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Educational Experiences of Embry-Riddle Students through NASA Research Collaboration

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ABSTRACT

NASA's educational programs benefit students and faculty while increasing the overall productivity of the organization. The NASA Graduate Student Research Program (GSRP) awards fellowships for graduate study leading to both masters and doctoral degrees in several technical fields. GSRP participants have the option to utilize NASA Centers and/or university research facilities. In addition, GSRP students can serve as mentors for undergrad students to provide a truly unique learning experience. NASA's Cooperative Education Program allows undergraduate students the chance to gain "real-world" work experience in the field. It also gives NASA a no risk capability to evaluate the true performance of a prospective new hire without relying solely on a "paper resume" while providing the students with a greater hiring potential upon graduation, at NASA or elsewhere. University faculty can also benefit by participating in the NASA Faculty Fellowship Program (NFFP). This program gives the faculty an opportunity to work with NASA peers. The Mission Analysis Branch of the Expendable Launch Vehicles Division at NASA Kennedy Space Center has utilized these two programs with students from Embry-Riddle Aeronautical University (ERAU) to conduct research in modeling and developing a parameter estimation method for spacecraft fuel slosh using simple pendulum analogs. Simple pendulum models are used to understand complicated spacecraft fuel slosh behavior. A robust parameter estimation process will help to identify the parameters that will predict the response fairly accurately during the initial stages of design. These programs provide students with a unique opportunity to work on "real-world" aerospace problems, like spacecraft fuel slosh,. This in turn reinforces their problem solving abilities and their communication skills such as interviewing, resume writing, technical writing, and presentation. Faculty benefits by applying what they have learned to the classroom. Through university collaborations with NASA and industry help students to acquire skills that are vital for their success upon entering the workforce.

Keywords: NASA, GSRP, NFFP, Research Collaboration

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1. PROGRAM BACKGROUND

The NASA Graduate Student Researchers Program (GSRP) awards United States citizens fellowships for graduate study leading to masters or doctoral degrees in the fields of science, mathematics, and engineering related to NASA research and development. The goal of NASA's GSRP is to cultivate research ties to the academic community, to help meet the continuing needs of the nation's aeronautics and space effort by increasing the number of highly trained scientists and engineers in aeronautics and space-related disciplines, and to broaden the base of students pursuing advanced degrees in science, mathematics, and engineering. Research in these areas gives practical experience that lead to aeronautics and space careers. The program supports approximately 300 graduate students annually. Each student typically has a local faculty research advisor, or faculty mentor, as well as several contacts at NASA to offer advice and to aid in research. GSRP participants also have the option to utilize NASA Centers and/or university research facilities. Mentoring and practical research experiences are important aspects of the GSRP Fellowship.

The NASA Cooperative Education Programs are designed to combine academic studies with on-the-job training and experience and to give students an opportunity to work at a NASA Field Center while completing their education. Unlike an internship, which typically lasts only a summer or semester, a student in the co-op program will alternate semesters of school with work at NASA, with the intent of receiving a full time position in a field related with any one of their co-ops upon graduation. A standard tour of duty consists of at least three semesters of work. This allows NASA to have a pipeline for qualified new hires that from experience will be good matches for their respective departments, while giving those same students the chance to preview what their job might be. Each NASA Field Center manages its own program. At NASA's Kennedy Space Center, the Cooperative Education Program is supported by many organizations throughout the center. These include Space Shuttle Processing, Spaceport Engineering and Technology, Space Station/Payload Processing, Spaceport Services, Safety/Health Independent Management, and Expendable Launch Vehicles.

The NASA Faculty Fellowship Program (NFFP) provides faculty who are United States citizens the opportunity to actively participate in a wide range of research projects with their NASA peers at several NASA centers or the Jet Propulsion Laboratory (JPL). Research fellowships typically last ten weeks and occur during the summer months, but can be extended into the academic year to support additional research efforts on a case-by-case basis. Embry-Riddle was first introduced to the fuel slosh project during a faculty fellowship in summer 2004. Some centers, like NASA's Kennedy Space Center (KSC) offer follow-on research opportunities to the faculty member, like the GSRP, once they have successfully completed the NFFP.

Embry-Riddle Aeronautical University (ERAU) is pleased to be a participant for each of these educational programs. NASA Kennedy Space Center's Expendable Launch Vehicles Division has utilized all of these programs with students from ERAU to conduct research in modeling and developing a parameter estimation method for spacecraft fuel slosh using simple pendulum analogs. Since the project began in August 2004, six technical conference papers with graduate and undergraduate students taking a leading role in research have been published as a result of this joint collaboration (Chatman et al., 2007, Schlee et al., January, July and December 2005, February and May 2006). One graduate master's thesis has also been produced as a result of this work (Schlee, July 2006).

The following two sections represent a portion of the past and present GSRP, NASA Faculty Fellowship Program, and NASA Cooperative Education Program, work being done under the joint cooperation between ERAU and NASA's Expendable Launch Vehicle Division.

2. PROJECT BACKGROUND AND PAST GSRP RESEARCH

Spinning a spacecraft or an upper stage is a well-established method for stabilizing a space vehicle with a minimum of hardware, complexity, and expense. While spinning a deployed spacecraft over its operational lifetime has generally fallen out of style in favor of the more modern three axis stabilized active systems popular today, there still is a community of users that have to deal with spin stabilized upper stage dynamics. Many NASA and United States Department of Defense (DoD) payloads are launched on Boeing Delta II expendable launch vehicles with spinning solid rocket third stages. This particular version of the Delta II has been very popular for NASA interplanetary missions. Because of this, NASA's Expendable Launch Vehicle program office at Kennedy Space Center has been investigating ways to improve their understanding and ability to model spinning upper stage dynamics.

