The Orientation Ratchet:
A Novel Concept for Producing Net Rotations in Zero Gravity

Topics addressed: Angular Momentum in microgravity

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Flight Week Preference

We would prefer to fly our experiment with Flight Group 2, the week of March 18 to March 27, 2004.
If this week is not available, our next preference would be Flight Group 5, the week of July 8 to July 17, 2004.
Our third choice for flight week is Flight Group 6, the week of July 22 to July 31, 2004.

Advisor/Mentor Request

We do not request an advisor or mentor for our project.

Abstract

Our experiment uses a simple robot consisting of two sections connected by an axle. The upper section will have attached, extendable masses. Through a series of expansions, rotations, and contractions of its parts, our robot will execute a net rotation while maintaining a net angular momentum of zero. This device may conceivably comprise an alternative to the reaction wheel – the system commonly used to rotate satellites in outer space. At the beginning of its motion, the mechanism containing the extendable masses will be closed, with the masses close to the central axis of the robot. It will then extend in a manner similar to the opening of an umbrella, increasing the rotational inertia of the upper section, which will then rotate relative to the lower section by a specified angle. The upper section will then contract, and the relative motion will be reversed, returning the robot to its initial configuration. This series of actions leads to a net rotation of the robot, while its net angular momentum remains zero. Our robot will employ the BrainStem module from Acroname Robotics corporation, programmed in the TEA programming language. Prior to periods of microgravity aboard the KC135, various programs will be downloaded to the robot from a laptop computer, each of which will prescribe a series of actions for the robot to take in order to reorient it by various angles using varying amounts of expansion, contraction, and relative rotation of its parts. Our experiment will be first approximated in the laboratory by suspending the robot from a long, thin string, taking account of the external torque generated by the string. We will video the motion, both in the laboratory and the aircraft, and analyze the data by computer. Using these data, we will compare the expected behavior to that which is observed.

Test Objectives

The purpose of this experiment is to test the feasibility of a device that allows for rotation of objects in zero gravity, while maintaining a net angular momentum of zero. Our hypothesis is that through a series of extensions, contractions, and relative rotations, we will be able to rotate our robotic device in zero gravity, through a prescribed angle, about a single axis. This experiment will determine how effectively the device is able to rotate a freely floating object. A small number of these devices, oriented along different axes within an object, could conceivably result in an alternative to the reaction wheel, the standard method used to rotate objects in outer space.

This experiment also serves an educational objective. Through the construction of our robot, and the results it produces, we hope to gain a greater understanding of the physics of rotational motion and angular momentum. We will also gain experience in designing, building, programming, and operating a robot.

Through our outreach plan, we will accomplish our additional objective of stimulating a wide age range of students and increasing their interest in science and technology. This is not a follow-up experiment.

Test Description:

For our experiment we will build a robot capable of orienting itself in zero gravity while maintaining no net angular momentum. Our concept is based upon rotational inertia- a phenomenon most school children are aware of even if they can't describe it in a rigorous way. Rotational inertia is something that is noticed on the playground in a very functional sense long before it is thought of as a physical concept. When a child notices that bringing his arms close to his body allows him to spin faster, he is using the very notions that will allow us to produce a net rotation in our robot without it having any net angular momentum at any point during the experiment.

To accomplish this we will create a roughly cylindrical robot composed of two sections. These two sections will be connected by an axle that allows them to rotate relative to one another. This arrangement in itself would not produce any useful effects leading us toward our goal. In this arrangement one piece of the robot would rotate through some angle and the other piece would rotate in the opposite direction through some other angle. The difference of these two angles would be the net rotation of one section relative to the other. During the rotation, the angular momentum must remain constant, therefore; the angular momentum of one part must be equal and opposite to the angular momentum of the other. This leads to the observation that the section with the lower moment of inertia will travel through a larger angle in one direction than the other section does in the other. During a second rotation in the opposite direction, the net relative angle traversed by the two sections would be the same as the net rotation in the first step and each section would undergo the same proportion of that net angular rotation. This would get us exactly back where we started; the two pieces would be in the same relative position to each other and the entire robot would have experienced no net rotation. What is interesting, and what has become the core idea behind our experiment is the observation that if the rotational inertia of one of the sections could somehow change between the first rotation (clockwise) and the second rotation (counter-clockwise) we could produce a net rotation in the robot without having any net angular momentum at any time during the process. A cat utilizes this principle in order to land on its feet when dropped upside down (cf. Halliday et al., 1994).

The idea of creating a robotic device that turns like a cat is not entirely new. Kawamura et al (1991) describes a complex device that simulates the structures of a cat as it falls. Our device, described below, is simpler in design.

