Test Equipment Data Package

2002 Reduced Gravity Student Flight Opportunities Program

Gr.A.I.N.S.
Granular Agglomeration In Non-gravitating Systems
Experiment 2002-035

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June 6, 2002

KC-135 Quick Reference Data Sheet

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Experiment Title: Gr.A.I.N.S.: Granular Agglomeration in Non-gravitating Systems

Flight Dates: July 23 and 24, 2002

Overall Assembly Weight (lbs.): 135

Assembly Dimensions (L x W x H): 24" x 24" x 30"

Equipment Orientation Requests:

Due to the potential need to remove our experiment from the aircraft between flights, we request that our experiment be placed near the door for easier removal and reloading.

Proposed Floor Mounting Strategy: Bolts/Studs.

Gas Cylinder Requests: None.

Overboard Vent Requests: None.

Power Requirement: No onboard power necessary

Free Float Experiment: No

Flyer Names for Each Proposed Flight Day:

Day 1: Justin Mitchell, Whitney Marshall and Shaun Schafer (journalist)
Day 2: Matthew Olson and Rebecca Ragar

Table of Contents

1. FLIGHT MANIFEST **5**

2. EXPERIMENT BACKGROUND **5**

3. EXPERIMENT DESCRIPTION **6**

4. EQUIPMENT DESCRIPTION **7**

4.1 EQUIPMENT LAYOUT 7
4.2 CARBON FIBER MAIN SUPPORT STRUCTURE 7
4.3 MECHANICAL SHAKER SYSTEM 9
4.4 SAPPHIRE BOX SET 10
4.5 OPTICAL SYSTEM 11
4.6 EXPERIMENT CONTROLLER 12
4.7 BATTERY POWER PACK 12
4.8 DOCUMENTATION EQUIPMENT 13

5. STRUCTURAL ANALYSIS **14**

5.1 BASE PLATE LOADING 14
5.2 FLOOR LOADING 16
5.3 CARBON STRUCTURE LOADING 16

6. ELECTRICAL ANALYSIS **18**

6.1 ELECTRICAL SCHEMATIC 18
6.2 LOAD TABLE 18
6.3 EMERGENCY SHUTDOWN PROCEDURES 19

7. PRESSURE VESSEL CERTIFICATION **19**

8. LASER CERTIFICATION **19**

9. PARABOLA DETAILS AND CREW ASSISTANCE **19**

10. FREE FLOAT REQUIREMENTS **19**

11. INSTITUTIONAL REVIEW BOARD (IRB) **19**

12. HAZARD ANALYSIS REPORT **20**

13. TOOL REQUIREMENTS **24**

14. PHOTO REQUIREMENTS **24**

15. AIRCRAFT LOADING **24**

16. GROUND SUPPORT REQUIREMENTS **25**

17. HAZARDOUS MATERIALS **25**

18. MATERIAL SAFETY DATA SHEETS **25**

19. PROCEDURES **25**
19.1 EQUIPMENT SHIPMENT TO ELLINGTON FIELD 25
19.2 GROUND OPERATIONS 25
19.3 LOADING 26
19.4 PRE-FLIGHT 26
19.5 TAKE-OFF/LANDING 26
19.6 IN-FLIGHT 26
19.7 POST-FLIGHT 26
19.8 OFF-LOADING 27
20. BIBLIOGRAPHY **28**

Index of Figures

FIGURE 1: Schematic diagram of the set of 8 boxes to be filled with balls. 6
FIGURE 2: Experiment Layout as Seen From Side 7
FIGURE 3: Front view of carbon fiber structure. 8
FIGURE 4: Side view of shaker assembly showing shaker and linkage to box slider. 9
FIGURE 5: Cross section through box set near one side of the box. 10
FIGURE 6: Schematic diagram of optical system alignment. 11
FIGURE 7: Side view of battery stack with cross-section of PVC battery containment. 13
FIGURE 8: Force loading through a cross-section along a body diagonal. 15
FIGURE 9: Force loading on carbon structure base attachment bolts 16
FIGURE 10: Electrical schematic for GrAINS experiment 18

Index of Tables

TABLE 1: Weights of experiment components 14
TABLE 2: Factors of safety for 10g loading 17
TABLE 3: Load Table for Battery Pack 18

1. Flight Manifest

Flyers for Day 1:	Justin Mitchell, Whitney Marshall, and Shaun Schafer (journalist)
Flyers for Day 2:	Matt Olson, Rebecca Ragar, and Shaun Schafer
Alternate Flyers:	Jeremy Cain

No flyers have flown on the KC-135 before.

2. Experiment Background

Recently, a great deal of effort both industrially and academically has focused on studying the interactions within and overall behavior of granular systems (Jaeger). Of particular interest have been studies of "gases" of macroscopic objects such as ball bearings, dust, soot, etc. Theoretical models have predicted (Grossman) and some experiments have shown (Maddox) that a gas of balls tends to cluster when the gas is undisturbed by external influences, such as gravity. The behavior of such clusters appears to be dependent on driving conditions, particle densities and coefficients of restitution of the balls. In 2D experiments the motions of individual balls have been analyzed; in 3D systems this has not yet been done. The only 3D experiment performed was on a set of fairly dense systems (Falcon). The density was high enough that correlation could not be made between collapse of the gas, particle energies, input energies, and effective gas pressure.

The 3D experiment mentioned above was performed on a free-floating gas of macroscopic balls. During the 200 seconds available during the sounding rocket's free-fall the experimenters were able to observe several regimes of collapsed and gas-like behavior. The experiment consisted of video taping three 1 cm^3 cubes containing 0.3-0.4 mm diameter bronze balls. It was limited by the time available for each set of driving parameters (5 to 15 seconds each) and by the video resolution. The experimenters were not able to observe balls with sufficient resolution to measure the velocity distribution function, nor would the optical system allow for detailed measurements of cluster size and dynamics. They were able to measure the average pressure impacting one wall for each box and determined that the measured pressure data agreed qualitatively with theoretical predictions.

The question of collapse has particular importance for a description of the dynamics of interstellar dust clouds and planetary ring systems (Jaeger). Measurements of asteroid densities have shown that objects less than about 1km^3 in volume have densities on the order of 1-1.5 g/cm^3 (Yeomans). At these densities, an object 100 meters in radius has an escape velocity of ~ 1 cm/s. With such small escape speeds these objects are not able to gravitationally accumulate mass and thus are not able to accrete dust and grow in size. Inelastic collapse, if shown to occur in dilute dusty systems, would provide an impetus for the formation of these moderately sized objects.

The reduced gravity environment aboard the KC-135 will enable use of a large variability in driving parameters and a longer duration test on the behavior of collapsed structures than has previously been examined. We will thus place much more stringent limits on the behavior of collapsed structures and push these results to include the low-density/low-speed distributions of interest for comparison with interstellar situations. This experiment will utilize an apparatus currently being constructed for the study of granular dynamics aboard the Space Shuttle. With minor modifications, it will fly as a NASA GAS payload.

3. Experiment Description

The GrAINS experiment focuses on studying the dynamics of a gas of macroscopic particles (ball bearings) in a driven system. The dynamics of this system begin with similar characteristics to that of ideal kinetic theory, but unlike ideal kinetic theory, our ball bearings will lose energy as they collide with one another due to a factor known as the coefficient of restitution. The coefficient of restitution is a fractional measure of the energy remaining after a given collision. A coefficient of 1 indicates perfectly elastic collisions and no energy loss while a coefficient less than 1 will cause a system to lose energy and eventually die out due to collisions. As was discussed in the experiment background, research indicates that clusters and other structural formations tend to develop as granular gases lose energy, although the exact system parameters that cause clustering are still unknown. Many of the experiments and models on this situation consider only direct impacts, ignoring glancing collisions, and fail to incorporate rotational effects and/or surface friction. Our experiment intends to take these additional factors into account when we analyze our results. With our experiment, we will obtain video and pressure sensor data to record the dynamics of various densities of ball bearings as they are driven at a series of set frequencies and amplitudes.

