Maine Space Grant Consortium
Maine Aerospace Workforce Development Program

Student Research Experiences at NASA Field Centers
Summer 2003

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Letter from the Executive Director
Dr. Terry Shehata

The Maine Space Grant Consortium (MSGC) is pleased to distribute the results from its "Maine Aerospace Workforce Development Program". The "Student Research Experiences at NASA Field Centers for the summer of 2003" is a compilation of extended abstracts from seven undergraduate students participating in a 10-week research project at a NASA field center.

Our goal in the program is to motivate outstanding undergraduates in Maine to seriously consider career opportunities related to aerospace research and education.

This program is supported with Workforce Development funds from NASA's National Space Grant College and Fellowship Program and provides undergraduate students attending Maine colleges and universities, who are interested in pursuing careers vital to the nation's aerospace-related industrial complex, with a 10-week productive research experience at NASA field centers.

The program's first year resulted in 12 applicants and seven awards to five different NASA field centers. One student was offered (and accepted) to continue on with a co-op position beginning in January 2004. Upon their return to Maine, each student was required to present to at least two different high schools in Maine to inspire students to continue into higher education in the fields of space and space-related sciences. In addition, students were required to present to an MSGC board and affiliate member meeting.

Each student is tracked academically and professionally for five years from the date of the award, to evaluate the success of the program and to monitor further participation in research programs, accomplishments in referring journal articles for publication, presenting at conferences, and submitting proposals.

MSGC distributed a survey to each student at the end of the summer and found from the data collected and the comments made by both students and NASA mentors, that this program was truly a success. One student comments "This opportunity has afforded me the options to apply to more challenging graduate programs" and another student comments "I look forward to my future endeavors within NASA, and thank the Maine Space Grant (Consortium) for starting my opportunities in the NASA family"

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The use of trade names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

Mark Corey
University of Maine

Participating at the Johnson Space Center

Title: "Product Development for Advanced Food Technology and the Bulk Ingredient-Based Menu Development Project"

NASA Mentor Dr. Michele Perchonok

Research objective: To develop a menu and food items to support humans living and working in space or other lunar or planetary surfaces beyond low earth orbit.

Introduction: The National Aeronautics and Space Administration (NASA) is developing a Bulk Ingredient-Based Menu (BIBM) that will provide food for people involved in lunar or planetary travel beyond low earth orbit. The BIBM consists of approximately 100 vegetarian-based recipes derived from several sources that will provide instructions on how to prepare and produce safe, nutritious, and acceptable food products. In it, there is a conversion chart that lists crop and bulk ingredients that will serve as the sole source of ingredients for the recipes. About 90% of calories from the recipes will originate from crops grown hydroponically on the lunar or planetary surface, and the remaining 10% of calories will come from bulk shipments of ingredients that will not be derived from the available crops. The development of these products is necessary to complete the BIBM database. In addition to work on the BIBM database and its related product development, additional work on products for the Shuttle food program was performed, since the experience gained was very related to work on the BIBM.

Development and Recipe Development for the Bulk Ingredient Project: The Bulk Ingredient-Based Menu Development Project required considerable time in developing the ingredient conversion chart, recipe protocols, formulating ingredient amounts, determining ingredient substitutions, and investigating other criteria. The conversion chart listed the ingredients that were available for recipe formulation and development. Ingredient conversions of cup, tablespoon, and teaspoon were converted into gram amounts and then used accordingly in recipe serving size calculations.

The recipes were formulated for 6 servings, and they listed ingredient types, amounts, and instructions on how to prepare the desired recipe, as well as estimated approximate preparatory and cooking times. The items on the conversion chart were all derived from bulk ingredients or available vegetable crops. Ingredient substitutions were performed for some items that were originally listed in recipes, but would not be available in an exotic lunar or planetary environment. These ingredients were substituted because of issues involving expense or feasibility of bulk shipment, processing capabilities, or the existence of a better substitute. For example, a substitution involved testing three types of oil. Vegetable, soy, and peanut oils were tested and compared using sensory testing. This issue was selected for testing among a number of recipes because of the feasibility of processing the different types of oils from the crops, and the possibility of having to send bulk shipments of oil prior to it being available, due to crop immaturity.

In-house sensory tests at the Johnson Space Center (JSC) were conducted using eight (8) panelists to provide preliminary data on product acceptability, such as acceptability in the type of oil used in a product formulation. These results determined which ingredient substitute was to be used for each particular recipe. Sensory tests rated acceptability on a 9-point hedonic scale. A score of 6 out-of-9 was required for a product or attribute to be considered acceptable. Sensory attributes such as overall acceptability, appearance, aroma, color, flavor, sweetness, texture, and other characteristics were tested among a few of the BIBM recipe products.

Protocols were developed for each recipe. Originally, most recipes only included information on required ingredients and suggested amounts, but did not provide instructions on processing or cooking. By researching sources from the Internet or other reference materials, protocols were developed that incorporated all of the ingredients required by each recipe, and produced an acceptable product that was prepared in minimal time.

In determining product formulation, following a product development schedule became necessary to ensure that recipes were created that provided nutritious, safe, and palatable products for consumers. When protocols were devised and ingredient amounts were determined, then the product was prepared and sampled. Very rarely did the initial product produce the ultimate desired results.

Product Development for the Advanced Food System: The Shuttle and International Space Station (ISS) food systems provide a vast assortment of food products for the astronauts while they are working in space. Food is carefully selected by NASA to provide the crew with a menu plan. Food is important, since it has been noted from space missions that it plays a vital role in the astronauts' overall well being. The astronauts are offered an allowance of food, besides the pre-determined menu items, in the form of bonus containers to take with them on space missions. In the bonus containers, they are allowed to select certain items that they personally want while in orbit, such as cookies or even fresh fruit. The time spent consuming food during meal times is another important wellness attribute, because it provides social interaction for the astronauts. Finally, food offers nutrition that fuels the astronauts' work. Food acceptability and consumption directly affects productivity and health.

The products produced for the Shuttle and ISS Food Systems are preserved many different ways. A common method is thermostabilized treatment through a retort. A retort is a machine that in food applications processes products under high temperature and pressure. The thermostabilized products worked on this summer have been processed at 121ºC/250ºF at approximately 20-25 psi. A water-immersion-overpressure retort was used that helped maintain the integrity of the pouches used for packaging.

Product Development Method and Discussion for Bulk Ingredient-Based Menu Development:

The Bulk Ingredient-Based Menu Development Project has required several product development steps to develop the recipes, so that they produce acceptable, quality products that are also easy to prepare. The following list describes the main steps that were followed to develop the recipes:

1) Obtain recipe and list of ingredients
2) Review similar past product formulations

3) Write protocol for developing existing recipe
4) Informal group feedback
5) Formal sensory panels

These five steps have been utilized extensively for the BIBM project. These steps were not always followed, and were often developed to varying degrees dependent on the nature of the product. Below are described these steps and how they were applied to BIBM applications:

1) In the BIBM, a basic recipe including a list of ingredients and amounts scaled to 6 servings existed.
2) In reviewing past product formulations, production time can be considerably minimized. Researching already proven data reduces the necessity for experimentation. In producing a Carrot Dill Bread, which was a recipe from the BIBM, past work from the Advanced Food System (AFS) group helped to determine the recipe formulation for the amounts of flour, water, oil, yeast, and other materials that needed to be added to the recipe.
3) Protocol for developing recipes was referenced from the Internet, past NASA recipes, and from other reference materials. The protocol included step-by-step instructions on how to produce the recipe, how to prepare raw ingredients, as well as suggested prep and cook times. In producing the Carrot Dill Bread, past AFS work on bread research enabled immediate determination of appropriate processing and bake times for production.
4) Informal group feedback sessions were used to determine product acceptability without having to conduct formal sensory panels. These sessions occurred in-house at JSC with Advanced Food System staff. Their comments and suggestions helped in identifying any changes in product formulation that may have been necessary, such as if the product needed more spice, less salt, more cheese flavor, etc.
5) Formal sensory panels are used to test the final acceptability of a product. In the BIBM, some initial products were tested for acceptability, but more importantly, were tested for their preference in use of ingredients. In a particular instance, the acceptability of different types of oil (i.e., vegetable, peanut, and soy oils) was tested in the Carrot Dill Bread. In the sensory panels, general acceptance was determined for a product on a hedonic scale if an average score of 6.0 or greater out of 9.0 was achieved for a specific attribute. Different product attributes or characteristics were tested, such as degree of sweetness, overall acceptability, flavor, etc.

<u>Product Development Method and Discussion for Advanced Food System:</u> Product development is essential to produce a desired product. While at the Johnson Space Center (JSC), product development has focused on recipes derived from the Bulk Ingredient-Based Menu Development Project, as well as products for the Advanced Food System. Developing food products for the two separate programs has demonstrated what combined efforts have been needed to produce products. The products originating from the two programs have required unique combinations of production steps, but by working on both programs simultaneously, an entire realm of product development has been

exposed. In product development for the Advanced Food System products, the steps from the Bulk Ingredient-Based Menu Development Project (BIBM) and more were used to develop products. More steps were required because these products were more extensively developed than the BIBM recipes.

The additional steps that have been required to produce the Broccoli Soufflé and the Mediterranean Omelette are listed below:

6) Perform nutritional analysis to verify compliance with nutritional standards
7) Initial product run
8) Recalculate ingredient percentages by weight of total product
9) Checking retort time/temperature data logs
10) Analytical tests
11) Scale-up and additional developmental steps

Each product developed has required a unique approach to development. Steps have been combined in a seemingly random manner to accomplish different goals. The Advanced Food System (AFS) products have required these steps as well as the BIBM steps to develop the products. Below are described the additional steps required of the AFS products, as well as how these steps have applied to actual processing and development processes.

6) Nutritional analysis was performed on the Broccoli Soufflé and the Mediterranean Omelette. NASA guidelines for ISS food items restrict sodium to less than 500 mg sodium/serving, and restrict total calories originating from fat to less than 30% of total calories.
7) The initial product run was used to develop the product formulation and test the stability and interaction of the ingredients. When retorting products, product outcomes are often unpredictable because many ingredients are not thermostable, and the interaction of other ingredients after being heat and pressure processed can produce markedly different results from the norm. For example, if peppers were added to a product and the product was to be retorted, then the retention of the pepper's color would become questionable. This is because the chlorophyll in the peppers could degrade under high temperature/pressure conditions. The addition of citric acid to the product formulation would help prevent the chlorophyll from converting to a form considered undesirable for the intended product. In addition, retort processing can alter the flavor profile of a product and influence other organoleptic changes over time. That is why, in addition to initially testing the product, shelf-life studies are necessary (e.g., it has been found that over time, the flavor of black ground pepper that was included in retorted products increased and became stronger).
8) Ingredient percentages by total weight are determined to use as a reference tool in product formulations. These are used to easily convert between smaller batch size amounts and when larger scale-up amounts are needed. For example, in a 3,000-gram batch, 300.0 grams of water would amount to 10.0% by total weight of the product formulation as water.

9) An important step in retort product development is checking retort time/temperature data logs. In high temperature/pressure processing, how long a product is exposed to extreme conditions of temperature and pressure has a direct effect on the end state of the product quality. Come-up time in retorts refers to the time that is necessary for the retort to reach processing conditions for temperature and pressure. It is important that this parameter is reached, and that the product reaches the appropriate processing temperature to ensure commercial sterility. In retortable products, the bacterium *Clostridium botulinum* is used as the reference indicator organism for thermal destruction, since it is one of the most heat-resistant human pathogens of concern in retort products. The time/temperature relationship established for thermal processing is based on the relationship of the log destruction of *C. botulinum* spores with increase in temperature and pressure. The come-up time for the retort and the actual internal temperature of the product were measured to ensure that commercial sterility indeed occurred, and to relate any product deviations that may have occurred with improper processing conditions.
10) Analytical tests are often performed to test for product consistency. Some analytical tests performed while at JSC included texture, color, moisture, and viscosity. These measurements may be applied when duplication of results becomes necessary, such as in scale-up operations for a given product. In the Mediterranean Omelette, measuring the viscosity of the batter at a certain stage of production served as a quality parameter to ensure that all ingredients had been added to the product at a given stage, and the batter was consistent with what should have produced a normal, acceptable product.
11) Scale-up production for the omelette and soufflé involved increasing the batch size by many times to a specified amount and then processing the product in the same manner that was originally determined. This process was intended to mimic actual production volumes, and discover any deviations that may have occurred.

More developmental steps may be necessary to complete products. This 10-step list summarizes what has been performed while at JSC.

<u>Results, Conclusions, and Personal Reflection:</u> Working at NASA on the Bulk Ingredient-Based Menu Development Project and additional product development for the Advanced Food System provided a wealth of new knowledge and experience for me. I have gained significant skills in the area of food product development. Before working here, I was unsure of my future career path, but I have now decided that product development and food chemistry are the areas that I wish to pursue.

In the Bulk Ingredient-Based Menu Development Project (BIBM), the initial goal of producing a menu plan based on crop utilization and bulk ingredient shipments was realized when the conversion chart was completed with only a few questionable items remaining. And now, a bank of recipes exists for when human pioneers are able to explore and colonize new lands beyond low earth orbit. The entire project is not yet complete, since only a fraction of the recipes have been completely tested and reformulated, but now, all of the preliminary work has been completed, and the remaining recipes and new recipes may be added.