Liquid slosh in the fuel tanks of an attached spacecraft has been a long standing concern for space missions with a spinning upper stage. Loss of rotational kinetic energy through the movement of liquid propellants affects the gyroscopic stability of the combined spacecraft and upper stage. Energy loss leads to an ever increasing wobble, or nutation, which can grow to cause severe control issues (Hubert, 2003). The nutation angle is defined as the angular displacement between the principal axis of rotation of the spacecraft and its angular momentum vector and is a measurement of the magnitude of the nutation (Wertz, 1978). The amount of time it takes for the nutation angle to increase by a factor of the natural logarithm, e^1, is defined as the Nutation Time Constant (NTC), and is a key parameter in assessing the stability of the spinning spacecraft during the upper stage burn. The NTC can sometimes be very difficult to calculate accurately during the early stages of spacecraft design.

The past GSRP research effort was directed toward modeling free surface fuel slosh on spinning spacecraft using simple 1-DOF pendulum analogs as illustrated in Figure 1. The pendulum analog models a spherical tank. An electric motor induces motion of the pendulum to simulate free surface slosh. Parameters describing the simple pendulum models characterize the modal frequency of the sloshing motion. The importance in accurately designing a one degree of freedom model will help to understand fuel slosh and serve as a stepping stone for future more complex simulations to predict the NTC accurately with less time and effort. Various simulation parameters are estimated by matching the pendulum model response to the experimental response of full sized test tanks in NASA's Spinning Slosh Test Rig (SSTR) located at the Southwest Research Institute (SwRI) in San Antonio, Texas.

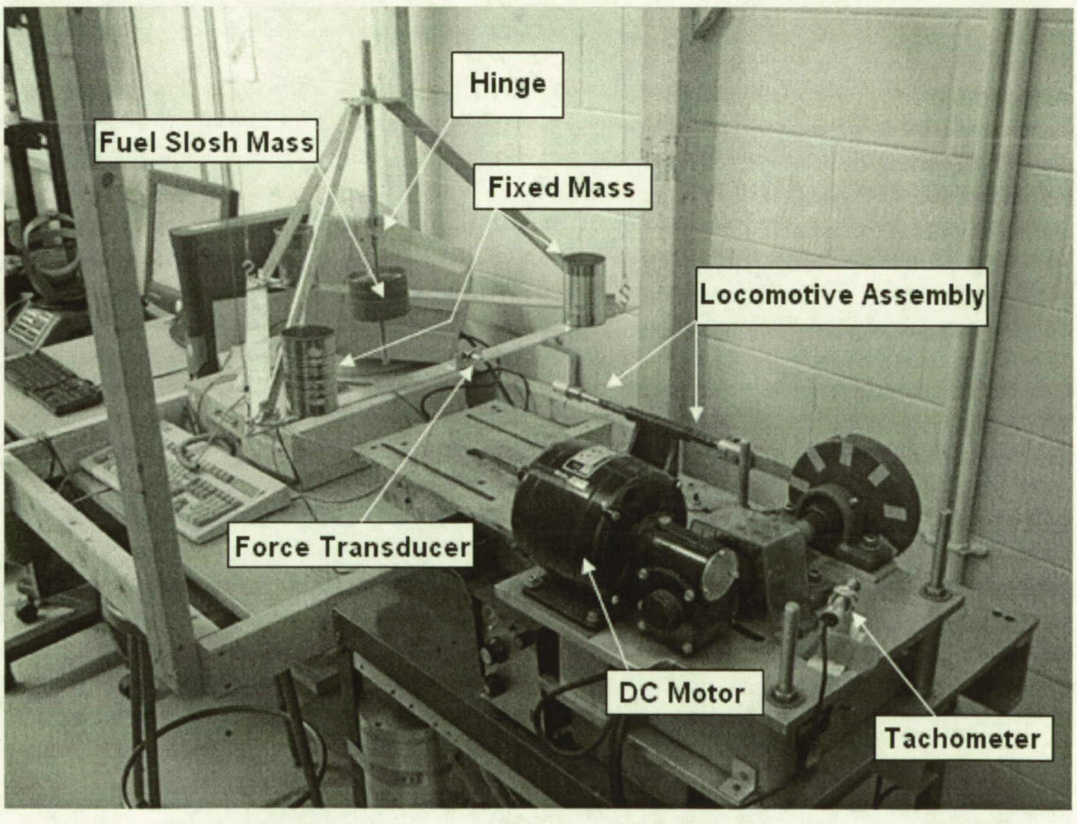

Figure 1: Photograph of the Pendulum Experiment at Embry-Riddle

The SSTR can subject a test tank to a realistic nutation motion, in which the spin rate and the nutation frequency can be varied independently, with the spin rate chosen to create a centrifugal acceleration large enough to ensure that the configuration of the liquid in the tank is nearly identical to the zero-g configuration. The propellant motion is simulated using models with various parameters (inertia, springs, dampers, etc.,) and the problem reduces to a parameter estimation problem to match the experimental results obtained from the SSTR (Gangadharan et al., 1991). The data from the tests are used to derive model parameters that are then used in the slosh blocks of a MATLAB/SimMechanics-based spacecraft and upper stage simulation. Currently, the identification of the model parameters at SwRI is a laborious trial-and-error process in which the equations of motion for the mechanical analog are hand-derived, evaluated, and compared with the experimental results.

