Test Equipment Data Package for

Inertial Property Algorithm Verification (IPAV) Experiment

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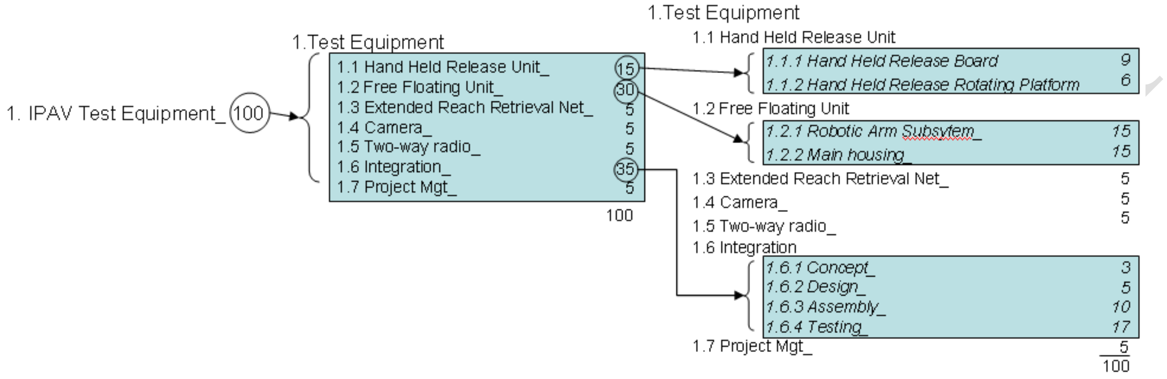
Experiment Title: Inertial Property Algorithm Verification Experiment

Work Breakdown Structure (WBS):



Flight Date(s): 6/4/09 - 6/13/09

Overall Assembly Weight (lbs.):

Assembly Dimensions (L x W x H):

Equipment Orientation Requests: Team members will orient the equipment in the upright position once microgravity commences

Proposed Floor Mounting Strategy (Bolts/Studs or Straps): 1 inch wide straps will be required for three pieces of equipment during Take off/landing. 1 inch wide straps will be required for two pieces of equipment and two team members during microgravity phases of flight.

Gas Cylinder Requests (Type and Quantity): N/A

Overboard Vent Requests (Yes or No): N/A

Power Requirement (Voltage and Current Required): N/A

Free Float Experiment (Yes or No): Yes

Flyer Names for Each Proposed Flight Day:

Camera Pole and/or Video Support: 1 video camera pole

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Flight Manifest

(NAMES DELETED)

Experiment Background

The necessity to accurately and efficiently calculate the changing inertial properties of a flying spacecraft is becoming more evident as on-orbit tasks and operations (such as rendezvous maneuvers, on-orbit refueling, hardware deployment, etc.) become progressively complex and aggressive. This is due to the fact that the control system of a spacecraft usually relies on the knowledge of these parameters to accurately control the spacecraft. A newly developed algorithm is proposed to identify a spacecraft's altered inertial properties by only requiring the excitation of the spacecraft by a robotic arm and measuring the resulting changes of the system's velocity. This robotics-based method is preferable to other methods that require the use of thrusters to excite the spacecraft and the measurement of multiple parameters, which consumes fuel and generates more error due to the noise inherently generated from measurement systems. The goal of this project is to experimentally verify this algorithm in a 6-DOF microgravity environment.

Last year the Inertial Property Algorithm Verification (IPAV) experiment was performed aboard the Microgravity aircraft in an attempt to experimentally verify this algorithm. Though the experiment was successful in many ways, some unforeseen hardware problems that occurred during the flight resulted in the loss of approximately two-thirds of the data. From that experiment, team members have learned a lot about the experiment and the related engineering process. They have new ideas that are anticipated to generate better results from a second test and are highly motivated to perform the experiment once again. This proposal is the result of such a desire.

Similar to last year, a single-axis robotic arm mounted on the top of a rectangular box will be used to represent a mock spacecraft-robotic arm system. The robotic arm will be preprogrammed to perform maneuvers that will excite the mock-up system. The ratio of the robotic arm mass to the main body and the final orientation of the arm relative to the main body will be varied in order to identify the affects that these parameters have on the accuracy of the algorithm. In order to measure the dynamics behavior of the system, an orthogonal set of gyroscopes, a tri-axial accelerometer, an encoder and a camera will be used. Many improvements in both hardware and software have been made to the equipment design and to the test procedures to account for the lessons learned from the last flight.

Experiment Description

Introduction

This proposal contains many terms that can be taken to have multiple meanings. To avoid confusion or misunderstandings of key terms we will provide a short explanation of each term. *Hosting body* or *Main housing* refers to the body that the robotic arm and other secondary bodies are mounted to. *Secondary body* refers to a body inserted into the hosting body in order to induce a change in inertia properties. The term *System* refers to the robotic arm, the hosting body, as well as any other attached bodies. *Inertial properties*, also referred to as *inertial distribution*, refer to the inertia tensor, center of mass, as well as the mass of the object in consideration.

Flight Experiment Description

At the beginning of the experiment, the equipment will be configured as follows: the Free Floating System (FFS) will rest on the rotating platform of the Mounted Release System (MRS) as shown in 1.

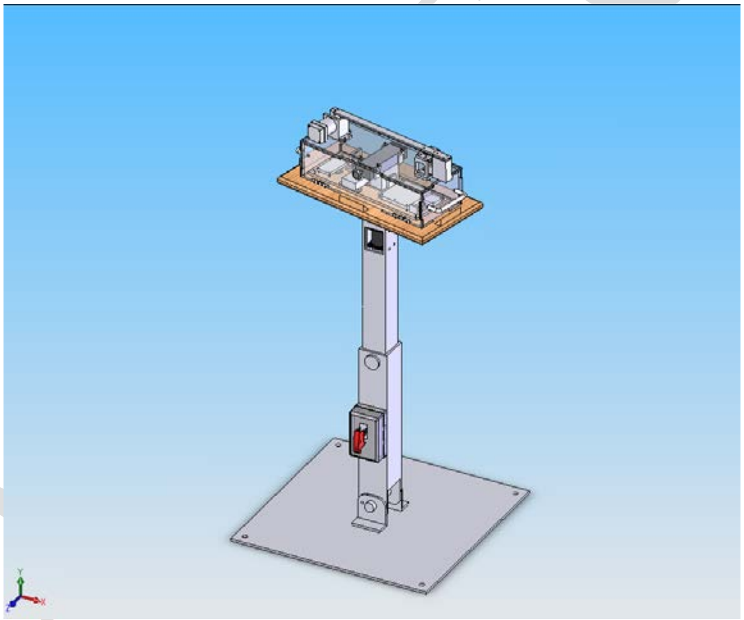


Figure 1. Initial test apparatus configuration.

The FSS will be constrained to the rotating platform during the initial rotational acceleration by electromagnets. Upon the commencement of microgravity, a video camera will begin recording the experiment and the platform on which the FFS rest will begin to rotate, providing the FFS with a controlled rotational velocity. During the experiment, team members will make verbal comments regarding their observations about the experiment into the microphone of the video recorder. These comments may include sudden acceleration or jostling of the fuselage as well as any perturbations in the FFS's dynamic response. Once the system has reached the desired rotational velocity, the electromagnets will be deactivated, releasing the FFS from the MRS. A team member will then pull a pin from the MRS, allowing the retraction of the rotating platform away from the FFS. Subsequently, another team member will pull the hinge pin which will allow the MRS to fold to the fuselage floor where it can be strapped down by a Velcro strap. Once the MRS has been safely stowed away from the experiment space, the team member will ensure that the FFS remains in control and does not leave the allotted experiment space. Ideally, this system will allow the FFS to float freely at the desired angular velocity with minimal external influences. The free floating state of the FFS after microgravity commences is shown in 2.

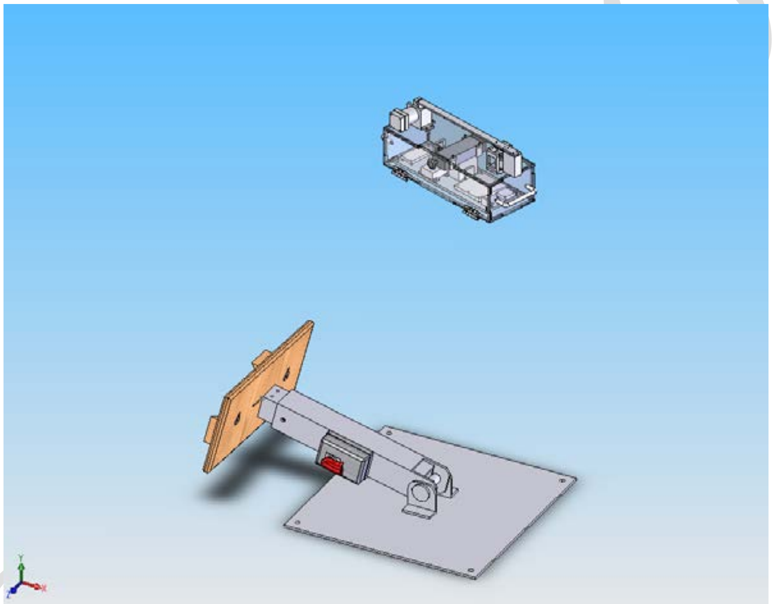


Figure 2. Free Floating configuration of test hardware.

The programming onboard the FFS will initiate when a magnetic sensor detects when the small magnet that is attached to the revolving platform is pulled away from the system. At this point, the systems onboard the FFS will begin logging measurements of the system's dynamic response using the onboard gyroscopes and accelerometers. Next, the electromagnet securing the robotic arm in the closed position will deactivate. A signal will then be sent to the microcontroller, telling it to actuate the robotic arm. The stepper motor will then open the robotic arm until it has reached a preprogrammed angle. The expected free floating time is about 6 to 10 seconds, so it is necessary for the arm to reach its final position inside this time frame. The data recorded for each run will include the initial, unperturbed, rotating state, followed by the dynamic response of the system as the robotic arm moves to its final position. These data will be applied to the Inertial Property Algorithm in an attempt to empirically prove the concept. For details on the aforementioned identification algorithm, see Reference 1.

