Project Number: JMW-NIAC

# Forecast of Space Technological Breakthroughs
## *The Influence of Expertise*

An Interactive Qualifying Project Report:

Submitted to the Faculty

Of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By


Dustin Gillis

Paul Stawasz

Tsung Tao Wu


Date: 14 March 2006

Professor John M. Wilkes, Advisor

# Abstract

This project is a Delphi study of the likelihood that "breakthroughs" in space technology will transform that field by the year 2050. It is based on assessments provided by a panel of researchers recruited from the ranks of researchers funded by NASA's Institute for Advanced Concepts. In conjunction with 2 prior panel studies of less expert panelists, it became a study of the impact of expertise and cognitive style rating of technological promise.

# Acknowledgments

The project group would like to thank the following for their support during the progress of this project.

Tim Climis, Amanda Learned, Damon Bussey, Brian Partridge, Tim Padden, and Vadim Svirchuk, members of the *Forecast of Space Technological Breakthroughs* group that this study was a continuation of.

David Saunders, Milat Sayra Berirmen, Sebastian Ziolek, Kemal Cakkol, and Chris Elko, members of the previous IQP group that did a historical projection forecast, titled *The Future of Space Exploration: A Second Moon Race?*.

Dr. Cassanova, Director of NIAC, for taking interest in this study and providing us with the support needed to assemble a panel of NIAC researchers.

All of the experts affiliated with NIAC or recommended by NIAC that took the time to fill out the questionnaire and provide us with their opinions and insights.

Ellery Harrington, who provided us with access to his web based analysis tool and help input our initial data.

Ryan Wallace and Joseph Holmes of the Science Fiction Technology group that provided information on some breakthroughs.

Jeff Patrone and Jeffrey Wilfong of the Forecast of Space Technological Breakthroughs group, that finished the Alumni panel study started by Climis et al.

And Professor John Wilkes for acting as an advisor on all of these projects.

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# 1. Introduction

In the world of scientific progress, technological advancements often build upon previous advancements in a gradual march forward. This incremental advance in technology is typical of technological development most of the time, but at times this process is greatly accelerated. Throughout the history of technology there have been dramatic breakthroughs, such as the Wright Brothers' development of the airplane about 50 years early, which have allowed technology to jump far ahead of the typical incremental progress. This project is a technology assessment focused on forecasting the future of space technology. In order to forecast advancements in space technology over the next 50 years one would have to take the possibility of breakthroughs into account. Through conducting a Delphi-type study with a panel of carefully chosen experts in the field of space technology we intend to assess several possible breakthrough technologies and conduct a comparative study with previous technology assessment projects.

### 1.1 A History of Breakthroughs

This project is part of a series of IQP studies at WPI focusing on a technology assessment of space technology. The original forecasting group, *The Future of Space Exploration: A Second Moon Race? By Saunders et al.,* focused on the incremental development of technologies in order to predict what will be possible in the near future. This group discounted the influence of breakthroughs on their forecast in their methodology. Their report was reviewed by Professor Sergey Makarov of the Electrical Engineering Department at Worcester Polytechnic, who asked the question: "Why did they not consider at least the possibility of technological breakthroughs?" This inquiry led to the development of a second forecasting project to take breakthroughs into account.

The *Forecast of Space Technological Breakthroughs* group, consisting of Tim Climis, Amanda Learned, Damon Bussey Brian Partridge, Tim Padden, and Vadim Svirchuk, conducted a Delphi-type study on the importance, likelihood, and possible time frame of breakthroughs in several space technologies. The study involved a multiple wave assessment survey given to two distinct panels. The current project is a continuation of the assessment of “breakthroughs” in space technologies conducted last year. Our study uses similar methods to those of the previous “breakthrough” group, with the differences coming in the form of a new panel and significant improvements to the survey items based on the results of last year’s study. While two previous groups gathered panels of WPI Alumni, Scientific "Experts", and Current WPI Students, this project will be paneling a group of researchers from NASA's Institute for Advanced Concepts (NIAC). These researchers are actively involved in advanced and breakthrough space technologies and have specific expertise in space technology research, including some of the specific technologies that this Delphi survey project, as well as some of the other WPI Space IQP groups, are looking at.

### 1.2 A Matter of Expertise

The influence of “expertise” on the evaluation of technological promise is of particular significance to this project. People with specific expertise are turned to in order to answer the difficult questions and solve the challenging problems facing their respective fields. It is understood that expertise gives one a more informed and knowledgeable perspective on current technology, but the impact of expertise on the assessment of future breakthrough technology is less certain. The previous technology assessment projects involved panels of distinct levels of expertise. There was a gradual increase of the expertise of the panelists from the current students of WPI to the WPI alumni and on to the “expert” panel. With the addition of the NIAC panel we will have added another level of expertise above the previous level of "experts." Analysis of the Alumni and Expert panels in the past project left the team members on that project far more impressed by the similarities than the differences between these two technically trained panel groups.

The panels involved in this project, and in the previous projects, were participating in Delphi-type studies. The Delphi technique is a manner of gathering opinions from a carefully selected panel in a multi-staged study. The sequence of events in Delphi study coupled with the selection of panelists allows the opinions of a specific population, in our case NIAC researchers, to be gathered in a very controlled environment without the individuals in the panel being influenced by "groupthink" or other drawbacks of open discussion that would pressure people to conform to the prevailing conventional wisdom. By this we mean there is no pressure to conform, until we want to introduce pressures toward consensus. In the case of this project, the study involves two waves of contact. The initial wave was used to gather the opinions of the panel members as individuals on a series of breakthrough technologies. Sometimes there is then a wave in which the panelists are told where their assessments were relative to those of the other panelists and the outliers given a chance to defend their "extreme" views. We are skipping that step and our (future) second wave focuses on the combination of those most likely and significant breakthrough technologies into logical scenarios of what the future might look like. The Delphi technique and the methodology used in this project will be discussed in detail in the body of this report.

### 1.3 Focus of the Study

Through our selection of a panel with expertise in the field of space technology and our use of a Delphi-type study we intend this project to answer several important questions. The initial result of this study will be an assessment of the breakthrough technologies by the panel of researchers who are working on some of the very technologies being discussed. This will allow us to answer the question of: What breakthroughs in space technology are considered most likely in the next 50 years by those currently funded to advance the field? This assessment will result in a forecast that, according to the level of expertise of our panel, may be a more reliable vision than in the previous studies, but will certainly be interesting by way of contrast.

The data gained from this study will also be useful for a comparative analysis against the previous findings even if the experts in the field prove to be excessively optimistic, due to vested interests in seeing this field well funded, and are not more accurate assessors. No one will know who is actually going to be right for some time, so what is really under study is the relationship between technological optimism and expertise. The findings from this study can be compared against the results of the Alumni and "expert" panels in several interesting ways to throw light on this relationship. One interesting question that will be answered through comparative analysis between this study and the previous studies is: Does the level of expertise of the panelist influence his or her assessment of breakthrough technologies in an optimistic or pessimistic fashion? We actually have counter hypotheses to test as we can make a case for the relationship going either way. With three levels of expertise to compare against this study will be able to address the expertise question in some detail. .