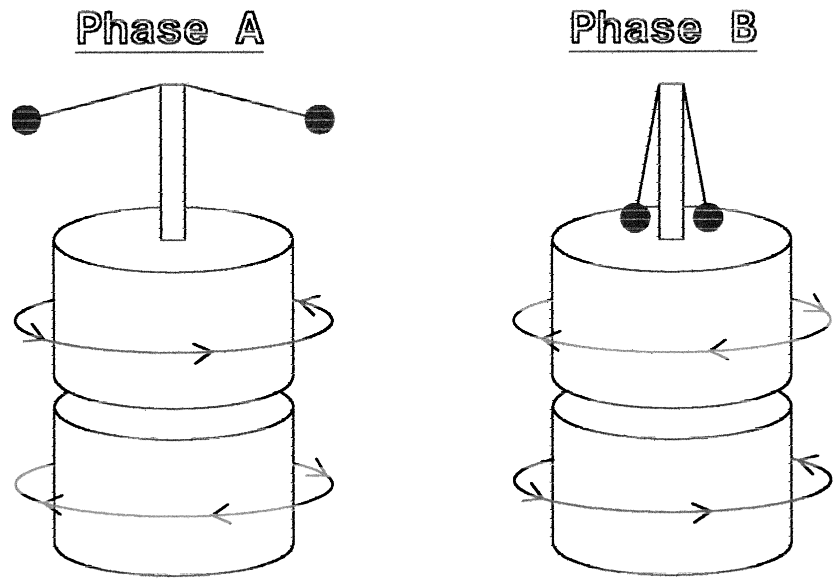

Figure 1: System appearance and relative rotation during both phases. During phase A, the upper section of the robot has a larger rotational inertia due to the extended masses. During phase B, this inertia is reduced and the relative rotation is reversed, resulting in a net rotation of the robot.

We will change the moment of inertia of the upper section by utilizing a system of extendable masses attached to the end of that section (see figure 1). The masses will start in their extended position causing the rotational inertia of that section to have a relatively large value, I_{1big}. When the first rotation occurs, this upper section will travel through a smaller angle because of its larger moment of inertia. Before the second rotation (in the other direction to bring the two sections back into their original position relative to each other) the masses will contract similar to the closing of an umbrella. With a portion of its mass much closer to the rotation axis, the upper section that had the larger moment of inertia during the first rotation will now have a smaller moment of inertia. Since the net rotation of the two sections relative to each other must equal the net rotation from the first step, the lower section with constant rotational inertia, I_2, will travel through a larger angle counter-clockwise (second step) than it did clockwise (first step). Thus the lower section with the constant moment of inertia will travel through the smaller of the two angles during the first step and the larger of the two angles during the second step (the proportions of the net angle that the sections travel through varies from the first step to the second because of the change in rotational inertia of the upper section). This leads to our desired result of having the relative positions of the two sections unchanged after the full sequence of motion while having the entire robot undergo a net rotation without any net angular momentum at any point during the process.

Experiment in Zero Gravity

Our experiment can only be realized in a true zero gravity environment, where external torque can be safely ignored. Under these conditions, as described in Appendix A, the total rotation, Φ, of the robot after the full prescribed sequence of motions is given by:

$$\Phi = \frac{I_2(I_{1small} - I_{1big})\Delta}{(I_{1big} + I_2)(I_{1small} + I_2)}$$

where the relative rotation angle of our robot's parts during phase A and phase B is Δ, and the rotational inertias of the upper part when extended, the upper part while contracted, and the lower part are I_{1big}, I_{1small}, and I_2 respectively.

By repeatedly performing the series of motions described above, and by choosing appropriate values for the variables in the above equation, we hope to cause our robot to rotate through prescribed large angles, thus illustrating its possible potential for use in the aerospace industry. The overall appearance of the motions of the robot closely resembles the action of a ratchet wrench. It was this resemblance that led us to the title for our experiment.

We recognize that our device for orientation in zero gravity has certain inherent disadvantages, first among them being a lack of spin stabilization: the device will have a tendency to slowly "tumble" due to any initial rotation, however slight it may be. However, reaction wheels – the system commonly used to rotate satellites in outer space – cause unavoidable vibrations in the satellites they orient (cf. Masterson, 2001). We believe that our concept's advantages of negligible vibration and possible increase in energy efficiency over reaction wheels may allow it to be of some value in industrial applications. This experiment will test the devices feasibility for reorienting satellites in space.

Experiment Description:
[Note: the following text is repeated in the safety analysis section under "Experiment Description." We reproduced it here for the benefit of the technical reviewers.]

Figure 2 is an enlarged rough sketch of our robot's design. There are two main body masses, referred to as the upper and lower parts of our robot. A servo located inside the upper part will work to rotate a rod connected to the lower part. This rotation will cause the relative motion between the two main body components. A small rigid column will protrude out of the top of the upper section in order to support extendable masses.

