Team Five

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Mid-term Summary of Work-in-progress:

Exercise Device for the Crew Exploration Vehicle

Biomedical Systems for Space Application

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SOW Report

Exercise Device for the Crew Exploration Vehicle

Introduction

As NASA prepares to return to the Moon by 2020, a new vehicle for space exploration is being developed. The Crew Exploration Vehicle is the capsule based vehicle currently being designed and tested under the Constellation program. The CEV will travel to the moon with the help of the Ares I and Ares V rockets. The Ares I rocket is an in-line, two-stage rocket that will launch both the Orion Crew Exploration Vehicle and the launch abort system. The CEV is capable of housing four to six crew members at a time. The Ares I rocket is capable of launching the CEV into low earth orbit where it will dock with an additional stage capable of delivering the CEV and the Altair lunar lander to the moon. The Ares I rocket will also be used to bring crew members and supplies to and from the International Space Station. The first crew transportation to the International Space Station via the Ares I rocket and the CEV is expected to occur in 2014. By 2020, NASA plans to return to the moon. With each lunar mission, a module will be left behind in order to construct a lunar habitat for long term lunar habitation. The initial lunar missions will involve 2 days of travel to the moon, a week long mission, and 2 days of return travel to earth. Once the lunar habitat has been sufficiently constructed, mission durations will last up to six months at a time. Current resupply missions to the International Space Station via the Space Shuttle can last up to 17 days at a time.

Exposure to microgravity has been shown to have a number of negative physiological effects. Astronauts often experience a loss of fluids and electrolytes, motion sickness, anemia, bone loss, and muscle atrophy (Fulford 1996). Astronauts participating in long duration missions have been shown to lose up to 19 percent of weight-bearing bone (Fulford 1996). Similarly, humans experience a significant and rapid loss in muscle tissue when exposed to microgravity (Fitts 2001). Even mission durations experienced by the crew of the CEV will experience the negative physiological effects of microgravity. Studies have shown that rats exposed to microgravity display a 37% reduction in muscle mass after only a single week (Fitts 2001). A similar study found that the human plantar flexor muscles exhibited a 21 percent decline in peak force after a 17 day shuttle flight. Mission durations aboard the CEV will last between approximately 11 and 17 days at a time. Therefore, a method of counteracting muscle and bone loss due to microgravity is necessary on board the Crew Exploration Vehicle.

Current methods available for counteracting muscle and bone loss in space environments involve some form of exercise. There are three main pieces of exercise equipment currently used in space (Canright 2007). The Cycle Ergometer is very similar to a bicycle, providing resistance to a crew member while pedaling. The Cycle Ergometer can be used to monitor heart rate and the amount of work being performed. A treadmill is also used to simulate walking or jogging on earth. The crew member is tethered to the treadmill via a harness system. Finally, the Resistance Exercise Device (RED) simulates a weight lifting machine. The RED provides a total body workout, providing resistance through the use of elastic bands and pulleys (Canright 2007). These three exercise devices provide a means of counteracting muscle and bone loss in space. However, the equipment is not completely effective, and tissue loss is experienced during long duration missions. There are two main efficacy issues with current microgravity exercise technologies. Primarily, the available exercise devices do not provide a linear force profile. The amount of force generated per unit displacement is not constant. The result of this non-linear force profile is that the user does not experience constant resistance throughout the entire range of motion. Also, a non-linear force profile provides variable resistance from user to user, as each user has a slightly different range of motion. The second issue with current exercise technologies in microgravity is that many available options do not provide both a concentric and eccentric exercise component. Concentric exercise is often referred to as a "positive rep" while eccentric exercise is referred to as the "negative rep". Eccentric exercise has been shown to be a vital part of preventing atrophy of skeletal muscle. In fact, it has been shown that eccentric exercise is actually more effective at atrophy prevention than concentric exercise (Fitts 2000).

