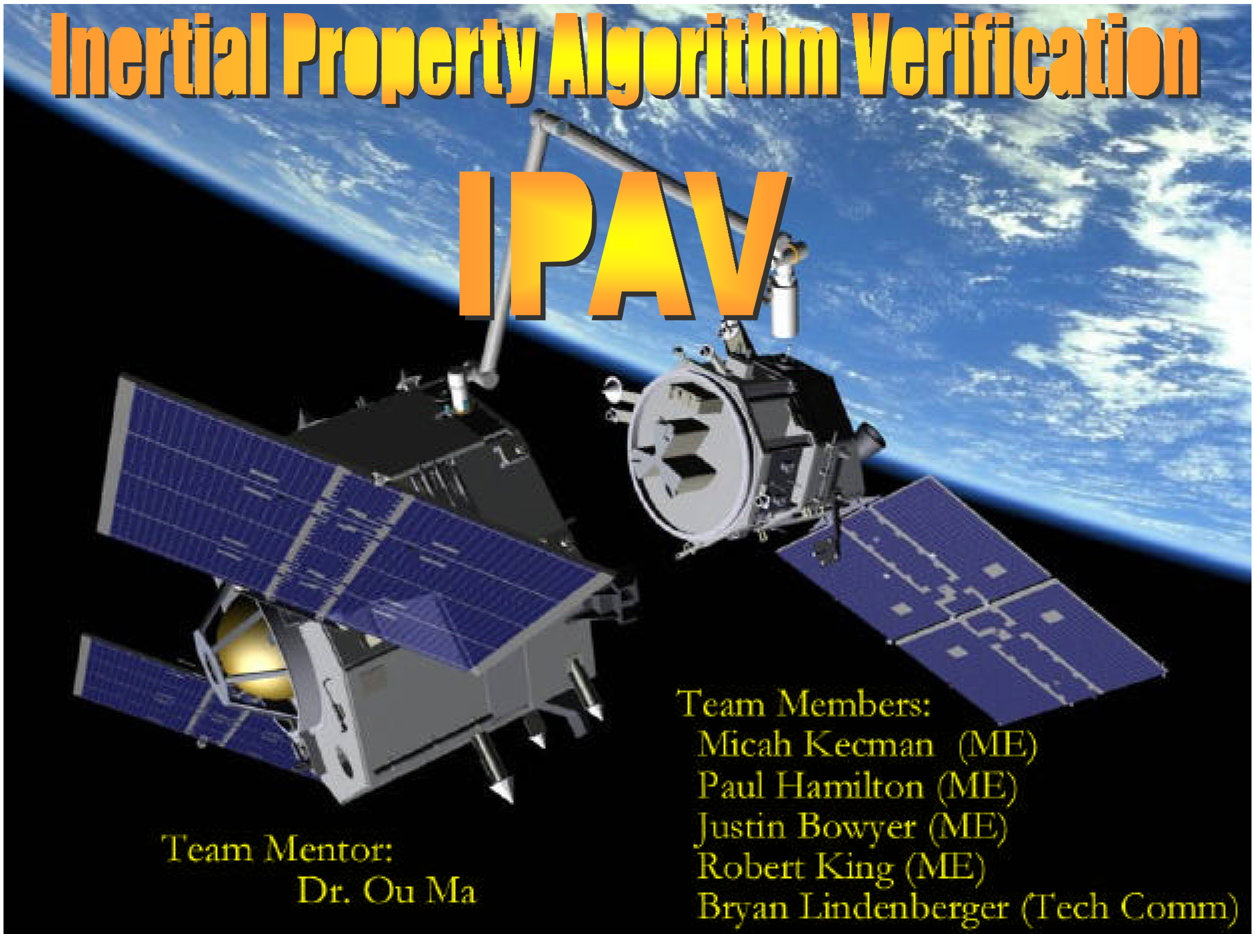
Capstone Design Spring 2009



Abstract

With over 600 active satellites in Earth's orbit as well as thousands of "dead" satellites and debris, the risk for orbital collision has never been higher. Furthermore, today's maneuvers—such as orbital refueling and rendezvous—require ever-increasing accuracy in measuring flight paths and inertia.

Today's orbital spacecraft make these calculations by firing thrusters and measuring the effects it has on the system. This method not only wastes valuable fuel, but it does not provide the level of accuracy required to optimize today's sensitive maneuvers.

Our team proposes a newly-developed algorithm to identify a spacecraft's inertial properties by means of extending a robotic arm measuring the resulting changes in velocity. This robotics-based method is preferable to other methods that require the use of thrusters, which consume fuel and generate error considered significant to today's advanced maneuvers. The goal of this project is to verify our algorithm in a microgravity environment.

This semester, the IPAV team set out to do this and continue our efforts to experimentally verify the proposed algorithm by means of a motorized, robotic arm attached to a mock "satellite" system (Free Floating System or FFS) released in a microgravity environment. A previous test aboard a Microgravity Aircraft yielded promising results, but a significant portion of the resulting data was lost due to impacts sustained by the FFS upon release in microgravity. In addition, the Hand Held Release Unit, used to accelerate the FFS to its initial state, released the FFS in an uncontrolled state, resulting in many trails being inaccurate or incomplete.

To address these problems, the IPAV team has focused on redesign of critical aspects of the FFS to ensure retrieval of data during the next microgravity test flight in June of 2009 based upon past testing. This work includes the addition of two accelerometers, the relocation of a microcontroller, and the integration of gearhead into the robotic arm drive mechanism to ensure sufficient critical power during testing.

Additionally, we have designed and constructed the MRS, again based upon previous 6-DOF test flights. We have performed stress tests of all test flight equipment and submitted the results of those tests to NASA as required by the Test Equipment Data Package (TEDP) and made preparations for the next flight, including (but not limited to) budgeting, submission of budget, and health physicals for all NMSU engineers attending the test flight.

We have also continued our efforts in public outreach to both fund the project and to help ensure public interest, from engineering graduates and others from the scientific community to school children, as well as potential benefactors from both public and private sectors.

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Contents

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Introduction

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.

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 previous test flight.

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The Goals of the IPAV team are to experimentally verify this new method. The flow chart in Figure 1 provides an outline of the goals for the overall project.