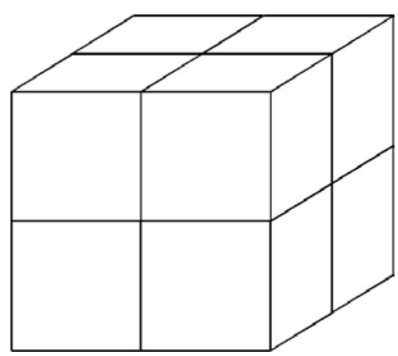

FIGURE 1: Schematic diagram of the set of 8 boxes to be filled with balls.

The experiment consists of a set of eight 1 inch^3 sapphire boxes arranged in a cube (see figure 1), seven of which contain varying numbers of 0.5 mm diameter brass balls. One box is empty for control purposes. In order to supply energy to the balls, the set of boxes will be shaken approximately sinusoidally along one body diagonal. This motion will be regulated using a computer-controlled shaker. Under zero-g conditions, this will cause the balls to be excited into a gas-like state. The microprocessor controlling our experiment will be programmed with an amplitude and frequency pair for each zero-g parabola. The energy input into the system will vary based on driving parameters. As a result we would expect the dynamics of each case to vary.

A set of three video camcorders will be used to monitor the three orthogonal sides of the set of boxes. These cameras have sufficient resolution, by means of zoom magnification and an additional achromatic lens, to allow tracking of individual balls. Direct measurement of the velocity probability distribution for the balls in each individual box will be achieved by computer analysis after the experiment returns to Tulsa.

Piezoelectric pressure sensors attached to one wall of each box will monitor the effective pressure exerted by the balls. Each of the sensors will be deformed slightly due to ball impacts. This deformation will result in a voltage being produced via the piezoelectric effect. The data from these sensors will be stored as voltage measurements in the audio channels of the video cameras. By detailed analysis of ball speeds and their correlation to pressure data, we will evaluate the experimental conditions under which the "gases" of balls in each box behave similarly to an ideal gas, as well as those conditions when clustering occurs.

4. EQUIPMENT DESCRIPTION

4.1 EQUIPMENT LAYOUT

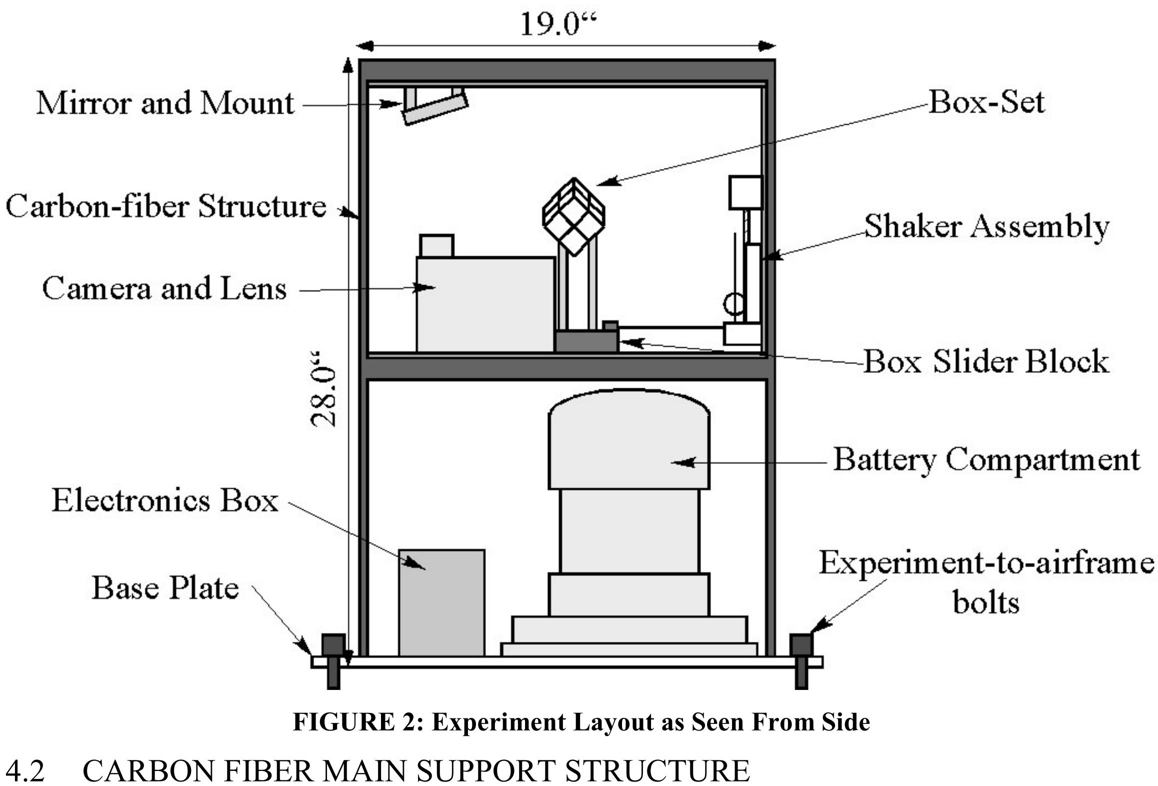

FIGURE 2: Experiment Layout as Seen From Side

4.2 CARBON FIBER MAIN SUPPORT STRUCTURE

The main structure consists of a hexagonal tube 19 inches corner to corner across the base and 28 inches tall and has a weight of 22 pounds as shown in figure 3. The bottom is open and there is a mid deck and top deck, both ~ 1 inch thick. On each deck, two of the sides are 'open' while the other four have an 'X' stiffener across the side opening. The 'open' sides are rotated by one wall section from the lower to the upper section to increase the stiffness of the finished structure.

The sides as shown in figure 3 are composed of Graphite/Epoxy (Gr/E) sheets cut and laminated to form open frames or frames with an 'X' through the center. The basic Gr/E sheet is composed of 5 fabric layers in a [0, +45, 0, +45, 0] lay-up to produced s finished bonded sheet with quasi-isotropic properties. These side panels are ~ 0.45 " thick and are composed of two 0.041" thick 5 layer Gr/E sheets separated by a 0.375" wide 0.041" thick stiffener sheet. Each side wall was prepared, glued and cured as a separate piece.

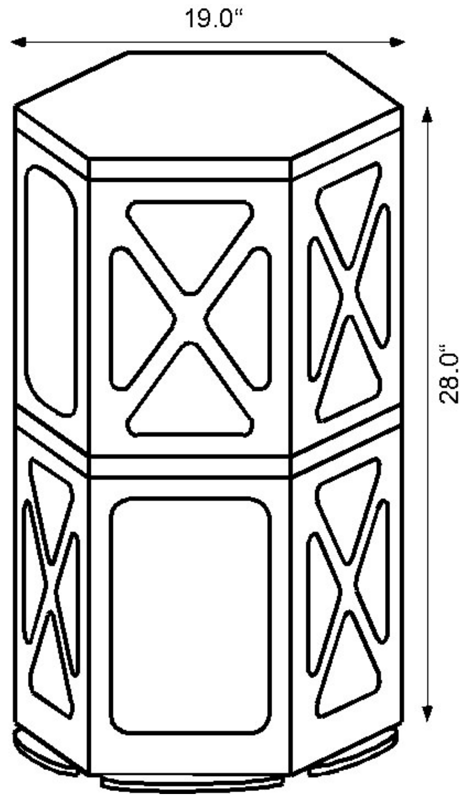

FIGURE 3: Front view of carbon fiber structure.

