Test Equipment Data Package

2003 Reduced Gravity Student Flight Opportunity Program

Gr.A.I.N.S. II
Granular Agglomeration In Non-gravitating Systems II
Experiment 2003-190

The University of Tulsa Granular Physics Group
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January 27, 2003

KC-135 QUICK REFERENCE DATA SHEET

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Experiment Title: Granular Agglomeration in Non-gravitating Systems II

Flight Dates: Flight Group 1 March 13-22, 2003

Overall Assembly Weight (lbs):

Assembly Dimensions (LxWxH):

Equipment Orientation Requests: None

Proposed Floor Mounting Strategy: Bolts/Studs

Gas Cylinder Requests: None

Overboard Vent Requests: None

Free Float Experiment: Yes

Flyers for Each Proposed Flight Day:
Day 1: Justin Mitchell and Adrienne McVey
Day 2: Rebecca Ragar and Ian Zedalis

Camera Pole and/or Video Support: No

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1. FLIGHT MANIFEST

Flyer	Flight Day	Previous KC-135 A Flight Experience	Date of Prior Flight
Justin Mitchell	Flight Day 1	Yes	07/23/02
Ian Zedalis	Flight Day 2	No	
Rebecca Seebirt (journalist)	Flight Day 1	No	
Rebecca Ragar	Flight Day 2	Yes	07/24/02
Adrienne McVey	Flight Day 1	No	
Jeffrey Wagner	Alternate	No	

2. EXPERIMENT BACKGROUND

Studies of the interactions of granular materials and overall behavior of granular systems have been areas of great focus in both industry and academia in recent years (Jaeger). Within the scope of granular materials, granular “gases” of macroscopic particles, systems in which granular media are excited to a level at which they demonstrate behavior in the kinetic regime typical of ideal gases, have been particularly interesting. Granular gases of balls have demonstrated an interesting tendency to cluster as a result of inelastic collisions between the particles if the gas is undisturbed by outside influences like gravity. This phenomenon has been theoretically predicted (Grossman) and demonstrated in some experimental situations (Maddox). The behavior of these clusters seems dependent on a number of factors. Among these are: driving conditions, particle densities, and coefficients of restitution between the particles themselves as well as between the particles and the enclosure. Analysis of individual ball motion has been performed on various 2D systems; however, such analysis has not yet been performed in 3D. The only 3D experiment known was performed on a set of fairly dense granular systems (Falcon). The densities used were high enough to prevent correlation between inelastic collapse and the effects of particle energies, input energies, and effective “granular pressure” of the system.

The 3D experiment mentioned above was performed on a free-floating gas of macroscopic balls. During the sounding rocket’s free-fall time, the experimenters observed 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. Each set was limited to 5 to 15 seconds of driving due to the overall time limitations of the experiment, 200 seconds of free fall. The video resolution also made ball tracking difficult due to shadows and difficulties in finding individual balls. Because of the resolution issues, the experimenters were not able 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 planetary ring systems and interstellar dust clouds (Jaeger). Inelastic collapse may also hold key information into the initial steps of planet and asteroid formation. Measurements of asteroid densities have shown that objects of 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.

Our experiment (Gr.A.I.N.S. II) is a second flight on the KC-135A following up on data gathered and difficulties encountered during the July, 2002 campaign. During that flight week we were able to gain video data of 21 reduced gravity parabolas. In the analysis of the collected video and impact sensor data, we encountered several unforeseen problems in our data collection. Focus and lighting issues from last campaign have been addressed and will be explained further in later sections of this document. Data collection methods for the impact sensor data have been substantially revised to eliminate signal coupling issues while greatly reducing pick up of extraneous signals which interposed themselves on our data channels during the last flight. Analysis of last year's data also led to the conclusion that some of our sets of driving parameters were not energetic enough to creating a granular gas given the negative accelerations of the aircraft (Mitchell). As a result, we have made our experiment free floating to alleviate some of the effects of the plane accelerations and we have also adjusted some of our driving parameter to allow for more parabolas of granular gas formations. This experiment, though run as a free floating experiment for this campaign, will with modification be flown aboard the space shuttle as part of the Get Away Special small payloads programs. The reduced gravity environment of the KC-135 will provide a plausible test environment for the modifications made following last year's flight to ensure that they will function properly for the space shuttle flight.