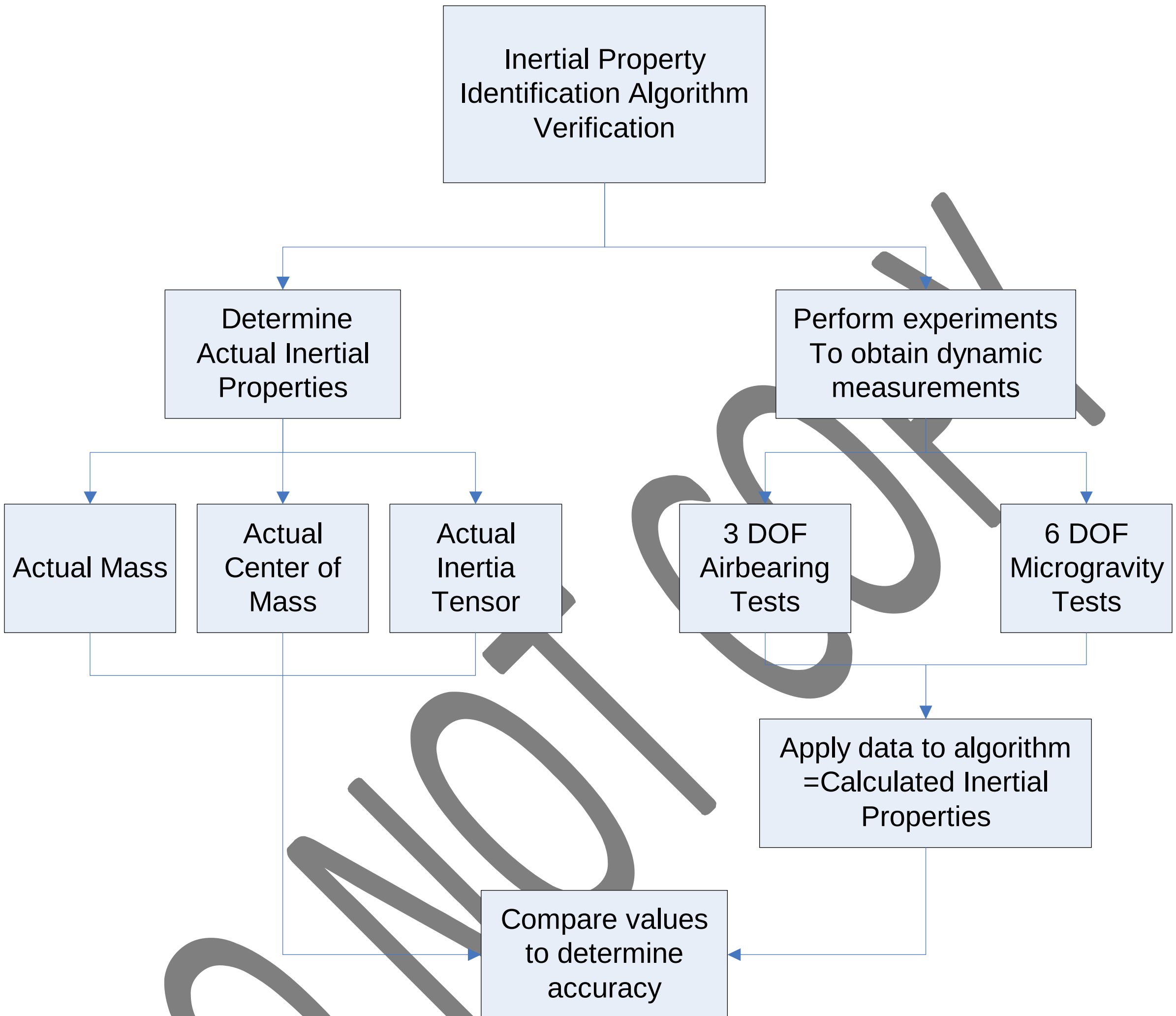

Figure 1. Overall Project Objectives.

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The process consists of two branches, one of which is the experiment branch, where two types of testing will be performed. One type of testing will be 3 degrees of freedom (DOF) testing, which will be performed on an air-bearing test-bed that utilizes air-bearings to allow the test system's dynamic responses to be unimpeded by friction. Due to the effects of gravity, this testing will limit the system's dynamic response to the plane defined by the precision ground granite table on which the testing will be performed.

The microgravity environment generated by NASA's Microgravity Aircraft (Vomit Comet) allows for system dynamics that are unrestrained and unimpeded by the effects of gravity, creating a more accurate simulation of a spacecraft's dynamics while in orbit. The testing consists of releasing a spacecraft-robotic arm mock up, which we referred to as the free floating system (FFS), into a free floating state. Once released, the robotic arm will begin maneuvers while the onboard sensors measures the systems dynamic response to the robotic arm's maneuvers. There were many lessons learned from the first 6 DOF test that will be applied to the next 6 DOF test.

The other branch of the process consists of identifying the actual parameters of the FFS using precision lab equipment and proven methods. These actual values will be used as a reference for comparison the experimental results. The resulting error will indicate the ability of the method to identify the inertial parameters of a spacecraft, as shown in the last block of the flow chart.

Method

Management

In order to ensure that the teams efforts were efficient and directed, a well-structured management approach was implemented. This approach consisted of using Microsoft Project Manager to break down the various tasks, assign tasks to team members, and to identify milestones and deadlines. Figure 2 contains a high level Gantt chart, which only displays the major tasks. Each of the major tasks can be expanded to show specific tasks, team member assignments and corresponding deadlines and milestones.

Figure 2. High Level Project Manager.

The Gantt chart illustrates how the project was broken down. These major tasks are as follows:

? Mounted Release System (MRS) Design
? Robotic Arm Motor/Gearhead Integration
? Encoder Relocation
? New Accelerometer Integration
? Additional Microcontroller Integration
? Air-bearing Testbed Development
? Microgravity Test Equipment Data Package

The bars on the right indicate the time at which the tasks were expected to be performed and the time that each of the tasks was anticipated to require.

A meeting each week to served as a time where team members could openly ask questions or express any concerns. This time was also used to check on the status of the individual tasks and to reassign new tasks if necessary.