The two deck sections are composed of two Gr/E sheets separated by a 1.000" thick layer of KOREX honeycomb lattice. The KOREX-Gr/E were bonded using Cytol Film and then thermally cured. Six 10-32 screw inserts were placed into both faces of the mid deck, and in one side of the top deck to facilitate attachment of experimental equipment into the structure. After curing the decks were cut to their final hexagonal form.

The walls and decks were attached to corner posts of Gr/E pultruded 120º angle sections 28" long. All wall-corner joints were bonded using HYSOL 9394 epoxy, an aerospace qualified epoxy.

Aluminum stiffeners were potted in the bottom 120º corners and aluminum 90º angle brackets were potted into the bottom edge of the structure for mounting to a base plate. These Aluminum-Gr/E joints were made using HYSL 9394. For added security, the bottom 90º angle brackets are also attached using 3 rivets along each wall edge. The bottom 90º angle brackets have 10-32 thru clear holes to match a 19" diameter circle of 24 equally spaced holes.

The Gr/E-Gr/E lap joints have been tested and shown to have a maximum shear stress of 1010 psi. The Gr/E-Aluminum joints were tested and determined to have a maximum shear stress of 550 psi.

4.3 MECHANICAL SHAKER SYSTEM

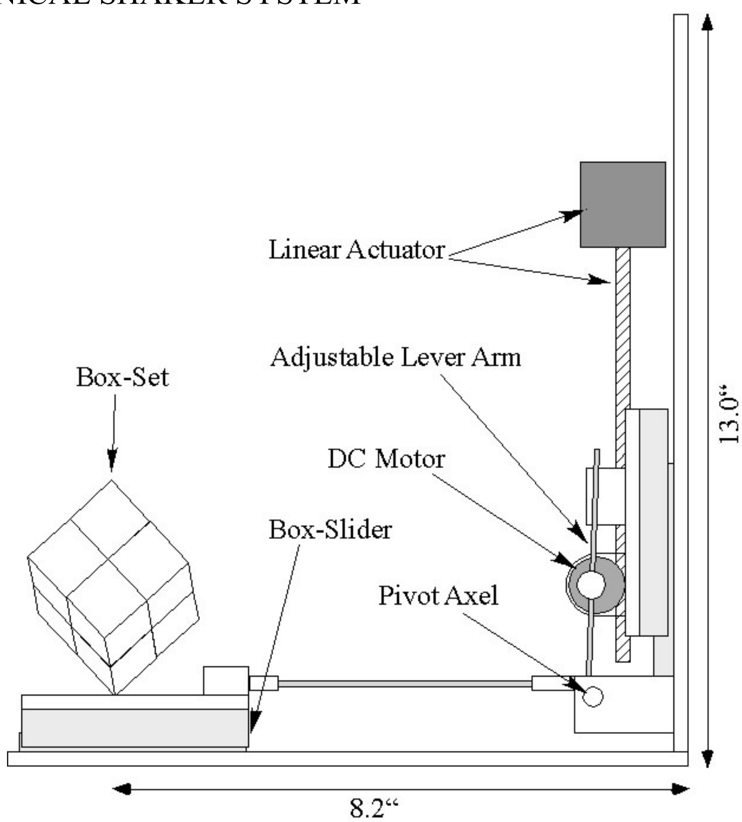

FIGURE 4: Side view of shaker assembly showing shaker and linkage to box slider.

The box set will be shaken using a computer controlled electromechanical system that allows for control of both the amplitude and frequency of shaking motion of the box set. A side view of this system is shown schematically in figure 4. The operation is two-fold; a DC motor attached to a crank provides oscillatory motion to one end of a steel shaft. This motor is placed on a sliding table whose position is controlled by a linear actuator. The actuator allows for modification of the length of a level arm attached to the DC motor. By changing the length of the lever arm we are able to adjust the resulting amplitude of oscillation of a second sliding table that carries the box set. The total weight of the shaker system is 5 pounds.

4.4 SAPPHIRE BOX SET

The experimental box set for this experiment is constructed from sapphire plates built into the shape of a set of cubes. The sapphire cubes are built outward from an aluminum support plate that divides the box set into halves. The aluminum support plate has 4 square depressions cut out of each side. Each depression contains four trenches cut for the sapphire walls. Two additional sapphire plates form the top of each cube. The total set is approximately two pounds.

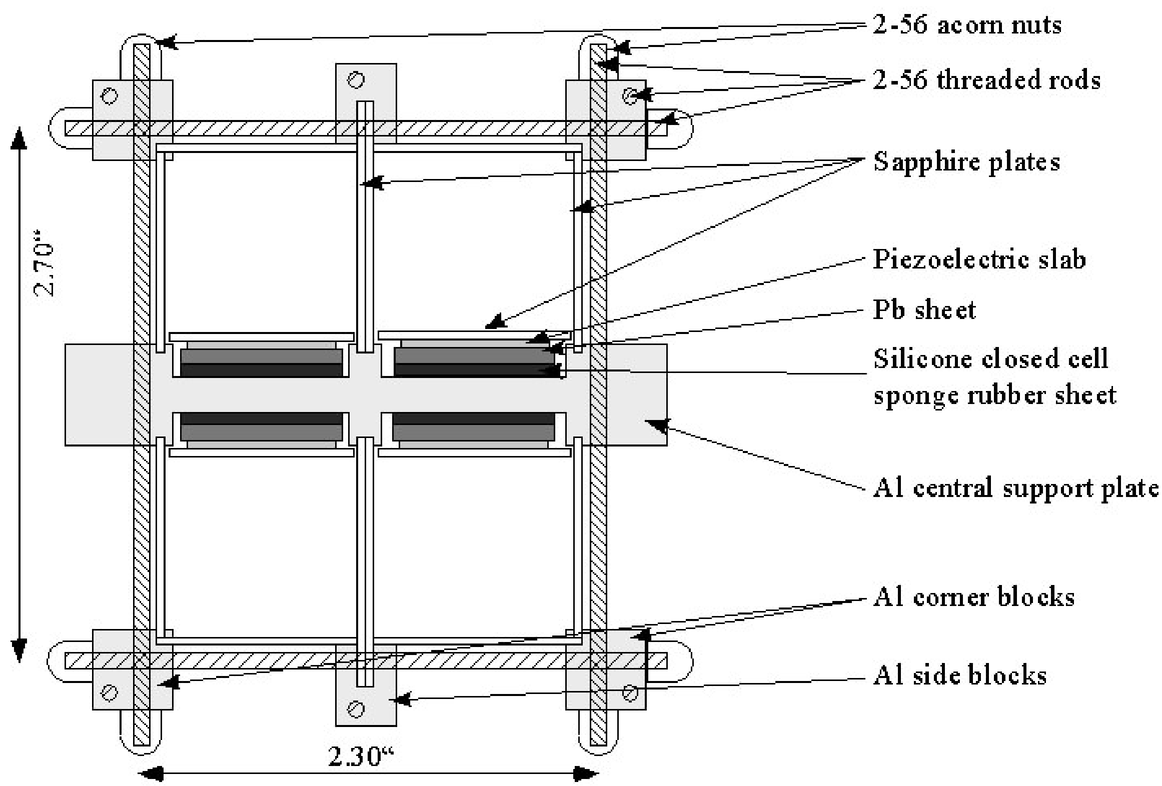

FIGURE 5: Cross section through box set near one side of the box.

The sapphire walls are held in place by a compression system constructed from 2/56 stainless steel threaded rod, aluminum corner pieces and the support plate. The way the compression system works is each corner piece will have three support rods running through it, in the x, y, and z directions. In each place where a support rod goes through a support piece there will be a nut so that it can be tightened and locked into place. There will be a support piece on the top of four cubes, where all the walls meet. This piece will have two steel rods running through it so that the walls are being held in place by the piece and compressed together so that they will not fall apart.