In addition to the functional issues with current exercise technologies, the CEV provides additional constraints. The previously mentioned exercise devices are currently in use aboard the Space Shuttle and the International Space Station. Both of these environments have less of a space constraint than the CEV. The CEV is currently projected to be only slightly bigger than the Apollo era capsules. The Orion CEV is expected to be 5 meters in diameter, with a mass of 22.7 metric tons. The interior of the capsule will contain only 2.5 times the volume of the Apollo capsule previously used to travel to the moon (NASA 2006). The increased mass and volume constraints of the CEV require that a new exercise device be developed. Therefore, the purpose of this design project is to develop a low mass and volume exercise device capable of preventing muscle and bone loss during missions aboard the CEV.

Mentor Identification

The sponsor for this project is Dr. Tara Ruttley at the NASA Johnson Space Center in Houston, Texas. Dr. Tara Ruttley works in the Biomedical Systems Division. The Biomedical Systems Division's main focus is to maintain crew health, which includes exercise countermeasures.

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Collaboration

In addition to the support of Dr. Tara Ruttley, the project mentor, the team has consulted with various other experts at the Johnson Space Center. These collaborators include Dr. Tomko of the Human Research program within the Advanced Capabilities Division. Also, Dr. Bruce Hather and Dr. Victor Schneider at NASA Headquarters have provided assistance. Both Dr. Hather and Dr. Schneider have been able to give valuable information concerning exercise in microgravity.

In addition to NASA staff, Dr. Charles Lessard of Texas A&M University has been consulted throughout the project duration. Dr. Lessard is a professor in the Biomedical Engineering Department at Texas A&M University, and he serves as the Faculty Advisor for the design project.

Team Identification

All members of Team Five are enrolled in BMEN 453-502, Analysis and Design Project at Texas A&M University. The course involves a group biomedical engineering analysis and design project. Students participate in the problem identification, solution development, design formulation, as well as system testing and analysis of a biomedical device.

To facilitate communication with both the Texas Space Grant Consortium and the Faculty Advisor at Texas A&M University, the team name of Team Five was chosen. The name Team Five was assigned by Dr. Charles S. Lessard, the faculty advisor of Team Five, and the name was selected for further use to provide consistency. Moreover, the name Team Five is a reflection of the Texas A&M Tradition of the 12^{th} Man, but is applied to a four member team.

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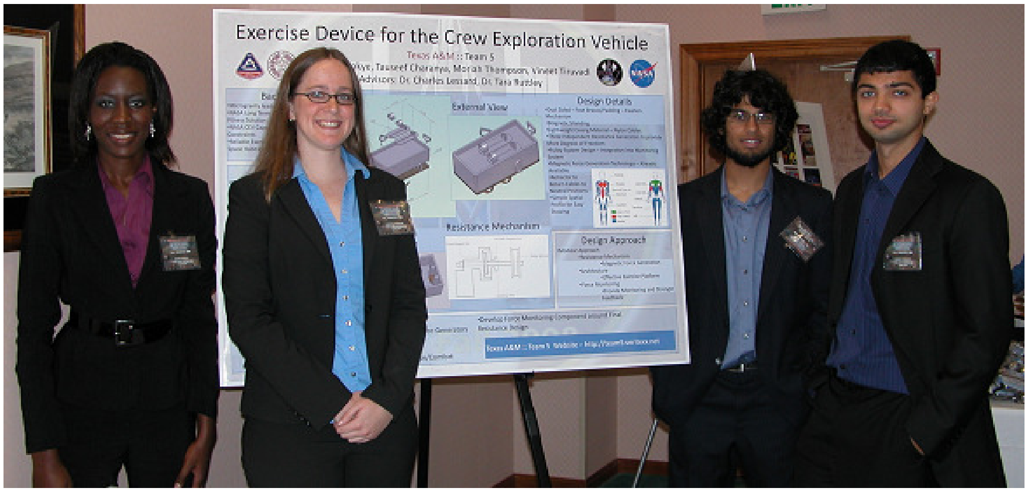

Figure 1: Team Members (from left to right) Boakye, Thompson, Tiruvadi, and Charanya