As a result of the IPAV Team's experiences with the test process in flight, an improved parameter alteration schedule will be followed. The system's parameters will be adjusted at a specified interval shown in Table 1. This will help determine the algorithm's accuracy given various conditions. Parameters will be changed so that the change in dynamic response of the system can be directly attributed to the change in parameters. The interval determined to be the best for the data set is ten parabolic maneuvers of the aircraft. This schedule will optimize the number of parameter changes and still provide a generous data set for sound statistical analysis.

Taking into account that each of the two flights should consist of thirty parabolic maneuvers, the schedule will allow for four changes of parameter in the experiment. Two parameters will be changed twice. The first five parabolic maneuvers will be used for team member acclimation, trial runs, and systems checks, while the next five will for determining a reference dynamic state.

The parameters that are going to be tested are the final orientation of the robotic arm and the ratio of the robotic arm mass to the primary body mass. The reference dynamic response will consist of the FFS free floating in an unperturbed state without rotation or actuating the robotic arm. Using the reference dynamic response will aid in determining how the dynamic response changes as the parameter are varied.

For all parameters, the FFS will be accelerated to an initial rotational velocity of 180 degrees per second. The first test parameter that will be varied is the final angle of the robotic arm relative to the FFS housing. It will be tested in two configurations for ten parabolic maneuvers each. The first configuration will limit the robotic arm to a relative angle of 90 degrees and the second will allow the arm to extend to a full 180 degrees. These desired final orientations are illustrated in Figures 4 and 5. This parameter is expected to increase the accuracy of the algorithm as the degree of final arm orientation increases.[1] The final parameter is the addition of a secondary body to the FFS. It has been indicated that the accuracy of the algorithm may be influenced by the ratio of the robotic arm mass to the mass of the joined bodies.[1] A secondary body will be secured inside the housing of the FFS to test this. This parameter will be tested for each of the robotic arm final configurations for ten parabolic maneuvers each. The MRS and FFS will be reset for each trial as well as any necessary modification of parameters between microgravity segments, when the aircraft is experiencing hypergravity. This will require team members to be positioned near the MRS and the experiment area.

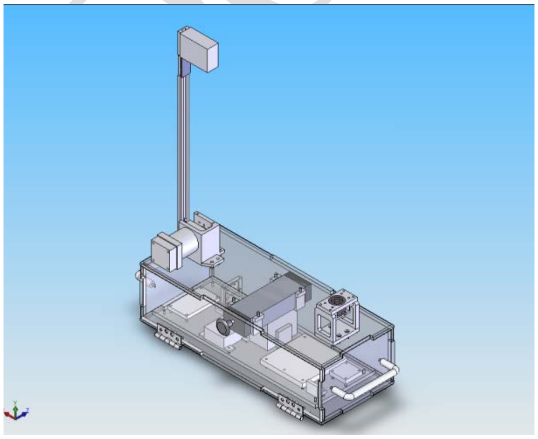


Figure 1. 90 degree final orientation.

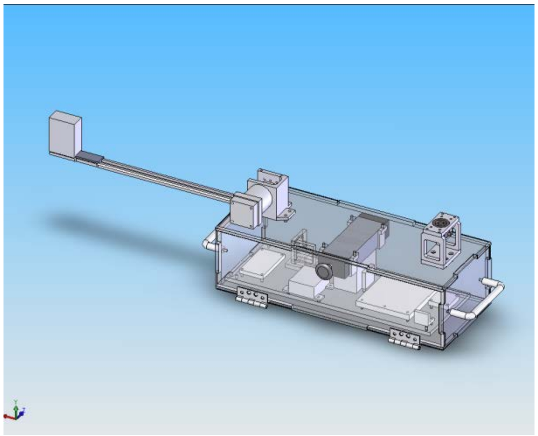


Figure 2. 180 degree final orientation.

Flight 1				
Test Run	Final Position of Robotic Arm	Additional Mass (10 N)	Reason	Notes
1-5	N/A	N/A	Acclimation and Trial Runs	These runs will be used for team member acclimation and systems checks.
6-10	N/A	N/A	Establish a reference dynamic behavior	These runs will be used for establishing a control for the dynamic response.
11-20	90°	No	Determine effects of arm position on algorithm accuracy	The arm will rotate to an orientation of 90° without any additional mass.
21-30	180°	No	Determine effects of arm position on algorithm accuracy	The arm will rotate to an orientation of 180° without any additional mass.
Flight 2				
31-35	N/A	N/A	Acclimation and Trial Runs	These runs will be used for team member acclimation and systems checks.
36-45	90°	Yes	Determine effects of added mass on algorithm accuracy	The arm will rotate to an orientation of 90° with an additional mass of 10 N.
46-55	180°	Yes	Determine effects of added mass on algorithm accuracy	The arm will rotate to an orientation of 180° with an additional mass of 10 N.
56-60	N/A	N/A	Outreach	These runs will be used for outreach demonstrations.

Science Goals

The desired results of this experiment are a strong data set consisting of various changes in the measured angular velocities as the orientation of the robotic arm varies. The anticipated method used to obtain these measurements will be to secure a set of gyroscopes and linear accelerometers to the hosting body. The acceleration measurements are not required, but they will still be obtained in order to provide a more thorough method of monitoring the dynamic behavior of the system. They can also be numerically integrated into computed velocity data, as the secondary measurements to enrich the primary velocity measurements.

Ground Experiment

As a part of the overall objective to experimentally verify the said algorithm, several intermediate steps must be taken. These steps are outlined in the flow chart below.

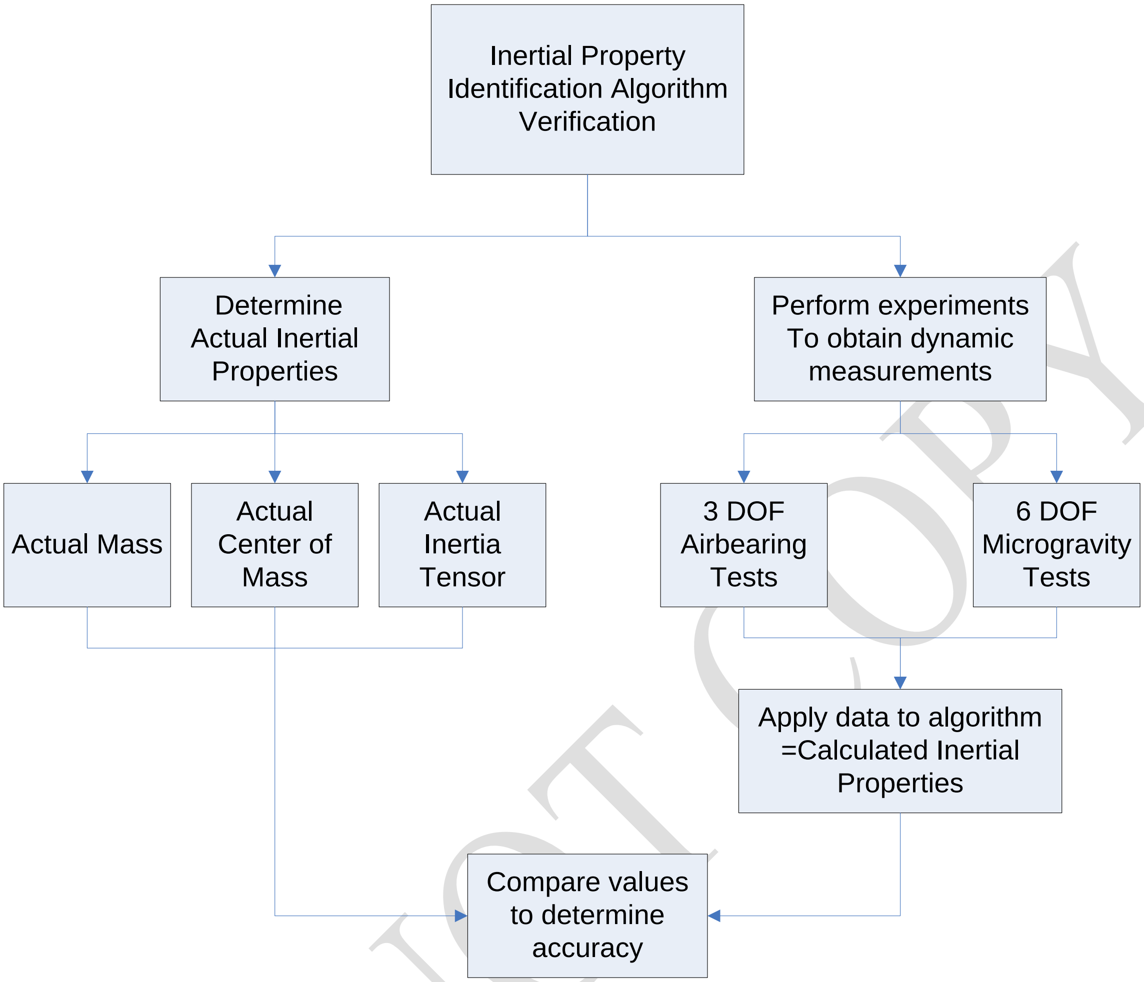
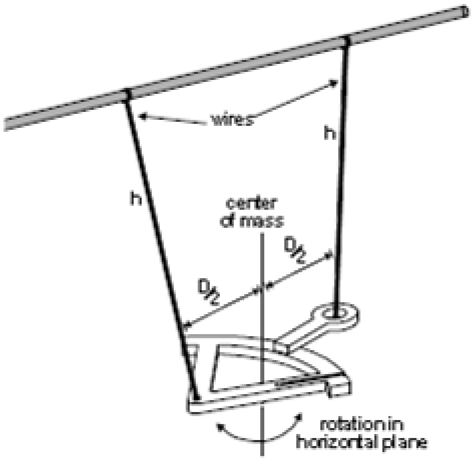


Figure 3. Algorithm Verification Flow Chart

The flow chart indicates the necessity to identify the actual inertial properties of the FFS. Identifying the mass and center of mass of the system are trivial tasks. However, obtaining the inertia tensor is much more complicated. A method known as the Bifilar Pendulum method has been chosen to identify certain constituents of the inertial tensor i.e. the moments of inertia. It is a method that has been proven to generate results that are accurate to within .1% of the actual values.[4] The method consists of suspending the object of interest in the air with two thin, parallel chords. The object is then rotated in the horizontal plane to a designated angle from the equilibrium point and released, as shown in figure 13.[5] Once released, the object will oscillate about the equilibrium position. This behavior can be modeled as an undamped harmonic oscillator. In doing so, the moment of inertia about the axis of rotation can be calculated with the following equation, which was derived from an undamped harmonic oscillating model.