Inside each sapphire cube, there is an isolated sapphire plate on which a piezoelectric sensor is mounted. This sensor will be used to obtain data relating to the pressure inside each box. The sensor is also attached to a small piece of lead and a rubber pad. The rubber pad isolates the pressure sensor from vibrations originating outside the experiment. The piezoelectric sensor must be deformed for it to produce a voltage reading; therefore, lead is in place to provide a massive surface that will ensure deformation when the isolated sapphire plate is contacted. Wires from the sensors will exit the box set at a common point for easier electrical connection.

4.5 OPTICAL SYSTEM

A set of three digital video cameras (one JVC model GR-DVM 80 and two JVC model GR-DVM 90) will be used to record the motion of our system of particles. In order to successfully view these particles with the required resolution. It is necessary to incorporate mirrors and additional lenses to lengthen the light path and increase the depth of field so that it is possible for the video camera to view the entire depth of our sapphire boxes and still resolve individual balls. A zoom magnification is set for each camera taking into account the automatic tele macro function, which has been activated. Each camera is then manually focused to image individual balls with the aid of an additional 400-millimeter focal length plano-convex achromatic lens. These settings will create a recorded image that will clearly distinguish each of our system particles in each of the visible boxes.

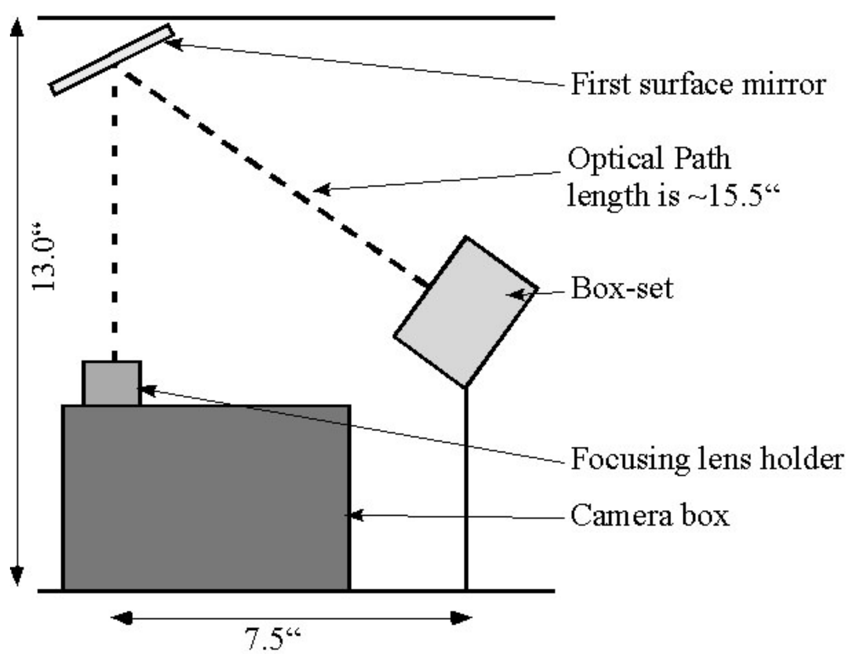

FIGURE 6: Schematic diagram of optical system alignment.

To extend the length of the optical path a 3” x 3” first surface mirror will be mounted opposite each video camera. The mirrors are oriented such that a ray of light from the center of the box will reflect off the center of the mirror and into the center of the camera lens. The mirrors are coated with a protected aluminum ($AlSiO_2$) finish to maintain a high reflectivity on the surface of the mirror. Mirrors are mounted onto a delrin backing with glass to plastic epoxy. Delrin backing is then attached by an aluminum mounting plate and three aluminum posts to the experimental frame. The mirror and mount weigh 1 pound each.

Each camera is enclosed in a box constructed from 3/16” aluminum plate. Closed-cell neoprene foam is packed around the camera to minimize any forces that the camera endures. The foam also confines the camera to prevent it from being jostled out of alignment as a result of vibrations and forces experienced during flight. Epoxied into the lens plate of each camera box is a T-mount containing the additional achromatic lens discussed earlier. A 20-gauge stainless steel (304) plate is placed inside the box and positioned via setscrews in the side of the box to obtain proper collimation of the optical path. Each camera weighs approximately three pounds.

Lighting for the experiment will be provided by high brightness blue LEDs. Blue lights were chosen due to the increased sensitivity of the CCD in each camera to the blue end of the visible. Lights will be embedded in ¼ inch thick delrin blocks and mounted to produce uniform lighting of the box set.

4.6 EXPERIMENT CONTROLLER

A custom designed controller was built to autonomously operate this experiment. The controller takes care of functions like turning cameras on and off, starting and stopping data acquisition, setting up experiment parameters, and recording error messages. The hart of this controller is an ATMEL 89S52 microprocessor that is part of the INTEL 8051 family of processors. The ATMEL 89S52 microprocessor has 32 IO pins operating at 12 MHz and cantinas a built in EEPROM. The software for the controller is written in assembly code and designed to be robust for autonomous operation. The entire electronics enclosure and cabling will weigh 7 pounds.

4.7 BATTERY POWER PACK

All power will be provided using an onboard battery pack. The pack consists of 6 strings of 8 batteries in series. The strings are split into two sections of 4 batteries each, these are then bound together using shrink wrap and a series connection is made across one end of the double set. This will produce a nominal voltage of 12 volts. Each string is then diode isolated and the positive sides are connected in parallel. A fuse is placed on the ground side of the set. The main fuse is a 15 Amp slow-blow fuse and all wiring internal to the battery compartment is 16 AWG wire.

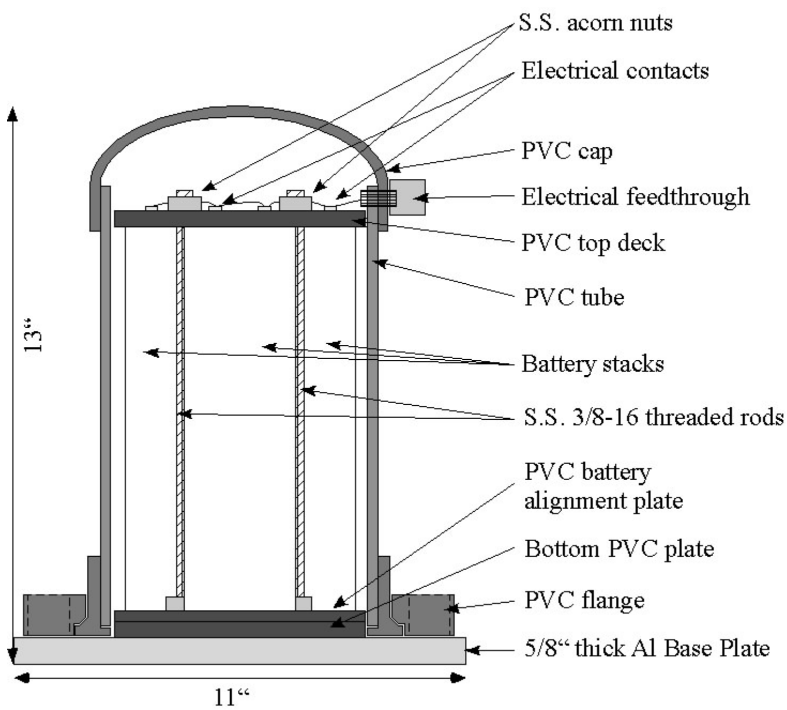

FIGURE 7: Side view of battery stack with cross-section of PVC battery containment.

The batteries are held together in a block using 3/8-16 threaded rod and PVC end caps as shown in figure 7. The rods provide a compression force on all the strings and the PVC layers are machined to help ensure proper alignment of the battery strings. All electrical connections are made through the top PVC plate. The diodes and fuses are also bonded to this plate.