Background

During the first semester, the team developed three different design options for the resistance mechanism as well as an overall architecture design. The resistance mechanism designs considered included magnetic, wind, and hydraulic resistance. A wind resistance device would require a large fly wheel, making this design option exceed the overall desired volume. Hydraulic resistance was considered, but this option provides counteracting concentric exercise instead of both concentric and eccentric exercise. A magnetic based resistance mechanism has the capability of providing large amounts of resistance with relatively low mass and volume. Therefore, the team made the decision to pursue a design based upon magnetic resistance. The original architecture design involved a rectangular encasing that could be worn much like a backpack. The user would strap himself or herself into the device and be free to exercise in any portion of the cabin. Based upon feedback received at the design review and TSGC Showcase Presentation, the team decided to alter the architecture design. Mobility within the CEV during use is both unnecessary and unwanted. There is limited space for crew aboard the CEV, making exercise outside of a designated area both uncomfortable and dangerous for the other crew members. Also, the previous architecture design was not found to have optimal mass and volume requirements. The arrangement of the resistance mechanism within the device allowed for unwanted free space within the design. Therefore, altering the architecture design was the first priority at the beginning of the second semester of the project. Images of the original design are provided in Figure 2 and 3 below. The overall design has changed significantly during the second semester, and the new design alterations are detailed in the Design Plan section.

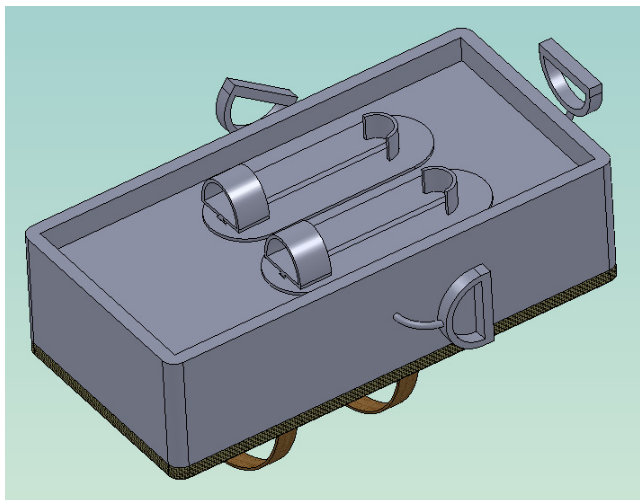

Figure 2: Former Device Design, Exterior View

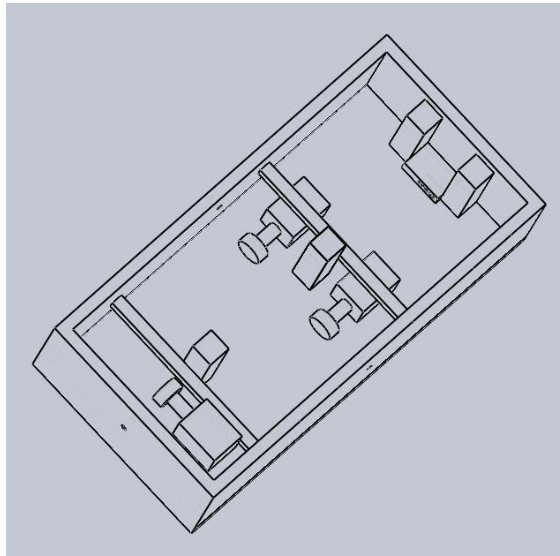

Figure 3: Former Device Design, Internal View

Accomplishments

Throughout the first semester Team 5 had several accomplishments. In the first semester, Team 5 completed the following design milestones: Base Level, Level I, Level II, and Level III requirements. In addition, Team 5 completed Option Area III, Website Design and Development. Team 5 earned the corresponding milestone-associated earnings. In the first semester TSGC showcase, Team Five presented their design and was awarded for their final report submission.

In the second semester, Team 5 completed the Level I design milestone, which qualified the team for the $75 award associated with this Level. Team 5 submitted an abstract to the Design of Medical Devices Conferences and won the opportunity to present their exercise device design in a technical poster presentation. Tiruvadi will be representing Team 5 at the Design of Medical Devices Conference on April 16th, 2009.