Throughout the semester, we utilized resources that helped us to refine our designs and our processes. In particular, Dr. Ma, our mentor, served as a great resource. He provided feedback during preliminary design reviews as well as guidance on technical issues relating to the ground based testing. We also had Electrical Engineering students at our disposal to aid in the electrical aspect of our design process.

FFS 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, three tri-axial accelerometers, 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 of the system via orientation and a prescribed mass.

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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 3. There will be a switch mounted to the top surface of the top panel 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.

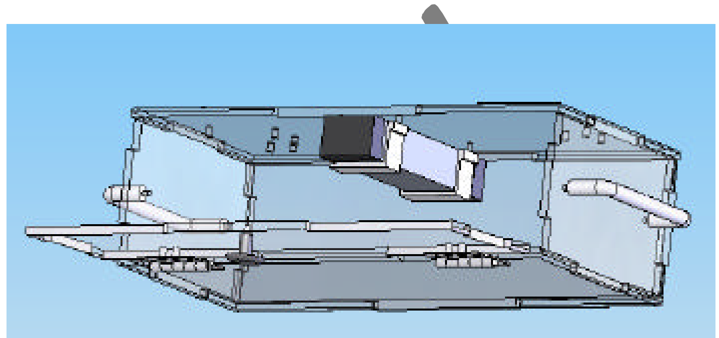

Figure 3. Secondary mass inserted into the main housing.

MRS Design

The Mounted Release System (MRS) unit will consist of four main components: the motor, top platform with support blocks, a two-part collapsing stand, and a square base plate with hinge brackets. The MRS system conceptual assembly is shown in Figure 4.

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 4). The rotating platform will be used to keep the FFS constrained while the system is rotating. The two-part collapsing

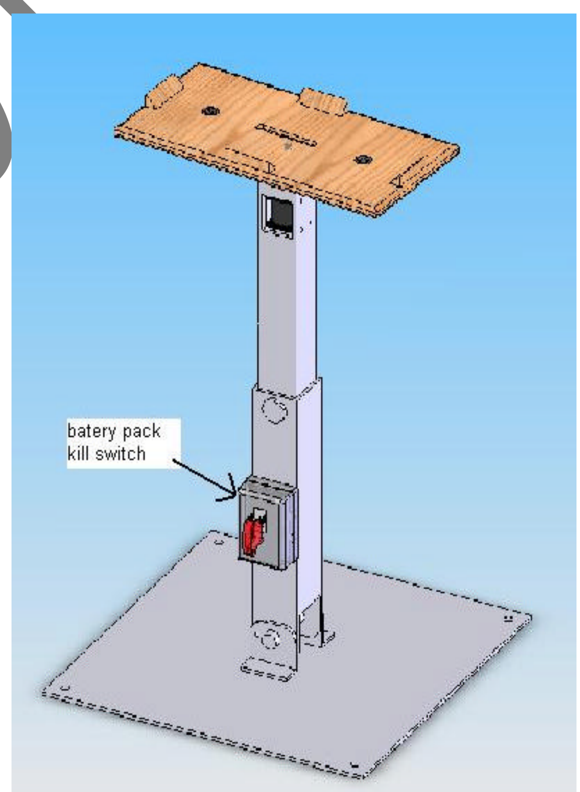

Figure 4. MRS in the upright, extended configuration.

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stand is designed to collapse by pulling a 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 5. The rotating platform provides the FFS with a controlled initial free floating state. A bungee cord 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.

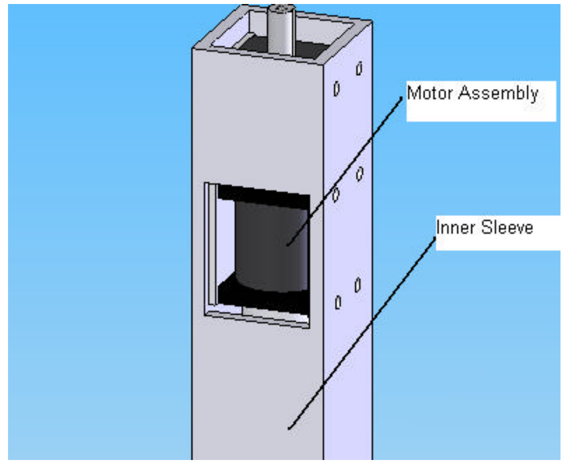

Figure 5. MRS Platform Motor mounted inside upper section of the stand.

The bungee cord will be mounted on the bottom of the lower section and attached to the bottom of the top section (Figure 6). There will be pin holes located on the upper section of the stand in such 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 pull pin.

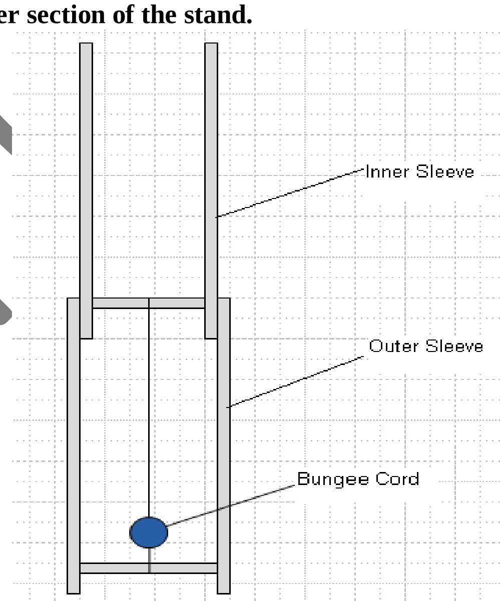

Figure 6. Bungee cord attachment method.

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 8.

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 7. The

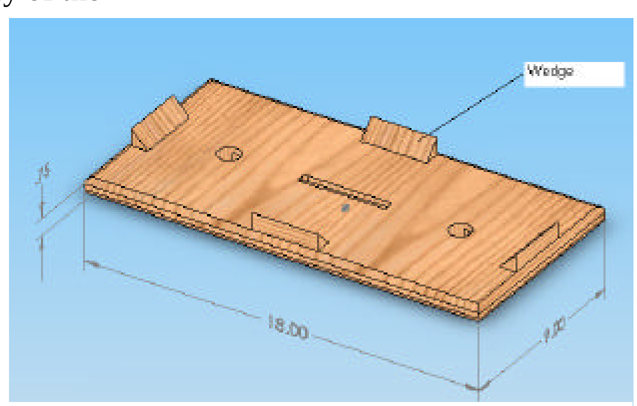

Figure 7. Platform design with wedge constraints.