Equation 3) $I = \dfrac{T^2 D^2 g M}{16\pi^2 h}$



In equation 3, all the following parameters are known: D represents the distance between the suspension chords, g is the acceleration due to gravity, M is the total mass of the object of interest, and h is the length of the suspension chords. The period T is the only parameter required to be measured. This measurement can easily be made with a photo emitter - detector pair and a precision timer. The result of this task will be the actual moment of inertia about the rotational axis. Various moments of inertia will be obtained by applying this method with varying orientations of the system.

Figure 4. Bifilar Pendulum test setup.

In addition, an experiment utilizing the planar air-bearing testbed shown in Figure 14 will be performed in order to generate similar data to the microgravity testing. This testing will be limited to 3 degrees of freedom (DOF) as opposed to the 6 DOF provided by the microgravity environment. The air-bearings will be used to slightly lift the mock-up system off of the precision ground surface of the granite table. This will eliminate any impedance of the system's dynamics due to frictional forces. Hence, any dynamic response of the system in the plane normal to the gravitational field will accurately represent the dynamics that would be exhibited by the system in a microgravity environment.

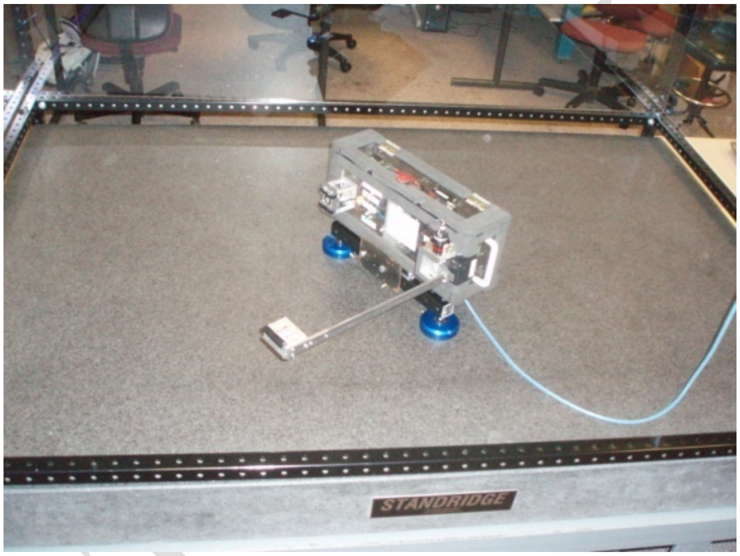


Figure 5. Airbearing testbed for 3 DOF testing.

During this testing the angular velocity, linear acceleration, and arm position will be measured. These parameters will be applied to a planar version of the algorithm in order to generate the inertial properties of the system relative to the test plane. These values will be used to supplement those obtained from the microgravity testing.

Equipment Description

The in-flight experiment equipment consists of two primary systems and a few operationally required components. Table 2 lists all of the hardware.

Table 1. Individual components of the experiment and their description

Item	Type	Description
FFS	Experimental	Primary piece of free floating hardware, polycarbonate box with corners and edges covered with closed cell foam
HHR	Experimental	Wooden handle and rotating platform, with all edges and corners rounded

Extended Reach Retrieval Net	Experimental	aluminum pole
Radio	Experimental	COTS
Video Camera	Experimental	COTS, cordless, color, large memory capacity
Restraint Straps	Experimental	RGO supplied straps

The following sections provide an in-depth description of these items.

Free Floating System (FFS)

The system consists of the main housing, the robotic arm subsystem, and in some cases a secondary mass secured inside the main housing. During lift-off and landing the FFS will be strapped down to the fuselage floor in the center of the allotted test area onboard the aircraft.

Main Housing

The main housing is essentially a box made from a high impact resistant, clear, polycarbonate material (aka Lexan®). The main housing contains most of the critical electronics for the experiment as well as the secondary mass. Table 3 lists the various interior components and their purpose.

The interior components are mounted inside the main housing on a removable polycarbonate plate. This will allow for ease of removal and installation of the components. Careful consideration was taken to configure the components in a manner that places the FFS's center of gravity (CG) in a location that coincides with the pivot location of the HHR unit's rotating platform. This was done in order to mitigate any undesirable moments generated while the HHR platform is spinning during the experiment deployment phase.

One of the sides will be used as an access panel in order to install and work on the interior components. The access panel will be hinged on its bottom edge and a set of "grab-catch" style latches will hold it shut during the test runs. All edges and corners of the main housing will be covered with a half-inch thick, close-cell foam that has a Durometer rating of extra soft.

Table 2. Interior components of the main housing

#	Component	Purpose
1	Orthogonal Gyroscope Configuration (OGC)	Obtain angular velocity measurements about the three principle axis of the FFS
2	Triaxial Accelorometers	Obtain linear acceleration measurements of the FFS
3	MicroController and Sensor Board	Control the robotic arm driver and motor and interface the sensors to the data acquisition system
4	Data Recorder	Record sensor outputs
5	Stepper Motor Driver	Controls pulsed input to the robotic arm stepper motor
6	Battery Pack A	Supply power to the seat bracket electromagnet and stepper motor driver
7	Battery Pack B	Supply power to the microcontroller and data recorder
8	Secondary Mass	Used during one interval of testing to alter the inertial properties of the FFS

In addition, vent holes will be drilled into each panel of the main housing in order to provide adequate heat ventilation to prevent electrical components from overheating.

Figure 9 is a mechanical drawing indicating its primary specifications, while figure 10 is an image of the fully assembled main housing complete with padding.