The GSRP research efforts focused on automating the process of slosh model parameter identification using a MATLAB/SimMechanics-based computer simulation of the experimental SSTR setup (Wood and Kennedy, 2003). Two different parameter estimation and optimization approaches were evaluated and compared in order to arrive at a reliable and effective parameter identification process. The first approach involved writing MATLAB code, or M-Code, to use Newton's method for nonlinear least squares, or the MATLAB `lsqnonlin` algorithm. The second estimation method was a "black box" approach using MATLAB's Parameter Estimator Toolbox where Newton's nonlinear least squares method was selected via a graphical user interface, or GUI. By applying each estimation approach to a simple system with known characteristics, their effectiveness and accuracy were evaluated.

Free surface slosh has a well defined resonant frequency where the liquid starts to oscillate with great turbulence over a narrow frequency range. The only sloshing motion assumed to be taking place in this simplified model is a surface wave that in turn is simulated by the pendulum. The rest of the liquid is essentially at rest and can be treated as if it were physically frozen. The experiment and the simulation were calibrated using frozen masses (no pendulum) where liquid mass was the only parameter. This was to verify that the model was accurately representing the experiment's way of oscillating the pendulum frame using the flywheel and locomotive arm. Once the simulation and experiment were calibrated, the estimation process could begin. The first step was to test the frozen masses to verify the experiment/simulation's calibration. The results for one of these tests are shown in Figure 2. Figure 2 also illustrates the accuracy of the simulation compared to the experiment in that each plot of Force vs. Time is virtually identical. Results for several other similar frozen mass tests are shown in Table 1.

Table 1: Parameter Identification Results for a 70% Frozen Fill Level

"Frozen" Pendulum Frame Simulation (M-Code)					
Measured 70% Mass (kg)	3.439				
Test ID	Test 1	Test 2	Test 3	Test 4	Test 5
Measured Test Frequency (Hz)	1.66	1.855	1.953	2.24	2.44
Predicted Mass (kg)	3.306	3.347	3.397	3.457	3.497
Mass % Difference	3.87%	2.66%	1.21%	0.52%	1.68%
"Frozen" Pendulum Frame Simulation (Parameter Estimator)					
Measured Test Frequency (Hz)	1.66	1.855	1.953	2.24	2.44
Predicted Mass (kg)	3.306	3.347	3.398	3.457	3.496
Mass % Difference from Measured	3.86%	2.66%	1.20%	0.52%	1.67%
Mass % Difference from M-Code	0.012%	0.000%	0.001%	0.000%	0.012%

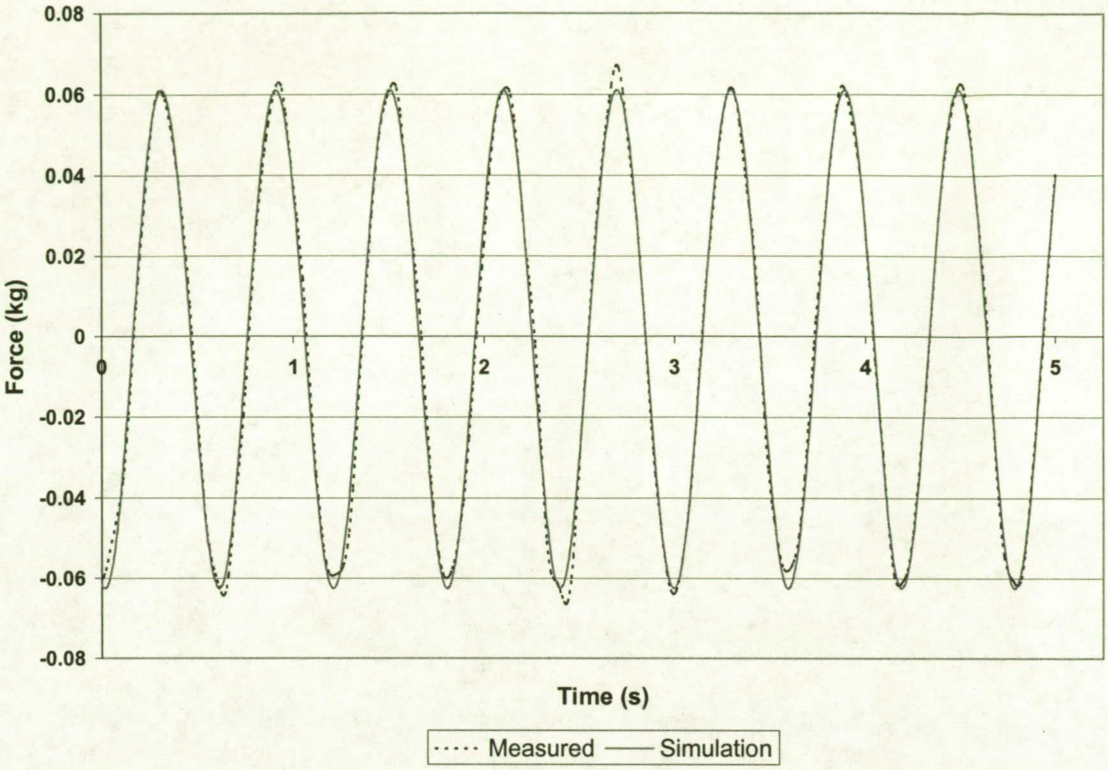

Figure 2: Comparison of Experiment and Simulation Results for a 70% Fill Level (Test Number 1: See Table 1 for Test Information/Results)