In the BIBM, working with new materials and developing and testing new food products provided invaluable experience. A particularly interesting project involved working with seitan. Because the recipes are vegetarian based, utilizing quality protein sources was important for planning to adequately nourish people dependent on the BIBM. Seitan is a meat analog derived from wheat. Being a meat analog, it is categorized and compared to meat in its amino acid content and makeup, similar to tofu derived from soybeans. Procedures were developed that explained how to extract the wheat gluten (uncooked seitan) from the wheat flour, and then incorporate the gluten into a recipe to make seitan.

In developing products for the Advanced Food System, I was able to witness and actually perform many phases of product development. I have not seen every aspect of product development, but I have been able to take a product from conception when it was only an idea, and develop its formula, test it, and see it into production. I have needed to apply everything learned thus far in my degree program to succeed at this job. My time here would not have been possible without the help of the Maine Space Grant Consortium (MSGC). Because of the MSGC, I have had the experience of working in NASA and in the Advanced Food Technology group, while working alongside incredible, intelligent people who have always been there whenever a need has arisen. And most importantly, we have all worked toward the ultimate mission of supporting people in space, whose lives depend on our work.

Christopher Hill
University of Maine

Participating at the Kennedy Space Center

Title: "Innov-x XRF Analysis of the H70-0570 Forward Orbiter Jacks"

NASA Mentors Doug Kverek and George Hamilton

Overview

Technicians in the Vehicle Assembly building came across a suspect weld during inspections of a H70-0570 Orbiter Forward Jacks. In analyzing the situation, it was soon discovered that the metal in the H70-0570 jack was unknown. The Innov-x XRF was called upon to analyze the composition of the metal in these jacks so that a determination could be made to return the jacks to service in the Orbiter Processing Facility. The questions then arise, what is an Innov-x XRF, and how can it be used to analyze the jacks?

X-ray fluorescence(XRF) spectrometry is used to identify elements in a substance and then quantify the amount of those elements. The XRF can identify an element by its unique x-ray emission wavelength or energy. The amount of the element present can be quantified by measuring the intensity of those characteristic qualities. Consequently, XRF spectrometry can determine the elemental composition of a material and in most circumstances it can identify the material itself.

Ultimately, it was through the familiarization, preparation, and trials of the Innov-x XRF that allowed for its successful analysis of the H70-0570 Orbiter Forward Jacks. The Innov-x XRF is a relatively new tool at Kennedy Space Center, so it was important to go through a learning process with the tool itself. The process consisted of creating a user-friendly fifty-step process on how to use the Innov-x XRF, creating a new library of standards called KSC1 so that the XRF could recognize more unknown materials, as well as trials of the system on known standards to see if the XRF gave results that were expected. Only after these steps were complete was it possible to use the device on an unknown material such as the orbiter jacks and produce meaningful results.

The Research

The Regent H70-0570 Forward Orbiter Jacks are used at Kennedy Space Center in the Orbiter Processing Facility(OPF), and for temporary storage of the orbiter in the Vehicle Assembly Building(VAB). They are also used at Dryden Flight Research Facility (DFRF) when the orbiter has to make its alternative decent into California rather than Florida. The jacks consist of a hydraulic cylinder with a plate at the top that can attach to the orbiter by moving forward, back, left, or right. The jack is placed on either side of the forward part of the orbiter just behind the flight deck, and uses an end of the payload bay longeron as its main lifting support. The longeron is the main interface, or the "backbone" of the entire orbiter, which can handle the upward loads from the jack. The jacks themselves are used to bring the orbiter to a working elevation so that tasks such as landing gear operations and tile repair can be performed.

Upon Technician Analysis of a set of the H70-0570 Forward Orbiter Jacks located in the Vehicle Assembly Building, suspicions arose as to the durability and reliability of a suspect weld. After modifying the jack, a crack was found along the weld that connected the cylinder of the jack to a standing platform. Consequently, research begins as to the exact chemical composition of the material that made up the jack to make the determination if the jacks could be certified again for use. It is quickly discovered that the exact material and chemical breakdown of the jacks are unknown. In order to address this problem, the Innov-X XRF is introduced to the situation.

X-Ray Fluorescence Spectrometry (XRF) is used to identify elements in a substance and quantify the amount of those elements present in an unknown sample. All atoms have a fixed number of electrons arranged in orbitals around their nucleus. In an atom that is not positively or negatively charged (not an ion), the number of the electrons equals that of the number of protons in the atom. The protons in an atom can be easily found on a periodic table of elements, and are the defining characteristic of an element. XRF will typically involve the activity of the first three electron orbitals, which are the K, L, and M orbitals. The K orbital is the closest to the nucleus. Each orbital represents a specific energy level that is unique to that orbital. In XRF spectrometry, the energy level change of one electron moving to a lower orbital is measured. The XRF can do this by emitting a high-energy primary photon that strikes the sample. The primary photon from the XRF has enough energy to knock electrons out of their innermost orbital, which are the K or L orbital. Once this occurs, the atom becomes an ion, or in other terms the atom becomes unstable. In order for the atom to stabilize itself, one of the electrons in one of the outer shells, for example the M orbital, moves down into the lower orbital that one of the electrons had vacated from the primary photon emission. The energy that is emitted from this process is known as a secondary X-ray photon. The process as a whole is called Fluorescence. The secondary X-ray primary photon has a specific energy value that is specific to a certain element. The XRF can then determine what element the process occurred on, as well as quantifying the amount of the element in the substance. It is through this process that an unknown material can be identified through X-ray fluorescence(Instructional Manual, Innov-x Systems X-ray Fluorescence Spectrometers, version 1.1).

In order to use the Innov-x XRF a few procedural duties must be performed. The user must gain a general understanding of the tool so that the data the Innov-x XRF produces can be analyzed into meaningful results. In order to achieve this, a fifty-step process is created so that any future user can quickly read through the manual if an unknown material needs to be shot and analyzed. This procedure details a step-by-step process that starts with configuring the device to the correct settings, and ends by outlining the procedure as to how to create graphs from the test data. The next step in the process is to create a KSC1 library in the Innov-X XRF software. This library would contain all of the standards that are located on KSC property that are not already entered into the standard library that the device came equipped with. This library would allow for the Innov-x XRF to recognize more materials than before, which enhances the chances that the Forward Orbiter Jacks could be positively identified. These standards are obtained and entered into the XRF from the chemistry lab located in the O&C Building at KSC. Finally, the device is tested on specific standards to see if it would produce the results that were expected, ultimately giving the user more confidence.

The actual process of testing the H70-0570 Forward Orbiter Jacks is three-fold. First, the user brings the Innov-x XRF to the Vehicle Assembly Building and uses the fifty-step process guidelines that were mentioned and developed above to shoot the bracket, bracket weld, cylinder, and the ring around the cylinder of the jacks. It is important to get multiple shots of the same area in case foreign materials are introduced into the sample window, such as paint from the orbiter jack. Next, the data is analyzed. By accessing a shared drive in the KSC system, the user can download the data from the Innov-x XRF onto the drive. The share drive allows the user to send the results from the flash card in the XRF to their personal computer at KSC. Finally, the data is opened and configured to create Microsoft Excel graphs that map the test data against specific standards used for comparison.

The analyses of the graphs, as can be seen in Appendices 1 and 2, provide some clear evidence as to the nature of the unknown composition of the Forward Orbiter Jacks. The importance of the graphs is to see that the peaks line up on the x-axis (Kev) and not that the peaks are the same on the y-axis (counts). The counts were not expected to be exact, in fact, it is expected that the counts of the standards would be higher than that of the test data before the process even began. This is because the standards are perfect; that is to say that they do not have any imperfections, where as the test data from the orbiter jacks most likely does. The key to the graph is to see that the peaks, representing elements, line up on the x-axis. This is what is primarily used to determine what type of metal an unknown sample is, and not whether or not the peaks have the same amplitude. The elements that are identified on the graphs are the distinguishing elements for the metal.

They can be found by reading the peak from the x-axis, and finding that number on a periodic table of elements that has the energy values listed on it for the different elements. As for the specifics of the analysis of the four main parts of the jack that are tested, the cylinder appears to be O2, a tool steel, which is in the category defined as being an oil-hardening cold-work steel. It is compared to O6 because there is reliable data on this standard on KSC property. O2 and O6 are very similar, with the only primary difference being that O2 has a little more Manganese (Mn); it has 1.40-1.80% by weight, as compared to 0.30-1.10 for O6. The average of the tests on the cylinder actually suggest it could be O6, so this is the graph the test data is compared to. The bracket appears to be plain carbon steel, the bracket weld appears to be Carbon 1-2 Mo, and the ring appears to be carbon steel. The overall types of the steels that are found to be used in the H70-0570 Forward Orbiter Jacks are oil hardening cold-work steels.

Research on oil-hardening cold-work steels yields the following description:
Oil-hardening cold-work steels have high carbon contents, plus enough other alloying elements that small to moderate sections can obtain full hardness when quenched in oil from austenitizing temperature. The most important service-related property of group O steels is high resistance to wear at normal temperatures, a result of high carbon content. On the other hand, group O steels have a low resistance of softening at elevated temperatures.

The ability of group O steels to harden fully upon relatively slow quenching yields lower distortion and greater safety(less tendency to crack) in hardening than is characteristic of the water-hardening tool steels. Tools made from these steels can be successfully repaired or renovated by welding if proper procedures are followed. In addition, graphite in the microstructure of type O6 greatly improves the machinability of annealed stock and helps reduce galling and seizing of fully hardened steel. (Davis 350)

The H70-0570 Forward Orbiter Jacks posed a unique opportunity to analyze and make conclusions about an engineering problem while on the internship at KSC. It incorporated knowledge of the Innov-x XRF that was gained weeks in advance; only to find out that it would be needed on this project. First, photons were shot from the XRF into the sample. The XRF then measured the energy changes that occurred when an electron from an outer shell moved to an inner shell. The energy changes are unique and characteristic of specific elements. The XRF can use this uniqueness to determine the type and quantity of a specific element in the composition. Ultimately, cold work iron hardened steel was found as the main composition of the orbiter jacks. The information was gathered and the graphs that are seen at the end of this document were sent to some of the orbiter engineers. It was the hope of this project that the information that was found would be help in their quest to determine if the jacks were suitable to be used again in the OPF. Will Judd, a Boeing Orbiter engineer, who received the information that was gathered had this to say: “Thanks for your excellent in-depth report and timely response on the material analysis that you conducted on the forward jacks. It will be a great help to determine the suitability of those jacks for returning to support processing in the OPFs”(Judd e-mail).

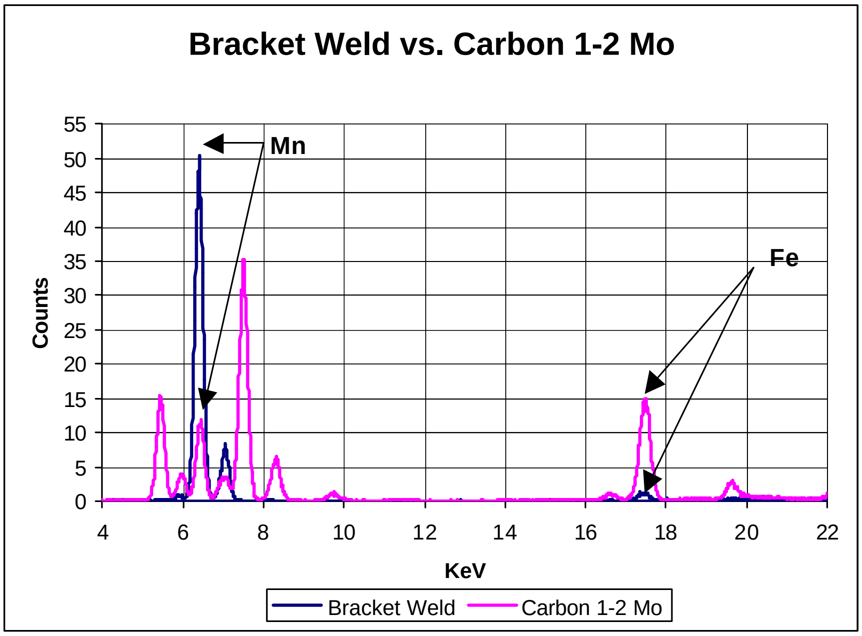
References

Davis, J.R., and Davis and Associates, eds. "Metals Handbook, Desk Edition *Second Edition.*" ASM International. Materials Park, OH. 1998

"Instruction Manual, Innov-x Systems X-ray Fluorescence Spectrometers(version 1.1)." Innov-x Systems, Inc. Woburn, MA. 2002