The battery block is then protected from accidental contact by a PVC shroud figure 7. This shroud has a small ½" diameter hole in one side to allow for pressure release in the event of gas evolution from a battery. The hole is stuffed with open cell foam so that any evolved fluids are contained within the PVC enclosure. This shroud is bolted to the base-plate using a PVC flange and 8 stainless steel 1-8 bolts. Which can support the 41 pounds of the battery pack.

4.8 DOCUMENTATION EQUIPMENT

A 35 mm camera and a digital video camera will be taken aboard the KC-135 to document the operation of the experiment.

5. STRUCTURAL ANALYSIS

5.1 BASE PLATE LOADING

The hexagonal frame, that contains all other experimental components, is 28 inches tall and 19 inches across. The frame is bolted onto a 3/8” thick 24” * 24” aluminum base plate by 18 10-32 steel bolts, three bolts on each of the frame’s six sides. This base plate will be bolted into the aircraft floor using four RGO-supplied AN-6 steel bolts. A shroud made of 1/8” thick Lexan surrounds the carbon fiber frame. The weight of the entire assembly is 135 lbs. The individual component weights are listed Table 2. For safety purposes, all structural analysis calculations will assume a 1-g weight of 150 lbs. The center of gravity of the full assembly is approximately 11 inches vertically above the base plate and 1.7 inches horizontally from the center of the base plate.

The frame supports its own weight as well as the weight of all other experimental components except battery pack, which is bolted directly onto the base plate. The weight of the apparatus minus these components is 72 lbs. For safety purposes, all calculations assume a 1-g weight of 85 lbs. The center of gravity of this assembly is approximately 20 inches from the bottom and along the central axis of the carbon fiber structure.

TABLE 1: Weights of experiment components

Component	Weight (lbs)
Carbon fiber frame	23
Aluminum plates inside frame (4)	12
Aluminum base plate	22
Battery pack and batteries	41
Cameras and mounts (3)	10
Electronics box	2
Electronic cables	5
Shaker assembly	5
Sapphire box set and brass balls	2
Mirrors and mounts (3)	3
Lexan shroud	10
Total:	**135**

The structure was analyzed assuming a 10-g force in all (x, y, or z) directions. First, the entire assembly (including base plate, lexan shroud, and battery pack) was analyzed.

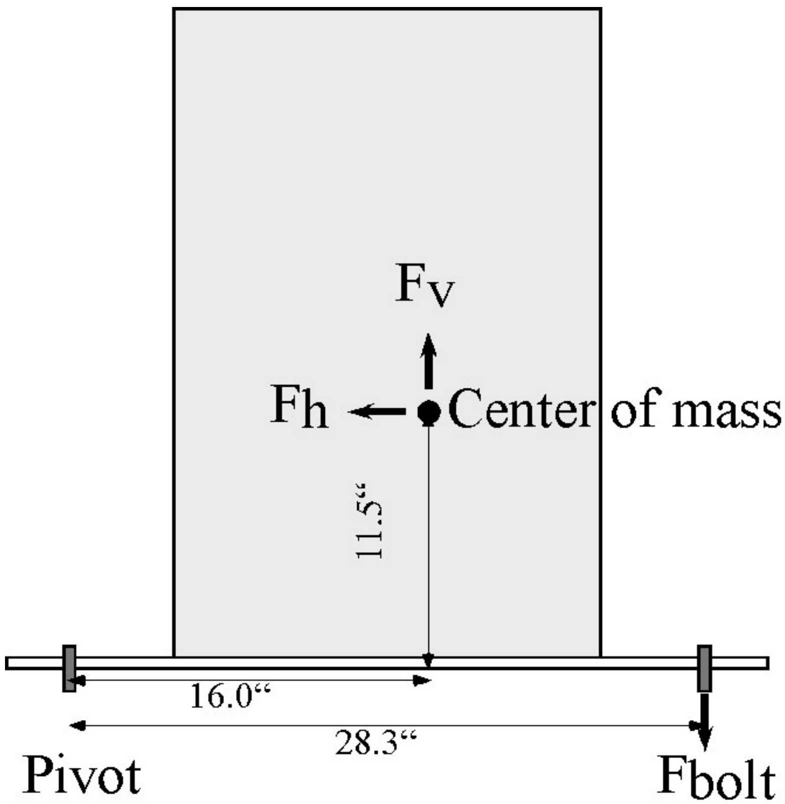

FIGURE 8: Force loading through a cross-section along a body diagonal.

The first analysis of the complete assembly was for the worst-case scenario of the entire 10-g force acting at the center of mass and along the direction of a diagonal of the square base plate. This would cause all of the force to be applied to one base plate bolt. The resulting force (assuming 10-g) is

$$150 \text{ lbs.} * 10 = 1500 \text{ lbs.}$$

This force leads to a torque about one corner of the base plate as shown schematically in figure 8. This results in a bolt force given by:

$$F_{bolt} = \frac{W * d_{CG}}{d_{LA}}$$

where W is the weight of the apparatus, d_{CG} is the distance from the effective pivot corner to the structure's center of gravity, and d_{LA} is the distance from the effective pivot point to the resisting bolt, in our case d_{LA} is $20\sqrt{2}$ inches. For the case of a horizontal load

$$F_{bolt} = \frac{1500 \text{ lbs.} * 11.5 \text{ in.}}{28.3 \text{ in.}} = 610 \text{ lbs.}$$

The yield strength of AN-6 bolts is 5,000 lbs., this force gives a factor of safety of 8.2

For the case of the entire weight acting upward, and all of the force being applied to a single bolt. This force results in a factor of safety of

5,000 lbs. / 1500 lbs. = 3.3

5.2 FLOOR LOADING

If the weight acts downward, the 1500-lb. force will act on the aircraft floor. Since four RGO-supplied floor spacers will be utilized in attaching the apparatus to the floor, the amount of weight resting on each spacer in a 1-g environment is 150 lbs. / 4 spacers = 37.5 lbs./spacer. This force, using the maximum allowable load of the floor spacers of 200 lbs./spacer, results in a factor of safety of

(200 lbs./spacer) / (37.5 lbs./spacer) = 5.3.

For quick reference, Table 2 shows the factors of safety for all cases.

5.3 CARBON STRUCTURE LOADING

The attachment of the carbon fiber frame to the base plate was also analyzed. The assumed weight of the applicable assembly (weight of full assembly minus weights of base plate and battery pack) is 85 lbs., which becomes 850 lbs. under 10g conditions.

The worst-case scenario is for this force to act along a line connecting opposite sides of the hexagon, which results in the force acting on only one set of three bolts. The appropriate diagram is shown in Figure 9.

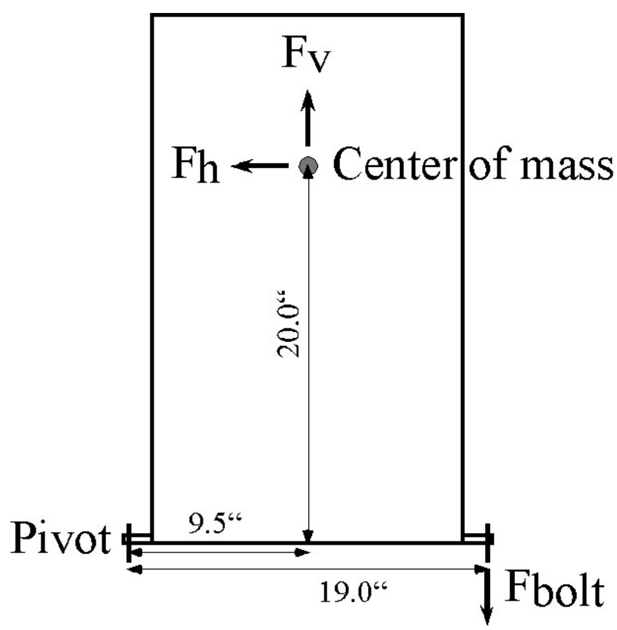

FIGURE 9: Force loading on carbon structure base attachment bolts

The equation for the force on the set of three bolts is the same as that used in the previous calculations. For the case of horizontal loading at the structure center of mass we find:

$$F_{\text{set of 3 bolts}} = \frac{850 \text{ lbs.} * 20 \text{ in.}}{19 \text{ in.}} = 895 \text{ lbs.}$$

where 20 inches is the vertical distance from the bottom of the apparatus to the center of gravity, and 19 inches is the length of the line connecting opposite sides of the hexagon. This force distributed among three bolts is 298 lbs. per bolt. With a yield strength for 10-32 steel bolts of 763.4 lbs per bolt, this results in a factor of safety of 2.5.