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wedges are used to constrain the FFS laterally to avoid any slipping before microgravity commences. 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 microgravity 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 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.

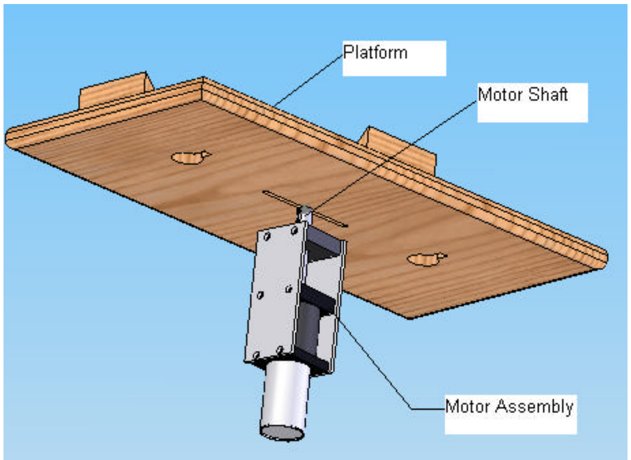

Figure 8. Interface between the Platform and the motor shaft.

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 not interfere with the FFS 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. Closed-cell foam padding will be applied to all sharp corners and pinch points to mitigate injuries.

Robotic Arm Motor/Gearhead Integration

Reasons for Redesign

The purpose for the redesign of the previously used robotic arm drive mechanism is because the former configuration did not have enough power. The drive system needs to be able to produce the required torque and power to actuate the robotic arm in the way it was programmed while enduring the forces of a full, dynamic response of the FFS. This will allow for more accurate and consistent data.

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Design Criteria

In the redesign of the FFS robotic arm drive mechanism, there were a few different criterion required to keep the data accurate and the FFS safe in a microgravity environment. First, the robotic arm mass needs to be at least 5% of the primary body mass in order for the algorithm to be accurate. For safety and structural reasons, it was decided that no component of the robotic arm drive mechanism should protrude past the envelope defined by the vertical planes of the side walls of the primary body. This should eliminate large stress loads due to any impact. Next, the lead/fabrication time needed to be considered. The controllability of the robotic arm is important so that the FFS has the ability to gradually accelerate and decelerate the arm. It is also important to minimize the cost of the redesign so that funds are not wasted. Finally, it is necessary that the robotic arm drive mechanism be highly accurate.

Encoder Relocation

Reasons for Redesign

The IPAV project was fortunate enough to be able to perform trials with NASA's Reduced Gravity Student Flight Opportunities Program in summer 2008. Unfortunately, the FFS lost control during one of the trials and the encoder was damaged. It was determined that the encoder sustained the damage during an unexpected impact because the sensor extended beyond the envelope defined by the vertical planes of the side walls of the primary body. This resulted in the loss of a great amount of vital data. For this reason, as well as a few others, the data from the trial were insufficient to complete a definitive empirical analysis. To avoid this, the encoder needed to be protected in some fashion from any unexpected impacts.

Design Criteria

There were two design criteria for the relocation of the encoder. First, the sensor must not extend beyond the envelope defined by the vertical planes of the side walls of the primary body. Finally, the encoder must be protected from any unexpected impacts that the FFS might have to sustain.

Accelerometer Integration

Reasons for Redesign

The FFS was originally fitted with a single tri-axial accelerometer to help measure the dynamic response of the system. While the original sensor worked perfectly, the analysis of the data proved to be difficult and not completely descriptive. To alleviate the problem, it was decided to incorporate two more accelerometers into the FFS hardware. This greater wealth of information will help to more accurately and easily determine the dynamic response of the FFS.

Design Criteria

When the mounting locations of the tri-axial accelerometers are determined there are three criteria that will help to maximize the effectiveness of the sensors. First, the three accelerometers must not be placed collinearly, which will help to reduce redundant data. Next, the measurement

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coordinate axes of the accelerometer must be parallel. This will greatly ease the analysis of the data. Finally, the accelerometers should be placed as far away from the center of mass of the FFS as possible to allow the sensors to gather more accurate data.

MRS Fabrication

Reasons for Redesign

The Hand Held Release Unit was the original design to launch the FFS in microgravity. Unfortunately, it consistently released the FFS in an uncontrolled state. The Mounted Release System (MRS) will be able to mitigate this problem. The assembly will be mounted to the fuselage of the airplane to eliminate any unwanted movements inherent of a hand-held unit. Electromagnets in the rotating platform will hold the FFS securely in place until it is time to release it. The MRS will also allow the retraction of the rotating platform away from the FFS and fold to the floor to make room for it to exhibit an unperturbed dynamic response.

Design Criteria

The MRS is designed following criteria from both NASA's guidelines as well as our feasibility assessment based on the equipment itself as well as the individual abilities of the team members. Based off the purpose for redesign of the hand held release unit, the MRS must have the ability to collapse and pivot perpendicular to the fuselage of the aircraft while integrating the motor, rotating platform, and other components of the MRS. To comply with a weight constraint given by NASA, the MRS design was not to exceed a 300 pound limit. Also, all components of the assembly will need to be bolted together, not welded. This helps eliminate any weld analysis required by NASA. The MRS needs to be strong enough to survive the forces equivalent to the following accelerations: 9G (meaning 9 times the acceleration due to gravity on earth) acceleration to the fore, 3G acceleration to the aft, 2G acceleration laterally and upward, and 6G acceleration downward. Finally, all components must have a minimum factor of safety (FOS) of 2.

Air-bearing Testbed Development

Reasons for Redesign

The air-bearing testbed consists of an extremely flat surface provided by a granite table, the air-bearings (the blue disks seen in Figure 9), and a platform for the air-bearings to mount to and hold the free floating system. The bearings are made of a very porous carbon material that allows air compressed from 60 to 100 psi to flow through it, allowing the bearings to float about five microns above the table (acting like a reverse air hockey table). This provides a near frictionless surface as well as three degrees of freedom for testing. With three degrees of freedom we can measure three parameters and verify part of the algorithm. Another reason for using an air-bearing table is that its environment is considerably easier to control over the six degree of freedom environment. However, by reducing the degrees of freedom to only planer motion

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across the table top and one axis of rotation normal to the plane of the table, this only allows for partial verification of the proposed algorithm.