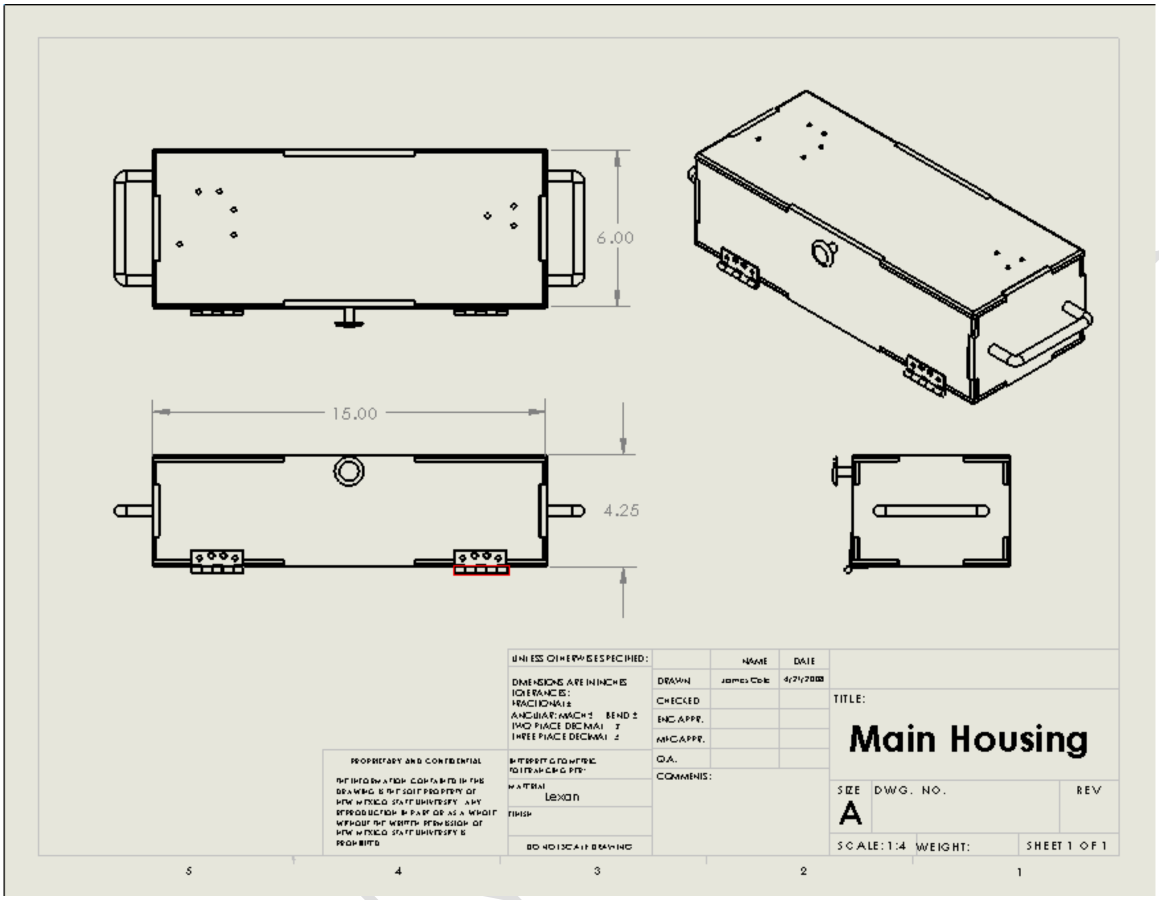


Figure 6. Mechanical drawing of the main housing

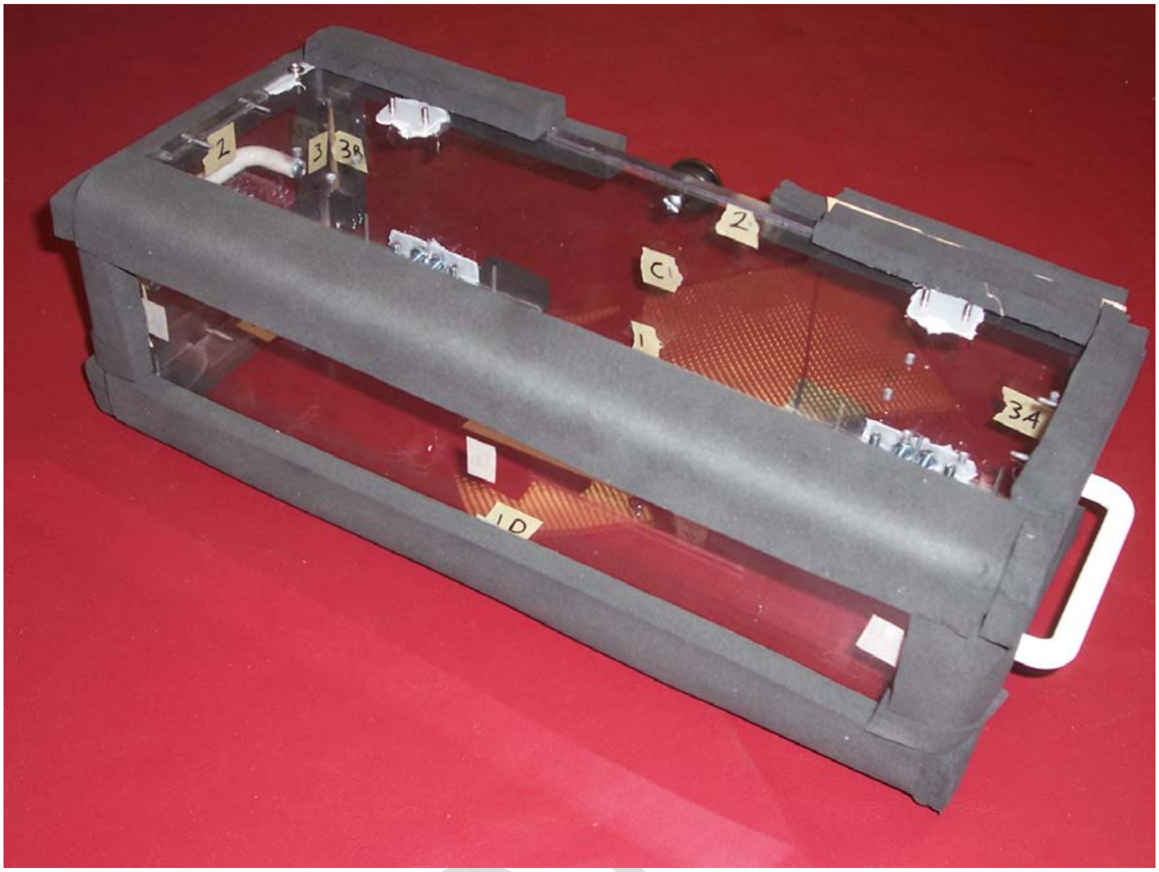


Figure 7. Fully assembled main housing with padding

Robotic Arm

The robotic arm that will be used to induce the dynamic response will be mounted on the top surface of the main housing. It consists of the pivot housing, the arm member with an attached block at its end, and the seat bracket. The arm is driven by an assembly consisting of a stepper motor, attached to a gearhead and a right-angle drive converter. This assembly is mounted to the pivot housing. Figures 11 to 13 are mechanical drawings indicating the specifications of the various main components of the robotic arm subsystem. Figure 14 is an expanded view of the pivot housing which illustrates how the motor interfaces with the pivot pin. A magnetic encoder that is attached to the motor shaft will provide readings of the robotic arm’s angular orientation at any given time with respect to the main housing. This data can be used to differentiate the angular velocity of the robotic arm relative to the main housing. Though these measurements are not critical, they will assist in describing the full dynamic response of the system.