TABLE 2: Factors of safety for 10g loading

G-Load Direction	**Component Force Acts Upon**	**Factor of Safety**
Assembly		
Diagonal	AN-6 Steel Bolts	8.2
Upward	AN-6 Steel Bolts	3.2
Downward	Floor Spacers	5.9
Carbon Fiber Structure		
Diagonal	10-32 Steel Bolts	2.5

6. ELECTRICAL ANALYSIS

All power for this experiment is provided from an on board battery pack that can power the experiment for the duration of the flight. Each wire carrying power in the experiment has a fuse installed at its source. List of these wires and their corresponding fuse sizes can be found in Table 3. All exposed metal parts are bonded together at their joints and a ground strap connects the battery box, main support plate and the experiment apparatus together.

6.1 ELECTRICAL SCHEMATIC

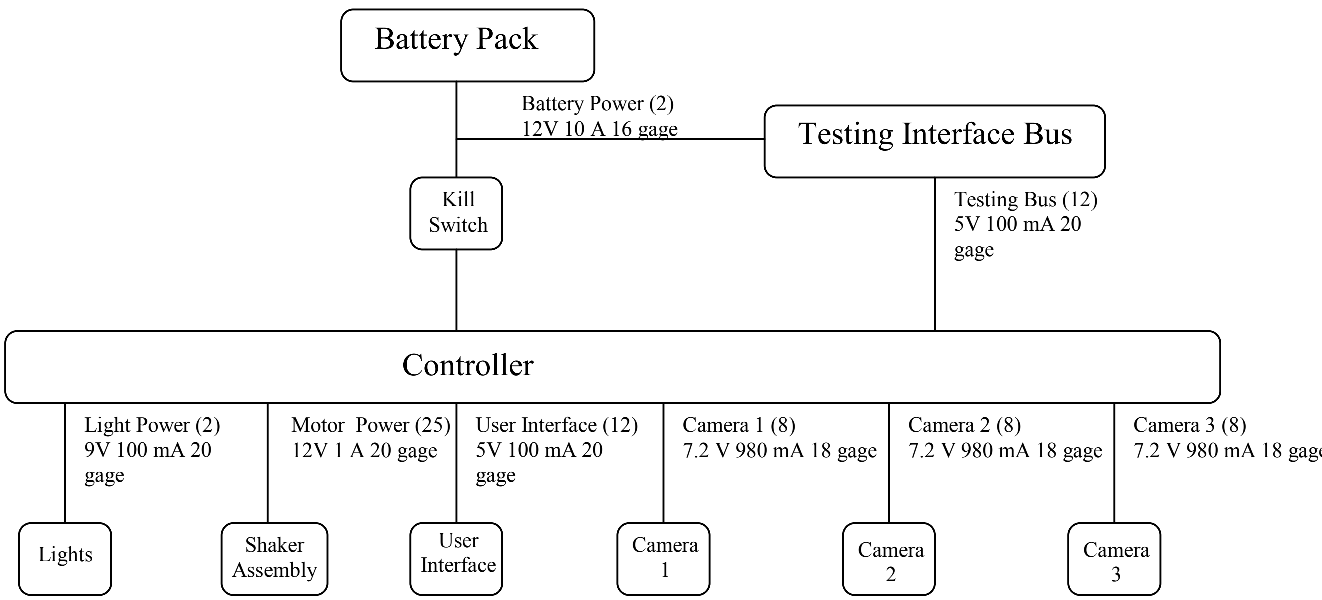

FIGURE 10: Electrical schematic for GrAINS experiment

6.2 LOAD TABLE

TABLE 3: Load Table for Battery Pack

Power Source Details	**Load Analysis**
Name : Battery Pack	DC Motor – 280 mA Stepper Motor – 960 mA Lights – 100 mA Camera 1 – 910 mA Camera 2 – 910 mA Camera 3 – 910 mA Electronics Board – 510 mA
Voltage : 12V DC	
Wire Gage : 16	
Battery Pack Fuse : **10 A**	Max Load : **4.6A**

6.3 EMERGENCY SHUTDOWN PROCEDURES

The experiment contains an emergency power off switch that will cut all battery power to the apparatus, this switch is in the main power wire leaving the battery box as shown in the electrical schematic. The experiment saves its status at the beginning of each experiment and upon reenergizing the experiment the controller will reset to the beginning of the experiment that was terminated.

7. PRESSURE VESSEL CERTIFICATION

Our experiment does not contain pressure vessels.

8. LASER CERTIFICATION

Lasers are not used in the GrAINS experiment

9. PARABOLA DETAILS AND CREW ASSISTANCE

The GrAINS experiment requires no special crew assistance.

10. FREE FLOAT REQUIREMENTS

This experiment contains no free floating objects of any kind.

11. INSTITUTIONAL REVIEW BOARD (IRB)

No human or animal test subjects are used in the GrAINS experiment, and no biological tests are performed. No IRB approval is necessary.

12. HAZARD ANALYSIS REPORT

Hazard Source Checklist

N/A	Flammable/combustible material, fluid
N/A	Toxic/noxious/corrosive/hot/cold material, fluid
N/A	High pressure system
N/A	Evacuated container
1, 2	Frangible material
3	Stress corrosion susceptible material
N/A	Inadequate Structural Design
N/A	High intensity light source
N/A	Ionizing/electromagnetic radiation
N/A	Rotating device
N/A	Extendible/deployable/articulating experiment element
N/A	Stowage restraint failure
N/A	Stored energy device
N/A	Vacuum vent failure
N/A	Heat transfer
4	Over-temperature explosive rupture
N/A	High/Low touch temperature
N/A	Hardware cooling/heating loss
N/A	Pyrotechnic/explosive device
N/A	Propulsion system
N/A	High acoustic noise level
5	Toxic off-gassing material
N/A	Mercury/mercury compound
N/A	Other JSC 11123, Section 3.8 hazardous material
N/A	Organic/microbial (pathogenic) contamination source
6	Sharp corner/edge/protrusion/protuberance
7	Flammable/combustible material, fluid ignition source
N/A	High voltage
N/A	High static electrical discharge producer
N/A	Software error
N/A	Carcinogenic Material
8	Detachment of box set from shaker system
9	Failure of box set assembly

Hazard Number: 1
Hazard Title: Mirror Fracture
Hazard Description:
Front surface mirror could shatter or detach from its mounting plate. The glass fragments would then become projectiles within the experimental system and possibly escape
Hazard Causes
1) Mirrors undergo unexpected forces and shatter.
2) Epoxy does not hold mirror to its delrin mount

Hazard Controls
1) Mirrors mount with Scotch Weld 2216 epoxy recommended specifically for use with the delrin.
2) Lexan shield will contain any glass fragment within our experimental container.