With the additional information gathered through the second wave of the survey we will be able to further analyze how the panel assesses the selection of possible breakthrough space technologies. The data returned from the scenario wave of the study will shed light on how putting the individual breakthrough technologies into clusters such that ways of reaching Low Earth Orbit and traveling from there to other destinations and then doing things of economic value in that environment and returning people and goods to Earth all fit together and affects the panelist's assessment of the alternative futures in space that are presented. Comparing the data from the two waves will let us answer the question:  How does grouping technologies into logical scenarios affect their assessment compared to the individual technology descriptions? Some people think that there are always implicit scenarios being assessed in this kind of expert judgment call, and making them explicit is likely to have a significant impact- as well as to provoke debate about the underlying assumptions.  In any case, we will be feeding back to the panel some of the implications of their prior assessments in a new form and seeing how they like what they said when it is placed in juxtaposed context.

# 2. Project Overview

This project is intended to enhance and improve, as well as work in conjunction with, the previous projects done in this area. When planning this project we had to find a way to incorporate the design and process of the previous studies while adding significant improvements at each step. The following section gives a brief overview of each of the major components that went into this project. This will give an understanding of the process we went through with this project. Each area will be discussed in greater detail in its own section of the report.

### History of this Project

Through the process of conducting IQP projects there are often interesting questions raised and ideas formed that would make for exciting projects in their own right. This leads to projects having long and complicated histories of their origins. This project is one of the projects that were originated through a chain of previous projects. In order to understand where we were going with our project it was necessary to get a good understanding of the two projects that directly led to ours, as well as some of the other related projects.

### Literature Review

Many of the concepts discussed in relation to this project and within this report require a good deal of research in order to get a real understanding. Much time was spent in the project gaining a firm understanding of the technologies, concepts, and organizations involved in this study. For the purpose of understanding this report and the concepts and terms within it a brief overview would suffice. To this end we have included a literature review that addresses the previous breakthrough project, the NASA Institute Advanced Concepts, the Delphi Method and the MBTI. Each of these topics will be touched upon throughout the report, but the most detailed explanation of each one will be found here in the Literature Review.

### Current state of world space policy technology development by the major Space Agencies

Along with a firm understanding of the concepts and organizations it was necessary to research which organizations are currently pushing space technology forward and what are they focusing on. For this project we researched the major contributors to the development and advancement of space technologies to see which ones were won't likely to be active in the coming space race, or at least were intended to reaching the moon. The previous projects had looked into the current state of world technology in order to come up with reasonable assumptions of where the next fifty years could bring us. An overview of the current state of world technologies has been included to give this point of reference.

## Methodology

In order to stay connected to the previous "breakthough" study we had to model our planned methodology on what had been done before, while still making significant improvements. We looked at what the "breakthough" group had planned to accomplish, and what they did accomplish, to plan our methodology around what was possible in our timeframe. Learning from the past reports helped us planned our goals and can be seen in the methodology section of this report.

## Selection of panelists

The major defining factor of this series of "Breakthrough" assessment projects has been the panel selected to make judgments about the promise of various competing technologies.. While each project has been making changes and improvements the panel selected is the major difference, as seen in the common reference to previous studies as the "Alumni panel," the "Expert panel," and now the "NIAC panel." The decision to seek our selection of panelists was not a difficult decision to come to, as the idea for a panel comprised of the researchers at NIAC was the foundation of this project. The question we had to answer was whether it was really possible to get this elite group of experts to participate. Secondarily, we did not want to embarrass ourselves by perpetuating the use of items the prior experts had found silly, so there was no question that the survey would have to be edited. We could not use the same one, but still had to preserve comparability where possible. The particulars of the revision process and methods used to assess questionable items are covered in detail further on.

### Survey

The use and construction of the survey used is a major area of the project that has significant carry over and legacy from the previous projects. The basic format of the survey was developed by the original breakthrough team and the changes and improvements that were made for this project had to be carefully chosen so that we could maintain enough overlap to be producing comparable results. The changes we made to the contents and delivery method of the survey were significant to this study and are covered in detail in their own section.

### Project Goals and Continuation

The goal of this stage of the overall “NIAC Breakthrough Project” was to set the framework, plan, gather the data and do the analysis. This was all accomplished. Panelists were identified and recruited, the survey was updated and sent out, and the data have come in, though it was not collected as rapidly as we would have liked nor did we get as much as we hoped. A complete analysis of the round one data is as far as we got. A follow-up of the panelists, analysis of the round one data, comparisons against the previous studies, took twice as long as we expected. The next stage involving the distribution of the composite scenarios will have to be completed by future WPI students.

# 3. History of this Project

As was mentioned in the introduction, this project is part of a series of IQPs at WPI focusing on technological assessment. The foundation of the series of projects was the original forecasting group, *The Future of Space Exploration: A Second Moon Race***,** (Saunders et al, 2004) which focused on the incremental development of technologies in order to predict what will be possible in the near future. This original project was of particular significance because it raised the questions that lead to projects assessing the potential of "Breakthroughs" in space technology. This project produced a picture of the future based on historical projection, i.e. what it would look like if there were no breakthroughs.

### "Breakthrough" Assessments

The *Forecast of Space Technological Breakthroughs* group was the first of the "Breakthrough" series of projects. Their project, which originally had been planned out as separate forecasts for manned and unmanned technologies and later join together, pioneered the use of a Delphi-type study on the importance, likelihood, and possible time frame of breakthroughs in several space technologies. The study involved a multiple wave survey controlling the discussion and questions for the individual panelists.

### Variety of Panels

The Forecast of Space Technological Breakthroughs group conducted their study using two distinct panels. One panel consisted of WPI alumni. This panel was chosen specifically for their individual cognitive types, as defined by the Myers-Briggs Type Indicator which is discussed in detail in the literature review. The rumors for selections of this panel were to gather people who were technically trained and of known cognitive types, but not quite at expert levels. They would provide a cognitively diverse and balanced panel. They were selected from the graduating classes of 2001 and 2002 at WPI, and thus the pool from which they were drawn was known to be different from the general population. Compared to the general population the WPI student body has more introverts, intuitives, thinking types, and perceptives. These tendencies were counterbalanced in the selection process so that equal numbers of the four types, (NP, SJ, NJ, and SP) were selected and invited to participate. However, the resulting panel was not equally well represented by the four types, twice as many NJ's were willing to participate in the study that the other types. Thorough contacting more of the remaining types the panel was balanced by type. T0he second panel involved in the initial "Breakthrough" project consisted of "Experts." These panelists consisted of a collection of space scientists, engineers and physicists found in the academic world, involved with NASA, or in the commercial sector. About 15% of those contacted participated; the university and NASA bared respondents, making up the bulk of the 18 panelists.

Follow up studies have also been conducted, including this one. Each study is based upon selecting a panel consisting of a specific segment of the population. One follow up study paneled about 38 current WPI students (also of known MBTI type), while another recruited a panel of 16 science teachers from middle and high school, and 24 "space enthusiasts" from the general public. This study's panel of NIAC experts was only made possible through the initial forecast project and the breakthrough project that followed it. We had hoped to be able to gather MBTI data on our NIAC Expert sample, but whether or not this is possible, the results will be interesting. At this point in time the panelists have agreed to participate in filling out the form, but have not yet done so.