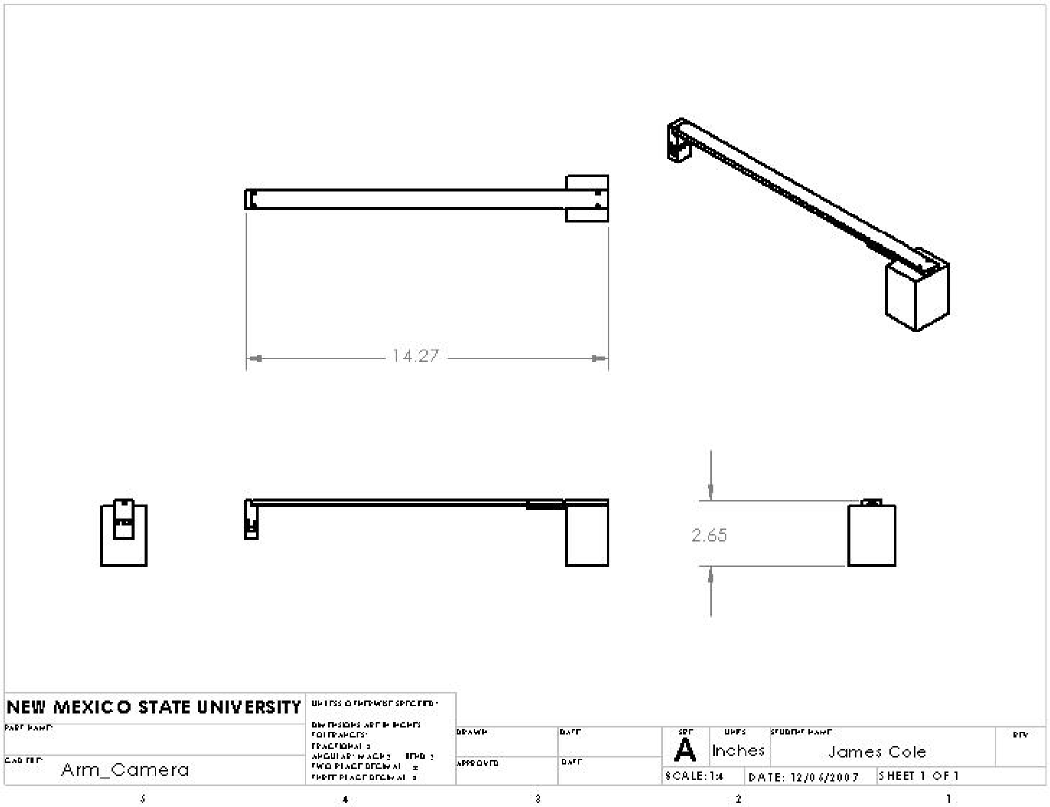


Figure 8. Arm Assembly

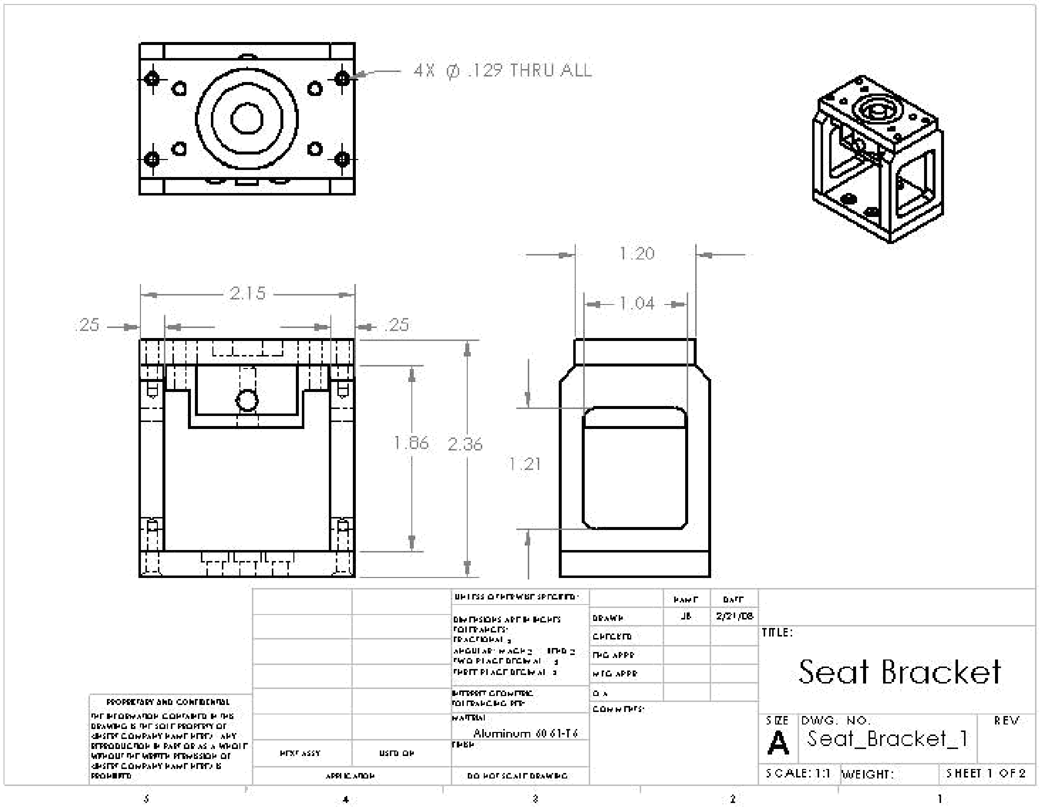


Figure 9. Seat Bracket assembly

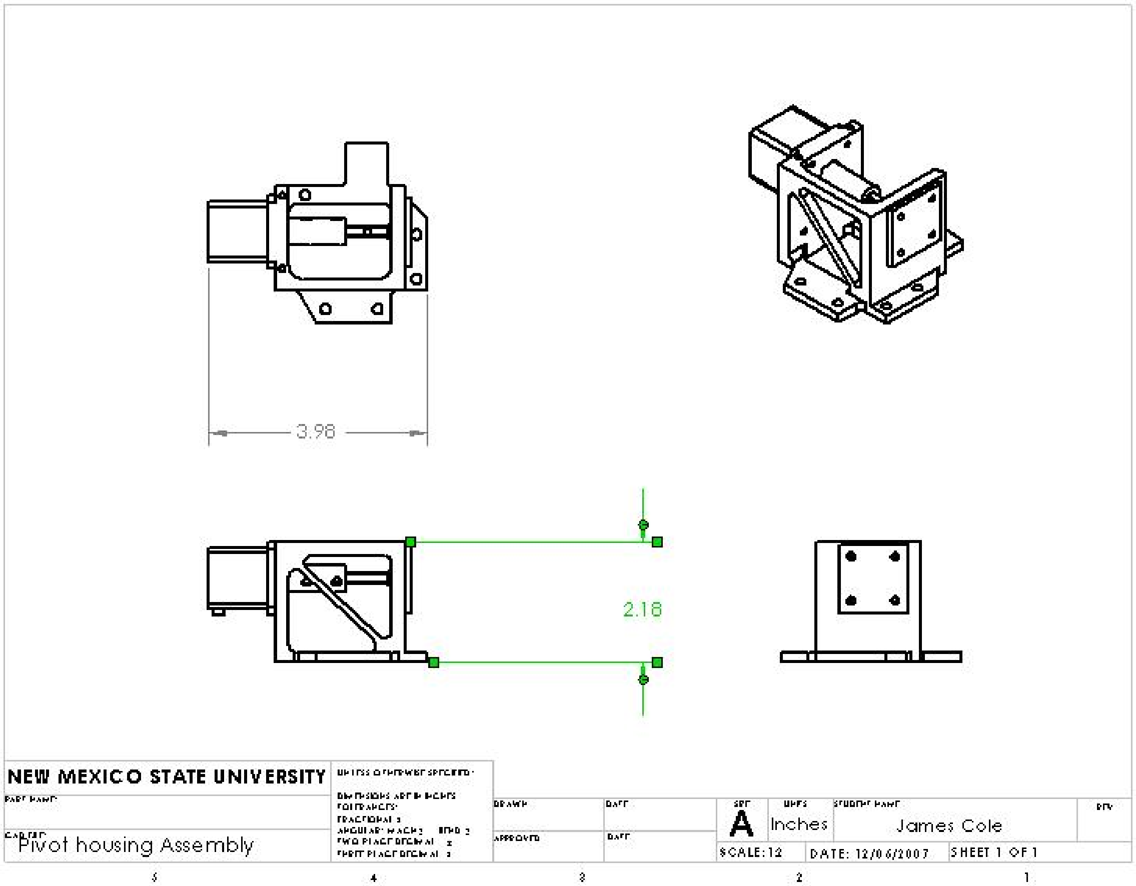


Figure 10. Pivot Housing Assembly

The seat bracket will provide the arm member with support until it has become active. The seat bracket will also be used to restrain the arm by implementing an electromagnet where the arm contacts the seat bracket. The electromagnet will be deactivated just before the arm becomes activated.

The various components of the robotic arm are made of T6061 aluminum along with a few Delrin® components where frictionless surfaces are required. All the components have been machined in-house using the NMSU Student Project Center's CNC and other machining equipment. They will be fastened to the main housing using socket head cap screws in order to make an Allen wrench set the only tool required to assemble the system.

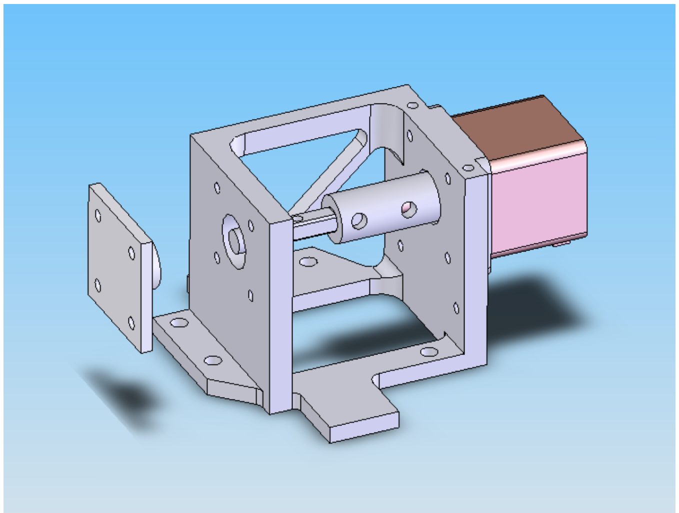


Figure 11. Expanded view of the pivot housing

Secondary Mass

The use of the secondary mass is necessary to induce a change in the inertial properties of the FFS during the selected interval of tests. The secondary mass is an aluminum bar with half inch pads on each end of the bar. Its specifications are indicated in figure 15.

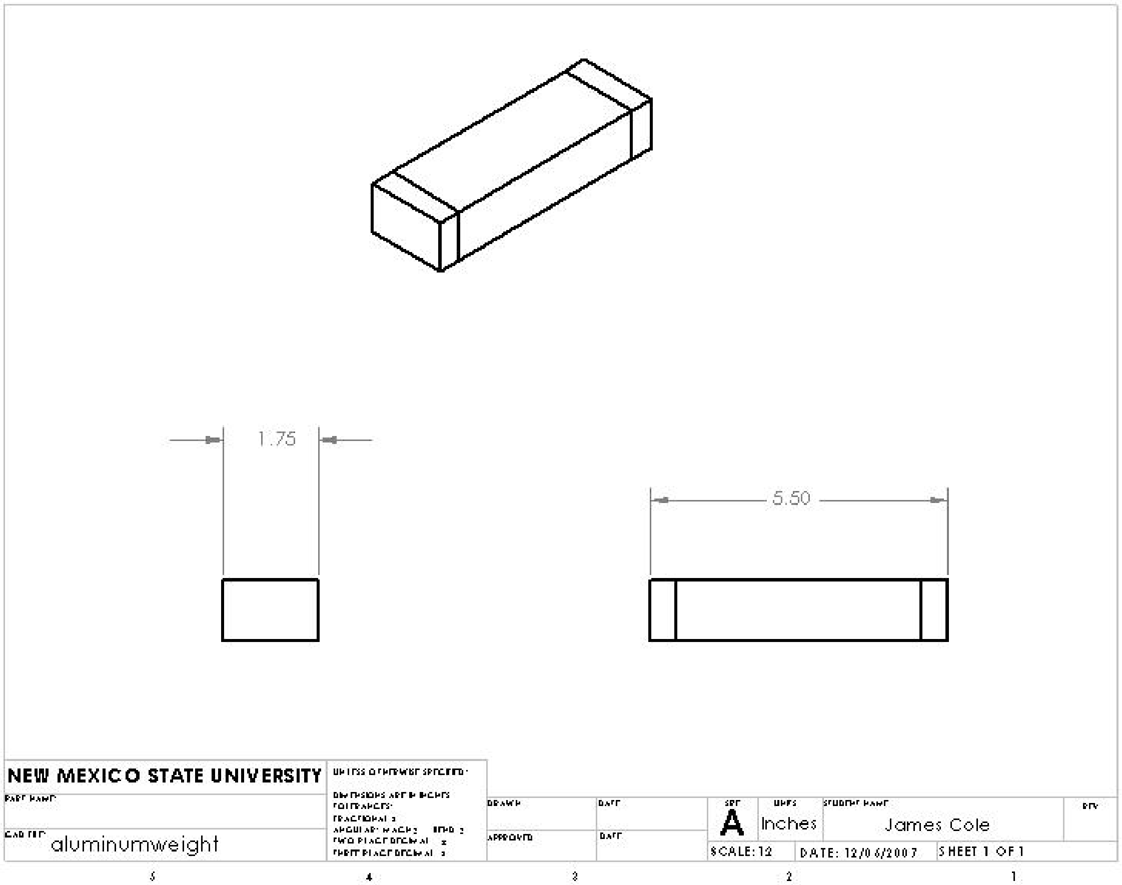


Figure 12. Specifications of the secondary mass

The bar is mounted on the inner surface of the top panel using two square brackets. It is allowed to translate freely from side to side through the brackets in order to enable quick installation and removal between the respective test intervals. For instance, just before the test that calls for the secondary mass to be applied, a team member will open the access panel and slide the mass into the brackets until the end of the mass contacts the side panel, restricting it from sliding any further in that direction. Then the access panel will be shut which will restrict the mass from sliding back the other direction. This will fully constrain the mass. The final configuration is shown in figure 16.

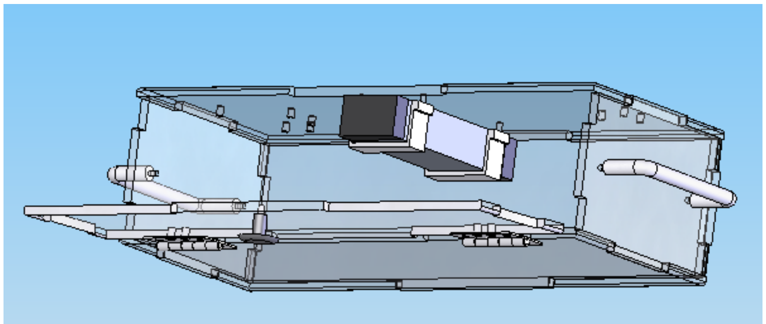


Figure 13. Installed configuration of the second masses

Free Floating System Design

The Free Floating System (FFS) design is made up of two main components: the main housing and the robotic arm subsystem.