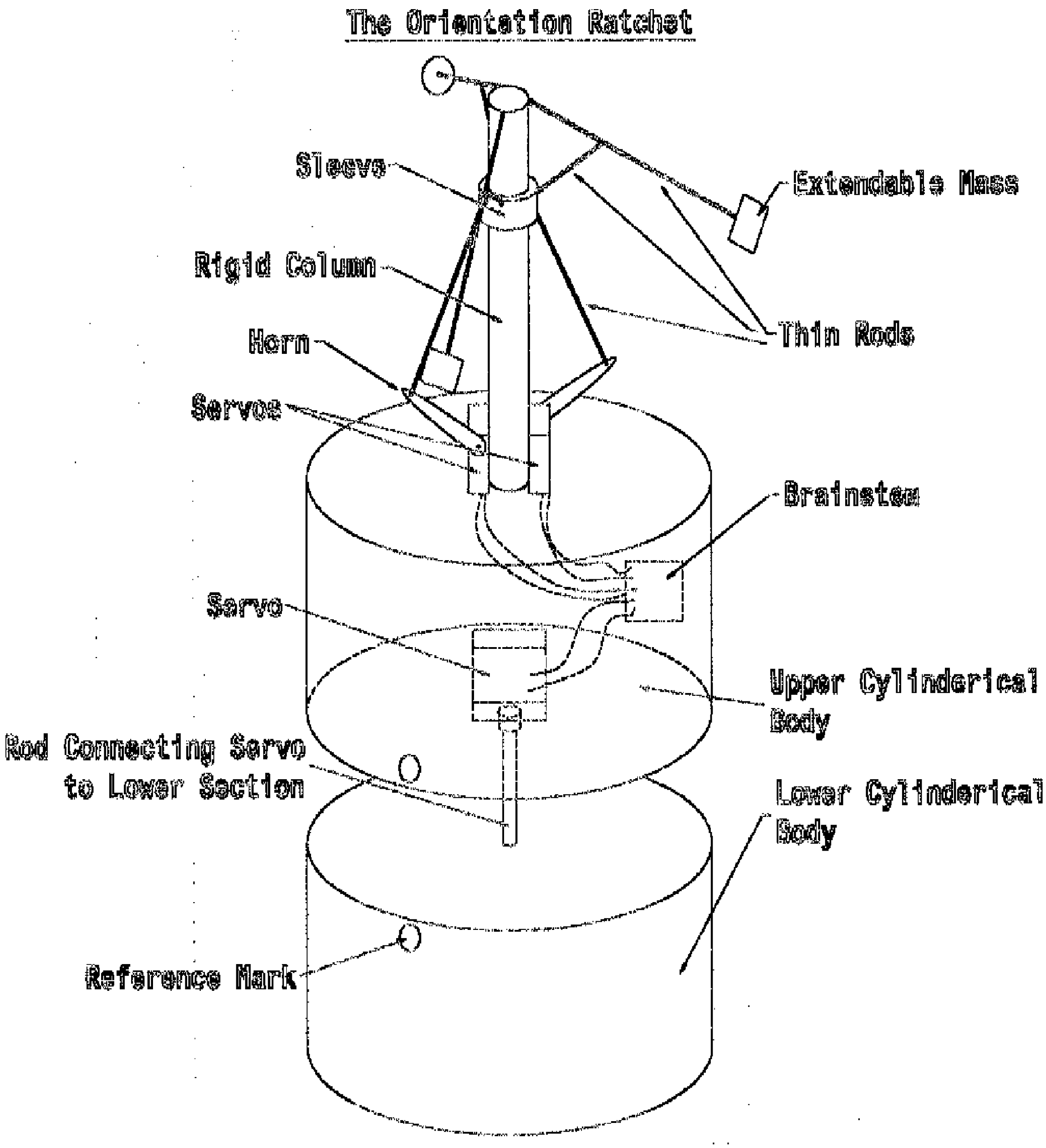

Figure 2: The robot consists of an upper section for which the rotational inertia can be changed by extending masses attached to rods like the action of an umbrella, and a lower section with fixed rotational inertia.

Two servos located at the base of the small column will act to drive a sleeve up and down the small column. Long "horns", or arms, will be attached to the servos. These horns when moved will cause thin rods to push or pull on the sleeve. The sleeve, in turn, will extend or contract the small masses located at the top of the robot. These extendable masses are attached to the sleeve, again, using metal rods. All the servos in the robot will be controlled by the brainstem located inside the upper part of the robot.

We will set up two video cameras in this experiment in order to record specific observations regarding the rotation of the robot. A camera to the side of the robot will detect the relative rotation of the upper and lower parts, and will serve to record the over-all experiment. Reference marks will line the two main body masses in order to indicate how they rotate relative to one another. Another camera at the bottom of the robot acts to record its net rotation. Reference marks will be placed on the bottom of the robot and a "reference disk" will be located in between the bottom of the robot and the camera (see figure 3). This reference disk, inscribed with radial reference lines, will be transparent (so the camera can see through it) and will be initially attached to the robot. This will give it the same initial velocity and spin as the robot itself before it begins its movements. Our intention is to make this motion as close to zero as possible, relative to the frame of the aircraft. However, we realize that some initial motion is inevitable, and that furthermore, as the aircraft travels its parabolic trajectory, the experiment will rotate relative to the frame of the aircraft. This experimental arrangement should serve to minimize these effects. As a result of the reference disk having the same initial slight spin and velocity as the robot, the movement of the reference marks in relation to the reference disk will provide a method for determining net rotation.