# 4. Literature Review

### Forecast of Space Technological Breakthroughs Report

As a continuation of a prior project, the basis for the current project has depended quite a bit on the previous report. The report, "The Forecast of Space Technological Breakthroughs" collected a set of possible technological breakthroughs for the future and developed a Delphi study based upon those breakthroughs in order to determine whether they would be likely to occur, when they would occur and how important they would be to the future of mankind in space if they did occur. The technologies were separated into categories depending on what area of technology they fit into. These categories included Propulsion in Space, Launch Vehicles, Materials, Shielding and Life Support. These technologies included nuclear drive, magbeam, slingatron, solar sail, laser propulsion, reusable single stage to orbit, ram accelerator, nanotube polymer space elevator, memory plastics, carbon nanotubes, "solid state" aircraft, electromagnetic shielding, cold plasma, aerogel, fusion reactor, roving lunar base, "bionic leaf", "gravity implant" and LEO air collector and processing plant.

The project also collected two sets of panelists based on education, profession and cognitive type where applicable. Furthermore, the data from the questionnaires was compared and the technologies were arranged according to the comparative ranking of the alumni and experts.

This report was thorough in terms of content and preparation, however actual analysis of the received data was somewhat lacking. Although the MBTI had been brought up numerous times in the planning stages of the report, little is seen in the results section of the report by Climis et al. because only the Alumni sample had MBTI results and they stressed the Expert panel in drawing their conclusions. In fact, the MBTI analysis was deferred because they wanted at least 30 cases of Alumni data to look at, given that there were 4 MBTI combinations of interest in their theory out of the 16 possible combinations that the MBTI can provide. They had only about 15 respondents at that point and 6 of them were of one type. That left them with only 3 of each of the other 3 types. A follow up team of Wilford et al. gathered another 15 alumni cases over the summer and completed the Alumni analysis based on the MBTI differences later.

As for the original Climis et al. report, it provided a reasonably good expert analysis based on about 18 Expert panel results, though they generally provided averages rather than the whole distribution of responses and did not distinquish the academics from the NASA respondents. Wilford 's partner Patrone took care of that oversight, separating the academics from the smaller number of NASA and Other respondents. We were particularly interested in seeing whether the NASA panelists were more or less optimistic than the academics. Though it varied by the technology on the classic space hardware technologies, the NASA and Other panelists seemed to be more optimistic on the whole than the academics. .

Aside from the specific results, the ideas brought up in the report held great significance to our current report. This is seen in many of the technologies included, the structure of the questionnaire, the structure of the report and the contact procedures for carrying out our own research. Aside from changes such as the exclusion of the slingatron and solid state aircraft and the addition of ion drive and mass driver, the instrument used and the reports share a similar basis and structure.  We hope to improve upon the previous report through these changes as well as a more complete, multi-stage study.  This report served as one of the most important sources of information for planning our current project.

### Potential Breakthroughs

In looking for breakthroughs to replace those which were determined to be unnecessary in our survey, we decided to re-examine breakthroughs not used in the previous report.  This lead to the examination of the *Science Vs Science Fiction* IQP report completed by Joseph Holmes and Ryan Wallace in January of 2005.  Included in this project was the ion drive.  The Ion drive is a propulsion technology that works by charging a particle to either negative or positive (making it an ion) and then making a network some distance away from the ion the opposite charge, therefore making the particle accelerate. When the particle leaves the craft, it causes the craft to accelerate. The problem with such a drive is that it requires a significant amount of energy to ionize the particles and to create the opposite net that creates the acceleration. With current technology it takes 15 months to move a probe to the Moon, while a conventional rocket can make the transit in three days. The major benefit of an ion drive is that the drive requires only very small amounts of material to create movement. 72kg of xenon gas on a satellite allowed for 16,000 hours of run time of the ion drive.

As it turns out, the prior group cut that item because they considered it "proven" and suitable for incremental development.  That means they did not consider its development a breakthrough.  We found that we could not agree, after examining the current state of the art.

This technology was determined to be a suitable replacement for one of our removed breakthroughs, since the emergence of a practical Ion drive with thrust comparable to current rocket boosters that can reach the Moon in 3 days, would be a very big deal indeed, even it such a drive is of no use in lifting off of the Earth to reach LEO.

Through the examination of studies carried out by the Space Studies Institute, a second replacement technology was found. This technology is referred to as a mass driver. According to the Space Studies Institute Mass Driver prototypes have existed since 1975. It is a form of spacecraft or cargo propulsion utilizing a linear motor to accelerate payloads up to high speeds. Payloads would be placed in a "bucket" which is fitted with an electromagnetic coil. This "bucket" is then accelerated by a series of electromagnetic drive coils spaced a certain distance apart forming a tunnel. The "bucket" is reusable and remains with the mass driver while the payload is sent on its way. Due to the thick atmosphere and high gravity of Earth, this is not currently suitable for Earth based launches, however ship and moon based configurations would not be as subject to these forces making them ideal for moving loads around in space or return trips to Earth. The mass driver requires no fuel for propulsion and instead can be operated solely on electricity from a local nuclear power plant or solar array. The literature of the Space Studies Institute thus provided a suitable replacement for the Slingatron, one of the breakthroughs we removed from the survey. The Slingatron was suggested as a means of reaching LEO by its author. The version offered in the prior survey was positioned in space on a space station. That would not have worked, but a Mass Driver could be used from such an installation in space without de-orbiting the space platform.

## NASA Institute for Advanced Concepts

The NASA Institute for Advanced Concepts (NIAC) is an organization formed for the explicit purpose of being an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its mission. (NIAC 2006) The main focus of NIAC is on developing advanced and revolutionary concepts which will possibly impact NASA in a 10 to 40 year timeframe. NIAC funds numerous studies including the Space Elevator, solid state aircraft and solar sails, some of which are included in our survey. Based in Atlanta, Georgia and directed by Robert Cassanova, NIAC is run by the Universities Space Research Association (USRA) under contract to NASA. NIAC is constantly looking for and adding new proposals to its research pool, nurturing a diverse cross-section of innovative researchers in established and emerging technical disciplines, thus providing highly visible technical leadership and support to researchers creating paradigm-changing concepts. NIAC then orchestrates the open analyses of these concepts by NASA and the technical community at large.

Because the researchers at NIAC are at the head of their field and constantly deal with the subjects which we are researching, they were the ideal panelists for giving us assessments of when our breakthrough technologies may occur and how much of an impact they would make. They actually are thinking about this kind of thing full time and are funded to help develop one of these leading ideas. Robert Cassanova, of NIAC, has given us his full support, but he can't force anyone to take part, nor will he explicitly endorse the study. He is willing to let us use his name and has provided lists of funded Principal Investigators which were our sole source of recruiting panelists for our study.

## The Delphi Method

In order to retain common bases for our study, similar survey methods were used as in the previous panel study. The central method used was the Delphi Method due to its appropriate nature, literally designed to produce forecasts of future technologies. The article "The Delphi Method" (Theodore Gordon) discusses the importance and structure of the Delphi Method as well as examples of the method put into use.