Judd, William. "Alloy Determination—Jack Stands." E-mail. 18Jun2003

Appendix 1



Bracket Weld vs. Carbon 1-2 Mo
Counts
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50
45
40
35
30
25
20
15
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5
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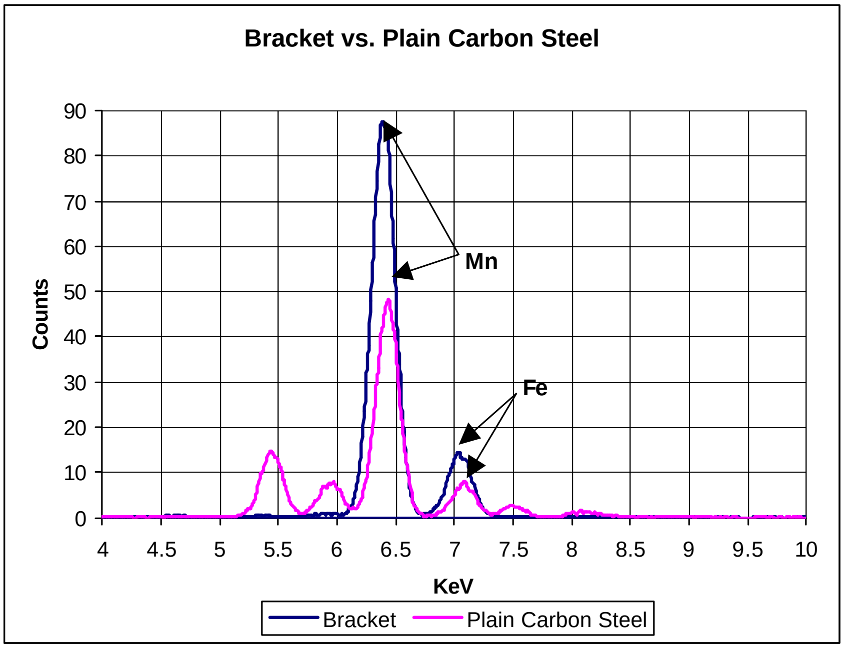
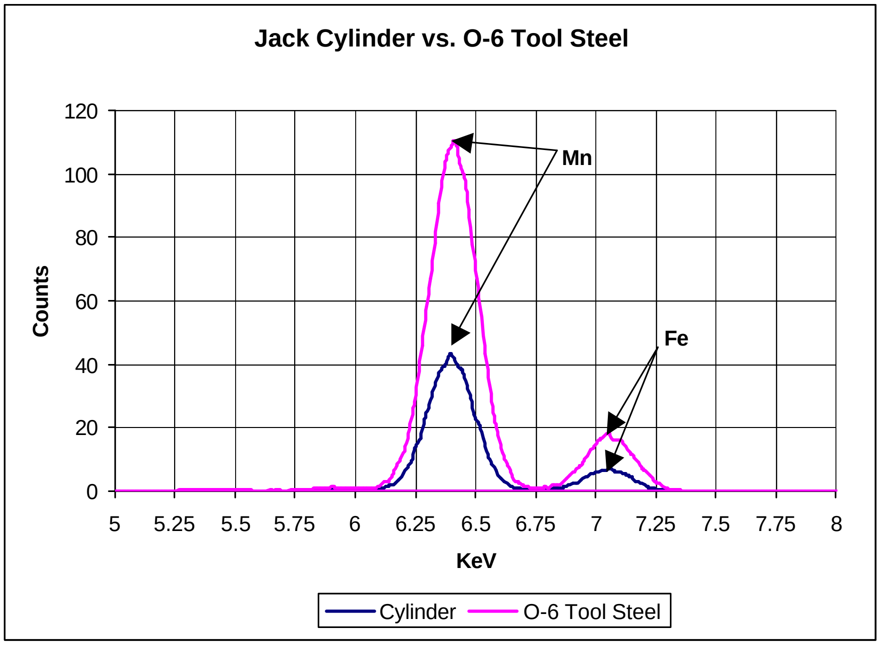
8
10
12
14
16
18
20
22
KeV
Mn
Fe
Bracket Weld
Carbon 1-2 Mo



Bracket vs. Plain Carbon Steel
Counts
90
80
70
60
50
40
30
20
10
0
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
KeV
Mn
Fe
Bracket
Plain Carbon Steel

Appendix 2



Jack Cylinder vs. O-6 Tool Steel
Counts
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100
80
60
40
20
0
5
5.25
5.5
5.75
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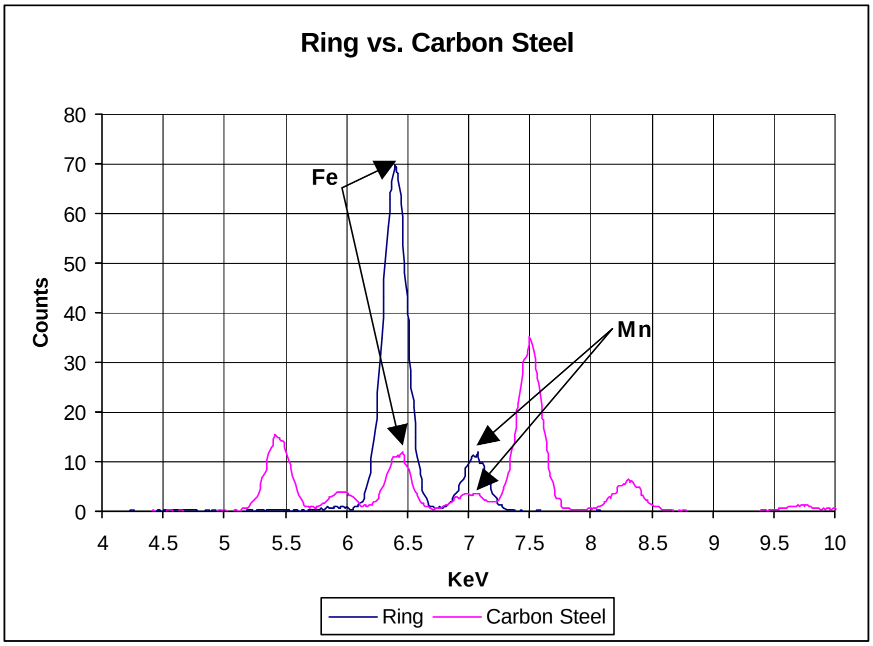
7.25
7.5
7.75
8
KeV
Mn
Fe
Cylinder
O-6 Tool Steel



Ring vs. Carbon Steel
Counts
80
70
60
50
40
30
20
10
0
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
KeV
Fe
Mn
Ring
Carbon Steel

Julie Morrison
University of Maine

Participating at the Jet Propulsion Laboratory

Title: "Development of Biosensor Cladding Protocols for the Detection of Bacillus Spores and Other Biomolecules"

NASA Mentor Dr. Ying Lin

Julie Morrison abstract

David Paul
University of Maine

Participating at the Marshall Space Flight Center

Title: “Future Propulsion Systems of the PRC:
The Need for Flightweight Magnets”

NASA Mentor Glen A. Robertson

ABSTRACT:

Space travel and exploration in the future will depend on humankind's ability to develop advanced forms of propulsion that allow us to go father and faster in space than previously possible. This paper examines several systems currently being designed at Marshall that may grant us this ability. It also investigates the weight versus field strength limitations of conventional magnets. Several possible solutions will be presented as well as a listing of relevant websites and publications.

I. OBJECTIVE

The objective of this report was to look at some of the general technical challenges of developing a flightweight magnet and examine several of the different magnet systems currently being developed at the MSFC Propulsion Research Center and affiliates (LSU, JSC, etc.).

II. APPROACH

The leaders of each of these projects were interviewed for information regarding their system as well as what they felt the term "flightweight magnet" means. Particularly of interest was what they felt needed to be done with magnets in the future to achieve faster interplanetary propulsion. This information is cataloged here and used to define Flightweight magnets.

III. PROBLEM

All indications show that the future of high-speed space travel will rely on plasma powered propulsion systems (this includes fission, fusion and anti-matter systems). These systems are capable of higher ISP's, which reduces the amount of propellant mass necessary for a given trip. However, the difficulty with these systems is that the high temperatures necessary to transform gases into plasmas are outside current materials limitations. The apparent answer to this problem is the use magnetic fields to contain, direct, and accelerate the plasma. However, for any of these technologies to be useful, we must first get it into orbit, which requires that we consider the weight of the system at takeoff. Conventional magnets are much too bulky to be put into space in any practical fashion. Therefore, flightweight magnets must be included in the development of new propulsion systems or we risk developing systems that are too costly to put into space.

It is obvious that there is a need to do more research in this area since it provides a critical technology in the development of future propulsion systems. A critical technology is one that must be developed and mastered before further breakthroughs can be made. The term flightweight magnet is often thrown around, but so far there has been little done to layout the specifications on what actually constitutes a flightweight magnet. The basic concept of the flightweight magnet does not deviate from the current perception that a magnet should be the lightest it possibly can be for a given system and still deliver the required field. What needs to be changed is the concept of what a conventional lightweight magnet is. Regardless, there are many questions to be answered about flightweight magnet technology. Should the magnets be made of ultra-pure metals, superconductors, or something else? Where can we eliminate the extra weight in the system? Is it more feasible to remove it from the magnet itself or the power source? We will attempt to touch on each of these in the report.

The most important thing in developing magnet technology for space applications is to get the most stored energy at the lowest possible weight. The ultimate goal is to achieve a magnet that delivers many megajoules per kilogram of energy out of the system. Current magnets produce .001 to .01 megajoules per kilogram. For in-space propulsion systems to be effective, values on the order of 1 to 1000 megajoules are needed. Clearly there is a long way to go in developing this technology.

The energy per unit mass is calculated with the equation

(1) $B^2/(4p*µ*?)$,

where B is the field strength in tesla, µ is the permeability constant and ? is the density of the magnet used to generate the field. From this equation we can see that to achieve more megajoules per kilogram either the field strength must be increased or the density of the magnet decreased. The field strengths that we have been able to generate have peaked recently at around twenty tesla for superconducting magnets and three to four times that for pulsed magnets. If we were to assume a maximum field strength of 20 Tesla and wanted to get 1000 megajoules per kilogram, the density of the material the magnet was made from would have to be .02526 kg per cubic meter. Such a material does not exist, and if it did it would be doubtful that it would be strong enough to withstand the stresses the magnetic field would subject it to. A stronger magnet would require a more dense material.

IV. POSSIBLE SOLUTIONS

For conventional magnet systems, the weight increases as the square of the magnetic field (B). Therefore, new techniques need to be developed that changes this earth-based paradigm. Possible solutions include:

Integrating the containment structure with the magnet material. Two possibilities are:
Nanotube Technology – Carbon nanotubes are a relatively new technology and as such not much is known about them. However, tests have shown them to have high tensile strength as well as high conductivity. The difficulty is dealing with their size. If there were a way to efficiently and effectively chain them together we could build very lightweight, very strong solenoid magnets.

Bulk SC magnets – Bulk SC materials can be used to create SC permanent magnets as long as the critical temperature, voltage, magnetic field or combinations of both are not exceeded. Integrating bulk SC materials into a coil design could help strengthen the overall magnet system and provide useful magnetic field when the power to the coils are off. Whereby, reducing the power load of the magnet system. Bulk SC magnets can also be made in configuration that would normally require heavier coil magnet system to achieve.

Using HTSC instead of LTSC -
Many systems are still being built with LTSC's, however, it seems to make more sense to switch to the HTSC's. They can be cooled with liquid nitrogen, which is much less expensive than the liquid helium needed for LTSC's. The HTSC's also tend to be able to generate stronger magnetic fields than a comparable LTSC, and would not require as extensive a heat control system while on-board a space vehicle.

Reduce power requirements-
One way this is done is by using a flux pump, which is designed to energize high current super conducting loads. The flux pump operates by turning two heat switches on and off, inducing currents in their respective loops. Each time the current is switched from one coil to another the current in the magnet coil is increased. Slowly, over time, the magnetic flux builds up in the superconductor to the desired level.

V. IN-HOUSE PROJECTS

All of the projects talked about in this report rely heavily on the use of magnets to operate. Using conventional magnets that have the proper specifications to prove the theory behind the system works is fine on the ground but the systems will need to be outfitted with flightweight magnets before they can be used in space. It costs around $10,000 per pound to put something into space so it's not very cost effective to put conventional magnets into orbit. It is clear this is a problem that confronts all engineers and physicists working on solving the plasma propulsion problem. This includes anyone working on systems for small orbiters, interplanetary satellites and perhaps even as large as integrating plasma systems into personnel-carrying shuttles.

-The VASIMR (VAriable Specific Impulse Magnetoplasma Rocket) System-

The VASIMR system is one of the oldest and longest running ideas for a plasma propulsion rocket. The rocket is made up of three stages. In the first stage, a light gas (usually hydrogen or helium) is injected into the rocket through a quartz tube. A helicon antenna then ionizes the gas. The plasma passes through the tube following the magnetic field lines generated by (at least) three solenoid magnets. In stage two, the plasma is excited even more by an ICRH (ion cyclotron resonance heating) antenna at the back of the magnetic containment field. In the final stage, the plasma expands and detaches from the rocket via a magnetic nozzle.