The bearings need a constant supply of compressed air to work properly, and the current supply source is with a hose connected to a compressed air supply, seen in Figure 9. Although this is effective for supplying enough air, it creates a drag on the system when it is rotating and can get wrapped around the experiment itself. This interference is affecting the data collected and has made testing difficult.

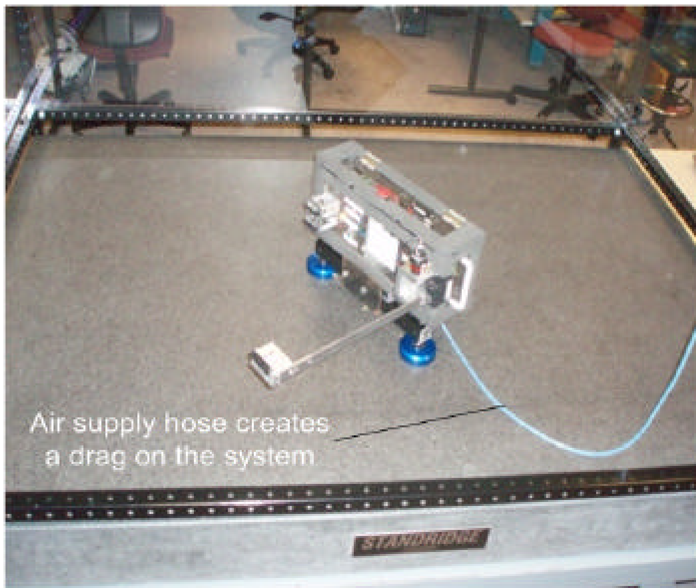

Figure 9. Air-bearing testbed with current air supply.

Design Criteria

In order for the 3DOF air-bearing experiment to be successful and accurate, there must be as little interference with the dynamic response as possible. The easiest way to eliminate the drag created by the air hose in the current configuration is to integrate the air supply into the bearing assembly. In order for the algorithm to be accurate, the mass of the robotic arm needs to be at least 5% of the mass of the primary body, which in this case is the main housing of the FFS as well as the bearing assembly. This means that the air supply tank must be as light as possible. Also, the bearings need to have a constant supply of at least 60 psi to work properly. Finally, the air tank must hold enough air to operate the bearings for a minimum of 5 minutes. This will allow testing to continue for multiple trials without the need to refill the tank.

Technical Equipment Data Package

The IPAV experiment was accepted to NASA's Reduced Gravity Student Flight Opportunities Program and is scheduled to perform the six degree of freedom experimentation in June. Our team will travel to Houston, TX and fly the experiment aboard a C-9 aircraft and experimentally collect data to verify the inertial property algorithm. This program is ideal for our purpose because the only cost to the IPAV team comes from travel and accommodation expenses.

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NASA requires that all participants in the program submit a Technical Equipment Data Package (TEDP). This document helps to describe to the engineers at NASA every aspect of our experiment. It must include a flight manifest, background, description, and goals of the experiment, detailed descriptions and analysis of experiment components, requests for crew assistance, and hazard analysis and mitigation plans. The most recent draft of the TEDP can be found in the IPAV team's Senior Design Laboratory project binder.

Results and Discussion

MRS Design Analysis

In order to be certain that the design of the MRS would be sufficient to meet NASA's safety standards, finite element analysis was performed on all major components liable to fail. As can be seen in Figures #,#, and #, the minimum factor of safety (FOS) for the MRS design is ###, well above the requirement of 2.0, set by NASA.

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Robotic Arm Motor/Gearhead Implementation

A modified Pugh's method was used to determine the best design to be the combination of a new stepper motor with an inline gearhead. Unfortunately, due to limitations in funding, the old stepper motor was reused to be combined with a new gearhead. In order to mate the motor and gearhead, two adapters were made. The output shaft of the motor is bigger than the input of the drive gear. The drive adapter was manufactured to alleviate this problem, seen in Figure #. It is made of aluminum, and attaches using a set screw. The bolt patterns of the motor and gearhead are incompatible, so the attachment adapter was created. The adapter, shown in Figure #, is made of aluminum, and was designed to be adjustable.

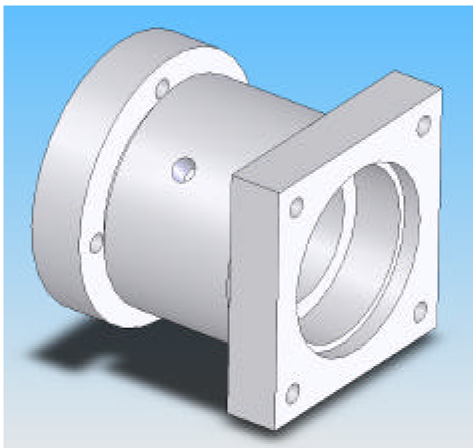

Figure #. Motor/gearhead attachment adapter

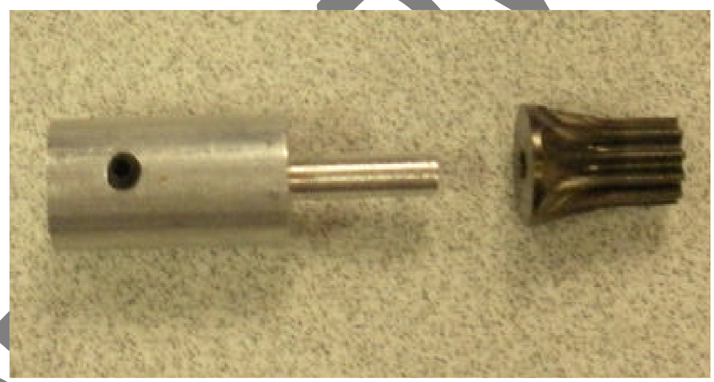

Figure #. Motor/gearhead drive adapter

Once the new drive assembly was complete, it needed to be attached to the pivot housing. Because the pivot housing was designed to have the motor directly attached, there was a lip machined around the mounting location to help reinforce the motor (Figure #). In order for the assembly to mount flush on the side of the pivot housing, the lip needed to be removed. This was accomplished using a manual mill at the Student Project Center.