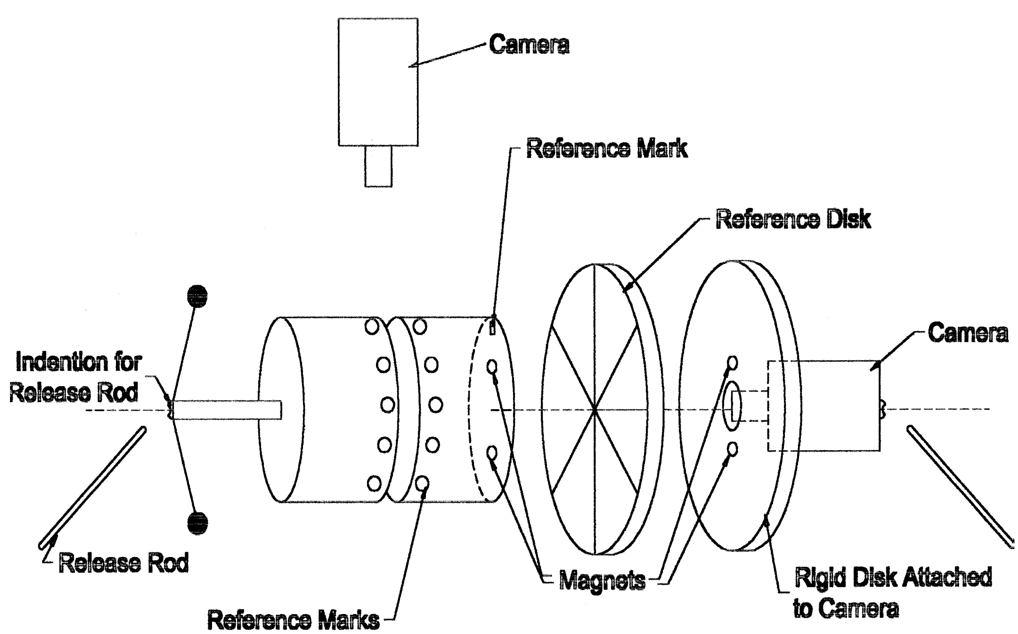

Figure 3: The robot will be initially connected to a transparent reference disk, and the camera housing. The assembly will gently separate during flight.

In order for the reference disk to have the same initial spin and velocity as the robot, we will use a three-part assembly. This three-part assembly will consist of the robot, the reference disk, and the bottom camera (figure 3). The bottom camera will have a smooth rigid disk around the front of it, that fits against the refernce disk and serves to orient the camera lens along the axis of rotation of the robot. Weak magnets will be attached at even intervals around this rigid disk. Around the bottom of the robot, there will also be attached weak magnets such that they align with the magnets on the rigid disk. The magnets on both the camera and the robot will have like poles facing out. Thus, the bottom of the robot and the camera will repel one another very slightly.

Initially the three-part assembly will be aligned with the reference disk centered about the bottom of the robot and the camera centered about the reference disk. Each on of these objects will be balanced, so that once aligned, they are rotationally symmetric about the same common center axis. The entire assembly will be held together along their common center axis using two blunt "release arms." At the top of the robot and the end of the camera along the common center axis, there will be slight indentations. The release arms will hold the three-part assembly together by applying pressure at these two indentions. In zero-g, once the pressure is released by the arms, the three part assembly will come apart very slowly.

As mentioned in the test description section, the central processor will be the General Purpose (GP) Brainstem from Acroname Robotics Corporation. We will program the robot on the ground, using the Tiny Embedded Application (TEA) language. The series of movements the robot will take during the flight will be programmed into it on the ground before the flight. Once experiencing reduced gravity, we will release the robot in order to observe its programmed cycle of movements. We will signal the robot to start its movements through the use of a simple electric switch. After the robot has completed a cycle of movements, it will be retrieved and prepared for its next sequence of movements.

We will prepare several TEA programs that will be downloaded to the robot before the zero-g time windows by use of a serial cable connection to a laptop computer. Through these individual programs we will experiment with the angle of extension of the attached masses, as well as the relative angle Δ through which the upper and lower sections are rotated relative to one another. Upon return to Drury University, we will analyze the observed motions and compare them with the theoretical predictions described in Appendix A and the Test Description Section of this proposal.