As was mentioned earlier, the VASIMR system currently uses 3 solenoid magnets to generate the necessary fields for plasma containment. However, these are made of copper. Greg mentioned that if this system were to actually be implemented in space, the current magnet system would have to be replaced by a superconducting magnet. The VASIMR team believes that superconductors are the answer to their flightweight magnet problem. Greg said that one of the main concerns with getting the magnets space-ready is developing the thermal management system. The superconductors must be kept below their critical temperature (T_c), otherwise they will quench and stop producing their magnetic field. This would cause a meltdown of the system, as the plasma would be too hot for the engine to handle. Right now, there is a 10-kilowatt solar powered satellite set to launch in mid-2004 with the VASIMR system on it. So, the team will have to finalize the retrofitting of the rocket soon.

-The MHD (MagnetoHydroDynamic) System-

Magnetohydrodynamics is a broad term that encapsulates electric propulsion systems. Marshall's MHD program is designed to create a system that augments chemical propulsion engines. The program builds off of 50 years of legacy data coming from NASA, the Air Force and even a Russian version of the technology. A successful engine of this type would allow engineers to reduce the fuel fraction and shirk the vehicle size without sacrificing payload delivery capability. The MHD accelerator being worked on at Marshall operates by heating a fluid medium (air, nitrogen, etc.) with a 1.5-MW_e Aeotherm arc-heater to a temperature of 4000-4500 K and a pressure of 10 atm. The gas travels to a mixing chamber where it is seeded with alkali metals (NaK is commonly used). The gas travels through the primary nozzle at high-speed into a 2- MW_e MHD accelerator. The MHD accelerator increases the energy and momentum of the flow, which is ejected out of the secondary nozzle at the highest velocity possible. In its current testing configuration, the secondary nozzle exhausts into a large test section so that the exhaust plume can be studied.

The magnet being used to demonstrate the basic principles of MHD work is an iron core magnet with a 4-inch air gap. The magnet looks like a giant iron "u", but with two arms at the top that extend toward the middle (creating the 4-inch air gap). Water-cooled copper coils are wound around the two arms. The actual current put into the magnet is run through the copper coils, but the iron core helps contain the current and field, increasing the efficiency of the magnet. The entire assembly weighs upwards of 12 tons, and only produces a two Tesla field in the air gap. Compare that to a 50-pound ultra-pure aluminum magnet that produces a two Tesla field that can be found right here in the PRC magnetics lab here at Marshall. Ron Litchford, one of the project leads, told the author that the magnet being used here on the ground could not be used in space. Obviously the weight of it is the limitation. Litchford said that to implement the engine in space would require the development of a superconducting magnet to take the place of the test magnet.

Litchford also brought up the problem of trying to decide what type of cryogen and superconductor to use in space. There are two types of superconductors, low-temperature and high-temperature operating. All of the low-temperature operating superconductors (LTSC's) require liquid helium temperatures (~4.2 K) while the high-temperature (HTSC's) only need liquid nitrogen temperatures (~77 K).

-The GDM (Gas Dynamic Mirror) System-

The GDM is fusion propulsion system that is basically just a big solenoid, but the fields at the ends are stronger to keep the plasma inside bouncing back and forth on the magnetic field lines. Propulsion comes from the plasma leaking past the mirrors from instability. The field strength of the mirrors is currently around two Tesla. Ideally, these will be higher in space. Currently, the GDM is outfitted with water-cooled copper magnets. Bill Emrich, the man in charge of the project, noted that you could never use copper magnets in space and that he is only using them in the lab because they are inexpensive and get the job done. Unfortunately, the interview with Mr. Emrich was not long and the author could not find any papers on the GDM, so it is not possible to explain exactly how the system works.

-The HiPAT (High Performance Anti-proton Trap) System-

HiPAT alone is not an advanced thruster system. As its name implies, it is a trap designed to hold anti-protons and will be used in conjunction with (most likely) an advanced fission/fusion engine. The difficulty with trapping anti-matter is that it is very reactive. Upon contact with any normal matter the two particles will undergo annihilation, releasing an amazing amount of energy. To give you an idea of just how much energy annihilation produces, consider the space shuttle. The 750,000 kg of fuel and oxidizers currently used on the shuttle has the energy as 42 mg of antiprotons (.6cc's). Even having a small amount of anti-matter can be lethal if not properly contained. The only way to contain anti-protons is with magnets.

The HiPAT system is currently undergoing initial testing to demonstrate it can hold 10^{12} ions for a period of 18 days. Once the team demonstrates that, the apparatus will be transported to Fermi National Accelerator Laboratories for anti-proton testing. The ions being used at this time are H^+ and H^- ions. These ions are generated by ion sources and fired down a beam line into the containment chamber. The ions are then held in the containment area by a potential well and a superconducting magnet. Right now the team is working on timing for the cycling process. The 10^{12} particles cannot be collected all at once, so they shoot packets of particles in pulses in a process called "stacking" to get the desired total number.

The magnet being used is a low-temperature operating superconductor that generates a 4 Tesla field and weighs on the order of 4-6 pounds. The magnet is also liquid helium and liquid nitrogen cooled and the apparatus is equipped with a cryo-cooler to help reduce the amount of cryogens needed to sustain the system over time. The containment unit is also equipped with proper shielding to protect the experimenters from dangerously high magnetic fields. All in all, the entire unit (including the magnet, cryogens, cryo-cooler, shielding and containment unit) weighs around 500 pounds.

-The PTX (Plasmoid Thruster Experiment) System-

A plasmoid is a compact plasma with an integral magnetic field. In the PTX, the plasmoid is generated using an aluminum theta-pinch coil and then ejected out the back of the field at a high velocity (confirmed 5.3km/s). The coil is a single turn and has a central conical half-angle of 17.5 degrees. The goal of the project is to produce a thruster with an ISP in the 5000-15000 second range. The team does not seem to have plans of shifting to a superconducting magnet (as the system depends on having a theta-pinch coil) to put it in space. However, it is made of aluminum and is very light. The one thing that has been suggested is that the magnet should be liquid nitrogen cooled to help minimize resistive losses and maximize the recapture of inductive energy in the coil and transmission line.

VI. CONCLUSION

Of all the projects currently under investigation within the PRC, only one of them is equipped with a superconducting magnet (HiPAT). However, all of the other project managers said that superconducting magnets needed to be added into their designs before they would be ready for space. This leads the author to believe that superconductors could be a viable solution to one of the weight problems if time and money are put into researching and developing the technology as it applies to our projects. It should not be overlooked, as all of the interviewees pointed out, using superconducting magnets necessitates the use of heavy equipment to sustain the magnet and keep it from quenching. Thus, any design engineer putting together a plan to build one of these systems must consider the weight and cost of proper cooling systems, radiators, cryo-coolers and power sources.

When asked about what they thought constituted a flightweight magnet, all of the interviewees generally had the same response. The term is not a fixed definition. What flightweight means to one project is not what it means to another. It would be nearly impossible to define a standard that would be uniform across the board. This leads to the conclusion that flightweight magnets, at this point, can only be defined as the lightest combination of superconducting magnets, cryogens, cryo-coolers and power sources that can be used while still maintaining all of the necessary strength and temperature requirements. Many systems are still being built with LTSC's, but it seems to make more sense to switch to the HTSC's. They can be cooled with liquid nitrogen, which is much less expensive than the liquid helium needed for LTSC's. The HTSC's also tend to be able to generate stronger magnetic fields than a comparable LTSC, and would not require as extensive a heat control system while on-board a space vehicle.

Another possible answer to the lightweight magnet problem may come from carbon nanotubes. These tubes were discovered during research relating to fullerene and "Bucky Balls". The tubes themselves look like a single sheet of hex-shaped carbon chains that has been rolled into a small cylinder. They measure just a few nanometers in diameter and a several micrometers in length. According to John Cole, who has done a work with carbon nanotubes here at Marshall, they show great potential to be the conductors of the future. He mentioned that testing has shown them to be thousands of times more conductive than copper. They also have a tensile strength that rivals steel. The difficulty with this technology is of course its size. To create a strong magnet one would need to have a chain of nanotubes measuring around one kilometer in length. That means one billion of them would have to be strung end to end and somehow fused together to form a submicroscopic wire. Then there is the difficulty of wrapping a wire you cannot see around a post to form a solenoid. Clearly there is much work to be done in this field before it can become a viable option, but at this point the possible results are quite tantalizing.

References/Bibliography

1.) Chang Díaz, F.R. "The Physics and Engineering of the VASIMR Engine." *36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Huntsville Alabama, 17-19 July 2000*. Reston, Virginia: AIAA

2.) Chang Díaz, F.R. "The VASIMR Rocket." *Scientific American*, November 2000: 90-97

3.) Cole, J.W., and Litchford, R.J. "Magnetohydrodynamic Augmented Propulsion Experiment: I. Performance Analysis and Design." *33rd AIAA Plasmadynamics & Lasers Conference/14th International Conference on MHD Power Generation and High Temperature Technologies, Maui, Hawaii, 20-23 May 2002*. Reston, Virginia: AIAA

4.) Good, J.A., Mitchell, R., Hall, R. "A 15T Cryogen Free Magnet System." *Journal of Magnetism and Magnetic Materials*, 2001: 226-230

5.) Goodrich, R.G. "High-Purity Aluminum Magnet Technology for Advanced Space Transportation Systems." NASA Publication. January 2002.

6.) Koelfgen, S.J., and Hawk, C.W. "A Plasmoid Thruster for Space Propulsion." *39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Huntsville, Alabama, 20-23 July 2003*. Reston, Virginia: AIAA

7.) Litchford, R.J., et. al. "Prospects for Nuclear Electric Propulsion Using Closed-Cycle Magnetohydrodynamic Energy Conversion." NASA Publication. October 2001.

8.) Martin, J.J., et. al. "Ion Storage Tests With The High Performance Antiproton Trap (HiPAT)." STAIF-2002. edited by M.S. El-Genk, AIP Conf proceedings 608. AIP. New York. 2002. pp 793-800

9.) Martin, J.J., et. al. "Design and Preliminary Testing of a High Performance Antiproton Trap (HiPAT)." STAIF-2001. edited by M.S. El-Genk. AIP Conf proceedings 552. AIP New York. 2002. pp 931-938

10.) Martin, J.J., et. al. "Ion Dynamic Capture Experiments with the High Performance Antiproton Trap (HiPAT)." STAIF-2003. AIP Conf proceedings. AIP New York. 2003.

APPENDICES

Appendix A

Relevant Web Pages

Since the future of lightweight magnets seems to lie in the production and development of superconducting wires and materials, the author has included a listing of helpful sites about this topic. The sites range from informational to commercial. Also included are a few links concerning carbon nanotubes so the reader can learn more about them if he/she so wishes.

1.) Superconductors.org

A fantastic site with the basics of superconductors as well as an extensive links page containing links for pictures/video, research and research centers, manufacturers, accessories, upcoming conferences, etc. Everything you need is right here! http://superconductors.org/

2.) American Superconductor Corporation

This company specializes in the use of superconductors for electric and power generating capability. However, they do produce a product they call HTS wire. The wire is capable of delivering 140 times the power of a copper wire of comparable size. They boast it is perfect for applications ranging from power cables to specialty magnets. There are several different types of wire available. They do not appear to make finished product. Details can be found on their website http://www.amsuper.com

3.) Cryomagnetics, Inc.

This company specializes in superconducting solenoids. The site lists dimensions and properties on standard solenoids ranging from 5-9 T. They also have split-pair magnets, high homogeneity solenoids, high field solenoids, low current solenoids and custom design magnets. For more details see http://www.cryomagnetics.com

4.) ACCEL

Produces many different types of magnets (superconducting and normal conducting) as well as cryostats and cryocoolers. The company seems to cater to research and industrial customers. For more see http://www.accel.de

5.) Janis Research

Company manufactures a variety of cryostats, dewars, and superconducting magnetic systems. They produce both cryogen and cryogen-free systems. Contact Janis for specialty requests at http://www.janis.com

6.) American Magnetics, Inc.

Provides a wide array of superconducting magnets, supporting equipment (i.e. dewars, support assemblies, etc) and power supply systems. They list several types of solenoids as well as contact information if you need something more specific than what they provide. All can be found at http://www.americanmagnetics.com

7.) Everson Electric Company

Has both finished product superconducting magnets as well as cryogenic systems to support them. Everson produces standard solenoid magnets as well as special magnet configurations. See http://www.eversonelec.com for full details.

8.) Space Cryomagnetics Ltd.