As an outreach experiment with the Gr.A.I.N.S. team, members of the Union Public Schools Young Astronauts Program have designed an experiment to determine the path of travel of ¼"-diameter brass balls as they interact and collide with a background of balls. The experiment stems from research in Brownian motion, a physical phenomenon in which particles suspended in a fluid exhibit continuous and irregular movement. Many experiments have been done to examine the behavior of microscopic particles under terrestrial gravity; however, few experiments have been performed examining macroscopic particles to determine conditions at which these particles would begin to exhibit continuous and irregular movement or Brownian motion. One such low-gravity experiment was conducted by the Canadian Space Agency when they examined the effect of spacecraft vibrations on encapsulated bubbles within a vibration isolation mount (Tryggvason).

Our experiment will analyze the path taken by selected brass balls as the move through acrylic boxes with varied packing densities of brass balls. In our analysis we hope to determine the extent to which these ball paths become Brownian as a function of packing density. A low gravity environment is needed for this experiment because on Earth the force of gravity dominates any of these random vibrations and causes energy losses due to rolling friction. With the reduced gravity environment, these external losses will be greatly reduced allowing the motions of the tracked particles to be dominated by interactions within our experiment and not by external forces.

3. EXPERIMENT DESCRIPTION

The Gr.A.I.N.S. II experiment studies the dynamics of collections of macroscopic particles, brass ball bearings, excited into a kinetic gas-like regime. The initial dynamics of the system are similar to those predicted by ideal gas kinetic theory; however, the dynamics depart from kinetic theory as a result of inelastic collisions between the particles. Each collision causes a loss of energy due to the coefficient of restitution between the particles being less than one. A coefficient of one indicates that the collisions are perfectly elastic with no energy loss due to the collisions. A number of the theoretical papers and experiment have shown tendencies for clustering and other pattern formation to occur although the exact parameters needed for these phenomena to occur is still a mystery. Much of the previous, particularly the 3D experiments and models have neglected factors such as rotational effects, glancing collisions, and surface friction which greatly complicate the dynamics of 3D granular systems. Our experiment will obtain video and impact sensor data for systems of various densities of 0.5 mm and 1 mm brass ball bearings. With this data, we intend to be able to track individual balls in the video to allow for complete analysis of their dynamics. We also intend to use the impact sensor data to isolate and analyze individual ball-sensor collisions to determine the "granular pressure of our granular gas systems. Previous experiments have shown that "granular pressure should behave as a power law with respect to the expectation value of velocity of the particles (Falcon). We intend to gather enough data to evaluate this relationship.

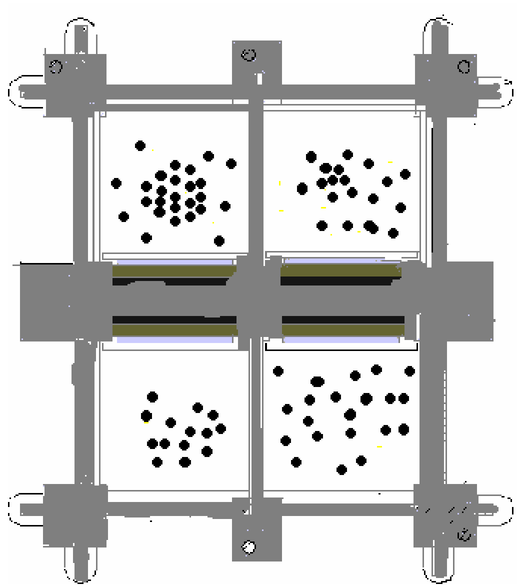

Figure 1 Side view sketch of box set filled with balls.