Each automated parameter estimation method was then applied to the pendulum frame (illustrated in Figure 1) and a fluid-filled spherical tank undergoing free surface slosh to verify the pendulum-analog approach. The overall parameter identification process used in this stage of the research is illustrated in Figure 3. Additional parameters used in the modeling pendulum and tank experiments were pendulum mass, pendulum length, and pendulum hinge spring/damping coefficients. However, presenting these results is well beyond the scope of this paper. Please refer to Schlee (July 2006) for more information about the automated parameter estimation process.

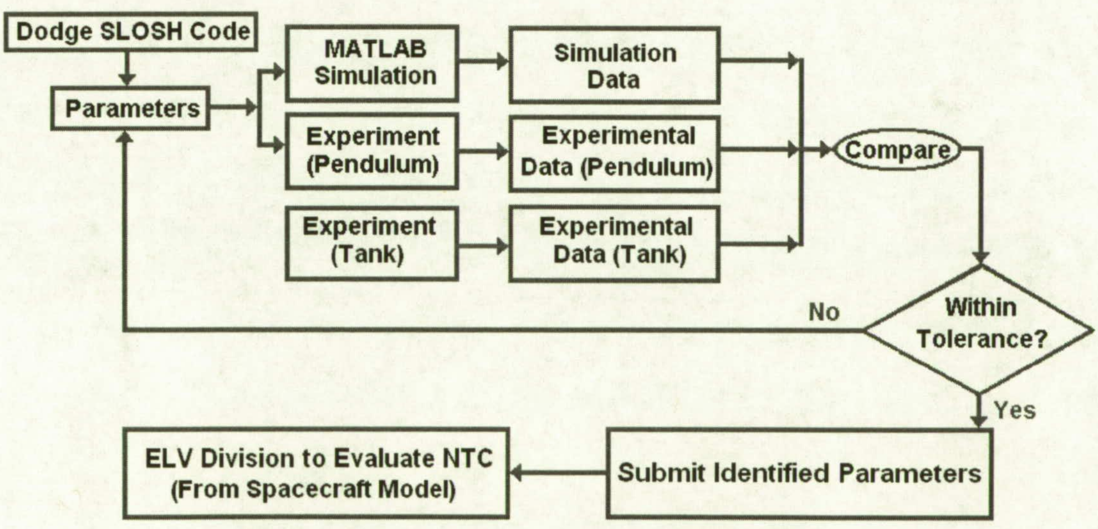

Figure 3: Parameter Identification Process

The results from Table 1 illustrate the effectiveness of each estimation method. This research verified the effectiveness if using Matlab and the Parameter Estimator Toolbox to automate the parameter identification process and made an excellent GSRP project. Ultimately, this proven process can be applied to the full sized SSTR setup to quickly and accurately determine the slosh model parameters for a particular spacecraft mission.

3. CURRENT GSRP RESEARCH

After the success of the first GSRP student project experience, there is a strong motivation to continue this collaborative fuel slosh research program at Embry-Riddle Aeronautical University with other students and to advance the knowledge in this area. As with the previous project, the current research will also involve active participation of NASA and other supporting organizations.

The previous research used mechanical analogs, pendulums in particular, to simulate sloshing mass as a common alternative to fluid modeling. It was also the first step to automate the process of slosh model parameter identification using a MATLAB/SimMechanics based computer simulation of the experimental SSTR setup at SwRI. The parameter estimation and optimization approaches were evaluated and compared in order to arrive at a reliable and effective parameter identification process. Extensive literature is available on different tank shapes and locations, as well as the use of propellant management devices (PMDs). A number of relatively simple mechanical models have been developed for these systems. As reported by Hubert (2003), one of the most difficult aspects of employing such mechanical models is in the selection of appropriate parameters in the model. The current research will utilize previously developed models of fuel slosh to account for the introduction of a diaphragm in the spacecraft fuel tank.

The first step is to experiment with several liquids with different viscosities and understanding the lateral fuel slosh effects. The resistance to flow of a fluid and the resistance to the movement of an object through a fluid are usually stated in terms of the viscosity of the fluid. By utilizing variation of viscosity, other fluids can be tested and the results can be compared with the results previously obtained. Liquids of varying viscosities with physical characteristics different from water are used in the propellant tank and tested. Various oils and glycerine are some of the liquids that will be used in the experiment (Table 2).

Table 2: Comparison of Viscosities of Different Liquids

Liquid	Viscosity (Poise)
Water	0.01
Oil (heavy)	6.6
Oil (light)	1.1
Glycerine	14.9

According to Ibrahim (ISBN-13), for higher viscosities the resonance frequency is slightly higher than the predicted value for an ideal liquid. The results of the data obtained from the new liquids introduced to the experiment should verify this theory and serve to further confirm the effectiveness of the fuel slosh modeling process used previously.