The final drive assembly consists of the following; the stepper motor is attached to an adapter (shown in Figure #); this is attached to an 80:1 planetary gearhead and a 90-degree drive converter. This assembly is attached to the pivot housing as shown in Figure #.

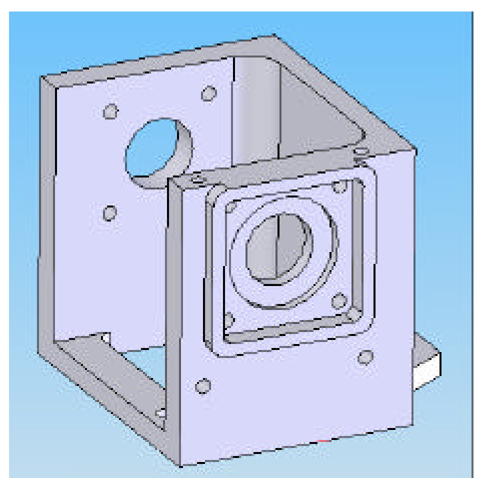

Figure #. Former pivot housing with lip

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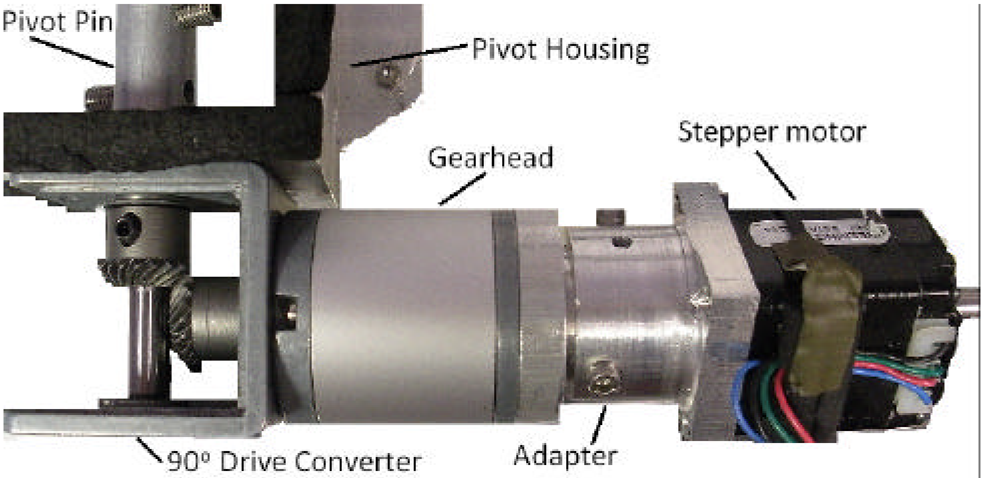

Figure #. New drive mechanism configuration

Encoder Relocation

There were three proposed design concepts to help mitigate the problem experienced by the encoder. The first design was to leave the encoder attached to the back of the motor, but fabricate a shield to cover it. The second concept was to move the encoder to the other side of the pivot housing so that it would no longer protrude beyond the envelope defined by the vertical planes of the side walls of the primary body. Finally, the last idea was to combine both the first and second idea. Ultimately, the second concept was determined to be the most feasible. The final configuration is shown in Figure ##.

In order to move the encoder to the other side of the pivot housing, the pivot pin was extended by drilling and tapping a hole on the bearing side of the pivot shaft, then inserting a screw into it. This allowed the encoder magnet to reach the sensor for proper function. The Delrin bearing was then modified to allow the screw to pass through the bearing, but still hold the pivot shaft in place. Finally, the encoder was attached and recalibrated.

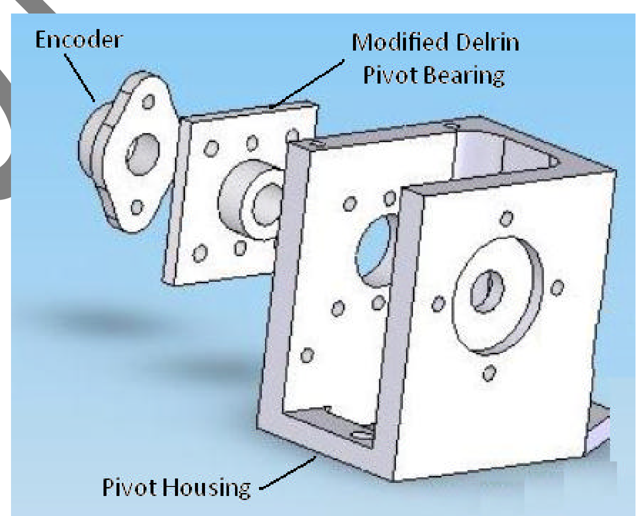

Figure #. New encoder location

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MRS Fabrication

The MRS is made up of four main components: rotating platform and motor, collapsible square box tubing, battery pack, and square base plate with pivot housing. All metal components of the MRS were manufactured using T6061 aluminum unless otherwise noted.

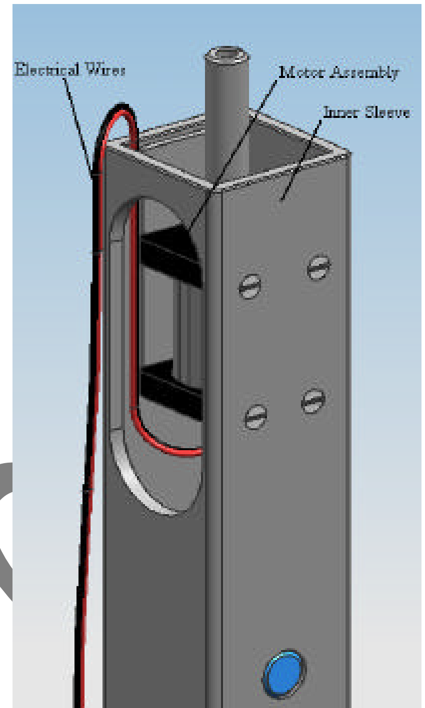

Figure #. Motor for rotating platform

The motor of the rotating platform is mounted inside the inner sleeve of the collapsible box tubing (Figure #) via 8 counter-sink screws, as shown. Counter-screws were used to ensure that the inner sleeve would slide properly, obstruction free, from the outer sleeve. To guarantee the motor is centered, shims were used between the motor and the box tubing.