Project Objectives

The objectives for Semester II are the following:

- Finalize the architecture design
- Optimize mass and volume requirements
- Incorporate retraction mechanism
- Select parts and materials for prototyping
- Construct a scaled prototype of the exercise device
- Test the device for resistance, user ease, and reliability
- Present prototype and findings to the TSGC, NASA, and Texas A&M University

Technical Objectives

The technical objectives of the exercise device for the CEV are to:

- Provide sufficient resistance in a zero gravity environment
- Facilitate exercise of the major muscle groups
- Meet volume and mass requirements of the Crew Exploration Vehicle
- Provide both concentric and eccentric exercise
- Provide resistance with a near linear force profile
- Measure the force exerted to provided for monitoring of muscle strength

Design Plan

Methodology

In order to achieve the Technical Objectives described previously, the project was divided into four major design categories.

- Resistance Design: Identification of the most efficient means of producing sufficient resistance in a zero gravity environment.

- Return Mechanism: A mechanism to return the device to its starting position and provide an eccentric exercise component.
- Architecture: Providing maximal degrees of freedom through the development of an adjustable system of minimal volume and mass.
- Force Monitoring: The development of a mechanism to measure the force exerted by the crew member for each muscle group targeted.

Dividing the project into these categories allowed for a systematic approach to developing a solution. Design work on the architecture of the device was able to be completed at the same time that the resistance mechanism design was being developed. The force monitoring system is dependent on both the resistance mechanism and the architecture design. Therefore, design of the force monitoring system has been tasked after the initial prototype and testing stage.

Resistance Mechanism:

The selected design is based upon the bike trainer concept for road bikes. A road bike can be converted into a stationary bike through a stand that lifts the back wheel off the ground and also provides resistance to the back wheel. The user can still change gears to alter the resistance. The benefit of modeling the design for a microgravity exercise device off of a bicycle trainer is that most trainers are designed to be both light weight and compact.

The proposed design for the CEV exercise device would utilize only the resistance generation mechanism of the bike trainer. There are three methods of bike trainer resistance mechanisms. The wind trainers utilize the air resistance of a fan to generate the appropriate resistance. Magnetic trainers use a series of magnets to create resistance. Sometimes the magnets are moveable in order to adjust the resistance. Fluid trainers utilize hydraulic resistance created by fluids in a confined space. Different fluids such as silicon get thicker as they are heated, creating more resistance with increased heat due to friction.

The selected resistance mechanism for the final design concept is based upon magnetic resistance. In this design, a metal disk is allowed to rotate between sets of magnets on each side. On one side the magnets are fixed so that they do not rotate. On the other side of the disk are a set of magnets that do not rotate with the exercise motion, but the position of this magnet set can be adjusted. Adjusting the movable magnet set will alter the level of resistance provided by altering the strength of the magnetic field. Magnetic fields generated between the magnets on each side of the metal disk result in eddy currents that resist the rotation of the disk. This magnetic resistive force is transmitted to a rotating axle running through the center of the disk. The axle is then connected the pulley-cable system that the device user will use to perform the exercise motion.

There are a number of magnetic resistance devices commercially available. The team made the decision to purchase a commercially available magnetic resistance device and incorporate it into the overall design. This decision reduced the overall complexity of the design and has allowed for further focus on the architecture and return mechanism designs. The magnetic resistance device chosen for prototyping is produced by Bell and is utilized in the Bell Motivator Magnetic Indoor Bicycle Trainer. A picture of the Bell magnetic bike trainer is provided in Figure 4 below. The boxed portion in Figure 4 highlights the magnetic resistance device that will be utilized.

Figure 4: Bell Motivator Magnetic Bike Trainer and Resistance Device

Return Mechanism:

The magnetic resistance mechanism provides resistance regardless of the direction of rotation. The resistance mechanism alone does not have means of inherently returning to its original position. Therefore, the design of a return mechanism was required. It was also essential that the return mechanism reduce any non-linearities in the force profile and incorporate an eccentric exercise component.