Laboratory Approximation of Experiment

Insert in relevant place above:

….alternative to reaction wheels, the standard mechanisms used to orient satellites in outer space (cf. Ping et al, 2000).

Satellite systems employing reaction wheels are well known to exhibit vibrations which can interfere with the goals of the satellite architecture (cf. Kenny, 2001, Masterson, 2001).

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Masterson, R. "Development and Validation of Empirical and Analytical Reaction Wheel Disturbance Models." Diss. Massachusetts Institute of Technology, 2001.

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Section II: Experiment Safety Evaluation

Flight Manifest

Flight Crew
(None have previous flight crew experience)

Primary Flyers:

James Stockton

Allison Harris

Jeremy Woolery

Daniel Ratchford

Team Journalist:

Greg Ojakangas

Experiment Description/Background:

In our experiment we plan to explore the concepts of angular momentum, rotation, and moment of inertia. During our study of these topics we discussed the possibility of producing a net rotation of an object with no angular momentum by altering the moment of inertia for a portion of the object. Our concept for this RGSFOP experiment arose from determining exactly how to go about producing this theoretically predicted phenomenon.

For our experiment we will create a programmable robot capable of demonstrating this phenomenon. To do so it will have two sections that can rotate along a single axis independently of each other. One of these sections will have an apparatus for changing its moment of inertia. To accomplish this that section will have masses whose distance from the rotation axis can be altered, thus changing the rotational inertia of that piece of the robot. In order to complete the desired motion we will first have the masses in their retracted position. Then the section with the extendible masses will rotate clockwise through a given angle with respect to the other section. Next the masses will extend; after which that section will rotate counter clockwise through the same angle, bringing the two sections back into their original orientations relative to each other. Next the masses retract. This sequence of motions will produce a net rotation in our robot; however, that robot will have had no net angular momentum at any point during the experiment.

This interesting phenomena can occur because the rotational inertia of the first section (the portion with extendible masses) is less than or equal to the rotational inertia of the se cond section when the masses are retracted, but greater than when the masses are extended.

Equipment description

Experiment Description:

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Figure 2 is an enlarged rough sketch of our robot's design. There are two main body masses, referred to as the upper and lower parts of our robot. A servo located inside the upper part will work to rotate a rod connected to the lower part. This rotation will cause the relative motion between the two main body components. A small rigid column will protrude out of the top of the upper section in order to support extendable masses. Two servos located at the base of the small column will act to drive a sleeve up and down the small column. Long "horns", or arms, will be attached to the servos. These horns when moved will cause thin rods to push or pull on the sleeve. The sleeve, in turn, will extend or contract the small masses located at the top of the robot. These extendable masses are attached to the sleeve, again, using metal rods. All the servos in the robot will be controlled by the brainstem located inside the upper part of the robot.

We will set up two video cameras in this experiment in order to record specific observations regarding the rotation of the robot. A camera to the side of the robot will detect the relative rotation of the upper and lower parts, and will serve to record the over-all experiment. Reference marks will line the two main body masses in order to indicate how they rotate relative to one another. Another camera at the bottom of the robot acts to record its net rotation. Reference marks will be placed on the bottom of the robot and a "reference disk" will be located in between the bottom of the robot and the camera (see figure 3). This reference disk, inscribed with radial reference lines, will be transparent (so the camera can see through it) and will be initially attached to the robot. This will give it the same initial velocity and spin as the robot itself before it begins its movements. Our intention is to make this motion as close to zero as possible, relative to the frame of the aircraft. However, we realize that some initial motion is inevitable, and that furthermore, as the aircraft travels its parabolic trajectory, the experiment will rotate relative to the frame of the aircraft. This experimental arrangement should serve to minimize these effects. As a result of the reference disk having the same initial slight spin and velocity as the robot, the movement of the reference marks in relation to the reference disk will provide a method for determining net rotation.

In order for the reference disk to have the same initial spin and velocity as the robot, we will use a three-part assembly. This three-part assembly will consist of the robot, the reference disk, and the bottom camera (figure 3). The bottom camera will have a smooth rigid disk around the front of it, that fits against the reference disk and serves to orient the camera lens along the axis of rotation of the robot. Weak magnets will be attached at even intervals around this rigid disk. Around the bottom of the robot, there will also be attached weak magnets such that they align with the magnets on the rigid disk. The magnets on both the camera and the robot will have like poles facing out. Thus, the bottom of the robot and the camera will repel one another very slightly.

Initially the three-part assembly will be aligned with the reference disk centered about the bottom of the robot and the camera centered about the reference disk. Each on of these objects will be balanced, so that once aligned, they are rotationally symmetric about the same common center axis. The entire assembly will be held together along their common center axis using two blunt "release arms." At the top of the robot and the end of the camera along the common center axis, there will be slight indentations. The release arms will hold the three-part assembly together by applying pressure at these two indentions. In zero-g, once the pressure is released by the arms, the three part assembly will come apart very slowly.