Flexible diaphragms provide an impermeable barrier between the liquid in a tank and its outer wall outside of the diaphragm. The diaphragm is attached to the periphery of the tank wall typically about the tank's mid-plane, or hemisphere in the case of a spherical tank. Diaphragms provide a substantial level of slosh damping as a result of the combination of viscoelastic flexing of the diaphragm and the increased viscous effects at the liquid-diaphragm interface. Like liquids with high viscosities, a diaphragm also increases the slosh natural frequency. This is because of the constraints imposed on the free surface shape. The effective mass of liquid participating in the sloshing is slightly smaller than for a tank of the same shape and fill level without a diaphragm (Dodge and Kana, 1987). Figure 4 illustrates the introduction of a diaphragm to the experimental setup used in the previous GSRP research. According to Quadrelli (2003), the nutation characteristics of the system also depend on the dissipation induced by the liquid viscosity, as well as on the presence and damping characteristics of the PMD.

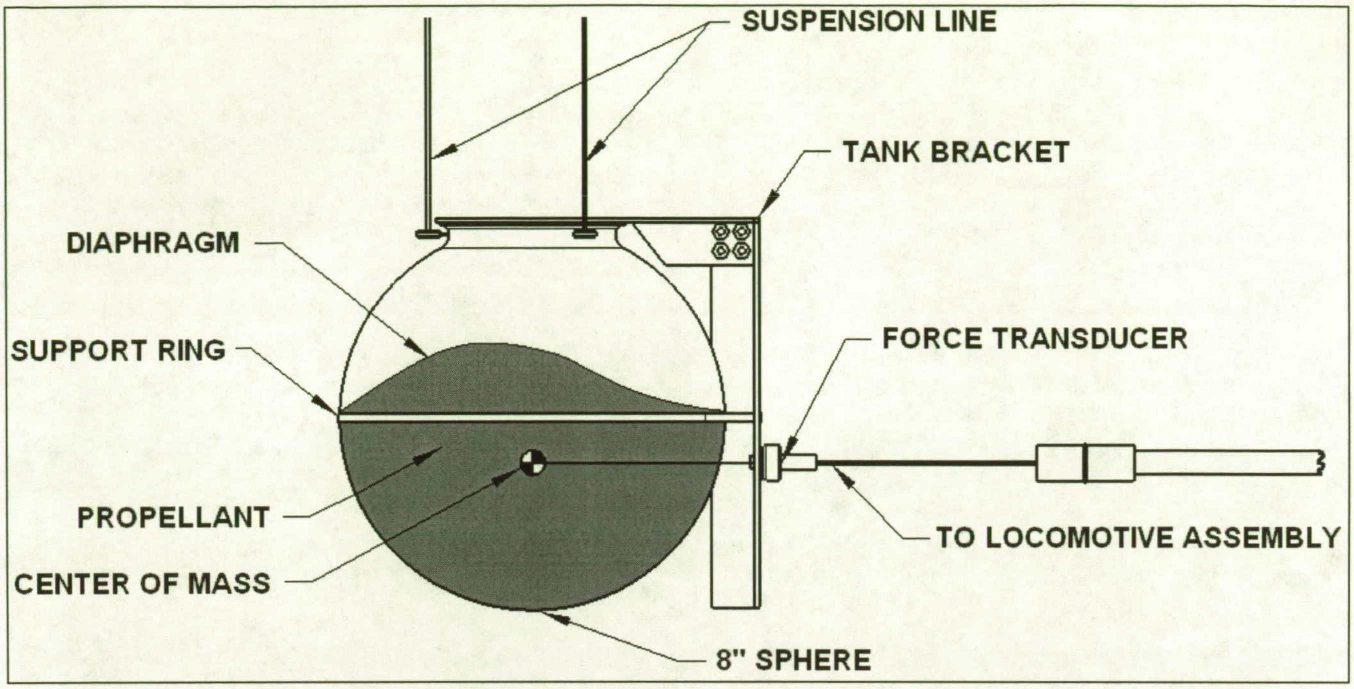

Figure 4: Schematic Diagram of Experimental Setup with Diaphragm

The ultimate goal of this research collaboration is to continue the effort to accurately model more complicated Matlab simulations and still be able to automate the parameter identification process. This will save time and thus allow earlier identification of potential vehicle performance problems. This in turn, can reduce the cost and avoid delays associated with design modifications. Applications of an automated process to find the NTC will benefit all space exploration missions involving spinning spacecraft. Using a combination of test derived fuel slosh parameters and computer simulations of the spacecraft dynamics, an improvement in the current ability to make predictions of NTC can be achieved.

3. JOINT BENEFITS OF RESEARCH COLLABORATION

The above descriptions of past and present research represent a small sample of the work that has been accomplished as a result of the GSRP, NFFP, and the NASA Cooperative Education Program. These collaborative education programs parallel similar collaborating efforts between universities and industry (Hendley, 1997). Benefits are numerous for the student, Embry-Riddle, and NASA.

3.1. BENEFITS TO THE STUDENT

The benefits of participating in the GSRP, or any cooperative education program, are invaluable in preparing the student for seamless transition from academia to industry. Research experience, as well as practical work experience, illustrates to the student many important aspects about what happens in that kind of learning environment. For example, in the fuel-slosh project, many imperfections existed in the physical setup that could not be compensated for and still stay within the budget specified by NASA. An example of one of these imperfections is the friction/vibration between the moving parts of the locomotive arm system. In short, the student ultimately realizes that "ideal" conditions are never experienced in the experiment. Intelligent assumptions must be made about these imperfections and accounted for. Another skill gained by the student as a result of practical experience is the development of communication skills. More than ever, organizations are collaborating together to solve problems. Presentations, technical writing, and non-technical writing all play an important role in this environment. Other beneficial skills, as a result of developing good communication, to the student include resume writing, interviewing, cover letters, and writing effective correspondence.