The experiment consists of a cube of eight 1 cubic inch sapphire boxes (see figure 1), seven of which contain varying numbers of 0.5 mm and 1.0mm diameter brass balls creating a wide range of packing fraction and densities our experiment can test. One box is empty for control purposes. As an energy supply for the particles, the cube will be shaken approximately sinusoidally along one body diagonal. This motion is regulated by a computer-controlled shaking system. Under reduced gravity 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 design to produce granular gases of varying energies to study energy effects on clustering and other phenomena. As a result we would expect the dynamics of each case to vary.

A set of three digital video camcorders will be used to record three orthogonal faces of the sample cube. These cameras will record with sufficient resolution, by means of optical zoom magnification and an additional 400 mm focal length achromatic lens, to allow tracking and measurements of individual balls. Direct measurement of the velocity distribution for the balls in each individual cell will be achieved by computer analysis upon the experiment's return to Tulsa.

Piezoelectric impact sensors attached to one wall of each cell will register the effective pressure exerted by the balls on the sensor. Each of the sensors will be deformed slightly due to ball impacts. This deformation will produce a voltage via the piezoelectric effect. The data from these sensors will be stored as voltage measurements in an external hard drive. 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. We also intend to relate the pressure readings to the velocities determined for each system in an attempt to verify the pressure relationship discussed earlier.

Our outreach experiment, designed in conjunction with the Union Young Astronauts Program, studies Brownian motion in microgravity using ¼ inch brass balls encased in acrylic chambers. Our objective for this experiment is to observe Brownian motion under different packing densities in micro gravity conditions. The apparatus consists of a frame constructed of extruded aluminum, an acrylic box split into four chambers, ¼ inch brass balls, and a digital video camera to record the experiment. There will be 25 brass balls in the first chamber of the acrylic box, 50 balls in the second chamber, 75 balls in the third chamber, and 100 balls in the fourth chamber. A solenoid will be used to provide the initial push to get the balls moving. One or more balls in each section will be marked to track the movement. By observing four different chambers with a different numbers of balls in each, we can observe how a greater number of balls will effect the movement of the colored ball. If Brownian motion works in microgravity as it does on earth, the balls will have an irregular and unceasing motion.

The aluminum frame is to be bolted to an aluminum base plate and then to the floor of the KC-135. The frame will be built using extruded aluminum connector pieces and bolts. The box that houses the balls is to be made from ½ inch thick acrylic and split into four sections. The acrylic pieces will be assembled with screws and/or acrylic cement. The size of the chambers will allow the balls to move horizontally without excess of vertical motion. The digital video camera will be focused on the chambers and will record the motion of the balls during the flight. It will be attached to the aluminum frame with a mounting plate and bolts. The camera will be supplied with power from the aircraft's 115 Volt AC/60Hz power supply. The camera footage will be fed to a computer program to track the pattern of the colored balls once back on the ground in Tulsa. All structures can withstand loading as specified by Johnson Space Center in the User's Manual.

During the microgravity parabolas, a Sony TRV-240 will record video data of each of our four chambers. In each chamber, In this video data we will focus on tracking a colored ball in each chamber through each frame of video. This tracking will be accomplished through the use of computer imaging software that will allow us to determine the location of the colored ball in each frame for a 15 second microgravity interval. This position data can then be plotted to determine the path taken by the selected ball. We will then compare the paths of the selected balls in the different chamber to determine whether the increase in ball packing density has a measurable effect on the path of our chosen ball.

4. EQUIPMENT DESCRIPTION

4.1 SAPPHIRE BOX SET

Our experimental box set consists of sapphire plates arranged into a set of eight cubes, approximately 1 in^3 in volume. The sapphire cubes are constructed outward for a 5/8" thick aluminum center plate. This support plate divides the box set into two halves, and it contains four depressions on each side, which house each cube's piezoelectric impact sensor. Around these depressions are four trenches design to hold the sapphire plates that make up the side walls. Four additional sapphire plates form the tops of the four cubes on each side of the support plate.