As mentioned in the test description section, the central processor will be the General Purpose (GP) Brainstem from Acroname Robotics Corporation. We will program the robot on the ground, using the Tiny Embedded Application (TEA) language. The series of movements the robot will take during the flight will be programmed into it on the ground before the flight. Once experiencing reduced gravity, we will release the robot in order to observe its programmed cycle of movements. We will signal the robot to start its movements through the use of a simple electric switch. After the robot has completed a cycle of movements, it will be retrieved and prepared for its next sequence of movements.

We will prepare several TEA programs that will be downloaded to the robot before the zero-g time windows by use of a serial cable connection to a laptop computer. Through these individual programs we will experiment with the angle of extension of the attached masses, as well as the relative angle Δ through which the upper and lower sections are rotated relative to one another. Upon return to Drury University, we will analyze the observed motions and compare them with the theoretical predictions described in Appendix A and the Test Description Section of this proposal.

Structural Design

Figure 2 is a sketch of our robot's design, and figure 3 illustrates the entire experimental assembly. Once selected, we will ensure the apparatus can withstand the g-force requirements stated in the JSC Reduced Gravity User's Guide. Our TEDP will describe our compliance with these requirements. Both the upper and lower sections of our robot will be constructed of PVC pipe. These cylindrical sections will be closed on all ends by standard PVC end caps. A PVC tube of small diameter will be used for the shaft that protrudes out of the top of the upper section to support the extendable masses. The sleeve on the column that drives the masses in and out will be a disk of slightly larger diameter than the shaft. It may be made of PVC or metal.

The rod connecting the servo inside the upper section to the lower section will be constructed of steel. The long "horns" that attach to the servos will be standard plastic parts obtained from a common hobby store. The thin rods used to push or pull on the sleeve and extendable rods will be constructed out of 440 all-thread steel. These rods will be strong enough to easily endure the torques applied as the attached masses rotate from the central axis. We will enclose them in plastic tubes to inhibit possible bending.

The masses attached to the ends of the rods will consist of washers attached by threaded steel nuts to the all-thread rods. We will make the ends of the extendable masses large and blunt by shrouding them with foam rubber, so there will be no sharp edges on the robot.

To make the connections between the metal rods and the various parts we will use eyelets, connectors, hinges, etc. obtained from a common hobby store. In order to balance the robot and the camera so they maintain rotational symmetry about the same central axis, we will use strips of metal attached by duct tape. For the marks on the robot used as references to detect its rotation, we will use colored stickers or perhaps a cloth measuring tape. The reference disk will be made of plexi-glass with a soft foam-rubber covered rim to eliminate sharp edges. The rigid disk around the camera will also have a soft foam-rubber covered rim. The blunt release arms will be made of wooden dowel rods.

Electrical Systems

All electrical systems used in this experiment are self-contained inside the robot and require only AA batteries for power. Two sets of four AA batteries will be used in the robot itself; each of which will run at approximately six volts. The voltage regulator contained within our robot has an output current rating of 1 A, and the Brainstem uses 50 mA at 6 V, unless connected to a computer when it will use 60 mA at 6 V. All servos will operate with 6 V. Beyond the robot, power for laptop computers and camcorders will be required, however, that can also be provided by batteries supplied by the team. The camcorders operate off 110 volt, 60 Hz AC adapters and draw an average power of 22 Watts. The Laptops will run off of their own batteries as well which run at……………

Pressure/Vacuum systems

No pressurized components (positive or negative relative to STP) exist in this experiment.

Laser System

No laser systems exist in this experiment.

Crew Assistance Requirements

No special duties will be requested of the ground or flight crews for this experiment.

Institutional Review Board (IRB)

This experiment will not require an IRB review because no human or animal subjects are involved, nor are there any biological substances present in the experiment.

Hazard Analysis

No hazardous materials are used in this experiment. Further, most of the moving parts associated with the motions of the robot are housed internally within the robot's outer shell. There is a remote possibility that one or more of the masses at the end of the expandable device could become detached. However, the size of these masses would be relatively small and they would pose no real threat to the safety of the fliers. If a mass were to become detached, the end of the rod that it was attached to could become pointed. This could risk harm to the fliers' eyes. Once again, the possibility of this happening is remote, and in the event that the masses became detached, the threat to the fliers would be minimal due to the generally low momentums involved throughout the experiment. The robot will be built so that when it is fully intact, there will be no sharp edges or protrusions. The electrical power involved with the robot and the video equipment is minimal, and poses no risk to anyone involved.

Tool Requirements

Should any portion of the robot malfunction during the experiment, we will have replacement parts available on the ground as well as the necessary tools for repairs. Also, a second robot will be brought onboard each flight so that if the primary robot does malfunction, the secondary robot can take its place for the remainder of the flight or until the primary robot can be repaired. All tools necessary for use and maintenance of the robot will be supplied by our team. Tools for programming the robot and recording its motion, laptop computers and camcorders respectively, will also be supplied by the team.