Unlike the typical classroom learning scheme, the GSRP program requires a great amount of responsibility and self-motivation on the part of the student. The classroom environment in the United States typically involves a one-way channel of communication from the faculty to the student via a resource such as a textbook. Assignments are given followed usually by a test. All the student needs to do is follow the instructions laid out by the professor and they will do well. This is not the case in a research program like the GSRP. Playing a lead role in a research program takes commitment, dedication, patience, tolerance and persistence from the student in order to be successful. There is no single source of information, and most importantly, no "right" or "wrong" answers. If there were these answers, odds are that there would be no need to conduct research in that area. The GSRP gives students the freedom to make decisions that can affect the research in a multitude of ways. For example, the experiment and simulation data for a frozen mass test are presented and compared in Figure 2. The conclusion by the student for the data from Figure 2 is that there is a close correlation. The criteria, developed by the student, for this conclusion was that the average percent difference between the data at the peaks of the force vs. time response be less than about 3%. Another student may have chosen 2% while another may have chosen 5%. Again, there is no "right" or "wrong" answer. Many decisions like this need to be made by the student on a daily basis while conducting groundbreaking research. This is because they are, in effect, writing the textbook that their peers will use in the future.

Of course, some similarities do exist between the classroom and the GSRP. One of the main similarities concerns meeting deadlines and working under pressure. However, new skills need to be developed by the student to meet the new challenges of meeting research deadlines vs. meeting test/homework deadlines. In the classroom, assignments are due and tests taken on specific dates with little or no room to change. These clear deadlines are practically the same for every class the student takes throughout their career as a student. Consequently, study skills are geared to meeting a set performance quota for these dates. Unfortunately, industry does not operate like this and that can be a shock to a new graduate. Programs like the GSRP prepare the student by giving a more accurate picture on what work is expected and when it is "due". Research is an ongoing process where the work is continuous and the deadlines can be subtle. Unlike the typical classroom test structure to indicate course proficiency, the GSRP has many assigned and optional milestones to indicate the progress of the student's research. Assigned milestones may include anything from submitting regular progress reports to meeting with the NASA or Embry-Riddle faculty advisors for research discussion. Optional milestones include presenting the research in events such as conferences. In the end, the primary goal of the GSRP student is to produce a graduate thesis directly as a result of their work. By having several major milestones, the road from starting the project to submitting a finished thesis is much easier to follow.

Conferences have played a pivotal role in the development of the successful GSRP project between NASA and Embry-Riddle. They have the benefit of giving the student an important milestone requirement to meet without having to completely finish the research. Also, conferences provide peer feedback which may even be important enough to affect the direction the research is heading. From fall 2004 until the present, there has always been a queue of paper ideas ready to be implemented and submitted to an appropriate conference. Leading up to the conference, the student must carefully map out their research so that a proper "break" point can be identified. This point will setup the parameters for that particular paper. A fundamental understanding of the research must be present in order to seamlessly accomplish this. For example, the abstract and final paper for the Winter Simulation Conference (Schlee, December 2005) was due six months before the conference. This forced the student to carefully make an educated prediction on where the research will be six months into the future in order to write an effective paper for presentation in the conference. Successful implementation of the prediction makes the presentation of the current research complement and support the paper, rather to contradict or attempt to redirect it. During the conference, the student is exposed to industry and other colleges/universities. This level of interaction greatly aids the entire research process as a result of this exposure. The student also gains valuable information by presenting the research in front of a crowd of peers knowledgeable in that area. Comments from the crowd may address aspects of the research that may even surprise NASA or the student's faculty mentors. As an added benefit, the student then has an official record of their work up until that point. After several conferences, a fairly detailed log of the progression of the research becomes vary apparent. This log provides an excellent recourse when it becomes time for the student to complete the graduate thesis and ultimately, their resume.

One of the largest goals for any student is finding employment after their graduation or an internship/co-op while still in school. Participating in the GSRP provides many benefits in this area. NASA and Embry-Riddle faculty research advisors serve as an invaluable resource for reference letters, internship/co-op opportunities, providing job contacts, and opening up a network linking the world of academia to the "real-world" of industry. This networking opportunity is perhaps the most valuable benefit the student receives during their time as a GSRP fellow. NASA civil servants and Embry-Riddle faculty also have contacts to hundreds of companies and other government agencies.

Another valuable piece of experience the student gains from participating in the GSRP and the NASA Cooperative Education Program is that they are exposed to the practical side of the engineering field. Constructing prototypes, keeping within budget, posting set hours, acquiring test equipment, and getting lab space are just as important to the project as making a Matlab simulation or deriving the proper equations for the pendulum frame. For example, in September 2005, a notice sent from Embry-Riddle stated that the experiment had to be moved into a different lab in a very short period of time. At the time, no lab space was apparently available. Only after the student negotiated with several faculty members was a replacement lab found. Developing skills to handle the practical side will greatly aid the student in industry.

3.2 BENEFITS TO EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

Along with all of the student benefits, there are numerous benefits to academia (ERAU and its faculty). As an educational institution, ERAU must strive to provide the best for its students while maintaining their reputation among industry and other universities. By endorsing a collaborative program such as those sponsored by NASA, ERAU will ensure that the priorities are met.