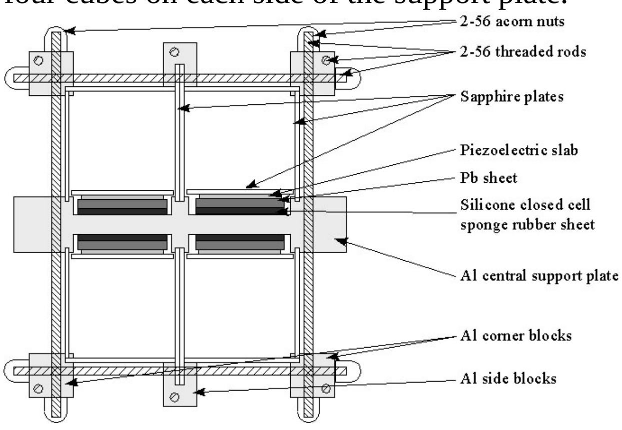

Figure 2a Labeled Side View of Box Set

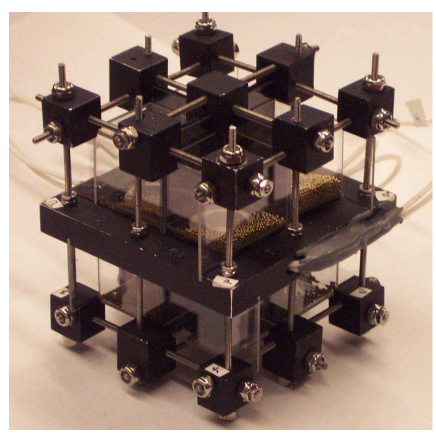

Figure 2b Photo of Constructed Box Set

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 compression system works by having three support rods running through the x, y, and z directions of each corner piece. Each place a support rod goes through one of the aluminum support blocks there will be a nut which is tightened and locked into place to ensure the stability of the sapphire cubes. There will be a support block on the top of four cubes, where all the walls meet. This piece will have one steel rod 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.

Each sapphire cube contains an isolated sapphire plate that is epoxied to the piezoelectric disk in each cube. Each sensor will be attached to a small piece of lead which is attached to a rubber pad intended to isolate the sensors from vibrations external to the experiment. The piezoelectric sensor must be deformed for it to produce a voltage reading; therefore, lead is in place to provide a dense surface that will ensure deformation of the sensor when the isolated sapphire plate is contacted. Wires from the sensors will exit the box set at a common point for easier electrical connection. These sensors are used to record impact data which will be used to attain a measurement of the "granular pressure" of our systems. Each sapphire cube is filled with varied amounts of 0.5 mm and 1 mm diameter balls. These varied fill ratios are designed to evaluate the effects of density on granular gas systems. The fully assembled box set weighs approximately 2 pounds.

4.2 MECHANICAL SHAKER SYSTEM

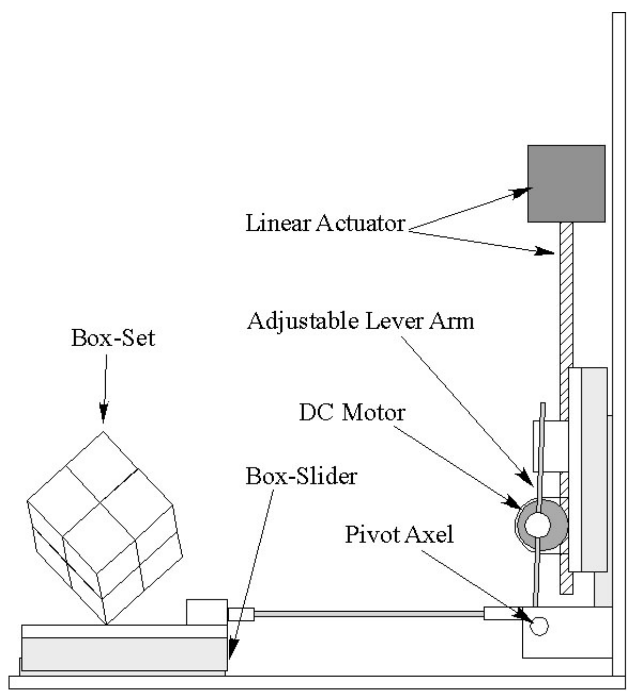

Figure 3 Side View of Mechanical Shaking System

The experimental cube will be shaken using a computer controlled electromechanical system that allows for control of both the amplitude and frequency of oscillation. A side view of this system is shown schematically in figure 3. The operation is twofold: 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 changes to the length of a level arm attached to the DC motor. Changing this length allows us to vary 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.