The interior of the main housing contains a majority of the electrical components. Within the main housing are three single-axis gyroscopes, a tri-axial accelerometer, a robotic arm driver, an electronic data logger, sensor controls, and a battery pack that will provide power to the free floating system. The exterior structure of the hosting body is made from high impact resistant polycarbonate panels. On the back and side panels there will be drilled vent holes. The purpose of these drilled holes is to enable the electrical components to breathe properly and not overheat. Handles will be mounted to the exterior of the main housing in order to ease the task of retrieving the FFS.

On the exterior of the main housing is a robotic arm capable of a 90 degree and a 180 degree orientation. A small mass will be mounted to the end of the robotic arm simply to increase the mass ratio of the robotic arm to the hosting body. One of the components in the robotic arm subsystem is a seat bracket that will be used to secure one end of the robotic arm while it is at rest. The other end of the robotic arm will be connected to the shaft of the gearhead that will be mounted to the pivot housing. An absolute magnetic encoder will be mounted on the alternate side of the pivot housing from the stepper motor/gearhead configuration and a protective cover will be mounted over it. This configuration is an improvement from the previously flown design. It is intended to ensure that any impacts to the system do not result in lost data. The encoder will be used measure the orientation of the robotic arm relative to the main housing, while the stepper motor/gearhead will drive the robotic arm to the desired position.

The three single axis gyroscopes will measure the angular velocity of the system to determine the dynamic reaction about all three orthogonal axes. The accelerometers will serve to record and enhance dynamic data recorded by the gyroscopes. The robotic arm's purpose is to change the dynamic response on the system via orientation and a prescribed mass.

Located on the exterior of the hosting body is an electromagnet within the seat bracket, providing a constraint to the robotic arm. This electromagnet will activate when the FFS is on the release unit platform, and deactivate once the release system platform is pulled away from the FFS. This is accomplished by implementing a magnetic field sensor that will be mounted to the lower surface of the FFS and a permanent magnet that will be mounted to the top surface of the MRS platform. When the magnetic field sensor detects the permanent magnet mounted to the top surface of the MRS platform the electromagnet will be activated.

In the reduced gravity setting, the hosting body's mass parameter is manually changed by accessing the interior of the FFS and inserting a secondary mass into the secondary mass brackets as shown in Figure 6. There will be a switch mounted to the top surface of the top panel

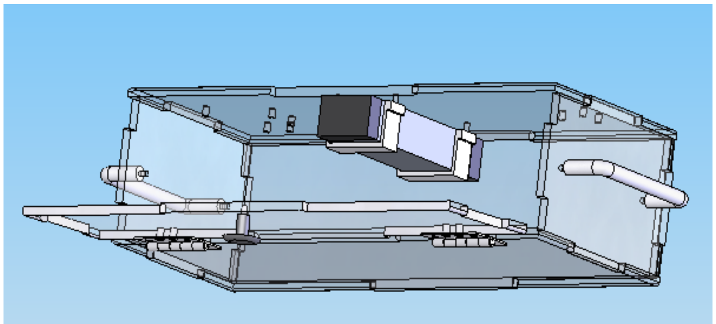


Figure 14. Secondary mass inserted into the main housing.

that will allow team members to alter the system's program to achieve either one of the two robotic arm orientations. While the free floating system is activated, data will be recorded via the data recorder. The recorded data will be stored on an SD card that will be removed and downloaded after one flight has been completed.

Mounted Release System Design

The Mounted Release System (MRS) unit will consist of four main components: a motor, top platform with support blocks, a two-part collapsing stand, and a square base plate with hinge brackets. The MRS system assembly is shown in Figure7.

The motor, which will be mounted inside the top section of the collapsible stand, will provide motion to the platform on which the Free Floating System (FFS) will sit. The motion induced by the motor will be the initial angular velocity applied to the FFS during times of reduced gravity. A battery pack will be mounted on the outside of the collapsible stand that will provide power for the motor and electromagnet constraints (figure 7). The rotating platform will be used to keep the FFS constrained while the system is rotating. The two-part collapsing stand is designed to collapse by pulling a spring-loaded pull pin mounted to the lower section of the stand. Once the pin is pulled, the platform attached to the end of the top section of the stand will be pulled away from the FFS. The platform is attached to the end of a motor shaft of a motor mounted inside the upper section of the stand as shown in Figure 8. The rotating platform provides the FFS with a controlled initial free floating state. A retractable lanyard will act as the downward force when the system is in a reduced-gravity state. This will result in the collapsing of the top portion of the stand into the larger lower section of the stand. The retractable lanyard will be mounted on the bottom of the lower section and attached to the bottom of the top section (Figure 9). There will be pin holes located on the upper section of the stand in such

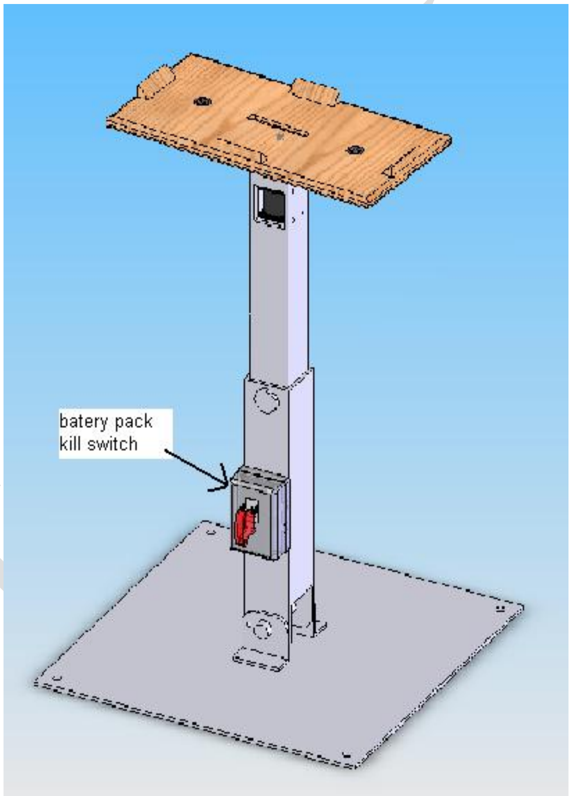


Figure 16. MRS in the upright, extended configuration.

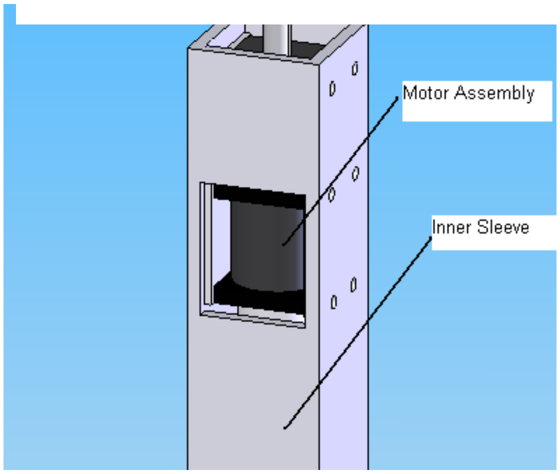


Figure 15. MRS Platform Motor mounted inside upper section of the stand .

a way that the stand can be locked in either the collapsed configuration or the expanded configuration once the appropriate hole passes in front of the spring loaded pull pin.
The stand sections will be made of 6061 aluminum with a square-tube cross section in order to allow for easy hardware mounting.

The platform will be attached to the rotating shaft of the motor. This configuration is shown in figure 10.

The platform will contain a slot that will allow team members to adjust the pivotal center of the platform. The purpose of this adjustable design is to compensate for the shift in the center of gravity of the FFS once the secondary mass is inserted into the main housing. By shifting the pivotal center of the platform to coincide with the FFS center of mass, we will effectively mitigate undesirable forces generated from the centrifugal acceleration caused by the rotational motion of the system.

The platform, made of wood, will contain four wedges as shown in figure 11. The wedges are used to constrain the FFS laterally to avoid any slipping before microgravity commences. The four wedges will be mounted to the platform in the same fashion as shown in figure 11. The position of the wedges is simply to minimize the effects of friction between the system and the wedges as the platform is pulled away from the FFS. This allows the system to maintain a controlled initial state by minimizing forces during the release sequence. The wedges are designed and made with a steep enough face to ensure proper restraint to the system before micro-gravity is exhibited. Additionally, two electromagnets will be implemented in order to constrain the FFS from lifting off of the platform prior to a stable microgravity environment. This phenomenon was experienced during previous testing which resulted in premature activation of the system. Thus the electromagnets were implemented in

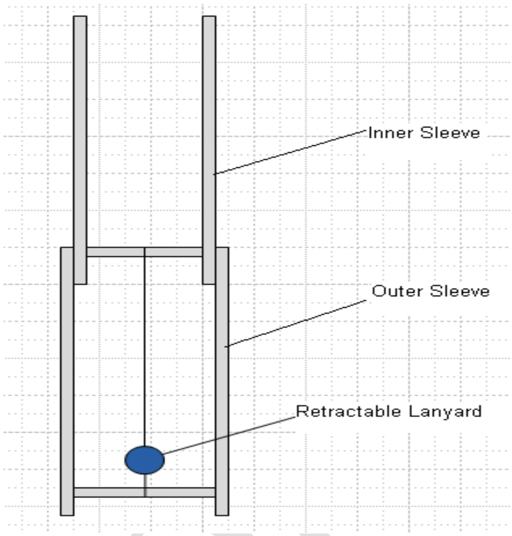


Figure 17. Retractable lanyard attachment method.