Provides complete service from design, through assembly, to installation and commissioning. Their focus is on custom-built and special magnets, but they also supply standard cryogenic equipment and consultancy services. Contact information is provided on the site. All information can be found at http://www.spacecryo.co.uk

9.) Oxford Instruments

Their magnet systems offer a full range of magnetic field and temperature environmental combinations for physical measurements. These solenoid magnet systems are available with fields up to 21 T with interchangeable variable temperature inserts, Heliox 3He refrigerators and Kelvinox dilution refrigerators for a full temperature range down to 7 mK. Full information at http://www.oxford-instruments.com/SCNCHP1.htm

10.) This is a great site for all kinds of information on carbon nanotubes. There is an extensive listing of relevant sites including general information and specific research and links to commercial and non-commercial producers of carbon nanotubes.

http://www.pa.msu.edu/cmp/csc/nanotube.html

11.) A mostly informational site although it does have links to nanotubes producers as well as research references. http://www.personal.rdg.ac.uk/~scsharip/tubes.htm

12.) This is a site listing the recent research on carbon nanotubes done by IBM.

http://www.research.ibm.com/nanoscience/nanotubes.html

13.) This is the website for the Center for Nanotechnology at NASA Ames Research Center and includes information on various types of new nanotechnology including carbon nanotubes. http://www.ipt.arc.nasa.gov/index.html

Appendix B

Interviewees

1. Cole, J. Personal Interview. June 2003.
2. Chavers, G. Personal Interview. June 2003
3. Emrich, B. Personal Interview. June 2003
4. Litchford, R. Personal Interview. June 2003
5. Martin, J. Personal Interview. June 2003

Appendix C

List of Acronyms

LSU – Louisiana State University

JSC – Johnson Space Center

LTSC's – Low temperature superconductors

HTSC's – High temperature superconductors

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The author would like to thank Tony Robertson, John Cole, Bill Emrich, Ron Litchford, Jim Martin, Richard Eskridge, Greg Chavers and Syri Koelfgen who provided their written work and their insight on this topic. The author would also like to acknowledge the AIAA, STAIF and NASA for the use of their publications

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Participating at the Stennis Space Center

Title: "GIS for Wetland Mitigation"

NASA Mentor Dave Golden

Abstract

Wetland Mitigation monitoring has been an ongoing effort at Stennis Space Center. The Center has been tasked with replacement of habitat lost due to unavoidable expansion of Site facilities. To facilitate mitigation efforts, four separate areas were established. Each area is monitored on an annual basis; guidelines indicating required crown-closure for desired species have been established for each site. While the areas had basic maps created for each, current mitigations efforts required the implementation of a GIS to assist with the monitoring efforts. Each site was surveyed with GPS and inventoried for historical monitoring of species composition and crown-closure.

Introduction

The Stennis Space Center Wetland Mitigation project requires constant monitoring of test sites, as well as the ability to share locations and attribute information concerning each site with outside entities. Also needed was a method to improve spatial data storage and enhance management decision-making. Including the mitigation site information into the ever-growing GIS database used by Stennis was a major goal of Natural Resource Management Team.

The mitigation project consists of 4 distinct sites, each with a separate management plan. The sites, ASRM, CTF, HES and Pearlington are located both on the center and within the surrounding buffer zone. Each site requires annual monitoring and inventory to quantify changes in species diversity and forest structure; this data is used as the measure of success for the mitigation efforts.

The Advanced Solid Rocket Motor Site (ASRM) is a 132-acre area located between the Rocket Motor Test Site and the eastern boundary of the Fee area. This site is being managed for pine savannah; current management plans call for regular prescribed burns and thinning of pine stems to 3-5 stems per acre. This area required survey and mapping of the 2-0.46-acre long-term monitoring plots that are located on either end of the site. The Component Test Facility (CTF) Site is a 6-acre area located behind the E-Complex Test Stand. This site, located in a natural depression, is well suited for the hardwood bottomland management plan implemented. Fifteen transects with three quadrants each were mapped for this site.

The Hardwood Enhancement Site (HES) is a 15-acre area, 500 feet outside the south gate of Stennis Space Center. This is an effort to re-establish hardwood bottomland in the Space Center's buffer zone. This site required mapping of 12 transects with a total of 45 quadrants.

The Pearlington Site, Phase 1[a], is 115-acre area located 8 kilometers south of Stennis, in the buffer zone. This site is being managed as pine savannah and as such has included the use of prescribed burns in current management plans. This area contained 2 long-term monitoring plots that required survey and mapping.

[a] The Pearlington Site has 3 separate Phases, for the consideration of this report, only Phase 1 was addressed.

Problem

The mitigation efforts required accurate mapping of each site, as well as the ability the ability to store attribute information for internal use, and export to others in the Natural Resource Team. Before the implementation of this project, no precision mapping of the areas had been completed, nor was the field data being entered into a database for monitoring and exportation. This project was to implement a GIS for use in Wetland Mitigation. The resulting spatial information was to be included into the GIS database already in place at Stennis, and a single map of each site was to be created. In addition, the required annual inventory data had to be collected and entered into the database for further analysis.

Method of Solution

In order to create the maps required, an initial survey of the field location for each post was conducted. The project specifications required the data to collected with an average precision of approximately 3 meters.

The survey was completed using a Trimble GeoExplorer II GPS unit, linked with a Trimble ProBeacon in an effort to receive real-time differential correction (1). Each post location was visually located and blazed, then recorded into a point feature using the GeoExplorer, as defined by the data dictionary (2) loaded on the datalogger (3). Each point feature was logged as the average position of 36 fixes (4), per the manufactures' recommendations for the desired precision for this project. The raw data was collected with an average precision of 6 meters, due to reception issues related to the sites location versus the base station location. This necessitated post-processing (5) of the GPS data after collection.

To accomplish post-processing, the Pathfinder Office software was employed. The USDA Forest Service Station at Pineville, Louisiana provided all base station files. Using the differential correction option, with both code processing and carrier-phase processing, the data was corrected to an average accuracy of 3.5 meters for most locations. This was within acceptable parameters for the mapping was to be preformed, and the data was exported from Pathfinder Office into Simple ArcView Shape Files (.shp). The export coordinate system for all locations; UTM Zone 16, WGS 1984.

The GIS software used to create the four maps was ArcView 8.0. The shape files with post locations were layered with a variety of Ikonos True Color Imagery, which has a standard resolution of 4 meters. The inventory data was field collected and entered into the database for monitoring of historical change, and future management decisions.

Discussion

The field survey conducted was initially to be preformed using real-time differential correction, however the site locations precluded reception of the corrected signal. The DGPS signal originally intended was not able to received due to the terrain and canopy cover in the area. The post-processing techniques were, however, able to improve the accuracy of the signal to within acceptable tolerances of approximately 3 meters.

Species diversity surveys were conducted visually. Crown diameter measurements were converted into area, $\Pi d^2/4$.

Conclusion

This project is part of a larger, ongoing effort to manage and restore habitat in and around Stennis Space Center. Storing the data in a GIS system allows the Natural Resource Management Team to quickly display and query spatial attributes for all sites. Each site presents its own unique mitigation challenges, and a successful effort can only be quantified through examination over time. The most efficient way to convey areas that have been successfully restored is to overlay these areas' exact positions with their vegetative characteristics. The ability to visually represent and analyze changes in forest composition requires this information. The collection of the spatial data for these sites has brought this project closer to being fully integrated in the ArcView GIS software.

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•***NASA Education Office***

•**Joy Smith,** University Education Specialist

•***Dr. Ramona Travis,*** *University Education Officer*

•***Maine Space Grant Consortium***

Glossary

[1] A technique that uses an extra GPS receiver located in a precisely surveyed location to increase accuracy common to all receivers

[2] A predetermined set of features able to be recorded with a datalogger

[3] An electronic storage device that is used to record GPS files and attribute information

[4] The term for the acquisition of a positional data from the satellite

[5] Using software algorithms that account for know variables to correct inaccuracies in the GPS signal

References

Golden, Dave. *2003 Annual report on the Continued Monitoring of Stennis Space Center Wetland Mitigation Areas: Advanced Solid Rocket Motor Site, Component Test Facility Site, Hardwood Enhancement Site, Pearlington, Phases I, II, and III.* SSC Natural Resource Team, July 2003.

Leick, Alfred. 1995. *GPS Satellite Surveying*. 2nd. ed. New York: John Wiley & Sons.

Monica Salazar
Maine Maritime Academy

Participated at the Jet Propulsion Laboratory

Title: "Viable but non-cultivable state of *Stenotrophomonas maltophilia*, an opportunistic pathogen, whose ribosomal DNA sequences were retrieved from the drinking water of the International Space Station"

NASA Mentor Dr. Kasthuri Venkateswaran

Genetic sequences of *Stenotrophomonas maltophilia* were retrieved in the International Space Station (ISS) drinking water processed from the STS-113 mission. An increase in the amount of this bacterium may be harmful to the health of the astronauts in the ISS because it is an opportunistic pathogen. One of the goals the Biotechnology and Planetary Protection group has at the Jet Propulsion Lab is to quantify and examine the activity of *S. maltophilia* in drinking water. Another goal is to find a way to isolate this kind of opportunistic pathogen. Through experimentation, *S. maltophilia* was induced to attain a viable but non-cultivable (VBNC) state. Using a model system with a type of strain of *S. maltophilia*, stress was induced by exposing *S. maltophilia* to various environmental conditions to enter into VBNC state. The viability of *S. maltophilia* was examined by RNA isolation and correlated with the colony forming units. Additional tests such as adenosine triphosphate (ATP) assays were performed to elucidate the viability. Among various stress conditions employed to make the bacterium enter into VBNC state, *S. maltophilia* was not found to multiply in sterile water and also under this condition viability was not lost. Furthermore, chemically induced VBNC state of *Burkholderia cepacia*, another opportunistic pathogen, was performed. The biocide (Iodine) used in the purification of the drinking water bound for the ISS was supplemented in the sterile drinking water and the VBNC state of *B. cepacia* was tracked. The biocide treatment did not affect the viability of *B. cepacia* and it did not induce the bacteria into a VBNC state. The Biotechnology and Planetary Protection group at JPL will perform further analysis on *S. maltophilia* and *B. cepacia*.

The health of astronauts is crucial for the missions they accomplish while in space. Whether staying in the International Space Station or in an orbiter, their health is immuno-compromised. The resources they need to survive in space need to be as health efficient as possible.

Drinking water samples were taken from the International Space Station (ISS) during post-flight and examined for microbial contamination [1, 2]. The 16S rRNA genetic sequences were retrieved from these ISS drinking water samples. The bacterium detected from the genetic sequences is *Stenotrophomonas maltophilia*, an opportunistic pathogen that could be harmful to the astronauts' health [1, 2].
In an effort to quantify and purify drinking water for astronauts, a series of water filtrations are performed from the Orbiter Processing Center at the Kennedy Space Center. After pre-flight filtration and after a biocide treatment, another opportunistic pathogen, *Burkholderia cepacia*, was found in the drinking water bound for the International Space Station.

In order to determine what conditions make *S. maltophilia* viable but non-cultivable, a model system using a same type strain of *S. maltophilia* from the ATCC was be used to determine these conditions. *S. maltophilia* from the ATCC is viable and cultivable.

<u>Methods</u>:

Using a model system with a type of strain of *S. maltophilia* from the ATCC, stress was induced by exposing the bacteria to different environmental conditions in order to attain a viable but non-cultivable state (VBNC). Before testing could begin, a growth curve for *S. maltophilia* was acquired. This curve would determine the mid-log phase in which the bacteria were most active. The stress factors used to induce *S. maltophilia* into a viable but non-cultivable state were temperature, sterile water, and tryptic-soy broth.

The optimal log-phase time point from the *S. maltophilia* growth curve was determined to be 5 hours. In the environmental tests, the temperature used to stress the bacteria was set at 42º Celsius and 28º Celsius. With each temperature, tryptic-soy broth (TSB) and sterile water were used to grow the bacteria.

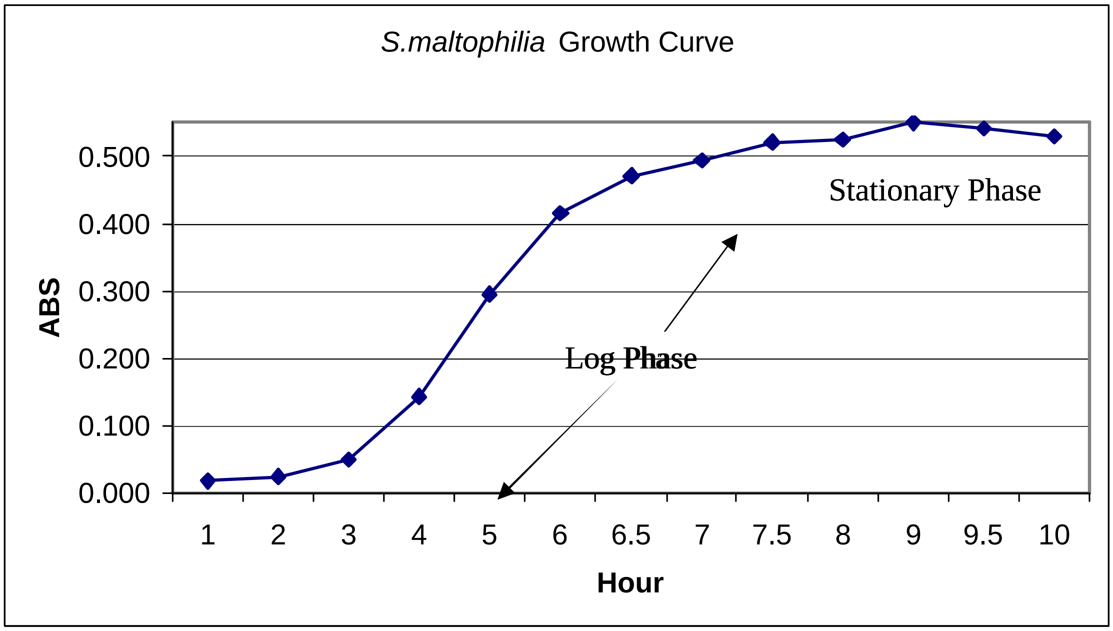
Burkholderia cepacia was retrieved from the pre-flight dinking water after a biocide treatment had been performed. This water was bound for the International Space Station. This set of experiments used 0.01% inoculation of iodine during the growth of *B. cepacia*. Different medias were used as stress factors on *B. cepacia* during experimentation. Iodine at a concentration of 8 ppm was introduced in each of the three medias while a control was used to compare results for each media. This experiment used yeast extract in M-9 media with and without iodine, M-9 media with no yeast extract and with and without iodine, and sterile water with and without iodine.