The effect of the magnetic resistance during the return of the device is removed by incorporating a ratchet design. The axle of the magnetic resistance mechanism is attached to a gear with angled teeth. The gear is partnered with the axle of the remainder of the device through a part with similar angled teeth that are angled in the opposite direction. The end results is that the magnetic resistance will only be provided in one direction. Upon return the ratchet based gear system will not catch, and the metal plate within the magnetic resistance mechanism will not spin. The internal design of the return mechanism is provided in Figure 5.

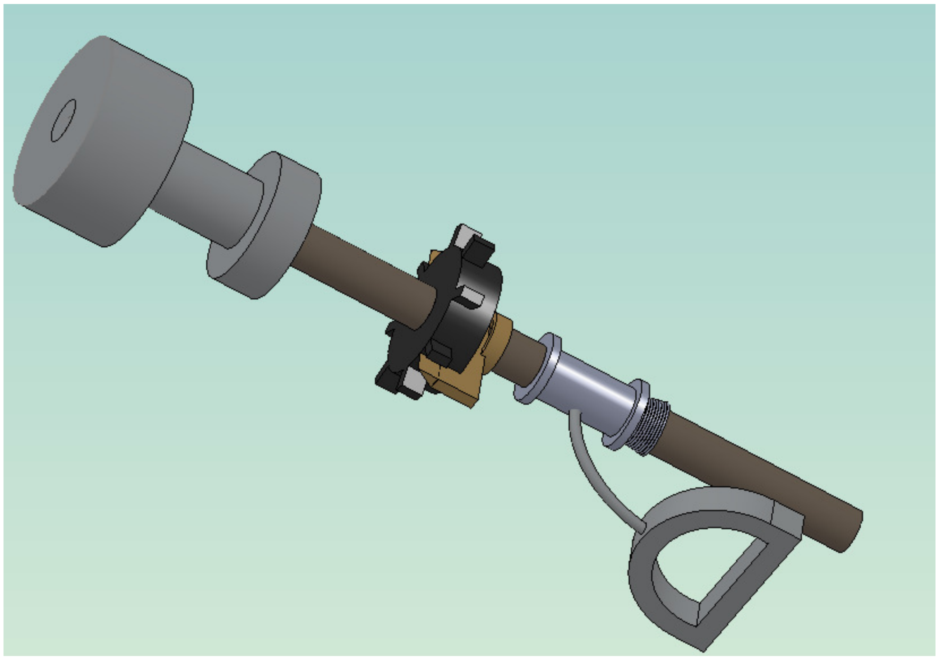

Figure 5: Return Mechanism Design

The eccentric component of the return mechanism is provided by the incorporation of a torsional spring. The torsional spring will tighten when the user performs the concentric motion of the exercise. The torsional spring will create tension that attempts to retract the cable. The incorporation of a torsional spring will introduce a non-linearity in the force profile. However, this non-linearity will be minimal due to the previously mentioned ratchet design. The torsional spring does not have to overcome the resistance of the magnetic resistance mechanism. The only forces that the torsional spring must overcome are that of the ratchet friction and the opposing force of the user. In this manner, an eccentric exercise component is provided. The non-linearity provided by the torsional spring is much greater during the eccentric exercise. However, the team believes that this design optimizes the desire for a linear force profile and the incorporation of a concentric and eccentric exercise component. Table 1 below illustrates the conflicting design objectives. The selected design attempts to optimize these conflicting design requirements.

Table 1: Conflicting Design Aspects

	Concentric & Eccentric Component	Force Profile
Torsional Spring Only	**Yes**	**Non-Linear**
Magnetic Resistance Only	**No**	**Linear**
Combination Design	**Yes**	**Slightly Non-Linear**

Architecture Design:

The design plan for the architecture design is now a compact box that can be easily installed and removed from the internal cabin of the CEV. The device could then be transported to the lunar habitat to provide exercise for the crew before the habitat construction is complete. The original architecture design is being reduced to less than half of the original dimensions. As parts are being procured for the return mechanism the final architecture dimensions will be determined. The device will have two handles for user interface. The user can take advantage of weightlessness to perform a full body workout. Straps on the floor and wall of the CEV would allow for stabilization of the user. A diagram detailing the targeted muscle groups of the device is provided in Figure 6.

