection: If exposure exceeds TLV air-supplied or combination organic vapor amine gas respirator.
Eye and Face Protection: Chemical worker’s goggles. Do not wear contact lenses.
Other Clothing and Equipment: Rubber, neoprene or nitrile gloves. An eyewash and emergency shower should be available. Launder clothing before reuse.
OTHER PRECAUTIONS

For research and industrial use only.

Storage and Handling: Store in sealed containers.

Containers require grounding during use.

TRANSPORTATION

DOT SHIPPING NAME: FLAMMABLE LIQUID, N.O.S.
(POLYDIMETHYLSILOXANE)
DOT HAZARD CLASS: 3
DOT LABELS: Flammable Liquid
DOT ID No: UN1993   PG: III

Prepared by safety and environmental affairs     ISSUE DATE DMS-T01:
7/1/98

SUPERSEDES: NONE

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