Analysis of all experimental samples of *S. maltophilia* and *B. cepacia* included spectrophotometer analysis and colony-forming unit (CFU) counts.

Figures:

GRAPH 1

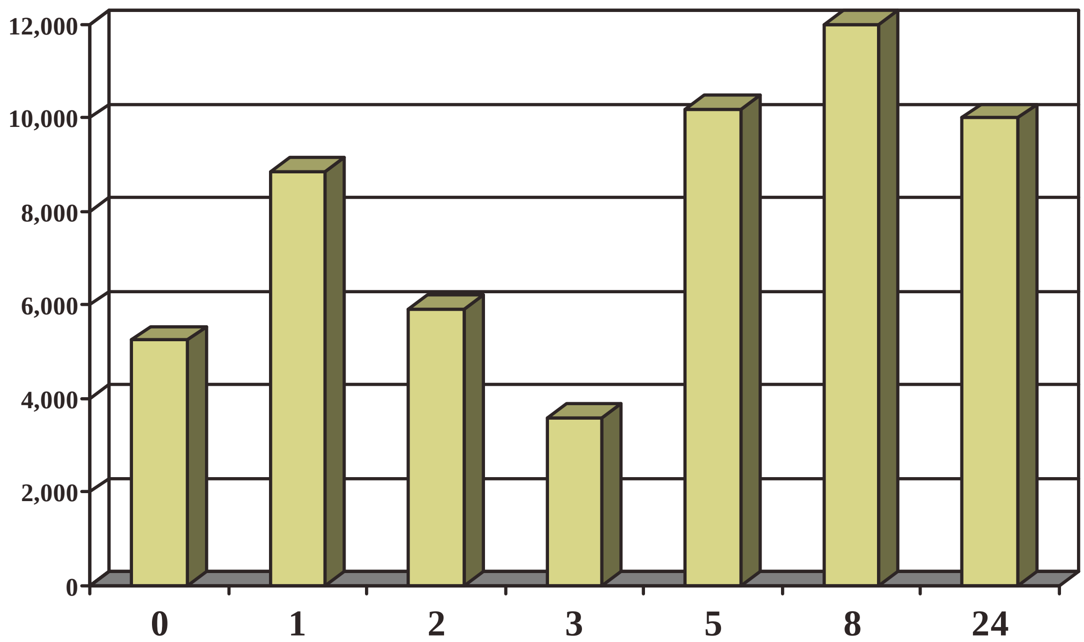
Maximum growth was attained at 8 hours, while the optimal mid-log phase can be seen in the graph at 5 hours.



GRAPH 2

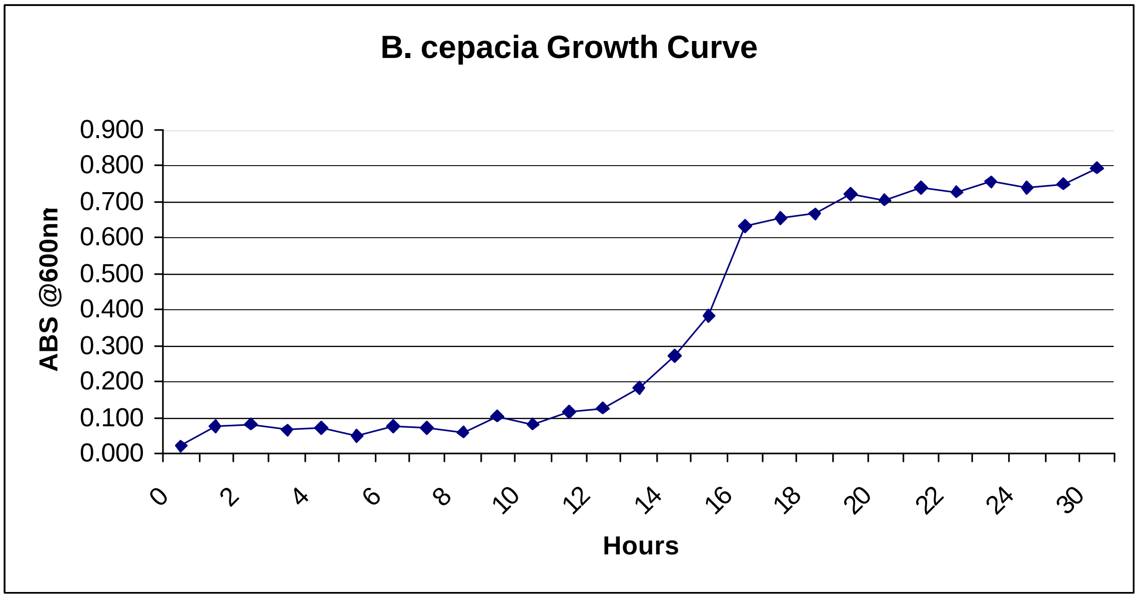
The Y-axis contains the number of colony-forming unit (CFU) counts per 100uL.
The X-axis is the hourly time point each sample was taken.
This graph shows *S. maltophilia* in sterile water at 42º Celsius

This graph shows that even though there was a decline after 3 hours from the initial sample (0 hour) taken, at 5 hours the growth of *S. maltophilia* jumps to twice the amount of colonies seen in the initial sample.



This growth curve shows that at 20 hours, maximum growth was attained, and that 16 hours is an optimal mid-log phase time.

GRAPH 3



X-axis is hourly samples taken, Y-axis is RLU counts for the ATP assay and CFU counts per 100 uL. Both measurements are the same in this graph.

An intra-cellular ATP assay compared to CFU counts was correlated. This graph verifies that both the CFU count and the intra-cellular ATP assay show the same pattern of results.

GRAPH 4

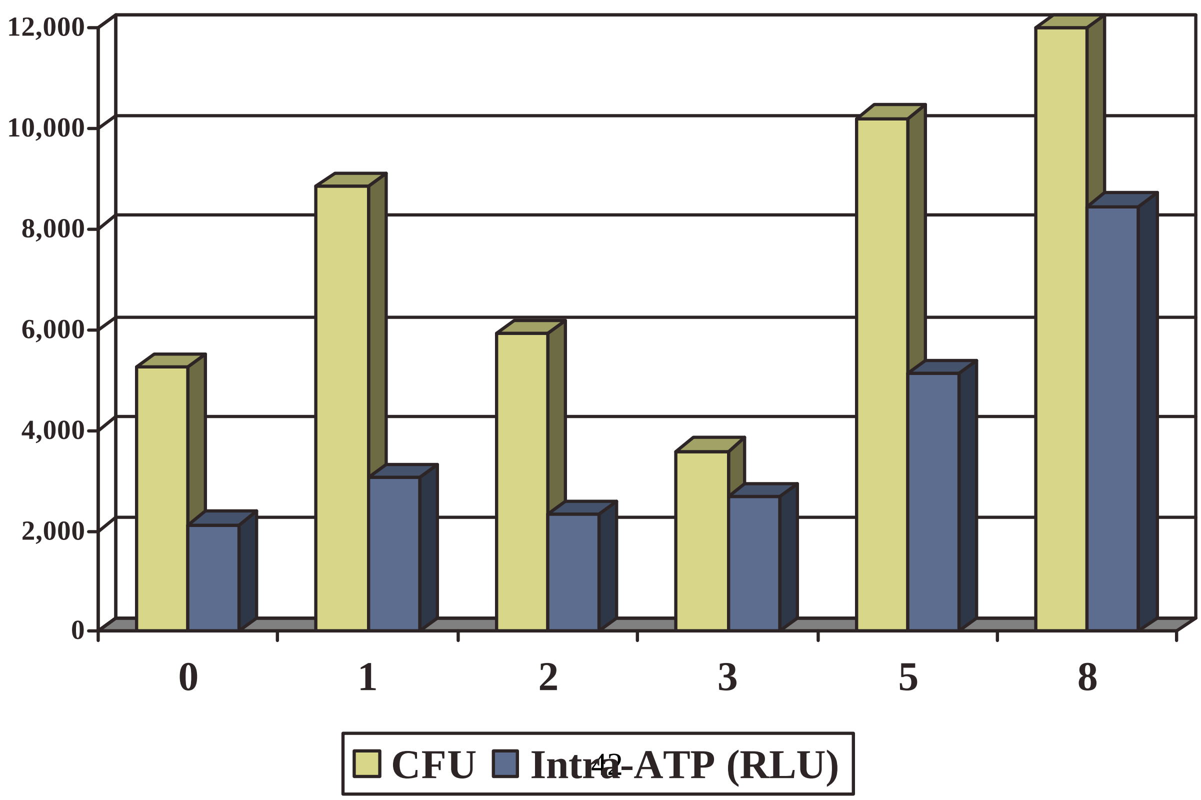


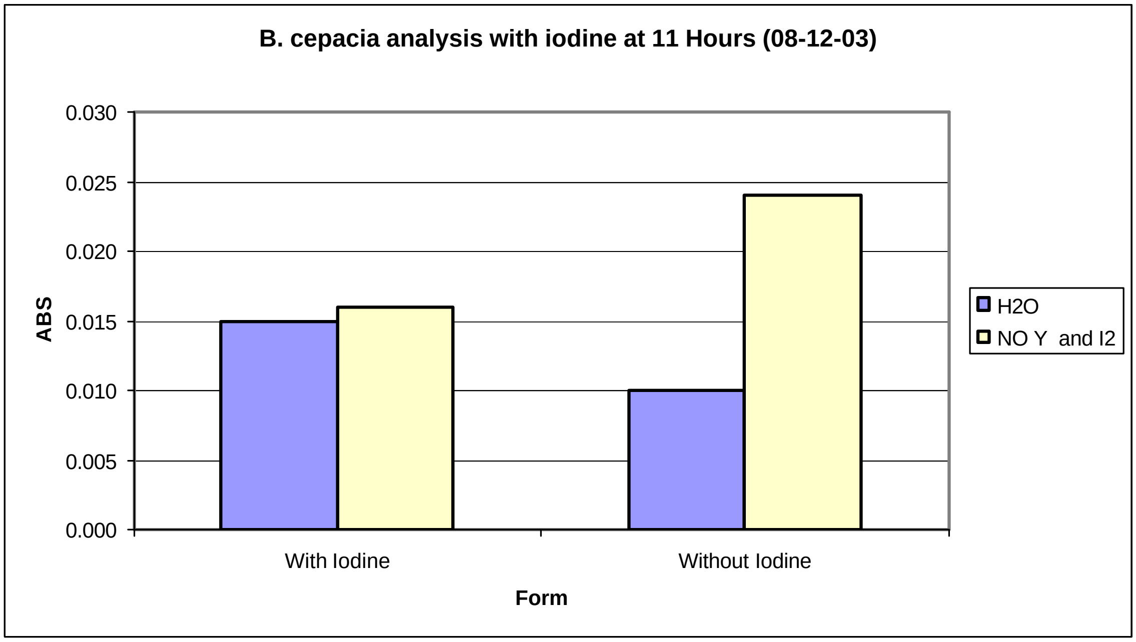
TABLE 1

S. maltophilia in TSB at 42 degrees Celsius

Broth							
A	395	128	TMTC	TMTC	**X**	**X**	**X**
B	29	29	397	TMTC	TMTC	**X**	**X**
C	0	12	94	306	TMTC	TMTC	**X**
D	**X**	4	14	TMTC	116	TMTC	TMTC
E	**X**	**X**	**X**	87	25	104	TMTC
F	**X**	**X**	**X**	24	2	1	TMTC

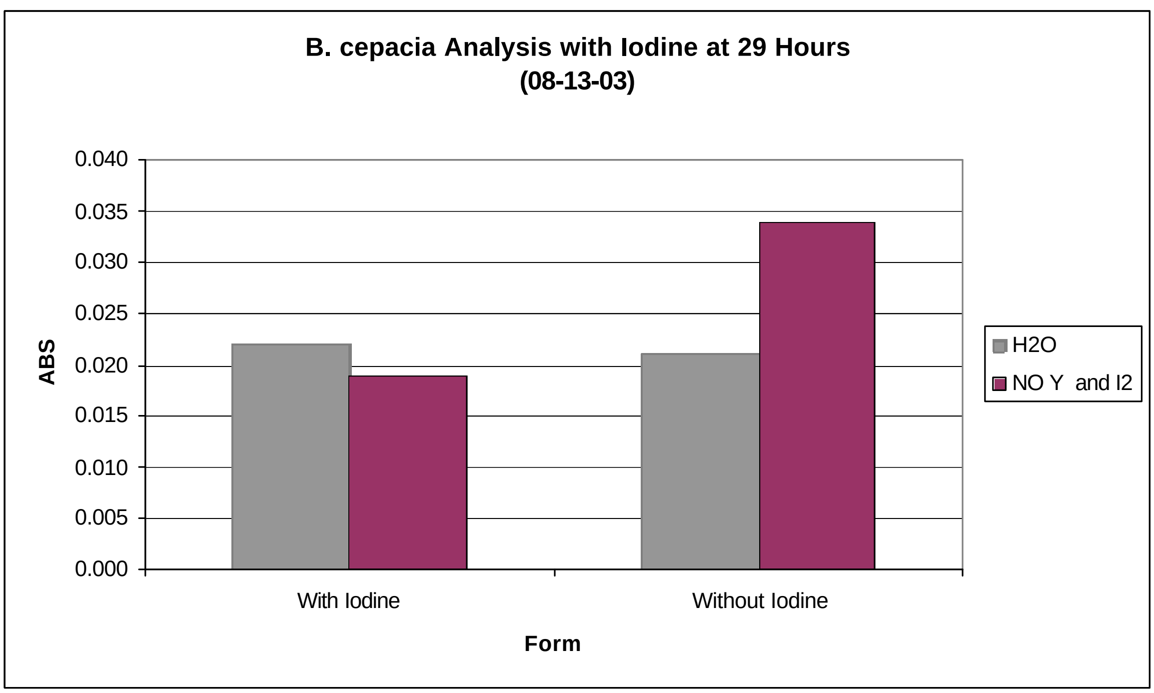
Graph 5

Spectrophotometer analysis of *B.cepacia* at 11 hours after 8 ppm of iodine was introduced.