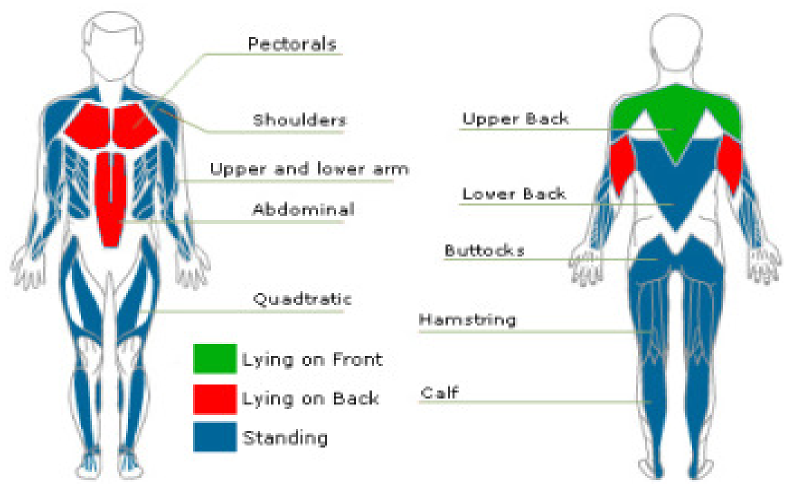

Figure 6: Targeted Muscle Groups

Evaluation

The three areas of evaluation that will be performed following the initial prototyping stage are resistance testing, reliability testing, and user ease. The actual resistance provided throughout the entire range of motion will be tested in the mechanical engineering laboratories at Texas A&M University. NASA standards for the acceptable physiological ranges will be utilized in this testing. Thus, the acceptable height and arm span ranges of an astronaut will be used during testing. The force generated will be measured and plotted as a function of displacement in order to observe the deviance from linearity of the device.

Furthermore, the prototype will be tested for user ease. Subjects of varying heights, builds, and arm spans will be selected to use the device and provide feedback. Adjustments to the design dimensions will be made at this time. Participants will be asked to give feedback on user ease, comfort, and the amount of challenge provided.

Lastly, the prototype will be tested for reliability. A number of fatigue tests will be performed on the encasing as well as the cables and handles utilized by the design. The device will be tested under repetition of normal exercise use until failure occurs or an acceptable time limit has passed. The effects of gravity will be minimized for this test by performing the exercises horizontally.

Risk Analysis

Exercise of any kind has an inherent risk component. The physical nature of exercise lends itself to the possibility of over-exertion, fatigue, or possible injury. The threat of astronaut injury will be reduced through extensive fatigue testing and designing the device to a factor of safety of three. User interface and ease testing will allow for alterations to be made that will facilitate ergonomically correct exercise motions. Proper training on using the exercise device will also reduce any risk of injury.

The failure of the exercise would have serious repercussions for crew health. Crew members currently spend approximately 2.5 hours per day devoted to exercise during longer duration missions. This emphasis on exercise is necessary due to the rapid and significant decrease in bone and muscle tissue when exposed to microgravity. Therefore, rigorous testing must be performed in order to ensure that all components are able to handle the loads and stresses of launch, repetitive use, as well as possible transport and installation in the lunar habitat. Also, a small bag with replacement parts could be provided to prevent the occurrence of an absolute failure while on a mission.