4.3 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 cells and still resolve individual balls. An optical zoom magnification is set for each camera taking into account the automatic tele-macro function, which has been activated. Each camera is 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.

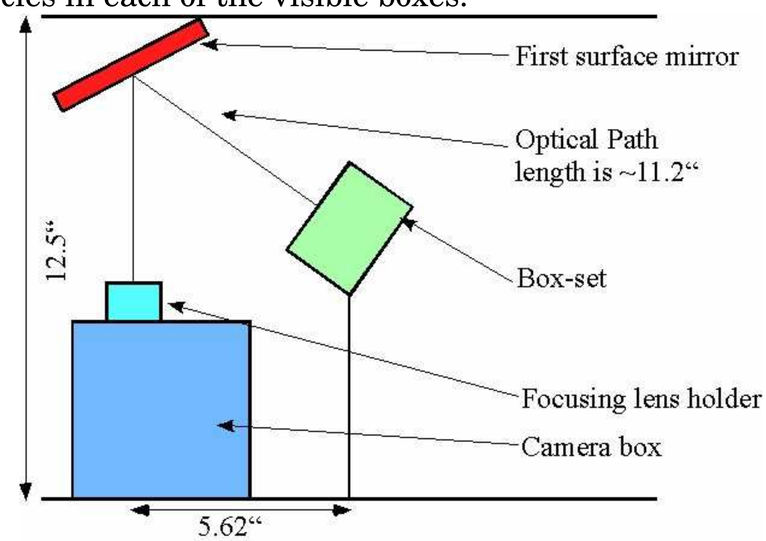

Figure 4 Schematic of Optical Path

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 2 aluminum side braces to the experimental frame. The mirror and its mount weigh 1 pound each.

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.

4.4 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 experime 89S nt parameters, and recording error messages. The hart of this controller is an ATMEL 52 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.

4.5 FREE FLOAT CHAMBER

4.6 OUTREACH EXPERIMENTAL CHAMBER

The Brownian motion experimental chamber consists of an acrylic rectangular container divided into 4 equivalent sections of dimension 4” x 4” x 0.30” (outer dimensions are 9.5” x 9.5” x 0.3”). The outer walls and top face of the chamber will be constructed from ½” thick acrylic sheet. This acrylic sheet will be sufficiently strong to withstand any of the brass ball collisions for all g-loading situations defined by the NASA JSC design requirements. The base will be constructed of ½” thick aluminum plate. The chamber is only 0.3 inches deep in order to limit the motion of the ¼-inch diameter balls to two dimensions by not allowing the balls to pass above one another. The container is divided into its four sections by 1/2” thick acrylic dividers. In each of the sections, a varied number of brass balls will be inserted to create a varied packing density (packing fraction) for each test chamber. Data for the each of the four test chambers regarding number of balls and packing density is listed in Table 1. Packing densities calculated as the number of balls multiplied by the ratio of the cross-sectional ball area to cross-sectional chamber area. These experimental parameters were selected so that the packing fraction would remain below 50 percent.

TABLE 1 : Experiment parameters for Brownian motion chambers

Experimental Chamber	**Number of balls**	**Packing Density percentage of chamber area**
1	25	7.67 %
2	50	15.34 %
3	75	23.01 %
4	100	30.68 %

Each experiment chamber will be continuously mechanically shaken by use of a solenoid. The chambers are shaken to ensure that the balls have sufficient energy to be in motion through an entire 15 second data interval. No damage will be done to the acrylic structure or to the brass balls during experiment operation. The experiment change will weigh approximately 5 pounds. An LED will be mounted to the box for data timing purposes. This light will turn on when the Gr.A.I.N.S. II experiment is advanced signifying the start of reduced gravity.