Graph 6

Spectrophotometer analysis of *B. cepacia* at 29 hours after 8 ppm of iodine was introduced.



Graph 7

Spectrophotometer analysis of *B. cepacia* at 56 hours after 8 ppm of iodine was introduced.

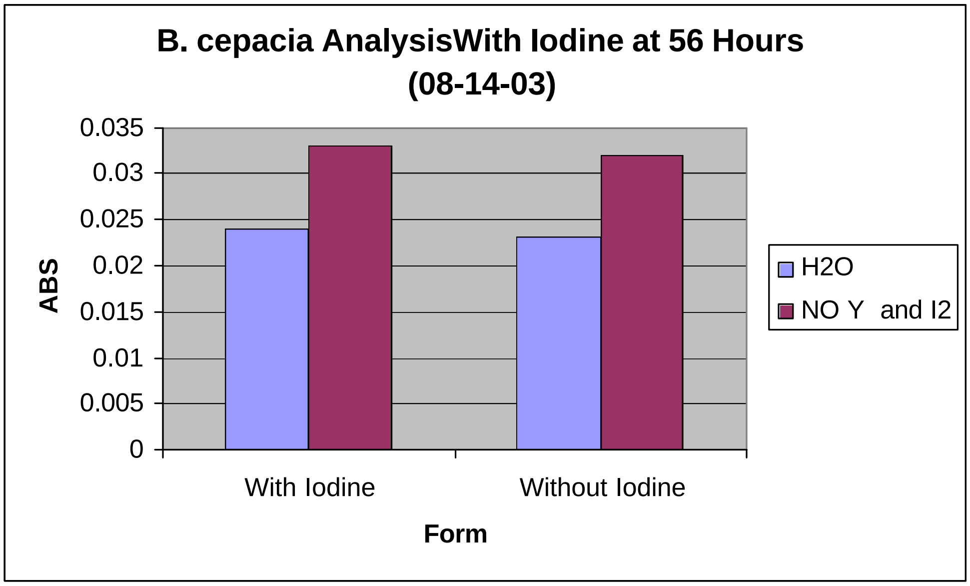


Chart 2

CFU counts of *B. cepacia* after introduction of 8 ppm iodine.

After 29 Hours

	Water, No I2	Water with I2	No Yeast, No I2	No Yeast with I2
1:1 Dilution	47,100	54,200	507,000	532,000
10,000 Dilution	4,710	5,420	50,700	53,200
1,000 Dilution	471	542	5,070	5,320
100 Dilution	181	216	507	532

After 56 Hours

	Water, No I2	Water with I2	No Yeast, No I2	No Yeast with I2
1:1 Dilution	218,000	127,000	293,000	383,000
10,000 Dilution	21,800	12,700	29,300	38,300
1,000 Dilution	2,180	1,270	2,930	3,830
100 Dilution	218	127	293	383

Results:

Three environmental tests were performed on *S. maltophilia*. These tests involved two different types of media and different temperatures. The first involved sterile water and a temperature of 28º Celsius. The second included tryptic-soy broth (TSB) and 42º Celsius. The last environmental test included sterile water and 42º Celsius.

The first environmental test performed showed that even though sterile water contains no nutrients, growing the bacteria at 28º Celsius is their optimal temperature for growth. There was no stress on the bacterium to induce them into a VBNC state. This particular environmental test had no affect on the cultivability of *S. maltophilia*.

The second environmental test used TSB as the growing media with a temperature of 42º Celsius. TSB contains a high amount of nutrients. 42º Celsius is considered a heat shock for this bacterium because this bacterium contains vegetative cells where the lethal temperature is 45º Celsius. The high amount of nutrients in the TSB gave the bacterium the ability to thrive at 42º Celsius after a 24-hour period of incubation.

The third environmental test performed on *S. maltophilia* used two stress factors, unlike the previous two tests that consisted of only one stress factor. For this experiment, *S. maltophilia* was grown in sterile water at a temperature of 42º Celsius. These are considered two forms of stress because the sterile water contains no nutrients for the bacteria to thrive in and the temperature was set at a heat shock level of 42º Celsius. This experiment was a main focus due to the two stress factors. Growth doubled from the initial time point to the five-hour time point during this test (Graph 2).

Even with two forms of stress on the bacterium, there was no affect on the cultivability. Therefore, the conditions that make *S. maltophilia* viable but non-cultivable were not found.

Burkholderia cepacia (currently *Burkholderia cenocepacia*) was another main focus during the summer. This opportunistic pathogen was found in preflight drinking water after a biocide treatment. *Burkholderia cepacia* survived this biocide (iodine) treatment of 8 ppm iodine as determined through CFU counts. *B. cepacia* was determined to have survived the preflight biocide treatment. CFU counts and spectrophotometer analysis were performed to determine the VBNC conditions that allow *B. cepacia* to survive the biocide treatment. During experimentation, 8 ppm iodine was added to different media. These media included sterile water and M-9 media with and without yeast extract. The results from these tests showed that cultivability was not affected with the addition of 8 ppm iodine. This bacterium thrived more than bacteria in the three different medias without iodine.

Tests were also performed using sterile water and TSB with and without iodine. However, in these tests, the iodine concentrations were increased by 8 ppm each time. Also, 16 ppm, 24 ppm, and 32 ppm were used in this set of experiments. *B. cepacia* also thrived under these conditions and cultivability was not affected.

Discussion:

Further analysis should be performed to determine if prolonged incubation of the bacteria in sterile water at 42º Celsius might lead to a VBNC state. Further analysis should also be conducted on *B. cepacia* to determine why they survive preflight biocide treatments.

References:

1. Venkateswaran, Kasthuri J. and Myron La Duc. Quantification of Opportunistic Pathogens from International Space Station Drinking Water. Unpublished.
2. Venkateswaran, Kasthuri, Myron T. La Duc, and Duane Pierson. Characterization and Monitoring of Microbial Species in International Space Station Drinking Water. Unpublished.

Acknowledgments:

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Jonathan Susee
University of Maine

Participating at the Marshall Space Flight Center

Title: “Plasma Preionization Using Pulsed Power”

NASA Mentor Richard Eskridge

Abstract

Current operation of the Plasmoid Thruster Experiment shows inconsistent plasmoid formation. Incomplete pre-ionization of the gas seems the most likely cause of the plasmoid formation failure. Use of a separate capacitor functioning as a transmission line to provide a high frequency oscillation with a short rise-time may produce a more reliable pre-ionization. A prototype blumlein transmission line constructed of copper and Teflon sheet with a pressurized spark gap switch produced a 600 gauss peak field with an 18kA peak current with an 8Mhz oscillation when charged to a 15.5 kV potential.

Introduction

The Plasmoid Thruster Experiment, henceforth referred to as the PTX, uses pulsed power to produce compressed plasma with an integral magnetic field. This magnetic field constrains the plasma shape, prevents contact with the chamber walls, and accelerates the plasma. The magnetic field gradient provides a driving force, in place of an electric potential, eliminating the need for electrodes which erode when in contact with high energy, high temperature plasmas. Observations of the plasma behavior and properties provide a foundation for the design of plasma engines.

In the PTX, a mixture of hydrogen and helium gas is used to back fill an evacuated chamber. A capacitor bank brought to a potential between 33kV and 37kV then discharges through an aluminum theta pinch coil. The depletion wave traveling along the capacitor reflects at the interface of the capacitor and the coil due to differences in impedance and this reflection continues back to the capacitor and the coil throughout the discharge providing an oscillating current through the coil. The oscillating current produces a rapidly changing magnetic field inside the coil and this results in the production of an electric field within the coil as well. The plasma pre-ionizes with the appearance of the electric field and then fully ionizes and compresses as the magnetic field reverses direction. The magnetic field then accelerates the plasmoid into an exhaust chamber.

High-speed cameras record images of the plasma immediately after leaving the theta pinch coil, as well as through view ports installed in the exhaust chamber. These images show the plasma structure and allow rough estimates of the velocity and acceleration. A velocimeter also measures velocity and acceleration by focusing light from the propagating plasma front on fiber optic wires that run through an optic-to-electric signal converter and then into an oscilloscope. Velocity and acceleration measurements are calculated using the time between successive signal peaks and the known distance between the fiber optic wires. Laser interferometry will be used to measure plasma densities and velocities in future tests.

Problem

Plasmoid formation remains somewhat erratic. Some discharges through the coil produce a plasmoid while others do not given the same conditions. This erratic behavior holds true over a variety of pressures, potentials and mixtures. A formation failure means that the plasma did not undergo compression from the magnetic field. However, using B-dot probes we detected the presence of a magnetic field and observed the electric discharge from the capacitor on monitors in the screen room. The problem cannot lie with either the coil or the capacitor as each trigger resulted in a complete discharge of the capacitor through the coil and the successive production of electric and magnetic fields within the coil. With the magnetic field present an ionized gas would compress resulting in a plasmoid. The lack of response to the magnetic field most likely results from an insufficiently ionized gas.

Solution

A typical plasma device utilizes three separate capacitor banks to perform the three functions of pre-ionization, bias-field generation, and compression. For simplicity, the PTX uses a single capacitor bank to perform all three functions, pre-ionizing the plasma with the electric field produced during the discharge by the created magnetic field. Pre-ionization of the plasma by another means prior to the discharge through the theta pinch coil by the original capacitor may increase the probability of successful plasmoid formation.

Pre-ionization requires a rapidly changing magnetic field to produce a large current using free electrons within the gas itself. This current will create more free electrons through an avalanche effect as the energized electrons in the current strike other atoms and transfer energy. An electric potential placed across the coil with a fast rise time creates a rapidly changing field suitable for pre-ionization.

A transmission line offers the simplest source of pulsed power with a fast rise time. The simplest transmission line consists of two conductors capable of transmitting an electric signal subject to an applied voltage. Transmission lines differ from electric circuits in that the wavelength of the applied voltage is not very long compared to the length of the circuit. The comparatively small wavelength results in the presence of a finite travel time for the electric signal, leaving the ends at different potentials while the signal traverses the circuit.

A higher output voltage produces a larger field and current within the gas. A simple transmission line only outputs half of the input voltage. A blumlein transmission line outputs double the voltage of a simple transmission line, or as much as the input voltage, without much added complexity. In concept a blumlein acts as two simple transmission lines charged in parallel and discharged in series.

Blumlein structure most often involves either three coaxial cylinders or three parallel plates. Parallel plates offered the simplest approach while also remaining within the spatial limits of the PTX frame. After deciding to use the three-plate approach, the blumlein must then be designed for low inductance operation to facilitate a fast rise time for the field and current.

The field and current must also be large, requiring a high voltage. Factoring in a safety factor of two, the breakdown voltage for air is approximately 10,000 volts/in. With the transmission line charged to 20,000 volts the plates and plate edges must be separated by an air gap of over two inches. Such a large gap would increase the inductance of the circuit and slow the rise time.

The blumlein design incorporates adhesively backed sheets of conductive copper and Teflon dielectric. The Teflon undergoes dielectric breakdown at 15,000 volts. Two sheets of Teflon provide insulation for up to 30,000 volts with a sub-millimeter separation between the copper plates. The Teflon sheets oversize the copper sheets by an inch on every side so that if the adhesive seal breaks near any edge, a spark must travel an inch under the Teflon and then arc back for another inch to reach the nearest plate edge, providing the minimum 2 inches of separation needed for operating at 20,000 volts.

The blumlien functions by connecting the top and bottom plate across a resistive load, in this case the aluminum theta pinch coil, and then charging the middle plate. This puts the top and bottom plate at equal potential, charged oppositely of the middle plate. The top and middle plate are then connected by an open spark gap that functions as a switch. The larger the spark gap the more inductance is introduced into the circuit, so a small spark gap will be best. Of course, a smaller separation breaks down at a lower voltage, so limiting inductance will also limit the maximum voltage. However, the breakdown voltage of air increases with pressure, so a pressurized spark gap will allow for a smaller spark gap to break at a higher voltage.