Hazard Number: 2
Hazard Title: Sapphire Boxes Shatter
Hazard Description:
Sapphire wall of box set shatters, causing fragments of sapphire as well as the brass balls to become projectiles.
Hazard Causes
1) Box set subjected to unexpected forces.

Hazard Controls
1) Use of 1 mm thick sapphire due to its inherent strength and shatter resistance
2) Lexan shield will contain any sapphire fragments and brass balls that could possibly become projectiles.
3) Aluminum support plate and sidepieces provide additional support and limit the magnitude of forces exerted on the sapphire plate.

Hazard Number: 3
Hazard Title: Battery failure and potential fluid leak
Hazard Description
D-Cell battery ruptures creating a fluid leak within the battery pack.
Hazard Causes
1) Battery endures a pressure great enough to cause mechanical failure
2) Unexpected mechanical fatigue or manufacturer's defect
3) Short circuit causes battery to rupture

Hazard Controls
1) Battery pack is in a PVC enclosure
2) Vent hole filled with sponge to prevent fluid escape

Hazard Number: 4
Hazard Title: Battery string overheating and potential rupture or explosion
Hazard Description:
Rapid current drain from battery could cause temperature of batteries to exceed safe limits of operation. Could result in battery rupture
Hazard Causes
1) Electrical short causes current surge within the battery

Hazard Controls
1) Individual battery strings are fused and diode isolated.
2) Solder contacts are insulated to prevent short circuits
3) Main power cutoff switch accessible outside of Lexan shroud.

Hazard Number: 5
Hazard Title: Battery off-gassing due to overheating or rupture
Hazard Description:
Batteries release gases in the battery pack
Hazard Causes
1) Over current operation causes battery failure and gas emission
2) Unexpected manufacturer's defect

Hazard Controls
1) Battery strings are fused to limit current
2) Batteries contained in vented PVC enclosure

Hazard Number: 6
Hazard Title: Sharp edges and corners of the experimental structure
Hazard Description:
Edges and corners of our experimental structure may be sharp enough to cause injury.
Hazard Causes:
1) Uncovered sharp corners of experiment apparatus
2) Jagged or rough edges of experiment housing
3) Sharp edges and corners of equipment housings (camera boxes, etc.)

Hazard Controls
1) Sharp edges on equipment casings are inaccessible during flight because of the Lexan shroud
2) Exterior corners will be padded with foam.
3) Experiment design minimizes sharp corners and edges

Hazard Number: 7
Hazard Title: Electrical short circuit to ground
Hazard Description:
Electrical contact is made with the experimental structure causing a rapid current flow through structure to ground and airframe. Short circuit provides a potential a potential for electric shock. Rapid current drain could lead to overheating the battery strings.
Hazard Causes
1) Faulty electrical connection allows electrical contact with experimental structure.

Hazard Controls
1) Solder contacts will be electrically insulated.
2) Individual battery strings will be fused and diode isolated to prevent any rapid current drain.
3) Care will be taken to manage experimental grounds.

Hazard Number: 8
Hazard Title: Detachment of Box-set from shaker assembly
Hazard Description:
Box set becomes detached from the shaking apparatus. Box set and its contents would become projectiles and attempt to escape the experiment housing.
Hazard Causes:
1) Mechanical Failure of linkage between shaker driver and box set

Hazard Controls:
1) Careful design of box attachment strengths to exceed all potential operational forces (> 10 g's in x, y, or z directions)
2) Lexan shroud will enclose the experiment apparatus.
3) Maximum projectile velocities are approximately 10 centimeters per second. Lexan shield will be able to contain the loose particles.

Hazard Number: 9
Hazard Title: Box Set Assembly Failure
Hazard Description:
Compression rod system used to hold sapphire plates together fails, causing sapphire plate, brass balls, and threaded rods to become projectiles.
Hazard Causes
1) Unexpected forces bend threaded rod, causing compression system to malfunction.
2) Unexpected forces cause loosening of the nuts on rod ends

Hazard Controls
1) Lexan shield will contain any experimental components should they become detached.
2) Use of acorn nuts and star washers on both ends of each rod

13. TOOL REQUIREMENTS

Tools we plan to bring to the Reduced Gravity office for this experiment is as follows:

Ground Based Operations

- Jewelers screwdrivers
- Cordless drill (model: Dewalt DW953)
- Number drill set
- Soldering iron
- Solder
- Desoldering tool
- Handheld voltmeter
- Function generator
- Oscilloscope
- Laptop computer for final microprocessor programming

All tools brought to Ellington field with be clearly labeled, numbered and inventoried prior to arrival in Houston. No in-flight tools will be necessary.

14. PHOTO REQUIREMENTS

The GrAINS experiment has its own video capabilities contained within the experiment. Our journal and/or student flyers will bring personal cameras for documentation of apparatus operation. All of these cameras will be properly stowed in the provided crash boxes during takeoff and landing.

15. AIRCRAFT LOADING

1) The test assembly will be lifted onto the aircraft using a forklift and lifting pallet.

2) On the ground and in the test cabin, four team members will carry the equipment by handles installed on the base plate. This ensures that no person will carry over 50 lbs.

3) There is only one assembly to be loaded onto the aircraft. It consists of the carbon fiber frame, which contains the smaller experimental components, a Lexan shroud that goes around the frame, and a 2 x 2 ft aluminum base plate, to which the frame and shroud are bolted. The base plate will be bolted to the floor of the KC-135 using four RGO-supplied steel bolts. The total weight of the experiment assembly is 135 lbs. Therefore, the maximum amount of load that will be placed on the aircraft floor during loading operations is

$$\text{Force / Area} = 135 \text{ lbs.} / 4 \text{ ft.}^2 = 32 \text{ lbs/ft.}^2.$$

16. GROUND SUPPORT REQUIREMENTS

Our group requires access to a 120 V AC power outlet for final component evaluations.

17. HAZARDOUS MATERIALS

The D-cell batteries used to power the entire experiment are the only potentially hazardous material brought onboard the aircraft (see hazard discussion Section 15). Manufacturer's published data on the D-cell batteries is provided.

18. MATERIAL SAFETY DATA SHEETS

No fluids or chemicals are used in the experiment; therefore, no material safety data sheets are provided.

19. PROCEDURES

19.1 EQUIPMENT SHIPMENT TO ELLINGTON FIELD

The test equipment will travel with the team via van to Houston. No shipping is necessary. All equipment may be stored at room temperature.

19.2 GROUND OPERATIONS

The apparatus will arrive fully assembled; however, to ensure proper functionality of our experiment, we will perform the following tests:

1) Check apparatus thoroughly for physical damage.
2) Check all electrical connections to ensure solid connections and proper insulation.
3) Set up remote power supply for ground testing.
4) Provide power to all electrical systems (microprocessor, video cameras, lighting, etc.)
5) Use the laptop computer for final microprocessor programming and instruction
6) Test microprocessor to ensure all controlled systems are functioning and proper experiments can be run.
7) Verify Camera alignment and settings so that box set is imaged properly.
8) Rewind cameras to ensure recording at beginning of tape.
9) Final overall check of experimental systems
10) Shutdown power to system
11) Disconnect the remote power supply.
12) Attach Lexan shield

Our team will need approximately 10 x 10 ft of floor space for ground testing

19.3 LOADING

The total weight of the test assembly is 135 lbs. A forklift and lifting pallet will be required for loading the experiment onto the aircraft. After the experiment is on the aircraft, four team members will carry the assembly to the assigned location using the provided handles on the base plate Then they will fasten the experiment's aluminum base plate to the floor of the airplane using four RGO-provided steel bolts and ensure that it is attached firmly.

19.4 PRE-FLIGHT

Ensure that all in flight tools, personal photographic equipment and other accessories are properly stowed.

19.5 TAKE-OFF/LANDING

No special procedures during these parts of the flight.