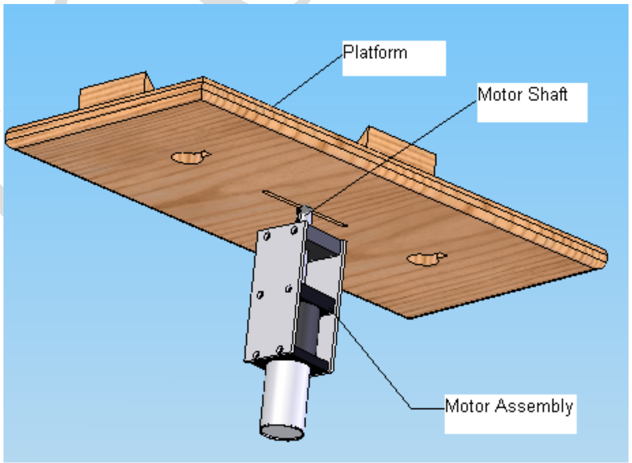


Figure 19. Interface between the Platform and the motor shaft.

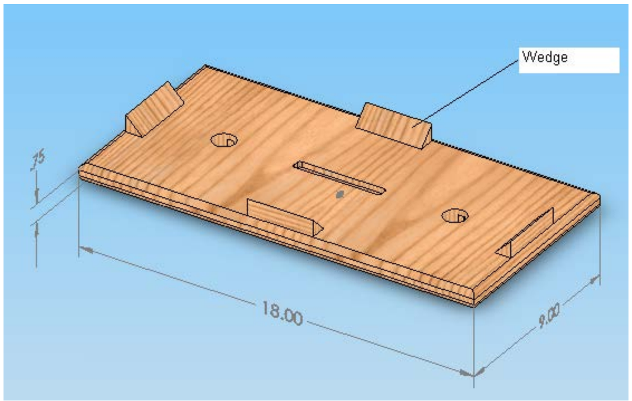


Figure 18. Platform design with wedge constraints.

the new design to improve the design previously flown. The electromagnets will be mounted to the rotating platform while two plates of ferrous metal will be mounted to the bottom surface of the FFS.

Upon Microgravity commencement a team member will disengage the electromagnets with a switch mounted on the power supply. Another team member will wait for approximately 2 seconds before pulling back on the collapsing spring loaded pull pin. This pause will allow the residual magnetic force to die off before the platform is pulled away from the FFS. The retractable lanyard will then pull the upper section downward, away from the FFS. At this point the platform motor will be deactivated and another spring-loaded pull-pin that is mounted on the hinge bracket of the MRS will be pulled allowing the collapsed stand to fold to the fuselage floor. A team member will then strap the collapsed stand to the fuselage floor with a Velcro strap. This configuration will ensure that the MRS does interfere with the free floating system as the test is being performed. Having a collapsible, folding stand enables the teammates to focus more on the FFS, hands-free, thus creating a safer environment. Additionally, closed foam padding will be applied to all sharp corners and pinch points to mitigate injuries to the team members and the flight crew.

Electrical Analysis

Schematics

Load Tables

Stored Energy

This project does not use any significant stored energy devices, so the only capacitors used are on the circuit boards and do not store voltages over 5V. The electromagnet used can build up potentially dangerous charges during periods of current transients; however a flyback protection diode has been included in the driving circuit to protect the transistors and prevent voltage spikes.

Electrical Kill Switch

There is one electrical kill switch located on the top of the containment box which has two circuits, one in series with Battery A and one in series with Battery B. If the switch is flipped it will open both battery circuits *after* the fuses to prevent any failures with the kill switch to damage batteries. There is also a kill switch located on the mounted release stand which operates identically.

Loss of Electrical Power

In the event of an electrical power failure to any number of electrical components, the system will simply shut down. A loss of power will represent an early-terminated test run but will not corrupt data from previous tests and may provide good data depending on when the power failure occurs.

Pressure Vessel or System

Not applicable to this experiment

Laser Certification

Not applicable to this experiment

Parabola Details and Crew Assistance Required

In order for the experiment to be successful the FFS will need to experience zero gravity while the experiment is being performed. Considering the critical nature of this requirement, it has been identified as a hard parabola requirement.

Due to the experiment being characterized as a free floating experiment the assistance of a flight crew member is requested. Other than what is required by the RGO for free floating experiments, the flight crew member will only be requested to monitor the team members performing the experiment. It may be necessary for the crew member to assist the team members to retrieve the FFS if he/she observes that the experimenting team members are having difficulty doing so.

Institutional Review Board (IRB)

Not applicable to this experiment

Hazard Analysis

HAZARD	YES	NO	CONTROLS/COMMENTS
ACCELERATION			
INADVERTENT MOTION	X		**Cause:** Unanticipated increase in the air craft speed or change in direction **Effect:** Operators lose control of the FFS and/or HHR **Control:** Straps are to be employed to secure equipment and personnel to the fuselage floor during times in flight that have increased possibility of unanticipated accelerations. The ERRN can be employed to restrain the FFS and/or the HHR unit during microgravity phases of flight
SLOSHING OF LIQUIDS		X	
TRANSLATE LOOSE OBJECT	X		**Cause:** None of the experiment equipment is fastened to the fuselage resulting in all equipment being classified as loose objects. Unanticipated accelerations or operators not monitoring the equipment. **Effect:** Operators lose control of experiment equipment

			Controls: Straps are to be employed to secure equipment to the fuselage floor during times in flight that have increased possibility of unanticipated accelerations and while operators are not using the equipment.
DECELERATION			
IMPACTS (SUDDEN STOPS)	X		**Cause:** operators unprepared to come out of zero gravity phase of flight, unexpected moments of extreme turbulence or low situational awareness **Effect:** injury to personnel and damage to equipment **Controls:** Operators will maintain proper situational awareness and pay attention to commands provided by flight crew members. Operators will receive training that will prepare them to remain vigilant and aware of their surroundings during all phases of flight. Padding and rounded edges applied to all equipment that can cause harm to personnel.
FALLS	X		**Cause:** tripping on tiedowns and fasteners; operators unprepared to come out of zero gravity phase of flight. **Effect:** Injury to operators **Controls:** Padding and rounded edges applied to all equipment that could cause harm to personnel. Operators will receive training that will prepare them for all phases of the flight.
FALLING OBJECTS	X		**Cause:** operators unprepared to come out of zero gravity phase of flight; operators not monitoring experiment equipment; unanticipated return to gravity environment **Effect:** Injury to personnel and damage to equipment **Controls:** Padding and rounded edges applied to all equipment that could cause harm to personnel. Operators will receive training that will prepare them for all phases of the flight. ERRN can be employed to rapidly retrieve equipment in case of emergency.
FRAGMENTS OR MISSILES	X		**Cause:** broken pieces of equipment floating around **Effect:** lodging in flight critical hardware causing malfunctions; lodging in crew members eyes **Controls:** The ERRN has a fine net that is capable of retrieving floating fragments; All hardware has been verified to survive anticipated maximum loads that could result in equipment fragmenting; crew members will wear eye protection
CHEMICAL REACTION (Non-Fire)			
DISASSOCIATION		X	
COMBUSTION		X	
CORROSION	X		**Cause:** moisture induced corrosion **Effect:** damage to equipment

			Controls: Experiment equipment has been fabricated from corrosion resistant materials
REPLACEMENT		X	
ELECTRICAL			
SHOCK		X	
BURNS		X	
OVERHEATING		X	
IGNITION OF COMBUSTIBLES		X	
INADVERTENT ACTIVATION	X		**Cause:** Operator error - accidental premature FFS activation
			Effect: operators lose control of the FFS or HHR unit
			Controls: In the event of an inadvertent activation the ERRN can be employed to contain the FFS and the master kill switches can be used to deactivate the rotation of the robotic arm and the HHR unit
UNSAFE FAILURE TO OPERATE	X		**Cause:** failure of armature restraining electromagnet due to loss of power
			Effects: uncontrolled release of the robotic arm while in rotating phases of deployment
			Controls: Charging will be done previous to loading the aircraft and monitored by team members to prevent overcharging. To prevent shortcircuiting fuses will be implemented.
EXPLOSION, ELECTRICAL	X		**Cause:** Over charging or shortcircuiting of the Lithium Ion Polymer Batteries
			Effect: Shrapnel
			Control: All batteries will be charged prior to boarding the aircraft using specialized battery chargers with built in controls to prevent overcharging
VOLTAGE (>50 VOLTS)		X	
BATTERIES	X		Chemistry: Li Po Qty: 2 packs Size:14.8V & 7.4V
			Chemistry: Alkaline Qty: 4 batteries Size:D cell
			Chemistry: Ni Cad Qty: 1 pack Size: 6 V
GENERATION/STORAGE (COILS, MAGNETS, CAPACITORS, ETC.)	X		Though magnets exist in the system, they are small enough that no potential hazards can be identified.
EXPLOSIVE/EXPLOSIONS			
EXPLOSIVE PRESENT		X	
EXPLOSIVE GAS		X	
EXPLOSIVE LIQUID		X	
EXPLOSIVE DUST		X	
FLAMMABILITY & FIRES			
PRESENCE OF FUEL	X		**Cause:** Overcharging of Lithium ion polymer battery pack
			Effect: Equipment may catch on fire