Normally, this switch operates only if the capacitor reaches sufficient voltage to break the gap and arc between the top and middle plate. However, timing of the discharge is critical to ensure pre-ionization of the gas just before the main capacitor bank discharges to compress and accelerate the plasma, so the switch must be triggered. The gap can be seeded to cause a break across the switch at a specific time. To accomplish this, a spark plug will be fired above the gap releasing free electrons and ultra-violet radiation that will excite surface electrons on the plates.

The spark plug screws into a metal cylinder against a lead seal that is then sealed inside a plastic chamber with Teflon seals and clamped over the spark gap. The spark gap is then attached to a tank of compressed air and pressurized. A pulser box attached to the spark plug provides a high voltage pulse causing the plug to arc to the plate and flood the spark gap with electrons and ultra-violet radiation. This pulser box provides the high voltage pulse after receiving an optical trigger. The response to optical stimulation from a fiber optic wire allows the pulser box to be electrically isolated and prevent high voltage surges from traveling back through the trigger device to computers and detection equipment.

Discussion

After triggering the spark gap to switch the blumlein, a discharge wave propagates along the length of the top capacitor toward the aluminum theta pinch coil. As the signal takes a finite time to travel, the discharge wave reaches the top end of the coil, lowering it's potential to 0kV while the bottom side of the coil lies at a 20kV potential. This creates an electric field without the use of electrodes.

Upon reaching the coil, the discharge wave encounters a drastic change in impedance and some of the wave reflects back along the capacitor. This reflected wave reflects once more at the open end of the capacitor and travels back to the coil where the now somewhat less intense wave again reflects at the coil interface. An observable oscillation continues throughout the capacitor discharge. This oscillation causes the field to grow in intensity, then shrink and reverse polarization and grow in the opposite direction. The plasma receives a magnetic orientation in the field's first direction and then compresses under magnetic pressure when the magnetic field reverses direction.

With the applied voltage wavelength smaller than the circuit length, the electric signal takes an observable transit time. With a non-instantaneous transit time circuit calculations become much more complex and difficult to model. However, breaking the transmission line into smaller circuits with a length smaller than the voltage wavelength allows modeling of the transmission line through an approximate electric circuit. This circuit consists of capacitors connected in series modeling each plate with inductors connecting each section of the capacitor series to the parallel capacitor series, to model the included inductance between the three plate sections.

Using approximations for the capacitance and inductance of the imaginary plate sections to create a Spice model, we calculated basic values to determine sufficiency of the transmission line. Operating at 20kV, the transmission line model provided a peak current of 8kA with an oscillation of 11mHz. The current and frequency of oscillation calculations proved adequate to warrant construction of a prototype.

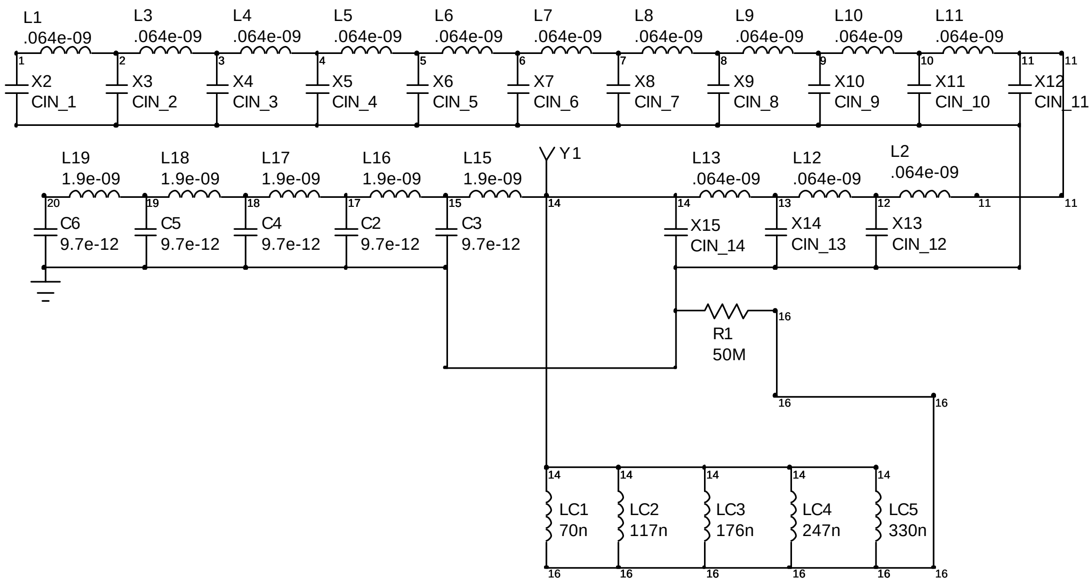

Figure 1. Spice model approxiamtion of the transmission line with L-C circuits

After discharging the blumein through the coil we recorded a waveform using a B-dot probe connected to an oscilloscope. The B-dot probe measures the time rate of change of the magnetic field within the coil as the blumlein discharges. Using Igor to plot and integrate the waveform we obtained information for one successful discharge. The blumlein produced a 600 gauss peak field with an 18kA peak current with an 8Mhz oscillation when charged to a 15.5 kV potential. Unfortunately, these results hold little value as data exists for only one successful run. We need more runs to compare results and develop an idea of the repeatability and consistency of the pre-ionization pulse.

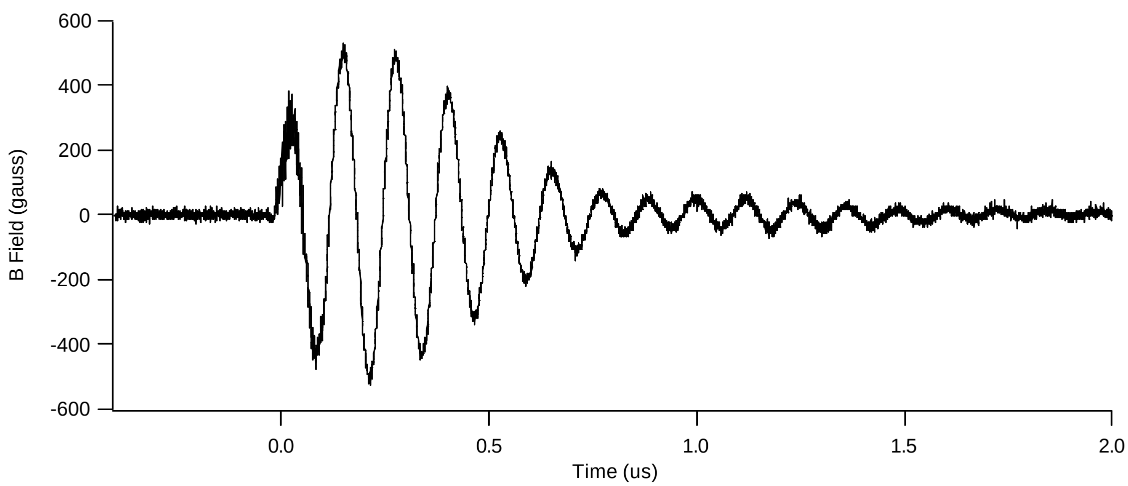

Figure 2. Waveform seen by B-dot probe inside the theta pinch coil as the blumlein discharged

The pulser box that triggers the spark gap brought other problems. After a few successfully triggered discharges of the blumlein, an scr in the pulser box inevitably fails. At this time we do not know if the scr fails because of a current or a voltage spike, a back

EMF from the blumlein discharge, or a build up of space charge within the box. The repeated failure of the pulser box presents an obstacle to reliable discharge of the blumlein. This accounts for the lack of discharge cases to analyze.

Work now focuses on the pulser box. A rogowski belt has been wound around low noise coaxial cable and potted in epoxy for rigidity. The rogowski belt measures the magnetic flux through the loops of wire to give dI/dt, the change in current over time. Capturing the waveform on an oscilloscope and then integrating the waveform with Igor resulted in a plot of the current over time. Calibrating this against the current measured by a Pearson probe over the same pulse and time allows the smaller rogowski coil to be used to measure the current in wires within the pulser box. Measurements of voltage with a northstar probe along with the current measurements from the rogowski belt will allow specification of the cause of the src failure at which point we can begin seeking a solution.

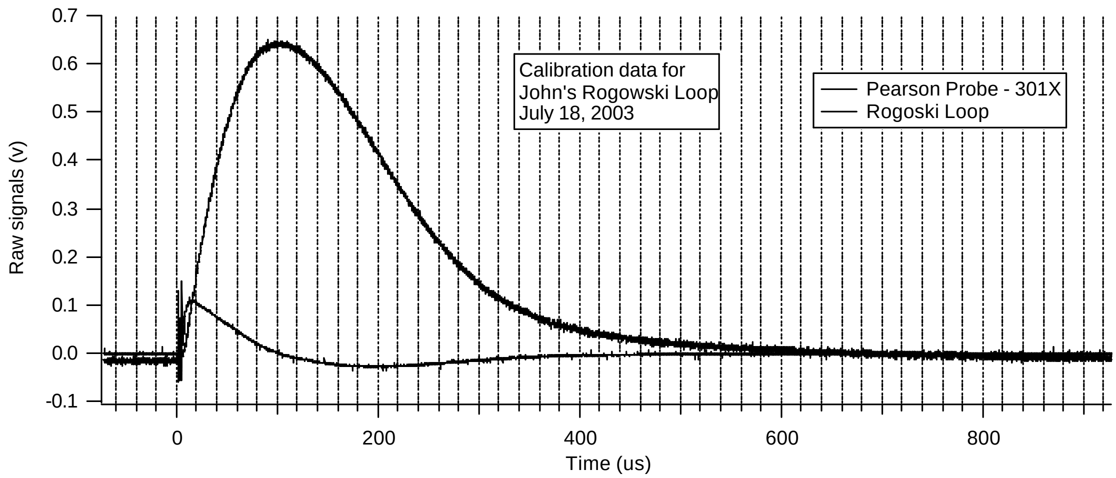

Figure 3. Initial Rogowski loop and Pearson probe plots

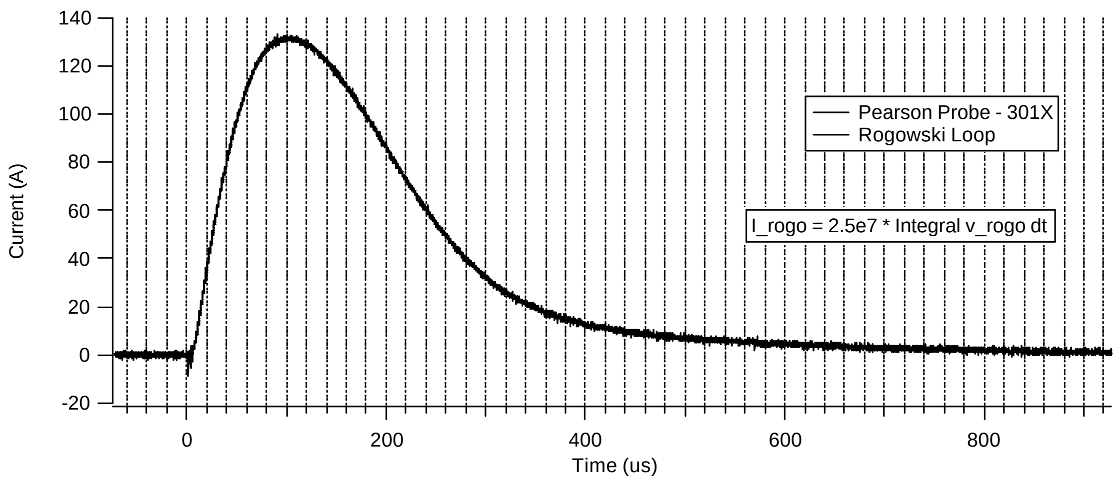

Figure 4. Rogoski loop calibrated by integrating and scaling to match the Pearson plot

Conclusion

Predictions and initial results show the blumlein transmission line to produce field and current oscillations that occur much faster than the main capacitor bank of the PTX produces. The increased frequency should cause a very intense current to develop within the gas due to the relation of current and the time rate of change of the magnetic field. However, we have no basis for judging the consistency or longevity of the blumlein

It would be of interest to build several prototype blumleins and switches, varying the gap length, pressure on the spark gap, the maximum potential, the number of Teflon sheets, and the shape of the transmission line at the coil interface to observe variations in transmission line inductance and signal rise time. Diagnostics on the current triggering system need to lead to the construction of a reliable pulser box and a predictable spark gap to make any pre-ionizer useful. If repeated testing proves the prototype reliable, I recommend the production of a new blumlein for use on the PTX for pre-ionization.

Acknowledgements

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References

Pai, S.T. and Qi Zhang. *Introduction to High Power Pulse Technology*. New Jersey: World Scientific, 1995

Koelfgen, Syri J. and Clark W. Hawk. "A Plasmoid Thruster for Space Propulsion." *39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Huntsville, Alabama, 20-23 June 2003.* AIAA-2001-3671