The square collapsible box tubing measures 2.5”x2.5” and 3”x3” for the respective inner and outer sleeves, with a ¼ inch wall thickness. The tubing was cut to length with the inner sleeve measuring 20.75” and the outer sleeve measuring 21.6”, for an operating height of 3’ 5”. The outer sleeve of the box tubing was modified by integrating a 45-degree cutout at the pivoting end of the box tubing to eliminate obstruction of pivoting motion (Figure #a). Rubber stops were also added to the inner portion of the inner sleeve to prevent damage to the pivoting bolt in the event of harsh collision (Figure #b).

The battery pack, which powers the motor, is mounted on the outside of the outer sleeve with 5 screws (Figure #). The electrical wires leading from the motor to the battery pack are integrated in such a fashion that they are obstruction free from the overall movement of the MRS.

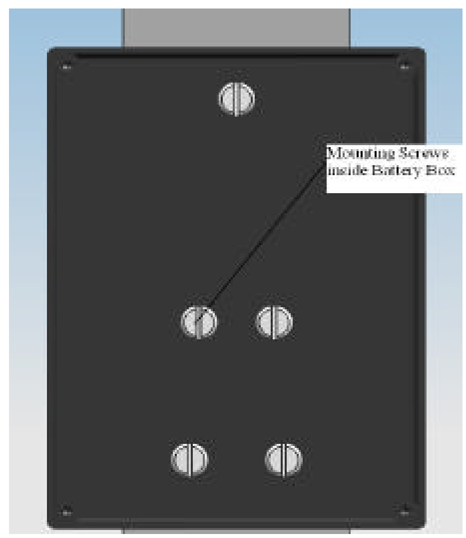

Figure #. Battery Box

The 2’x2’ square base plate, has a bolt pattern of 20”x20” to mount the unit to the fuselage of the aircraft. The pivot housing, made of two 90-degree steel L-brackets, is mounted to the base plate and aluminum sidewalls for reinforced support. There is also an integrated stop to prevent the collapsible box tubing from pivoting 180 degrees and thereby ensuring 90 pivoting only. The corners of the base plate were rounded to meet safety guidelines.

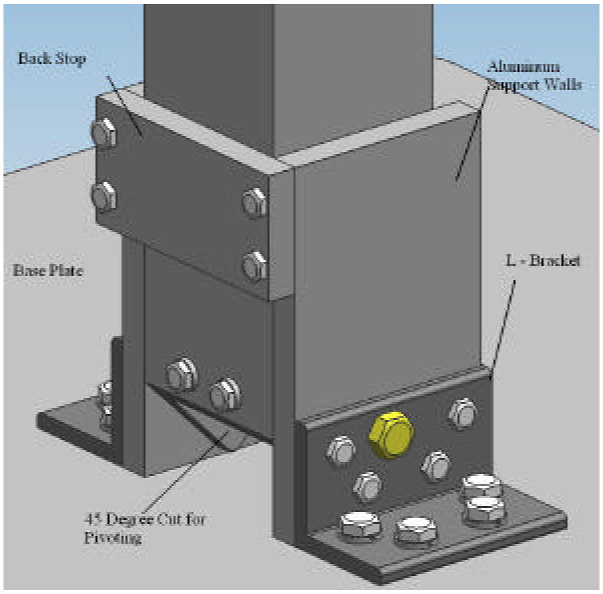

Figure 3a. Pivot Housing

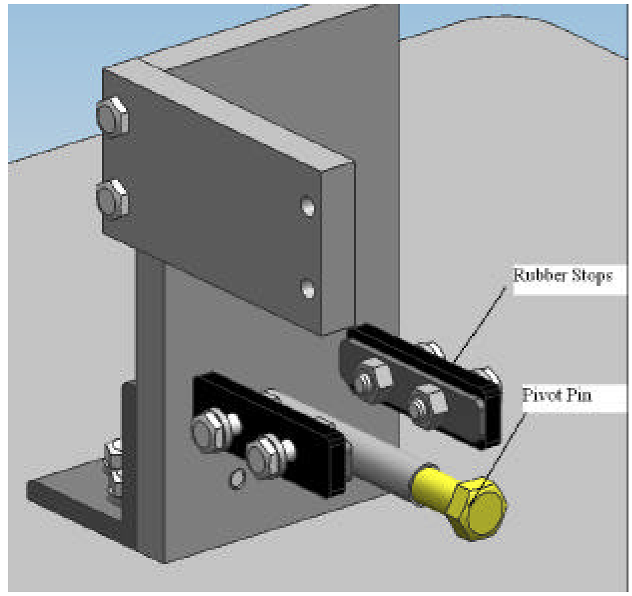

Figure 6b. Rubber Stops/ Pivot Pin

All major fabrication on the MRS has been completed. The system has a functional collapsible stand, a functional pivot housing mounted to the base plate, and the motor has been mounted inside the collapsible stand. There are still some minor components that need to be finished. The base plate needs to have holes drilled for mounting the MRS to the fuselage of the plane. A pull pin needs to be added to the pivot housing. A bungee cord needs to be integrated into the collapsible stand assembly. A nylon strap needs to be added to limit the travel of the inner sleeve. Electromagnets need to be integrated into rotating platform. A slip ring needs to be added to provide electricity to the electromagnets.

Air-bearing Testbed Development

The redesign of the 3 DOF air-bearing experiment requires that a testbed be developed with an integrated air supply. To accomplish this, an emergency scuba tank was chosen as a lightweight and affordable compressed air source. Two pressure regulators were added to the tank so that a constant pressure would be supplied to the bearings. In order to mount the compressed air source to the air-bearings, a platform was added to the testbed. The platform frame was fabricated out of two C-channel rails. The surface of the platform was made out of the polycarbonate that the FFS housing is made of. The air tank was secured to the new platform using hose clamps, attached directly to the frame. This assembly allows the new platform to move freely without any drag on the system. The redesigned testbed can be seen in Figure #.