Gordon explains that "experts are more likely than non-experts to be correct about questions in their field", however when experts are brought together in person, often the expert with the "loudest voice" will sway the others to agree with their viewpoint regardless of how sound their argument is. Gordon states that "As with normal thinkers, the give-and-take of such face-to-face confrontations often gets in the way of a true debate [on the merits]". The Delphi Method takes the individuals away from these confrontations and allows them to think independently of these issues without the interference of strong or loud personalities, what would be called the Extraversion - Introversion dimension in MBTI terms. The prior group has demonstrated that other personality characteristics measured by the MBTI (such as Intuition - Sensing or Judgment - Perception) will still play a role in shaping technical assessments.

Gordon explains that the Delphi Method involves a series of anonymous questionnaires that are sent to a selected group of panelists. Each of the questionnaires has a range of possible answers. Once completed, another questionnaire is sent to the panelists whose responses are at the extremes, asking them whether they desire to change their response with the knowledge that they are outliers, and if not, whether they would like to defend their choice. Subsequent questionnaires would be sent out until a consensus is reached.

Gordon also speaks of the main strengths and weaknesses of the Delphi Method. He states that studies such as this often take a large amount of time and require meticulous selection of panelists and proper wording of statements in order to convey the same idea to all of the panelists. On the other hand, the study's strength lies in its ability to attain answers to appropriate questions.

Methods such as the Delphi Method are best suited to determining forecasts on the occurrence of future developments and the means for achieving or avoiding a future state. Thus, the strengths of the Delphi Method closely correspond to the type of information which we hope to obtain.

### The MBTI

The Myers-Briggs Type Indicator (MBTI) is an instrument used to identify people's preferences among sets of mental processes (Lawrence 1995). Each item answered is counted on one of four scales, each scale having two extremes. This creates 16 combinations, which represent 16 cognitive types. The four scales are extraversion versus introversion, identified as E versus I; sensing perception versus intuitive perception, S versus N; thinking judgment versus feeling judgment, T versus F; and judgment versus perception, J versus P. Similarly to the previous project, we plan to focus on S versus N and J versus P dimensions since they hold the most relevance to the type of research being dealt with and to keep continuity between the two projects' results for the facilitation of comparison.

The first scale is S versus N. According to Lawrence, someone who uses sensing perceives with five senses and attends to practical factual details and the present moment, while someone who uses intuition, perceives with memory and associations, sees patterns, meanings and possibilities and projects possibilities for the future. It would seem especially likely that an individual who deals with research regarding future possibilities would be an intuitive type, but if so, this means there is a cognitive bias in the most expert of panels that one can assemble from pioneering scientists and technologists. The impact of a lack of diversity in how people process information and come to conclusions would be worth examining, and the imposed diversity in the WPI Alumnus sample should allow us to make some estimates of how that is affecting our expert sample's assessments.

The second scale is J versus P. According to Lawrence, someone who takes a judging attitude, uses thinking or feeling judgment outwardly, decides and plans, is goal oriented and wants closure, even when data are incomplete. Someone who takes a perceiving attitude, uses sensing or intuitive perception outwardly, takes in information, is open-minded and resists closure to obtain more data. In short, P's are better able to tolerate ambiguity than J's, since they do not have as strong a preference for closure, but are less likely to commit to a plan.

It is not clear whether NIAC will have attracted more J or P researchers, or whether teams of mixed type on this dimension will be the most common. These are the people who settled on a specific fundable proposal for NAIC and won support, so they are not unable or unwilling to commit to a plan. On the other hand, MBTI lore tends to consider the NP combination as the one typical of the most creative and visionary people., so it is possible that the NIAC panel will be skewed to one of the 4 types. It is a relatively rare type in the general population as well; about 22% of the population, about 48% of the population has the SJ preference, cognitively opposite the NP's. A mere 14% are the NJ combination, the type which we think will dominate the NIAC sample, as they live in the future but strive for solutions, i.e. logical closure.

Assuming that we have cognitive diversity in the panel, as there was in the WPI alumni study, it is expected that comparisons between a person's MBTI type and the manner in which they react to the breakthroughs in the questionnaire will reveal commonalities amongst the different types, at this level of expertise. Indeed, the overall goal of the study is to see if cognitive style or expertise is the more powerful factor in shaping Delphi assessments.

# 5. Current state of world space technology

Along with a firm understanding of the concepts and organizations it was necessary to research which organizations are currently pushing space technology forward and what are they focusing on. For this project we researched the major contributors to the development and advancement of space technologies to ensure that their direction and focus had not significantly changed. The previous projects had looked into the current state of world technology in order to come up with reasonable assumptions of where the next fifty years could bring us. An overview of the current state of world technologies, as it is viewed through the eyes of the organizations fostered to create it, has been included to give this point of reference.

**NASA (National Aeronautics and Space Administration)**

NASA was established by the National Aeronautics and Space Act of 1958 to plan, direct, and conduct all U.S. aeronautical and space activities, except those that are primarily military. NASA's signature achievement was the Apollo program of the 1960s, which succeeded in landing astronauts on the moon and returning them safely to earth. NASA arranges for participation by the scientific community in planning scientific measurements and observations to be made through use of aeronautical and space vehicles, and provides for dissemination of information concerning results. Under the guidance of the President (and especially the Vice President), NASA participates in the development of programs of international cooperation in space activities. (NASA)

With the introduction of the space shuttle, NASA became more frequently involved in military activities despite its original intent as a civilian agency. Because of the long delay caused by the 1986 *Challenger* disaster, however, the military started expanding its own fleet of booster rockets. In 1996, NASA announced a $7-billion, 6-year contract under which the agency would gradually turn over routine operation of the shuttle program to private industry. The *Columbia* disaster in early 2003 brought a halt to the space shuttle program, until key proposals made by the independent Columbia Accident Investigation Board could be implemented. Whether industry would want to build and operate the shuttle was also thrown into question. The 2003 disaster also prompted calls for NASA to reexamine whether, in a time of budgetary constraint, its commitment to the space shuttle and the International Space Station represented the most cost-effective approach to space research. The Bush administration has announced plans to retire the shuttle fleet by 2010 and replace it with a new space transportation system, the

Crew Exploration Vehicle (CEV). So, there is current turmoil at NASA and it seems more interested in recovering part of the capabilities now lost, than pioneering. However, it will have to stretch its wings technologically again to carry out its new mission.

In a speech in January 2004, U.S. President George W. Bush laid out a revised set of long-term goals for the agency, including the establishment of a human colony on the moon by 2020 that could serve as a launching point for a piloted expedition to Mars. The current NASA plans involve reaching the moon again in 2018 using the CEV to lift astronauts into orbit and using heavy lift rockets to get the required lunar lander and other vehicles into orbit. (Malik) NIAC seems oddly removed from all this emphasis on going back to the Moon, where the Apollo program left off more than 30 years ago.