4.7 VIDEO DATA RECORDER FOR OUTREACH EXPERIMENT

4.8 EXTRUDED ALUMINUM EXPERIMENTAL FRAME

Our outreach experiment will be housed in an extruded aluminum experimental frame measuring 21” x 20” x 36”. The frame will construct by bolting together with ¼”-24 fine thread bolts lengths of T-slotted aluminum extrusion in the dimensions specified. Once the frame is constructed a rail will be created connecting two sides of the frame base along one axis. This rail will support the experiment chamber by the use of two 2.8” linear slide extrusions, which contain low friction Teflon bearings which will allow the experiment to slide. A solenoid will be attached to the slide mechanism to provide energy input to the experiment. A similar cross rail will be used on the top of the frame. The rail in conjunction with a T- bracket will serve as tripod mount for the experiment’s video camera. The camera will be positioned above the center of the experiment chamber.

4.9 DOCUMENTATION EQUIPMENT

The Gr.A.I.N.S. II flight crew will bring aboard the KC-135 35-mm camera for visual documentation. Also a clipboard and notepad will be brought aboard for the recording of operational notes and comments pertinent to data analysis. The clipboard and notepad will be secured to the experimental structure. Cameras and writing implements will be stored in the provided crash boxes for takeoff and landing.

4.9 DATA LOGGING AND STORAGE

5. STRUCTURAL ANALYSIS

TABLE 2: Weights of experiment components

Component	Weight (lbs)	Part of Free Float?
Aluminum superstructure	14.5	Y
Handles (4)	0.75	Y
Aluminum plates inside frame (4)	12	Y
Aluminum base plate	22	N
Cameras (3)	3.6	Y
Camera mounts (2)	1.5	Y

Lights (6)	1	Y
Mirrors and mounts (3)	4.5	Y
Electronics box	2	Y
Tether		Y
Wiring harness		N
Shaker assembly	5	Y
Sapphire box set and brass balls	2	Y
Experiment chamber (outreach)	5	N
Video recorder (outreach)	2	N
Extruded aluminum frame (outreach)		N
Lexan shroud	5	Y
Total:	**90.1**	
Free Float Total:	**50**	

6. ELECTRICAL ANALYSIS

7. PRESSURE VESSEL CERTIFICATION

Neither the Gr.A.I.N.S. II experiment nor our outreach experiment with the Union High School Young Astronauts Program use any sealed pressure vessels; therefore, certification is not applicable.

8. LASER CERTIFICATION

The Gr.A.I.N.S. experiment will use a laser system for shaker amplitude measurement. The laser used will be a class 2 visible laser diode manufactured by the Aromat Corporation. It is a laser range finder used to measure the amplitude of our mechanical shaking system. It will be in operation for the duration of each parabola so it can provide real-time amplitude measurements. Due to the low light intensity of the device (3000 lx) no restraints or covers appear necessary.

9. PARABOLA DETAILS AND CREW ASSISTANCE

Each microgravity parabola, the Gr.A.I.N.S. II experiment will be allowed to free float in the aircraft cabin. The experiment will be started by pressing a button on the user interface console, and then will be released just above the floor of the KC-135. Because the Gr.A.I.N.S II experiment is a free float, RGO guidelines require that we operate the free float under the supervision of a test director to ensure that its operation does not interfere with the operation of other experiments aboard the KC-135. Prior to the 2-g portion of each parabola we will secure the free float to its Velcro pads. As the experiment operates the free float chamber with be securely attached to our aluminum base plate via a tether constructed of tubular webbing. We ask that the test directors supervise us as we check the security of our tether upon aircraft loading to ensure the safety of its operation.

Additional crew assistance will be requested to help load the experiment into the aircraft . The test directors will be requested to assist our team in securing the experiment to the floor of the aircraft. Our flight team will check all of our security restraints during aircraft loading; however, assistance may be required in securing these restraints.

10. FREE FLOAT REQUIREMENTS

The Gr.A.I.N.S. II experiment has a free floating portion of its apparatus. During each parabola of the flight days The experiment chamber will be allowed to free float in the aircraft to attempt to reduce the effects of the plane's vibrations/accelerations on our experimental data. Our intention in free float is for our experiment to obtain better data without posing any additional risk to the experimenters and their projects. To do this, we have included our free float procedure.