			Control: All batteries will be charged prior to boarding the aircraft using a specialized battery charger with built in controls to prevent overcharging
PRESENCE OF STRONG OXIDES		X	
FIRE DETECTION		X	
HEAT & TEMPERATURE			
SOURCE OF HEAT, NON-ELECTRICAL		X	
HOT SURFACE BURNS (>113O F, 45O C)		X	
VERY COLD SURFACE BURNS (<39O F, 4O C)		X	
INCREASED GAS PRESSURE		X	
INCREASED FLAMMABILITY		X	
INCREASED VOLATILITY		X	
TEMPERATURE DIFFERENTIALS STRESSES		X	
HARDWARE SAFE THERMAL LIMITS KNOWN		X	
MECHANICAL			
SHARP EDGES OR POINTS	X		**Effect:** Injury to operators **Controls:** All edges and corners have been rounded or padded with half inch close-cell foam
ROTATING EQUIPMENT	X		**Effect:** Injury to operators **Controls:** All edges and corners have been rounded or padded with half inch close-cell foam; kill switches have been implemented to quickly stop the rotating equipment in the event that it becomes a hazard. Eye protection is to be worn by operators.
RECIPROCATING EQUIPMENT		X	
PINCH POINTS	X		Though pinch points exist in the design no control has been taken due to the improbability of the occurrence and the minor effects that would result from the occurrence.
WEIGHT TO BE LIFTED (exceeds 40 lbs. or 4 ft. in diameter)		X	Weight________lbs. Approximate Size________
STABILITY/TOPPLING TENDENCY		X	
EJECTED PARTS/FRAGMENTS	X		**Cause:** fracturing or fragmenting of the experiment equipment **Effect:** lodging in flight critical hardware causing malfunctions; lodging in crew members eyes

			Controls: The ERRN has a fine net that is capable of retrieving floating fragments; All hardware has been verified to survive anticipated maximum loads that could result in equipment fragmenting; crew members will wear eye protection
INADEQUATE DESIGN	X		**Effect:** experiment equipment failure **Control:** critical components of the experiment equipment has been tested and analyzed to ensure that the equipment can survive the maximum anticipated loads with a safety factor of no less than 2; In the event that a piece of equipment fails the ERRN will be employed as needed and the kill switches will be employed
STORED ENERGY (SPRING, WEIGHTS, FLYWHEEL, ETC.)		X	
PRESSURE & GASES			
DYNAMIC		X	
COMPRESSED GAS		X	
COMPRESSED AIR TOOL		X	
ACCIDENTAL RELEASE		X	
BLOWN OBJECTS		X	
HYDRAULIC HAMMER		X	
FLEX HOSE WHIPPING		X	
STATIC		X	
CONTAINER RUPTURE		X	
PRESSURE DIFFERENTIAL		X	
NEGATIVE PRESSURE EFFECTS		X	
LEAK OF MATERIAL WHICH IS:		X	
FLAMMABLE		X	
TOXIC		X	
CORROSIVE		X	
RADIATION			All radiation sources must be approved by RSO(SD3)
IONIZING RADIATION		X	
ULTRAVIOLET LIGHT		X	
HIGH INTENSITY VISIBLE LIGHT		X	
INFRARED RADIATION		X	
MICROWAVE RADIATION		X	
LASER		X	
TOXIC			
GAS OR LIQUID		X	
ASPHYXIANT		X	
IRRITANT		X	
SYSTEMIC POISON		X	
CARCINOGEN		X	
OTHER ADVERSE PROPERTY		X	

COMBINATION PRODUCT		X	
COMBUSTION PRODUCT		X	
POTENTIATION		X	
SYNERGISM		X	
VIBRATION			
VIBRATION TOOL		X	
HIGH NOISE LEVEL SOURCE		X	
METAL FATIGUE CAUSATION	X		
FLOW OR JET VIBRATION		X	
SUPERSONIC		X	
MISCELLANEOUS			
CONTAMINATION		X	
LUBRICITY		X	
VIOLENT ODOR		X	
TRAINING	X		Provided by the RGO
HYPOXIA	X		Provided by the RGO
STRUCTURAL FAILURE	X		**Effect:** experiment equipment failure **Control:** critical components of the experiment equipment has been tested and analyzed to ensure that the equipment can survive the maximum anticipated loads with a safety factor of no less than 2; In the event that a piece of equipment fails the ERRN will be employed as needed and the kill switches will be employed

Tool Requirements

Tools that will be brought to the Reduced Gravity Facility for use on the ground are as follows:

- Phillips screwdriver
- Flathead screwdriver
- Standard set of Allen wrenches
- Needle nose pliers
- Knife and scissors

Tools that will be brought to the Reduced Gravity Facility for use in flight are as follows:

- Phillips screwdriver
- Standard set of Allen wrenches
- Flathead screwdriver

The tools that will be taken on board will be contained in a pouch with a zipper. The pouch will be anchored to a tiedown floor lug that is provided by the RGO. An inventory of all the tools taken to JSC and onboard will be generated.

Photo Requirements

Through the duration of the testing a digital video camera will capture the dynamic behavior of the FFS. One camera poll will be required to secure the camera to the fuselage floor in order to accomplish this.

This photo requirement, combined with the RGO provided photographers and video operators that will be generating media for outreach purposes, will be all that is required to sufficiently document the experiment and the team's experiences.

Ground Support Requirements

A 120 V AC power source is required to charge the video camera, and the FFS system battery packs. Besides this item, there is no other ground support necessary from the RGO personnel.

Hazardous Material

There will be no toxic, corrosive, explosive, and/or flammable materials used to perform the experiment.

Material Safety Data Sheets (MSDS)

Not applicable to this experiment

Procedures

The members of the flight team will be broken into two teams for the experiment.
The teams are as follows:

1. Mounted Systems Operator (MSO)
    a. In charge of all related duties of the system, including:
        i. Installation
        ii. Maintenance
        iii. System initiation
        iv. System retraction
        v. Operation
        vi. System reset
        vii. Voice log operations
    b. Other responsibilities can be found in the procedure
2. Free-floating Systems Operator (FSO)
    a. In charge of all related duties of the system, including:
        i. Mounting the FFS on MRS
        ii. Operation of system electronics
        iii. System reset
        iv. Camera Operations

    b. Other responsibilities can be found in the procedure

All team members will share the responsibility of the systems safety

2.14.1 Ground Operations

Ground operations will be conducted as follows:

1. Unload and inventory all equipment
2. Thoroughly examine equipment for damage
3. Assemble Mounted Release System
4. Perform a check of all systems according to Verification Procedures
    a. Activate subsystems
        i. Mounted Release System
        ii. Free Floating System
    b. Trial data acquisition run
        i. Check for sensor malfunctions
5. Power down
6. Charge batteries

Store equipment

2.14.2 Pre-Flight Operations

1. Re-inventory equipment
2. Mount MRS in the designated section using bolts
    a. Set MRS to the folded-extended configuration
    b. Secure to fuselage floor with Velcro strap
3. Mount video camera on supplied pole and orient toward experiment space
4. Secure tool pouch to fuselage floor with carabiner
5. Secure outreach equipment to fuselage floor
6. Confirm proper functioning of systems
    a. Mounted Release System
    b. Free float system
7. Initialize systems for first test run
8. Store FFS in overhead compartment
9. Mount banner to fuselage
10. Distribute Personnel Protection Equipment (PPE) to team members
    a. Safety glasses

Secure team members for take-off

2.14.3 In-Flight Operations

To test the accuracy of the algorithm, the experimental parameters will be changed as specified in the experiment description. For each parameter configuration, the following procedures will be applied.

- Once Flight Altitude is reached
    1. FSO retrieve FFS from overhead storage compartment

    2. Put on PPE
        - Ensure proper usage
    3. Proceed to experiment workspace
    4. MSO configure MRS in upright position
    5. FSO set FFS on MRS
    6. MSO engage MRS electromagnets
    7. Assume pre-experiment positions
    8. Begin recording with camera
- 0g Commencement
    1. Ensure accelerometer reads 0g.
    2. FSO flip FFS master switch to ‘on’ position
    3. MSO initiate MRS platform rotation
    4. After desired angular velocity reached, MSO disengage MRS electromagnets
    5. FSO apply tension to MRS retraction cord
    6. MSO pull pin to collapse MRS and secure platform in collapsed position
    7. MSO deactivate platform motor
    8. MSO secure MRS in folded position with Velcro strap
    9. RUO pulls platform away from the system
    10. FSO monitor and comment on FFS activity
    11. FSO Retrieve FFS after robotic arm finishes maneuvers
    12. FSO flip FSS recording switch to ‘stop’ position
    13. FSO flip FSS master switch to ‘off’ position
- Coming out of 0g
    1. MSO reset the MRS to the upright-extended position
    2. FSO place the FFS back on the MRS platform
    3. MSO engage MRS electromagnets

Repeat these processes without altering parameters until all trials for each specific parameter configuration are complete.

- Parameter alteration
    1. The alteration of each parameter will be performed by both team members
        - For final arm orientation parameter, the respective switch will be flipped
        - For addition of mass, the mass will be added during a 5 minute pause in the parabolic flight pattern using the following procedure:
            - Open the FFS access panel
            - Slide the mass into the mounting brackets

Close the FFS access panel

2.14.4 Post Flight Operations

1. Turn off all equipment
2. Return borrowed equipment
3. Download all data to a hard drive
4. Re-inventory all equipment according to the equipment list
5. Compile all data for post processing

6. Condense/repack all equipment for transport
    a. Experiment
        i. Mounted Release System
        ii. Free Floating System
    b. Recording equipment
        i. Video camera
        ii. Hard drive
7. Debrief as a team
    a. General observations
    b. Problems
    c. Success

Off-Loading

No special procedures are required for off-loading the equipment. IPAV team members will carry by hand all equipment.

Emergency/Contingency

In the case of off-nominal operation or equipment malfunction, testing will stop and the equipment will be restrained. The equipment will then be assessed to determine the best course of action. If the equipment can be quickly repaired testing will resume, otherwise it will be stowed away until a nominal environment is restored.

In case of an emergency, testing will stop immediately and all equipment will be stowed away. IPAV team members will then follow all emergency procedures. In case of a fire there are no specific firefighting procedures, the fire will be put out according to RGO protocol.

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