**ESA (European Space Agency)**

The ESA is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe. The purpose of ESA is to draw up the European space program and carry it through. The Agency's science projects are designed to find out more about the Earth, its immediate space environment, the solar system and the Universe. (ESA) However, it is famed most as a commercially successful space venture.

ESA is an international collaboration among the countries of Europe. ESA has 17 Member States (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, Canada, Hungary and the Czech Republic). It is a non-military agency by charter, and budget restrictions are very strict. Nothing is allowed to go more than 10% over budget without either canceling the project or re-appropriating the necessary money.

The ESA created an organization called Arianespace to control the commercial launches of payloads into space. Arianespace carries out the clear majority of the current commercial launches. It controls this market due to inexpensive, reliable, expendable rockets, and an excellent launch location in French Guiana. 15% of the ESA budget is mandatory and meant primarily for space science, and the other 85% is voluntary; the contracts going proportionally to contributing nations. The space scientists at ESA use the mandatory budget as they see fit. This has been in unmanned research as of late, but is sometimes invested in the development of new launch vehicles, as well as to develop satellite-based technologies and services, and to promote European industries.

The Marco Polo mission, launched in 2002, was the first of a series of flights to carry commercial, biomedical instruments into space. This experiment marked the beginning of a positive future relationship between European industry and the International Space Station and with the expertise, knowledge and support of ESA. The space craft recently sent to map the Moon using an ion drive (15 months in transit) was an ESA project, so ESA is clearly interested in advancing the technology, especially for unmanned applications.

**RKA (Russian Space Agency)**

The Russian Space Agency (RKA) was formed after the breakup of the former Soviet Union and the dissolution of the Soviet space program, and still uses the technology and launch sites that belonged to the former Soviet space program. The RKA has had a lot of long-term manned experience including significant experience with unmanned space flight. Most notable in the manned realm has been the development of space stations, culminating with the space station MIR. RKA also has done several interesting unmanned probe projects including missions to Mars and Venus. Now the agency is working closely with Chinese on the next generation space craft after the Soyuz ( which the Chinese modified into their current Shenzhou capsule) and their expertise and experience will play a key role on Chinese's Project 921 moon base mission plans for the next 20 years.

Currently, the RKA has centralized control of Russia's civilian space program, including all manned and unmanned nonmilitary space flights, and is training cosmonauts, as well as astronauts, for the International Space Station (ISS) and launching ISS modules. They also work closely with Chinese space agency on helping the Chinese Taikonauts with their training and developing the next generation solar sailing spacecraft.

The prime contractor used by the RKA is the Energiya Rocket and Space Complex, which owns and operates the Mission Control Center in Kaliningrad and operated the Mir space station when it was still flying. Energiya developed the powerful Energiya booster which is a heavy launch vehicle and was used to propel the ill-fated and rarely flown space shuttle Buran into space. However, due to current military influence and budget restrictions, the RKA has not been focusing on space science. It is now seeking commercial contracts outside of the country for funding. Today the Russian space agency has started to cut into ESA's share of the launch market.

**JAXA (Japan Aerospace Exploration Agency)**

At the dawn of space aeronautics in the 20th century, three organizations were established in Japan: The Institute of Space and Astronautical Science (ISAS), which was devoted to space and planetary research; the National Aerospace Laboratory of Japan (NAL), which focused on research and development of next-generation aviation; and the National Space Development Agency of Japan (NASDA), which was responsible for development of large-size launch vehicles, as represented by H-IIA launch vehicle, satellites, and the International Space Station. On October 1, 2003, ISAS, NAL and NASDA were merged. These agencies still follow similar guidelines, but now merged in order to facilitate the sharing of research and development, facilities and equipment, researchers and engineers, and cooperative education. Japan now has an agency that operates all the processes within one organization, with the aspirations to be ranked with the American and European space agencies in terms of capabilities. (JAXA)

On December 9 JAXA succeeded in an optical communication experiment between the "Kirari", which was launched by Ukraine's Dnepr launch vehicle on Aug. 24, and the Advanced Relay and Technology Mission (ARTEMIS) of the European Space Agency. The experiment was for two satellites that are moving several kilometers per second in respective orbits to communicate over a distance of about 40,000 kilometers. JAXA also responsible for several other technology breakthroughs in various areas including launch vehicles, an ISS International Space Station module designed for doing materials research and other Space science researches. This agency seems to have aspirations to move into the commercial launch market but the HI rocket was similar to the American Delta and used some parts made in the USA so it could not be used to compete with the US aerospace industry- though the US had already lost that market to Arianespace.   The HII has no American made parts but NASDA has not been able to get its launch costs down on the HII booster enough to compete with ESA.  However, this area of activity is now is showing promise now with the less powerful but much cheaper HIIA. This booster should also be able to lift the proposed HOPE shuttle craft which is designed for 2 or 3 passengers.  The NASDA part of JAXA seems to be interested in building habitat facilities on the Moon and considers the module built for ISS good experience.  The technology compatibilities between American and Japanese equipment make it relatively easy for them to collaborate.

### CNSA (China National Space Administration)

CNSA was established as a government institution to regulate and develop space technology, with the approval by the Eighth National People's Congress of China (NPC). The Ninth NPC assigned CNSA as an internal structure of the Commission of Science, Technology and Industry for National Defense (COSTIND). The main responsibility of the agency is signing governmental agreements in the space area on behalf of organizations, inter-governmental scientific and technical exchanges; and also being in charge of the enforcement of national space policies and managing the national space science, technology and industry. (CNSA)

Since the agency’s birth in 1956, China's space program has gone through many stages of development including arduous pioneering, overall development in all related fields, reform and revitalization, and international cooperation. Now it has reached a considerable scale and level. A comprehensive system of research, design, production and testing has been formed. Space centers capable of launching satellites of various types and manned spacecraft as well as a TT&C (Telemetry Tracking and Command) network consisting of ground stations across the country and tracking and telemetry ships are in place. A number of satellite application systems have been established and have yielded remarkable social and economic benefits. A space science research system of a fairly high level has been set up and many innovative achievements have been made.

Up to now, China has signed governmental space cooperation agreements with Brazil, Chile, France, Germany, India, Italy, Pakistan, Russia, Ukraine, the United Kingdom, and the United States. Significant achievements have been made in the bilateral, multilateral and technology exchanges and cooperation. The Great Wall Corporation offers commercial launch services on the Long March Rocket to the international market at rates considerably below those of ESA.

China recently became the third nation to launch a manned orbital mission, after Russia and the USA. There have been two such missions thus far, but they seem to be part of a plan (Project 921) to go to the Moon and set up a base there. So far, the announced plan is that by 2017, China will begin an effort to send astronauts to the moon, with a landing some time after that. The moon landing would cap a lunar program begun in 2004 with the launch of a probe. In October 2005, China launched its second manned space flight, a successful five-day mission.

Ouyang Ziyuan, the Chinese lunar program's chief scientist, said that unmanned lunar probes will be ramped up in three stages until about 2017, when the manned program will begin. A program to send unmanned space vehicles to and from the moon will begin in 2012 and last for five years, until the manned program gets underway. China places great emphasis on its space program, seeing it as a way gain prestige and to validate its claims to be one of the world's leading scientific nations.