19.6 IN-FLIGHT

1) Two minutes prior to the first parabolic maneuver, turn on the experiment by pulling the master switch. The control system will power up individual components automatically.
2) Just prior to the zero-g part of each parabola, press the "next" button, which tells the microprocessor to begin shaking the set of boxes with the amplitude and frequency specified for that particular experiment. Repeat for each parabolic maneuver (~ 40 separate experiments per flight).
3) In the event of an unforeseen error resulting in poor data collection, press the "back" button instead of the "next" button just prior to the start of zero-g to run the previous experiment again.
4) In the event of a major problem that requires the experiment to be powered down immediately, depress the master switch.
5) Following the last parabolic maneuver depress the master switch to power down the experiment prior to landing.

19.7 POST-FLIGHT

1) Detach experiment from airframe and remove to ground operations site to refit experiment for the next day's flight. Turn around time for refit is approximately 4 hours
2) Check battery strings for voltage drain and replace strings if necessary for the next day's flight.
3) Using laptop and firewire card remove flight data from the video cameras and store it on the laptop.

4) Study video data so that the next day's experiments can be tailored to achieve the best possible data set.
5) Recheck all equipment to ensure safety and functionality.
6) Reprogram the microprocessor using the laptop computer.
7) Reset the videotapes so that recording begins at start of tape.
8) Once experiment is ready for next flight, replace the Lexan shield.
9) Reload experiment onto aircraft.

19.8 OFF-LOADING

The test assembly will be unbolted from the floor by the flight crew and the bolts returned to the RGO. Four team members will carry the apparatus to the door of the aircraft cabin, where it will need to be removed using a forklift and pallet. Equipment will be transported from Ellington Field by team members and loaded into the van.

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The information contained within is provided for your information only. This battery is an article pursuant to 29 CFR 1910.1200 and, as such, is not subject to the OSHA Hazard Communication Standard requirement for preparation of a material safety data sheet. The information and recommendations set forth herein are made in good faith and are believed to be accurate as of the date of preparation. However, EVEREADY BATTERY COMPANY, INC., MAKES NO WARRANTY, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THIS INFORMATION AND DISCLAIMS ALL LIABILITY FROM RELIANCE ON IT.

PRODUCT SAFETY DATA SHEET

PRODUCT NAME: EVEREADY Battery **Type No.:** **Volts:**

TRADE NAMES: ENERGIZER, ENERGIZER e², INDUSTRIAL ZMA; HERCULES **Approximate Weight:**

CHEMICAL SYSTEM: Alkaline Manganese Dioxide-Zinc **Designed for Recharge:** No

SECTION I - MANUFACTURER INFORMATION

Eveready Battery Company, Inc.
25225 Detroit Road
Westlake, OH 44145

Telephone Numbers for Information:
(440) 835-7368
(800) 383-7323 (USA)

Date Prepared: October 17, 2001

SECTION II - HAZARDOUS INGREDIENTS

IMPORTANT NOTE: The battery should not be opened or burned. Exposure to the ingredients contained within or their combustion products could be harmful.

MATERIAL OR INGREDIENT	PEL (OSHA)	TLV (ACGIH)	%/wt.
Graphite (CAS# 7782-42-5)	15 mg/m³ TWA (total dust) 5 mg/m³ TWA (respirable fraction)	2 mg/m³ TWA (respirable fraction)	2-6
Manganese Dioxide (CAS# 1313-13-9)	5 mg/m³ Ceiling (as Mn)	0.2 mg/m³ TWA (as Mn)	30-45
Potassium Hydroxide (CAS# 1310-58-3)	None established	2 mg/m³ Ceiling	4-8
Zinc (CAS# 7440-66-6)	15 mg/m³ TWA PNOR* (total dust) 5 mg/m³ TWA PNOR* (respirable fraction)	10 mg/m³ TWA PNOC** (inhalable particulate) 3 mg/m³ TWA PNOC** (respirable paeticulate)	12-25

* PNOR: Particulates not otherwise regulated
**PNOC: Particulates not otherwise classified

SECTION III - FIRE AND EXPLOSION HAZARD DATA

In case of fire, it is permissible to use any class of extinguishing medium on these batteries or their packing material. Cool exterior of batteries if exposed to fire to prevent rupture.
Fire fighters should wear self-contained breathing apparatus.

SECTION IV - HEALTH HAZARD DATA

Under normal conditions of use, the battery is hermetically sealed.

Ingestion: Swallowing a battery can be harmful.

Contents of an open battery can cause serious chemical burns of mouth, esophagus, and gastrointestinal tract.

If battery or open battery is ingested, do not induce vomiting or give food or drink. Seek medical attention immediately. CALL NATIONAL BATTERY INGESTION HOTLINE for advice and follow-up (202-625-3333 collect) for advice and follow-up, day or night.

Inhalation: Contents of an open battery can cause respiratory irritation. Provide fresh air and seek medical attention.

Skin Contact: Contents of an open battery can cause skin irritation and/or chemical burns. Remove contaminated clothing and wash skin with soap and water. If a chemical burn occurs or if irritation persists, seek medical attention.

Eye Contact: Contents of an open battery can cause severe irritation and chemical burns. Immediately flush eyes thoroughly with water for at least 15 minutes, lifting upper and lower lids, until no evidence of the chemical remains. Seek medical attention.

SECTION V - PRECAUTIONS FOR SAFE HANDLING AND USE

Storage: Store in a cool, well ventilated area. Elevated temperatures can result in shortened battery life.

Mechanical Containment: If potting or sealing the battery in an airtight or watertight container is required, consult your Eveready Battery Company representative for precautionary suggestions. Batteries normally evolve hydrogen which, when combined with oxygen from the air, can produce a combustible or explosive mixture unless vented. If such a mixture is present, short circuits, high temperature, or static sparks can cause an ignition.

Do not obstruct safety release vents on batteries. Encapsulation (potting) of batteries will not allow cell venting and can cause high pressure rupture.

Handling: Accidental short circuit for a few seconds will not seriously affect the battery. Prolonged short circuit will cause the battery to lose energy, and can cause the safety release vent to open. Sources of short circuits include jumbled batteries in bulk containers, metal jewelry, metal covered tables or metal belts used for assembly of batteries into devices.

If soldering or welding to the battery is required, consult your Eveready Battery Company representative for proper precautions to prevent seal damage or short circuit.

Charging: This battery is manufactured in a charged state. It is not designed for recharging. Recharging can cause battery leakage or, in some cases, high pressure rupture. Inadvertent charging can occur if a battery is installed backwards.

Labeling: If the Eveready label or package warnings are not visible, it is important to provide a package and/or device label stating:

> **WARNING:** do not install backwards, charge, put in fire, or mix with other battery types. May explode or leak causing injury. **Replace all batteries at the same time.**

Where accidental ingestion of small batteries is possible, the label should include:

> Keep away from small children. If swallowed, promptly see doctor; have doctor phone (202) 625-3333 collect.

Disposal: Dispose in accordance with all applicable federal, state and local regulations. Appropriate disposal technologies include incineration and landfilling.

SECTION VI - SPECIAL PROTECTION INFORMATION

Ventilation Requirements: Not necessary under normal conditions.
Respiratory Protection: Not necessary under normal conditions.

Eye Protection: Not necessary under normal conditions. Wear safety glasses with side shields if handling an open or leaking battery.

Gloves: Not necessary under normal conditions. Use neoprene or natural rubber gloves if handling an open or leaking battery.

SECTION VII - REGULATORY INFORMATION

The transportation of dry cell batteries manufactured or sold by Eveready Battery Company is not regulated by the U.S. Department of Transportation or the major international regulatory bodies.
SARA/TITLE III - As an article, this battery and its contents are not subject to the requirements of the Emergency Planning and Community Right-To-Know Act.