ERAU has a responsibility to provide the best education to its students and programs like the GSRP provide a means to allow the faculty advisor to accomplish that. The faculty advisor must strive to meet the requirements that are expected of them in successfully serving as a mediator between the student, NASA, and industry. By communicating between these three groups, the faculty advisor will gain valuable "real-world" experience that can be applied in the classroom. Practical aspects of engineering projects will be better understood and project assignments can be modified to reflect this. For example, as mentioned in Section 2, the GSRP project deals heavily in the use of Matlab and its applications. New classroom assignments, along with practical discussion about each particular assignment, can now involve applying these applications. Without the knowledge gained using the tools such as Matlab in actual research, many students lose out on an excellent opportunity to learn about a tool commonly used in industry today.

Another benefit to faculty advisors is that there are other collaborative educational programs, such as the NASA Faculty Fellowship Program, that allow them the opportunity to spend their summer months at a specific NASA center. This provides even more practical "real-world" knowledge and experience by directly working in a non-academic environment. By removing the faculty from the classroom and placing them in industry, new ideas for practical assignments and projects can be incorporated upon their return to academia. Attending a NASA Faculty Fellowship Program at Kennedy Space Center (KSC) during summer 2004, the ERAU faculty member started to work with NASA engineers and co-ops on the spacecraft fuel slosh project. Efforts on the faculty member's part, along with the knowledge gained while at KSC, lead to ERAU's involvement in the GSRP program.

A subsequent benefit for the faculty member in participating in these programs is that their professional reputation builds not just within NASA, but within industry as a whole. This in turn builds the reputation of ERAU as a world-renowned institution. Faculty members have the option to publish work related to the programs that their students are working on as well as expand these projects to involve new students as they graduate or if new research paths open as a result of any specific finding. Faculty's reputation also builds with each graduating student by having the opportunity of being the chairman of that student's thesis committee. Currently, the research is in its second generation. That is, the faculty member has graduated one student and is working with their replacement. Naturally, faculty research advisors can find new projects for their students as bridges are built between them and the organizations they have worked with successfully in the past. By constantly developing these healthy working relationships, future projects can be carried out with less effort.

3.3 BENEFITS TO NASA

The benefits gained through collaborative education, such as the GSRP, are just as important to NASA as they are to the student and to academia (ERAU). Fresh, creative minds with new outlooks on projects are able work with them on a short-term basis with a minimum of commitment on NASA's part. The faculty brings a deep conceptual understanding of a wide range of text-book knowledge that is typically lost in the day-to-day assignments and projects performed by engineers at NASA, and industry in general, while the student brings a broad breadth of knowledge that can be an excellent resource for many novel ideas. Also new methods, theories, and/or processes may be the current academic standard, but not yet adopted in industry. For example, SwRI is just starting to use Matlab in their fuel slosh research as a direct result of the work done between NASA and ERAU. Innovations in research such as this can then be applied to other projects unrelated to the original. In short, having faculty and students constantly rotating in and out of the workplace exposes NASA to the most recent processes taught in academia today.

Like any industry, NASA has a task list of the side-projects they would like to complete. Tasks in this list can range from simple day-to-day operations to large, complex projects that may take many fulltime engineers several months to complete. Programs like the GSRP are designed to take some of the pressure off of the fulltime engineers for some of these projects. These programs have many levels of difficulty so NASA must choose which program each project is to be assigned to. NASA has successfully worked with ERAU in three cooperative education programs involving fuel slosh research. These are the GSRP, Faculty Fellowship Program, and Cooperative Education Program. Another benefit to NASA having students participating in these programs is that they now have a pool of possible future civil servants and contractor employees. By observing aspects such as work ethic and project quality, NASA will have a much better picture of their new-hires than the typical interview/resume hiring process. Two ERAU students have been hired by NASA and their contractors as a result of these educational programs.

Along with the time it takes to complete the side-projects, the economics of each project are very important to NASA, and again to industry as a whole. Compared to sub-contracting with another company, GSRP Fellows, Faculty Research Fellows, and student co-ops provide an economical resource for work of comparable quality on those projects not requiring extensive hardware or lab resources. For example, the entire budget for the first generation GSRP thesis project cost less than the single diaphragm used in the SSTR at SwRI (Section 2). As a result of this, NASA can sponsor many programs utilizing collaborative educational programs for the cost of a single conventional program involving a sub-contractor.

Like ERAU developing positive relationships with industry, NASA can develop positive relations with academia and industry through each of their cooperative educational programs. One tried-and-true method of accomplishing this used in the joint NASA/ERAU GSRP program was through the presentation and/or publication of good technical papers in conferences and journals. This ongoing exposure reinforces NASA as a leader in forming long-term healthy working relationships with elementary schools, secondary schools, colleges, and universities all over the world. The working relationship between ERAU and NASA for this fuel slosh research is planned to be a long-term one with the second generation research having a planned completion of spring 2008. Plans are in the works to carry this research to a third generation starting in fall 2008.

4. SUPPORTING ORGANIZATIONS

The research collaboration for this project has been supported by a several organizations in industry along with Embry-Riddle Aeronautical University (ERAU) and National Aeronautics and Space Administration (NASA). The participating organizations include The MathWorks, Southwest Research Institute (SwRI), and Hubert Astronautics. All of these organizations have helped in this research signifying a true collaborative effort between industry, government, and academia. A block diagram illustrating the involvement of each organization is shown in Figure 5.