Ground Supports Requirements

Our team will require no ground support for our experiment.

Hazardous Materials

There are no hazardous materials involved in the experiment.

Procedures

Ground Operations: While on the ground the team will prepare the robots for flight. This includes downloading rotation protocols to the robots' memory, making any changes/repairs to the robots, preparing the camcorders for data collection, determining the responsibilities of each team member during a flight, and rehearsing the actions that each team member will perform during the course of the experiment.

Pre-Flight Operations: Pre-Flight operations will include ensuring the functioning of the robots, camcorders, and laptops prior to boarding the KC-135 as well as a final run through of the in-flight procedures to be performed by the flyers during the flight.

In-Flight Operations: Our procedures during each parabola and the associated pullout maneuver will be roughly as follows:

Before initiation of parabola:	1. Check that the camcorders are operating.
	2. Ensure robot is set in its initial phase
	3. Place robot into starting position
While experiencing micro-gravity:	4. Initiate robot's rotation cycle.
	5. Record motion of robot with camcorders
During pullout maneuver:	6. Prepare experiment for next run.

Post-Flight Operations: Post-Flight operations will include compiling and analyzing the data obtained from the previous flight as well as downloading new rotation protocols into the robot's memory. Different protocols governing the behavior of the robot during its rotation cycle will be created and utilized experimentally in order to analyze the effects of altering variables such as: angle of extension of masses, relative rotation of the two sections (Δ), order of operations, etc.

Section III: Outreach

Objective:

We will attempt to share our findings and methods to a diverse group of people. We plan to target elementary and high school students along with students from other universities. We also hope to share our results with the general public in order to spread our enjoyment of the subject matter. During these presentations we will be discussing the laws of motion and how our robot works within these set laws, along with a demonstration of the working robot (as tested in the laboratory). By these presentations we hope to inspire children into the field of physics and show them some engineering applications.

Website:

We have developed a website at the following address:

http://www2.drury.edu/physics/zerog0304

This website shows and discusses our project, along with aspects of the development of the robot and theory behind the concept. We will also have this site registered with different search engines such as yahoo and excite. The main purpose of this website will be to distribute our data showing the effectiveness of this idea behind reorienting an object with no angular momentum. We will also have MPEG clips and photos showing the development of this project, as well as others demonstrating the theory behind our proposed robot. Contained within the website will be a link to the NASA Reduced Gravity web page along with contact links for Drury University in case there are any requests for more information.

Target Audiences:

Elementary Aged: We will be presenting our project to Truman Elementary School in Springfield as an audience in which to share our project with. This will hopefully stimulate and excite elementary aged children to physics, and help them gain a broader understanding of the different areas in which physicists might work. We are also presenting our work to the Constellation Club of the Young Astronauts Society. This presentation will be in the second week of October and will serve to show children that are already interested what the world of physics contains. During each of these visits we will discuss the laws of motion as described by Isaac Newton and show some of these principles with our robot.

High Schools: We will also be giving a presentation to the Branson High School physics class in Branson, Missouri. Here we will go into more detail about some of the physical principles behind our project, such as angular motion. These students will also be shown video clips of our work, and also our results, as well as one's about the concept. We will go through some mathematical theory to explain more thoroughly the principles behind our project.

Universities: As well as younger children we also plan to present our findings to several Universities. These include Southwest Missouri State University and the University of Minnesota. We will be presenting to their physics departments and hope to stimulate exciting discussions about the subject matter. Within these presentations we will be able to fully illustrate the idea of angular momentum and prove the theory behind our project.

General Public: As an integral part of our outreach plan we have formed a partnership with The Discovery Center of Springfield, a science museum very near to our campus. The

Discovery Center has agreed to integrate our research into their curriculum in all three of their major educational endeavors.

First is their after school program; agencies that provide after school activities for children such as Boys and Girls club, Salvation Army, Boys and Girls Town, and Springfield Community Center often come to the Discovery Center for one hour classes on various subjects in the sciences. One of these classes covers the concepts of physics. In cooperation with our team, the Discovery Center has created a portion of that lesson that uses the research we have done (and hope to further in microgravity) to illustrate physical laws. The second program we are involved with is the Summer Workshop programs. These are 4-6 hour lessons that take a much deeper look into areas of science than students can receive in their normal classes at school. Some past topics of these workshops relate very well with our research endeavors: The Physics of Flight, Electronics, and Robotics. The results of our research will be incorporated into these classes as they continue to be taught throughout the school year. Also, James Stockton, one of our team members, is currently working with educators at the Discovery Center (Ann Cater- Education Director; Mindy Bowen- Outreach Coordinator) in developing curriculum for a new workshop that focuses on our experiment. The third way in which the Discovery Center is incorporating our research into their education curricula is by utilizing it in their own outreach program. The Discovery Center provides eight week sessions (4 sessions per school year) of supplemental science curriculum to elementary classes at area Title I schools. These are schools where 70% or more of the student body receives free or reduced lunch from the state. These schools generally cannot afford the tools and supplies necessary for hands on science activities. The Discovery Center's curriculum for its 4th and 5th grade classes in the outreach program has been modified to incorporate our research as both an example of science outside the classroom and as an example of student led investigation.