Cost Analysis

The objective of this project is to develop an exercise device for the Crew Exploration Vehicle that will maintain crew muscular, bone, and cardiovascular health with minimal mass and volume. Due to restricted volume and mass capabilities within the newly-developing Crew Exploration Vehicle (CEV) there is a need for a multi-functional, compact exercise machine that can incorporate both resistive and aerobic exercise capabilities during missions. Our proposed design provides constant force eccentrically and concentrically and can be stowed in a volume of one cubic foot. The cost of occupying one cubic foot on the CEV is estimated to be $22,000. Therefore, due to the compactness of our design it would be extremely cost efficient in terms of the volume it occupies. With an approximate weight of 1.75 kgs and volume of one cubic foot, the device would increase the current benefit to cost ratio to a value greater than one. Including the travel expenses, model materials, display materials, and postage, the total cost of the project comes out to only $1384.80.

Timetable

Team Five will accomplish the overall design and analysis of the exercise device for the CEV by adhering to the following timetable. The necessary tasks for completion are divided into four different levels according to the requirements set forth by the Texas Space Grant Consortium. Included in the timetable are Option Areas that Team 5 plans to fulfill. The tasks included within each level are detailed below. Also, important deadlines throughout the coming semester are provided in Table 2 below. Note that the Base Level, Level I, and Level II requirements have been fulfilled at this time.

Table 2: Project Timeline

BASE LEVEL	**LEVEL I**
Establish a team Recruit a faculty advisor Figure out a Team Name Name Team Leader Choose a Topic Brainstorm ideas Complete and Submit Design Brief	Include feedback from the reviewer Contact Mentor Start Tuesday Tag-Up Reports Team Photos Turn in Design Project Proposal Continue Researching
LEVEL II	**LEVEL III**
Continue Tag-Up Reports Design Team Patch Field Experience Write and Submit Mid-Term Report "Rough Draft" Power Point Presentation	Final Design time Continue tag-up reports Participate in TSGC Design Challenge Showcase Complete and Submit Final Technical Report Submit Program Evaluation Present poster presentation Option Area III-Website Design and Development Team Travel Grant

The Gantt chart provided in Figure 7 below contains a graphical representation of the timetable for the second semester. The "Supply Procurement" task refers to obtaining the parts that the team will require for the construction of the device. The "Weekly Meetings" include the times that the team intends to physically meet to work on the project. "Sponsor Communication" includes the times that the group will contact the mentor and/or TSGC via e-mail, and "Conference Call" refers to the times that the group will be in direct contact with the mentor or another NASA staff member via a formal meeting or conference call between the mentor and the team members.