Given this situation, it is evident that the Saunders et al. team was not making wild claims when it predicted a new space race to the Moon between the USA and China with both nations landing teams in 2018 to start building Moon bases. Neither nation had made their public announcements at the time this prediction was made. Saunders et al. predicted a 30% probability that the US and Japan would team up against China and Russia, but that China would increasingly disassociate from Russia as it gained experience. The implications of a breakthrough in the midst of a Space Race would be far reaching, as they would be followed up on relatively quickly.

# 6. Methodology

As discussed in the Literature Review this study was conducted as a Delphi-type study. Multiple waves will be used to get an educated response from our specific panel of people, without letting the individuals of the panel directly influence each other as they would in a more traditional discussion. In the case of this study our panel was gathered to consist of people doing research with NIAC. The details of choosing and gathering the specific people for our panel can be found in the "Selection of Panelists" section of this report. Our study involves two waves of contact with panelists as well as one final contact to gather the MBTI data for the panelists.

The planned first wave of the study involved sending out a survey to "Breakthrough Technologies" survey (located in Appendix A2) to each of our initial panelists. The details of the developments and contents of this survey can be found in the "Survey Development and Improvement" section of this report. Each of our initial panelists was asked to complete and return the survey, as well as provide us with the contact information for additional panelists relevant to our "NIAC" panel. This process was intended to give us some initial data while increasing the size of the panel. As a continuation of the first wave we contacted the people who were recommended by the initial panelists and asked them to complete the survey too.

The planned second wave of the survey involves sending a selection of scenarios derived from the breakthrough technologies to the panelists. These scenarios will be assessed in a similar fashion to the original technologies on the survey. These scenarios will be created as logical combinations of the possible breakthrough technologies.

The final planned contact to gather information from the panelists would be for the cognitive data. The panelists will be asked to log into the Consulting Psychologists Press (Palo Alto) website and use a password to access the MBTI SkillsOne test site. They would then fill out the 100 item MBTI online and we could download the results and send a copy to them electronically as well, on a feedback form. This information will be useful for the analysis of our panel results and to compare our panel distribution to the other panels in the study for which we have MBTI data.

# 7. Selection of Panelists

The foundation of any study or questionnaire is the people who are successfully recruited to take it, from the pool of those invited to do so. Through careful selection of panelists, a person can attain more accurate results in a specialized subject with fewer people than if they were to select panelists at random and in large numbers.

### Prior Panels

In the previous study, of which ours is a continuation, Alumni panelists were selected and arranged based on cognitive type data collected when the classes of 2001 and 2002 where freshmen in 1997 and 1998. These students were administered the Myers-Briggs Type Indicator

(MBTI) at that time. The experts were selected based on credentials or experience in the fields of space science or technology. They were recruited for the other panel without regard to psychological (MBTI) type. The panelists in that study ranged from alumni of WPI to Professors in Space Science and other more specialized individuals at Boeing, NASA and on the Planetary Society. The initial panelist pool consisted of about 60 alumni with about 33 mechanical engineers, 14 electrical engineers, seven physics majors, seven biotechnology majors, and seven chemical engineers but they were "literate" not expert regarding space technology. About 1 in 4 responded. This low response rate was a blessing in disguise as it ensured that the alumni panelists had some background or interest in the relevant technology sector.

The Expert panelists were invited based on credentials and job descriptions ranging from professors from schools with space science units such as MIT and Cornell to NASA administrations and researchers. The goal was 30 experts and about 70 were contacted. In the end, the previous study yielded only 16 alumni responses and the majority of the 17 expert/professor responses consisted of professors and advanced graduate students. It was not balanced between academia and industry through NASA staff who research space concepts and applications for a living were a notable subgroup. Due to the limited response rate from experts in the previous study, the question of how people more specifically knowledgeable about space technologies (rather than astrophysics more generally) would respond, still needed answering.

### A Panel of True Experts

In our study, we desired panelists who specialized in the advanced technologies included in the study rather than existing aerospace technology on space science as a more theoretical endeavor. By doing so, we felt that we could get more credible and grounded results due to our panelists actually being involved in the research of the field in question. At a later time, we planned to attain cognitive data using the MBTI in order to determine what type of person would most likely be attracted to their field and reach the funded expert specialist level. These data could then be compared to data from the previous study to see how certain cognitive types felt about the possible breakthroughs.

During the previous study, interest in involvement in a follow up study was shown by the director of the NASA Institute for Advanced Concepts (NIAC), Robert Cassanova. NIAC is an organization which seeks concepts and funds research for future space technologies. Because the concepts researched by NIAC were similar or identical to those which were covered in our survey, we felt that the researchers in NIAC would be best suited to give us very realistic assessments of the technologies which we were covering. Professor Wilkes had recruited Cassanova to be a panelist in the prior study, but then decided to negotiate with him to create a second panel. They exchanged lists of names based on the publicly available list of funded NIAC researchers on the NIAC website and implicitly developed some “relevant” research criteria, to identify those working in the areas closest to the range of technologies under study. The selection was not random. With this list, we immediately set up a means of contact with Dr. Cassanova to discuss our ideas and gain the approval of NIAC. Having attained approval, we requested and received the names of the heads of eighteen of NIAC’s funded research studies that were clearly dealing with related aerospace issues. Within each of these research teams, we hoped to recruit two to four researchers, giving us a pool of about fifty panelists, though at this point we only had PI names-contact people for each research team. Among these research groups were projects involving solid state aircraft, space elevator and solar sails, all of which were topics included in our survey. Once a list of potential panelists had been obtained, we contacted the individuals and informed them of the goals and future waves of our study. In contacting these potential panelists, we requested recommendations for anyone of their associates whom they saw fit to invite to take part in the "expert" survey as well.

At the time of the writing of this report, we have received fifteen responses from the heads of the research groups and four names for recommendations of researchers to take the survey. Reminders and follow-up emails were sent to all potential panelists who have not yet responded. It was unexpectedly difficult to get the PI's to "delegate" the task of responding to two associates or subordinates. Their own response rate in deciding to personally participate was quite good, 50%.

# 8. Survey Development and Improvement

The previous survey had given us significant insight into the types of breakthroughs that would be either somewhat plausible or completely unreasonable and impossible. Many of the breakthroughs used in the previous survey were seen in a positive light by the panelists. Examples of these were the carbon nanotubes, solar sail, nuclear drive and the reusable single stage to orbit launch vehicle. Some of the possible breakthroughs however were heavily criticized highly by the panelists. Examples of these were the slingatron, solid state aircraft, gravity implant and low earth orbit compressed air collector. Criticism based on skepticism of the promise of a possible approach is not a problem, but comments about relevance or logical impossibility would have to be addressed.

## Analyzing the Breakthroughs

Our task was to analyze these results and determine which possible breakthroughs we would keep and which we would discard or replace. We could not simply discard the concepts which we disliked or the previous panelists ranked unlikely. Instead, we needed to analyze why unpopular concepts ranked poorly, and see whether the concepts could be removed without creating a hole in the range of space capabilities covered by the survey. If they did leave a hole, what could we replace them with to fill in that hole? Removing or replacing items was carefully considered before any changes were made because we wanted to keep the survey items comparable to the previous Delphi panel studies. We also wanted to keep the survey of similar length and the technological mix comparable. In some cases we might want to improve upon an item in order to clarify the intended idea without having to replace it entirely.