James Stockton is an employee of the Discovery Center of Springfield and teaches classes in all three programs in which our research will be incorporated. Being both a team member and a teacher at the Discovery Center, James will ensure the accurate and appropriate use of our research in the education of the museum's and the city's students.

All of the listed institutions have been contacted and have shown great enthusiasm for hearing our presentations, which will be held during either the Fall 2003 or Spring 2004 semesters. (see attached letters)

Publications/Media:

In addition to the presentations above we plan to submit a paper about this project to the following journals:

<u>The American Journal of Physics</u>

<u>The Physics Teacher</u>

We will also be contacting local media agencies. Included in this are KOLR 10, KY3, and Springfield 33 (television stations). We will also be contacting the Springfield NewsLeader with information about our project and also presentation dates for anyone interested.

Conferences:

We will be presenting our results and work at the National Council of Undergraduate Research in Spring 2004.

IV. Administrative Requirements

Letter of Institutional Endorsement

Statement of Supervising Faculty

Funding/Budget Statement

We are seeking funding from the following sources:

National Space Grant College and Fellowship Program

Sigma Xi Scientific Research Society

These two grants along with others will help to fund our trip who's expected expenses are estimated as follows:

Equipment: $500
Shipping/Operating: $0
Testing: $0
Transportation (to and from Houston): $150
Lodging for four students: $1400
Food: $400
Flight Physicals: $400

Total: $2850.00

Institutional Animal Care and Use Committee

Our experiment does not involve the use of animals.

Parental Consent Forms

All members of our team our over age 18. Therefore, no parental consent forms are necessary.

Appendix A:

In this appendix, we use Newton's rotational equations of motion (cf. Marion and Thornton, 1995) to arrive at an expression for the net rotation of our robot after a full sequence of expansions, contractions, and relative rotations.

Applying Newton's first law to rotation, we find that an object with no net angular momentum will maintain a net angular momentum of zero unless acted upon by an external torque. From the application of Newton's third law we know that if Part 1 of our robot applies a torque to Part 2 of our robot, then Part 2 will apply an equal but opposite torque on Part 1. Thus we know that when one section of our robot rotates, the other section rotates in the other direction such that the sum of the two angular momenta is zero.

$$L_{net} = 0 = I_1\vec{\omega}_1 + I_2\vec{\omega}_2 \qquad \text{(A1)}$$

Since we know the sum of the angular momenta of the two sections to be zero we have:

$$I_1\vec{\omega}_1 = -I_2\vec{\omega}_2 \qquad \text{(A2)}$$

The angular velocity, ϖ, for each part is the time derivative of its angle, θ, of rotation about the central axis.

$$I_1\frac{d\vec{\theta}_1}{dt} = -I_2\frac{d\vec{\theta}_2}{dt} \qquad \text{(A3)}$$

Integrating both sides with respect to time and evaluating while assuming initial values for both angles to be zero in an inertial reference frame:

$$I_1\theta_1 = -I_2\theta_2 \qquad \text{(A4)}$$

Solving for θ_1, we arrive at:

$$\theta_1 = \frac{-I_2}{I_1}\theta_2 \qquad \text{(A5)}$$

At this point we describe the motions of our robot. Its rotations occur in two main phases, referred to as phase A and phase B. In phase A the rotational inertia of the extendible mass section will be at its largest value, I_{1big}. In phase B the rotational inertia of the extendible mass section will be at its smallest value, I_{1small}. We will first deal with phase A.

By defining the net rotation of one section relative to the other as $\Delta = \theta_1 - \theta_2$, solving this for θ_2, and substituting this into the equation from the previous step, we have:

$$I_{1big}\theta_{1A} = -I_2(\theta_{1A} - \Delta) \quad \text{(A6)}$$

Solving for θ_{1A} we arrive at:

$$\theta_{1A} = \left(\frac{I_2}{I_{1big} + I_2}\right)\Delta \quad \text{(A7)}$$

Through a similar process for phase B we have:

$$\theta_{1B} = \left(\frac{I_2}{I_{1small} + I_2}\right)(-\Delta) \quad \text{(A8)}$$

Adding the formulas for θ_1 from phases A and B we arrive at an equation for the net rotation, ϕ, experienced by our robot during one cycle:

$$\Phi = \frac{I_2(I_{1small} - I_{1big})\Delta}{(I_{1big} + I_2)(I_{1small} + I_2)} \quad \text{(A9)}$$