Takeoff/Landing

1. Free float apparatus will be secured with Velcro and tied down with adjustable straps to ensure that apparatus cannot float during takeoff or landing.
2. All straps and securing mechanisms will be checked both immediately after experiment loading and again before takeoff

Prior to First Parabola

1. Straps will be removed from the free floating chamber
2. Experiment will remain secured to Velcro pads

During Each Parabola

1. Experiment will operate via the controller chip
2. Member of our experiment team will remove free float chamber from Velcro pads and release it near the floor of the aircraft
3. The chamber will be tethered to our aluminum base plate to ensure that it cannot leave our team's area.
4. Our team members will observe the chamber carefully to prevent our experiment from interfering with the experiments of other teams or causing any form of safety concern for the experimenters and crew.

Prior to 2-g Portion of Each Parabola

1. Free float chamber will be secured to Velcro pads on our apparatus
2. Experiment will be stopped by the controller chip

11. INSTITUTIONAL REVIEW BOARD

No human or biological testing is being performed in any part of the Gr.A.I.N.S. II experiment. As a result, no institutional review board was needed

12. HAZARD ANALYSIS REPORT

12.1 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
N/A	Stress corrosion susceptible material
N/A	Inadequate Structural Design
N/A	High intensity light source
N/A	Ionizing/electromagnetic radiation
N/A	Rotating device
3	Extendible/deployable/articulating experiment element
4	Stowage restraint failure
N/A	Stored energy device
N/A	Vacuum vent failure
N/A	Heat transfer
N/A	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
N/A	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
5	Sharp corner/edge/protrusion/protuberance
6	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
7	Detachment of box set from shaker system
8	Failure of box set assembly
9	Failure of free float tether

12.2 HAZARD DESCRIPTIONS

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: Free float experimental chamber
Hazard Description: Free float chamber if not properly tethered and monitored by our flight team could pose injury risk due to collisions with experimenters.
Hazard Causes
1) Free float Chamber detaches from base plate due to tether failure.
2) Other experimenter floats into contact will the chamber

Hazard Controls
1) Tether will be strong enough to ensure safe experiment operation
2) Our experimenters will carefully monitor the experiment to make sure that it does not interfere with students or other experiment.

Hazard Number: 4
Hazard Title: Free float experiment restraint failure
Hazard Description: Free float experiment restraints fail during takeoff or landing
Hazard Causes
1) Unforeseen forces cause strap restraint to break and fail due to unexpected turbulence or emergency maneuvers
2) Restraint straps are not capable of withstanding normal force load of apparatus under takeoff and landing acceleration conditions.

Hazard Controls
1) Free float apparatus will be held to base plate by Velcro pads to ensure security above and beyond the restraining straps.
2) Restraining straps will be designed to withstand the takeoff forces applied to the apparatus with a sufficient factor of safety to ensure safety.

Hazard Number: 5

Hazard Title: Sharp corners and jagged edge of bolted experimental apparatus and free float chamber
Hazard Description: Sharp corners and jagged edges of bolted aluminum structure may be an injury risk in the event of accidental contact with experiment
Hazard Causes:

1) Experimenters accidentally come in contact with a sharp corner or jagged edge of the experimental structure.

Hazard Controls:

1) Sharp corner and jagged edges will be filed to reduce injury risk.
2) All corners and edges will be padded with pipe foam.

Hazard Number: 6
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 creates a potential for electric shock.
Hazard Causes
1) Faulty electrical connection allows electrical contact with experimental structure.
Hazard Controls

1) Solder contacts will be electrically insulated.
2) Care will be taken to manage experimental grounds.

Hazard Number: 7
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: 8
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

Hazard Number: 9

Hazard Title: Free float chamber tether failure

Hazard Description:

Tether which keeps the free float chamber attached to the base fails causing the free float chamber to be an unrestrained projectile in the aircraft

Hazard Causes:

1) Tether subject to unforeseen forces during an emergency procedure.
2) Tether not properly attached during pre-flight.