The breakthroughs which stood out the most in terms of being out of place were the slingatron and solid state aircraft. From analyzing the comments from the previous survey, the common criticism was that the slingatron would essentially de-orbit itself if it were used in a low earth orbit configuration. Due to conservation of energy, if an object were to be propelled forward using the slingatron, the structure of the slingatron would be thrown backwards toward Earth. Simply moving it back to Earth, as its author originally proposed was not much help. The slingatron would be subject to high stresses having to compete with the ram accelerator idea. That would leave a hole in the survey in term of in orbit freight transport system that do not require on board fuel. The item was not a way to reach LEO, but a way to travel in space, as it was previously presented. The solid state aircraft was seen as a step backward in aviation (by some respondents) due to lack of moving parts. We also saw that it did not fit particularly well into the space oriented theme of the project and was more of an atmospheric transportation device than a space vehicle or technology.

Before these two concepts could be removed, replacements would be needed so that no unnecessary gaps were created in the survey. The concepts chosen for replacement were the ion drive and the mass driver. The ion drive was one of the potential breakthroughs discarded from the previous survey due to belief of Climis et al. that it was an existing technology that fiction (the TIE, or twin ion engine, "Fighter" of Star Wars fame) had undercut in terms of credibility. However we determined that there was a significant amount of scientific fact behind the Sci-fi concept and existing models were very crude. The ion drive was seen as a suitable replacement for the solid state aircraft since its purpose was clearly movement through space and not for lifting off of the Earth. The mass driver was a new concept for the study located by our own research of developing technologies. Based on increasingly utilized electromagnetic propulsion seen in monorails and particle accelerators, the mass driver was seen as a suitable replacement for the slingatron for sending payloads through space without an onboard drive.

Other criticized breakthroughs, such as the roving lunar base and the low earth orbit compressed air collection and processing plant, were more difficult to justify replacing just because they were unpopular. These concepts by themselves were not particularly important and depended on breakthroughs in other technologies in order to become useful. Once these other breakthroughs were achieved however, these concepts would be crucial for the future of space exploration and settlement. They were part of a package to achieve Earth-Lunar trade of Helium-3 for H2O and CO2, which would probably be stressed in the Wave 2 Scenario assessment part of the study. We wanted to maintain continuity between these related concepts, so they were not altered or removed from the survey. With these two alterations, the breakthroughs that were to be included in the final survey were all accounted for, resulting in a 90% overlap with the prior project's instrument.

### Analysis of the Survey Format

How a survey is assembled and handled can be just as important as the content and the panelist selection. If a survey is too complex or doesn't convey the message very well, the panelists could become discouraged or miss the point of the survey entirely. Similarly, the method of information exchange can be crucial to the success or failure of the survey.

The previous project group chose a relatively simple format for their survey. Doing so ensured that the survey would create no confusion and ensured that they would receive the information in a manner which they had intended. The survey consisted of the name of each possible breakthrough followed by a numerical ranking of 1 – 6 for both the significance and likelihood of the breakthroughs. The translations for the significance rankings were as follows: 1 = trivial, 2 = marginal, 3 = small, 4 = moderate, 5 = major and 6 = revolutionary. For the likelihood rankings, 1 = impossible, 2 = improbable, 3 = unlikely, 4 = likely, 5 = probable and 6 = expected. There were then spaces where the panelists could fill out the time period in which they felt the breakthrough would occur using rankings of early (by 2020), middle (2020-2035), late (2035-2050) and never, as well as leave any comments which they felt were necessary. A limited amount of space was provided for the comments so that panelists would be encouraged to be concise with their comments. An example of one item of the survey is seen below.

Significance Likelihood

Name of Breakthrough 1 2 3 4 5 6 1 2 3 4 5 6
Time period: ________________
Comments: ________________________________________________________
__________________________________________________________________

For the current survey, we felt that the previous survey format was quite appropriate for our purposes, only necessitating small adjustments to aid clarity and ease of use for the panelists. Also, we wanted to keep the format as close as possible to the original so that the results could easily be compared to those of the original survey. The revised survey was designed to be distributed online (Appendix 2) and included drop down menus with descriptions for the significance, likelihood and expected time period numbers for each breakthrough.

Delivery method for the survey was somewhat of a disputed issue. In the previous survey, the survey documents were initially mailed to the panelists as hard paper copies. The rationale behind this was that the panelists would be more likely to fill out the survey if they actually had a hard copy in front of them. Later however, the group made an online version in hopes that the information could be quickly distributed and recovered. The online version proved to be unreliable and some data was lost. The hard copies did not encourage participation as much as was hoped.

In selecting the method for information exchange for the current survey, we were able to review the methods used by the previous group and determine which method would prove most beneficial to us. When discussing which method we would use, the benefits and handicaps of the three main methods, e-mail, internet and hard copy, were weighed.

With hard copies, time was a significant issue. Hard copies typically required a large amount of time and resources to be sent out and retrieved. Hard copies, however, were typically more dependable with much lower rates of data loss than the two other methods. Due to time constraints in our project, hard copies were rejected as a preferred means of information exchange.

As with the previous survey, an online format was considered so that panelists would be able to fill out the survey immediately and easily have the data transmitted back to us. The previous online version of the survey was plagued by instances of data loss, making this method risky. In our case, all information was crucial to the project and the risk of data loss was too much to justify the benefit of rapid information exchange.

The third option of e-mail delivery of a survey designed to be printed out or filled out and returned online had its own benefits and risks. With e-mail, information can be lost through e-mail server errors and messages can be confused with junk mail and be discarded. Still, E-mail is much faster and less expensive than mailing hard copies. Also, due to the technological expertise and orientation of our panelist base, it was felt that e-mail based information exchange would be welcome, familiar and significantly more efficient than a hard copy based alternative. We wanted to have our contacts “forward” the instrument to colleagues, so we should make that easy to do. By weighing these benefits and risks coupled with the experiences of the prior survey group, it was determined that e-mail attachments would be the most dependable and rapid method of information exchange with our panel. All contact including survey distribution and follow-up notices were to be carried out through the use of e-mail, though another group was preparing a new improved and reliable online version as part of a website. That would become available as a backup plan, if needed, in December or January.

# 9. Planned Analysis methods

With plans for the analysis phase of this project being completed in the following term by another student it is important for us to outline our intended analysis methods. Using what we have learned from the previous report and improve it.