Since we need to perform multiple trials with the airbearing, we need to be able to refill the tank in the lab to diminish down time between trials. Therefore, a full size scuba tank and adapter were acquired to refill the small tank (Figure #). This large tank can be filled to 3000 psi, and came with 5 free refills upon purchase.

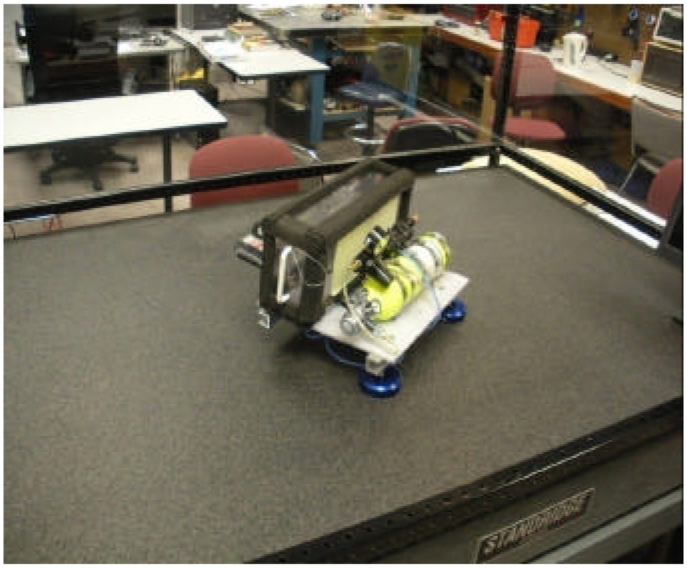

Figure #. Redesigned air-bearing testbed

Figure #. Refill scuba tank with adapter

Although the air-bearing testbed currently works, another bearing still needs to be added to support the robotic arm. This will help to negate the effects of gravity. A final design for this is being formulated and will be finished over the summer.

Test Equipment Data Package

The first draft of the Test Equipment Data Package (TEDP) has been submitted to NASA. Engineers there will review the document and instruct the team accordingly. If the Test Equipment Data Package meets NASA's standards and contains all necessary information then it will be accepted and the requirement will be fulfilled. If this is not the case, the document will be sent back to the IPAV team with change requests, and the document will be changed and resubmitted until it is satisfactory.

Conclusion and Recommendations

MRS Design Analysis

The Mounted Release System will enable the Free Floating System to enter a free floating state obstruction and hands-free in a more controlled state. By designing the system to be mounted to the floor of the aircraft, it will enable the team members to focus on the FFS during free floating state in a safe and more accurate manner as well as eliminate any human error in releasing the unit. The MRS's ability to collapse and pivot perpendicular to the aircraft body will greatly help to reduce any interference with the FFS as well as provide safety to the overall test.

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Robotic Arm Motor/Gearhead Implementation

A modified Pugh's method was used to determine the best design to be the combination of a new stepper motor with an inline gearhead. Unfortunately, due to limitations in funding, the old stepper motor was reused to be combined with a new gearhead. To attach the motor to the ne gearhead, an adapter was fabricated out of aluminum. In order to attach the new drive assembly to the pivot housing, a lip was machined off. In this new configuration, the robotic arm has enough power to perform the desired maneuvers while experiencing the effect of earth's gravity. In a microgravity environment, the new FFS robotic arm drive assembly is expected to vastly outperform the former drive configuration. This will ensure accurate results for all trials in a 6 DOF environment.

Encoder Relocation

The most feasible method of protecting the encoder from accidental impacts was determined to be relocating the unit to the other side of the pivot housing. An extended pivot pin was fabricated and the pivot pin bearing was modified to allow the pin to protrude. This allows the encoder to be able to reach and measure the position of the pin in its new location. The new configuration will allow the encoder to most accurately measure the exact angle of the robotic arm without out noise introduced by backlash in the gearhead, etc.

Accelerometer Integration

Once the new accelerometers have been integrated into the FFS circuitry they will help to more accurately and efficiently determine the true dynamic response of the FFS during both 6 DOF and 3 DOF testing.

MRS Fabrication

The rotating platform and motor was integrated into the collapsible stand and shimmed to allow for optimal spacing and fit inside the inner sleeve of the stand. The inner and outer sleeves were trimmed to length for ergonomic operation during testing. The end of the outer sleeve was fabricated with a 45 degree cut to eliminate interference with pivoting movement. The pivot housing was created using steel L-brackets, aluminum side walls, and a back stop to constrain the stand rotation. The base plate has the ability to be mounted to the fuselage of the aircraft through mounting bolt holes. The majority of the MRS was fabricated using 6061 aluminum to reduce weight. However, steel L-brackets were used to mount the pivot housing to the base plate because of the immense stress on the part. All major fabrication of the MRS has been completed, with absolute completion expected in June 2009.

Air-bearing Testbed Development

The newly developed testbed will help to create far more accurate results from any trials recorded in a 3 DOF environment. The new configuration successfully eliminated all the negative effects of the former design by integrating an air supply in to the testbed. This new

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testbed will also help to speed up the process of collecting data as well as ease the process of performing the trials.

Outreach

During the semester the IPAV team also participated in 2009 AIAA Southwest Regional Technology Symposium in Las Cruces, NM on April 16th. The team gave a 30 minute presentation on the progress and goals of our experiment to help support and raise awareness for the project.

Future Tasks

The future work for the project is divided into two sections; the microgravity experiment and the ground experiment. The future of the microgravity experiment is dependent on the results of the 6 DOF testing. The future work is outlined as follows.

- Microgravity Experiment
  - Successful Experiment
    - If the experiment is successful, the data can then be analyzed to empirically prove the algorithm for a 6 DOF environment.
  - Unsuccessful Experiment
    - If the experiment is not successful, then steps will have to be made to correct for any errors found and another appropriate venue will have to be arranged to retest the hypothesis.
- Ground Experiment
  - Air-bearing testbed
    - The final tests need to be performed and analyzed once the FFS in operational.
  - Bifilar Pendulum
    - Fixtures need to be developed for the FFS so it can be tested.

Once each section of the experiment is finished, all recorded data will have to be analyzed and accumulated to determine the results of the experiment.

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