Hazard Controls

1) Tether will be designed with a sufficient factor of safety to support the free float chamber through any acceleration less than 10-g.
2) All tether connections will be checked during loading and preflight to ensure safety of operation.

13. Tool Requirements

14. Photo Requirements

Data for the Gr.A.I.N.S. II experiment is collected via video cameras in the apparatus. Our flight crew will take aboard 35-mm still cameras for experiment and outreach documentation. All cameras will be stowed in crash proof boxes provided for takeoff and landing.

15. Aircraft Loading

16. Ground Support Requirements

17. Hazardous Materials

No hazardous materials are brought onboard the aircraft as part of the Gr.A.I.N.S. II experiment.

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

All test equipment will travel to Houston with the team via van. No shipment is necessary. All equipment can and will be stored at room temperature.

19.2 GROUND OPERATIONS

The Gr.A.I.N.S. II experiment will arrive in Houston fully assembled; however, several alignment and operation checks will need to be performed to ensure optimal performance during flight.

1) Check apparatus thoroughly for damage and/or misalignments that may have occurred in transport.
2) Check all electrical connections to ensure the experiment will be properly powered and to verify that all connections are properly insulated.
3) Set up power supply and proceed with ground testing of entire apparatus.
4) Provide power to all electrical systems (microprocessor, lighting, video cameras
5) Turn on and set up the desktop computer for final checks of optical alignments via test recording through the Firewire port on all three cameras
6) Record 2 or 3 experiment runs through each camera on the ground to verify the optical alignment and focus of the video data.
7) Repeat step 6 as many times as needed to reach the optimal alignment and focus setup
8) Use computer to finalize microprocessor programming.
9) Power the microprocessor to test all controlled subsystem operations and verify the desired experiments can be run.
10) Rewind the tape to the start for flight video recording.
11) Shutdown the power to the experiment.
12) Assemble outreach experiment.
13) Verify power to the driver circuit and solenoid.
14) Verify power and operation of video recorder.
15) Attach Lexan shield to both experiments

Our group will require a 10’ x 10’ area for ground testing operations.

19.3 AIRCRAFT LOADING

The total weight of the test assembly is ____ 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. The free float chamber will be secured to the base plate during loading. Upon loading into aircraft, our tether will be secured to both the base plate and the free float chamber and checked to ensure security of connection.

19.4 PRE-FLIGHT

Ensure that all in flight tools, personal photographic equipment and other accessories are
properly stowed. Verify that all restraints on the apparatus are securely fastened.

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, Plug in and turn on programmable power supply.
2) Turn on the experiment by pulling the master switch. The control system will power up individual components automatically.
3) Also prior to first parabola, remove restraining straps from the free float apparatus leaving it secured on its Velcro pads.
4) Just prior to the first reduced gravity parabola, power the outreach experiment and video recorder. Begin recording outreach chamber.
5) 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 (~ 30 separate experiments per flight).
6) When the "next" button is pressed on our user interface, the solenoid driving our outreach, and an LED on the outreach apparatus will light. This will signify the beginning of entrance into reduced gravity. For data analysis purposes, we will begin taking ball path measurements 2 seconds after this LED lights.
7) As experiment starts, release the free float chamber near the floor of the KC-135.
8) Carefully monitor the free float chamber to ensure safe operation while preventing interference with other experiments.
9) Before entering the 2-g portion of each parabola, secure the chamber onto its Velcro pads.

10) After the final parabola, power down both experiments and secure the complete apparatus for landing.

19.7 POST-FLIGHT

1) Check experimental apparatus for damage incurred during the first flight.
2) Remove Lexan shield from both experiments to allow access to the video cameras.
3) Detach each camera from its mount.
4) Use laptop to check data through Firewire connection.
5) Change tapes for day 2.
6) Secure cameras to their mounts.
7) Make any optical adjustments needed to improve next run's data.
8) Reprogram microprocessor (if needed)
9) Secure Lexan shield.
10) Secure apparatus for flight day 2.

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.