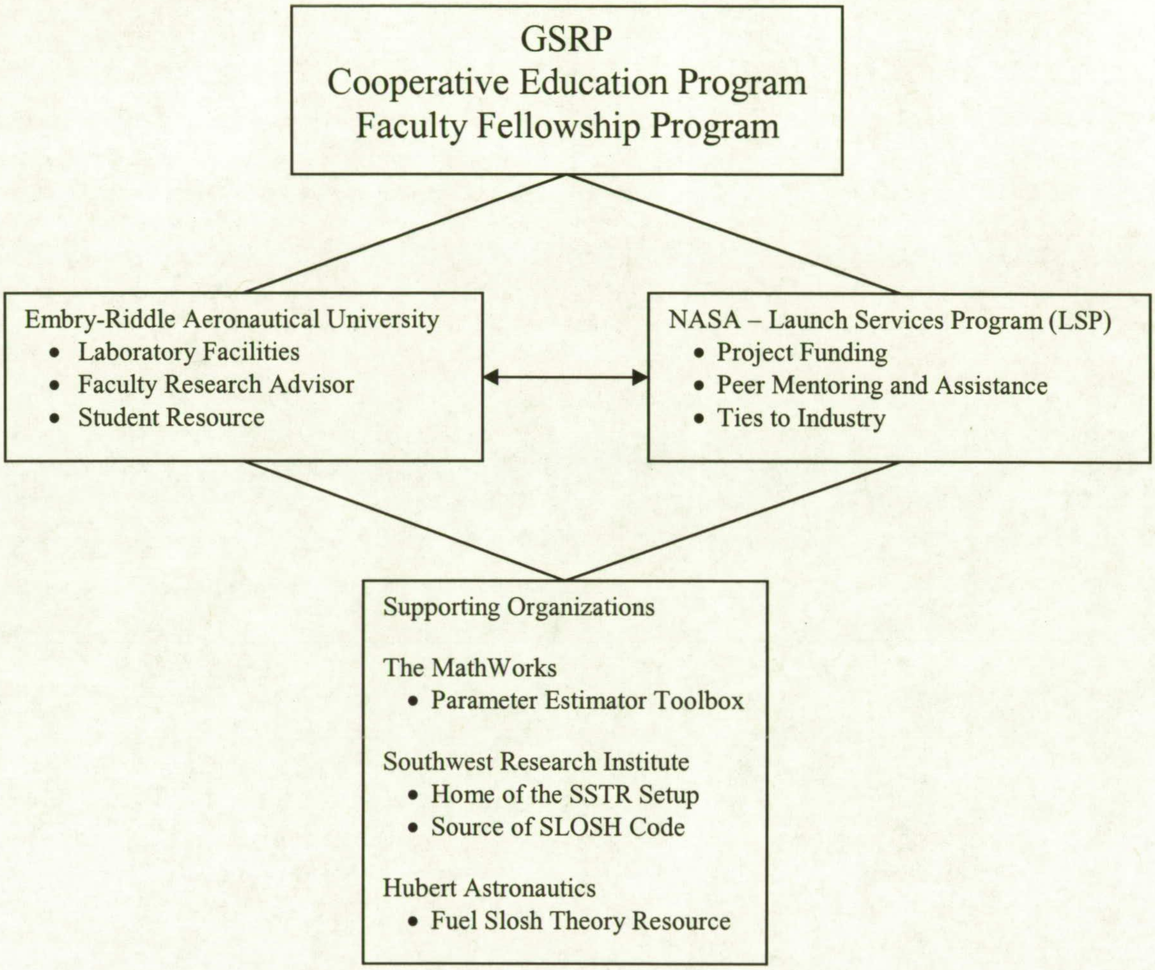

Figure 5: Block Diagram of the Organizational Structure of NASA/Embry-Riddle Fuel Slosh Program

5. CONCULSTIONS

The role that ERAU has played in the NASA's Graduate Student Researchers Program (GSRP), Faculty Fellowship Program (NFFP), and Cooperative Education Program has had a tremendous positive reaction from all organizations involved. ERAU students/faculty and NASA engineers have all gained from this work and will continue to do so. Future collaboration between each organization is continuing at Embry-Riddle with new second generation fuel slosh research in progress with third generation goals already in the works. This successful working relationship has opened doors for research opportunities on many other projects in the future.

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14. ABSTRACT
The NASA Graduate Student Research Program (GSRP) awards fellowships for graduate study leading to both masters and doctoral degrees in several technical fields. GSRP participants have the option to utilize NASA Centers and/or university research facilities. In addition, GSRP students can serve as mentors for undergrad students to provide a truly unique learning experience. NASA's Cooperative Education Program allows undergraduate students the chance to gain valuable work experience in the field. University faculty can also benefit by participating in the NASA Faculty Fellowship Program (NFFP). This program gives the faculty an opportunity to work with NASA peers. The Expendable Launch Vehicles Division at NASA Kennedy Space Center has utilized these two programs with students and faculty from Embry-Riddle Aeronautical University (ERAU) to conduct research in modeling and developing a parameter estimation method for spacecraft fuel slosh using simple pendulum analogs. Through university collaborations with NASA and industry help students to acquire skills that are vital for their success upon entering the workforce.

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