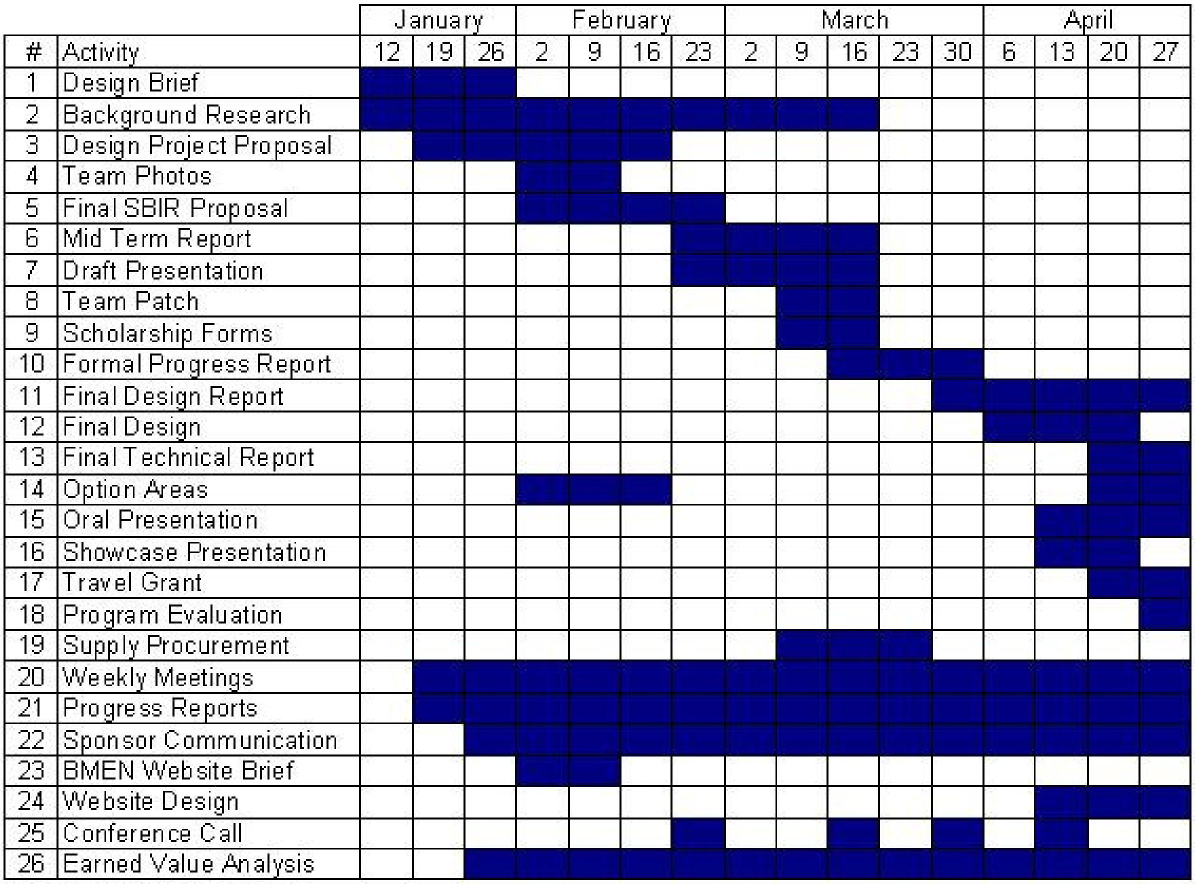

Figure 7: Project Gantt Chart Spring 2009

Budget Plan

The only expenditure for the Spring 2009 semester has been parts procurement for $79.99. The majority of the expenditures are expected throughout the next month. The expenditures for the current semester will include travel costs in order to complete the Field Experience requirement as well as travel costs for attending the final presentations in Houston. The expenditures will include both travel and supply procurement for prototype fabrication. The projected budget for the completion of the project is provided in Table 3. All funds for project completion will be obtained from the TSGC upon timely completion of each of the required deliverables.

Current Earnings:

- Project Funds F08-S09 running total : $975.00
    - S09 Project Funds running total: $75.00
    - F08 Project Funds + Travel Grant + Option II total: $900.00
    - Invoices received to date: $0.00

Projected Cost of Continuation:

Table 3: Detailed Projected Budget

Postage	$10
Display Materials	$50
Model Materials	$500
Team travel *	$412.4
Field Experience *	$412.4
Meeting Registration Fees	None as of now
Total Expenses (As of now)	**$1384.80**

*Both Team Travel and Field Experience involve transportation and housing costs in order to visit the Johnson Space Center. Travel cost estimation includes 204 travel miles at $0.85 per mile reimbursement for a gas expenditure of 173.4 miles per trip. Hotel expenses for an overnight trip for four people are estimated to be $239, making the total expense per trip $412.40.

Conclusion

In summary, the team has completed the preliminary design phase and is now entering the prototyping phase. The architecture and return mechanism designs are being finalized. The magnetic resistance mechanism has been selected and purchased for prototyping. The remaining materials will be purchased in the next two weeks following approval from the Faculty Advisor. Prototyping and testing can then be completed. The overall design will provide sufficient resistance to prevent atrophy of muscle and bone tissue in a zero-gravity environment. The device will be low mass and volume, contain an eccentric and concentric component, and display a near linear force profile.

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Appendix A: Final Report Copy

A copy of the Fall 2008 Final Report can be found at the following URL:

http://www.tsgc.utexas.edu/challenge/preview/TAMU_TeamFive/

Appendix B: Trip/Budget Reports

The only cost encountered so far has been the Magnetic Resistance Device for $79.99. A Budget Report will be submitted when confirmation of payment receipt is provided by the vendor.

Appendix C: Option Reports

No Option Areas have been completed at this point. The team plans to complete a website and participate in a technical presentation before the Level III deadline.