With our methods of gathering the data for this study largely unchanged from the previous study we found it helpful to examine the benefits and drawbacks to how the data was analyzed before deciding whether we would be changing that.  There is a time saving if we do tables comparable to theirs, though re-analysis of their data is also possible. The following is a collection of data prepared for analysis from last year's report:

**Table 1 –** Analysis Table from Previous Study

| | Likelihood | | |
|---|---|---|---|
| | Experts | Alumni | Overall |
| SSTO | 4.4 | 4.6 | 4.5 |
| Ram Accelerator | 2.7 | 3.3 | 3.0 |
| Laser Propulsion | 2.5 | 3.2 | 2.9 |
| NPSE | 2.4 | 2.3 | 2.4 |
| The Gravity Implant | 2.4 | 3.5 | 3.0 |
| Fusion Reactors | 3.3 | 3.3 | 3.3 |
| LEO CAC | 2.8 | 3.2 | 3.0 |
| Roving Lunar Base | 3.3 | 3.0 | 3.2 |
| The Bionic Leaf | 3.1 | 3.0 | 3.1 |
| Carbon Nanotubes | 4.6 | 4.7 | 4.7 |
| Memory Plastics | 4.1 | 4.6 | 4.4 |
| Solid State Aircraft | 3.4 | 3.4 | 3.4 |
| Solar Sail | 4.8 | 4.5 | 4.7 |
| Nuclear Drive | 4.3 | 3.8 | 4.1 |
| Magbeam | 2.5 | 3.2 | 2.9 |
| Slingatron | 1.9 | 3.1 | 2.5 |
| Aerogel | 4.9 | 5.0 | 5.0 |
| EM Shielding | 3.6 | 3.7 | 3.7 |
| Cold Plasma | 2.6 | 2.7 | 2.7 |

As seen in Table 1**,** the results from the previous “Breakthrough” study were based on the average of the score of each item from the selected panel. The average, or statistical mean, was not the best way to analysis this type of data. We believe that the analysis of data from last year had a significant oversight in that it does not take the range, (especially the outliers) from each group into account. Given the limited size of the pool of data these studies have been collecting, the outliers could actually make a large difference in the final average. It is not the same finding if an average of 3.5 is achieved by having everyone agree on that figure or if no one selected that figure but were distributed equally and broadly over the range centering on that figure. In one case there is consensus and in the other there is not.

We plan to use a more complicated statistical and mathematical method to analyze the data we collected from the panelists we selected this year, as well as re-do some of the analysis they did last year so that we can do proper comparisons. We have been fortunate enough to be conducting this study at a time when another student was developing an online reporting and analysis tool to be used view the results of all of the “Breakthrough” projects. Ellery Harrington developed a tool that can not only provide in depth and easy to use analysis of the data, but even collect it. Unfortunately, at the time we were making the decision on how to proceed with our data collection we were not comfortable with the reliability of the online tool and opted not to risk any data loss. We have been able to take advantage of the analysis features on the initial data and will likely make good use of the data collection feature in the future, as the follow-up process is carried out.

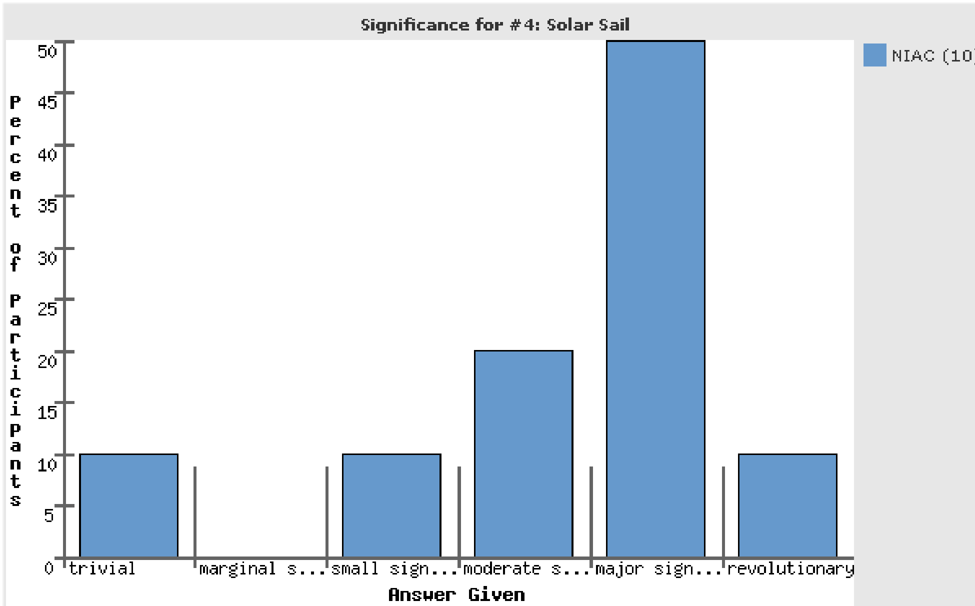



**Figure 1 –** Example Graph Displaying the range of 10 NIAC Respondents to the question about the potential significance of a Solar Sail Breakthrough.

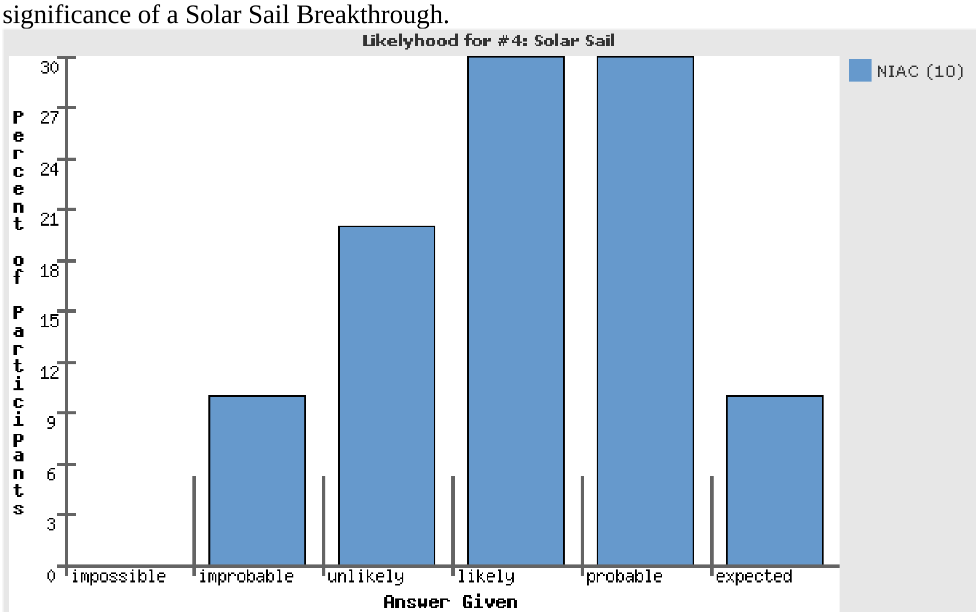



**Figure 2 -** Example Graph Comparing Likelihood result for the same item and the same 10 respondents.

The figures above are examples of the visualizations of the data we will use in our analysis. Figure 1 is an example of the graph used to display the results of one technology. In Figure 1 the graph shows the significance of the Solar Sail based on the results of the first ten NIAC surveys. In this case, the average is 4.3. Figure 2 shows the likelihood data in the same fashion. The average in this case is 4.1, seemingly similar to the significance rating but actually the skeptical group is larger but less extreme in the case of likelihood.  There is less real consensus.  These graphs will make it easy to visualize the data and spot outliers, so that one knows, as in this case, that the similar averages are deceptive.

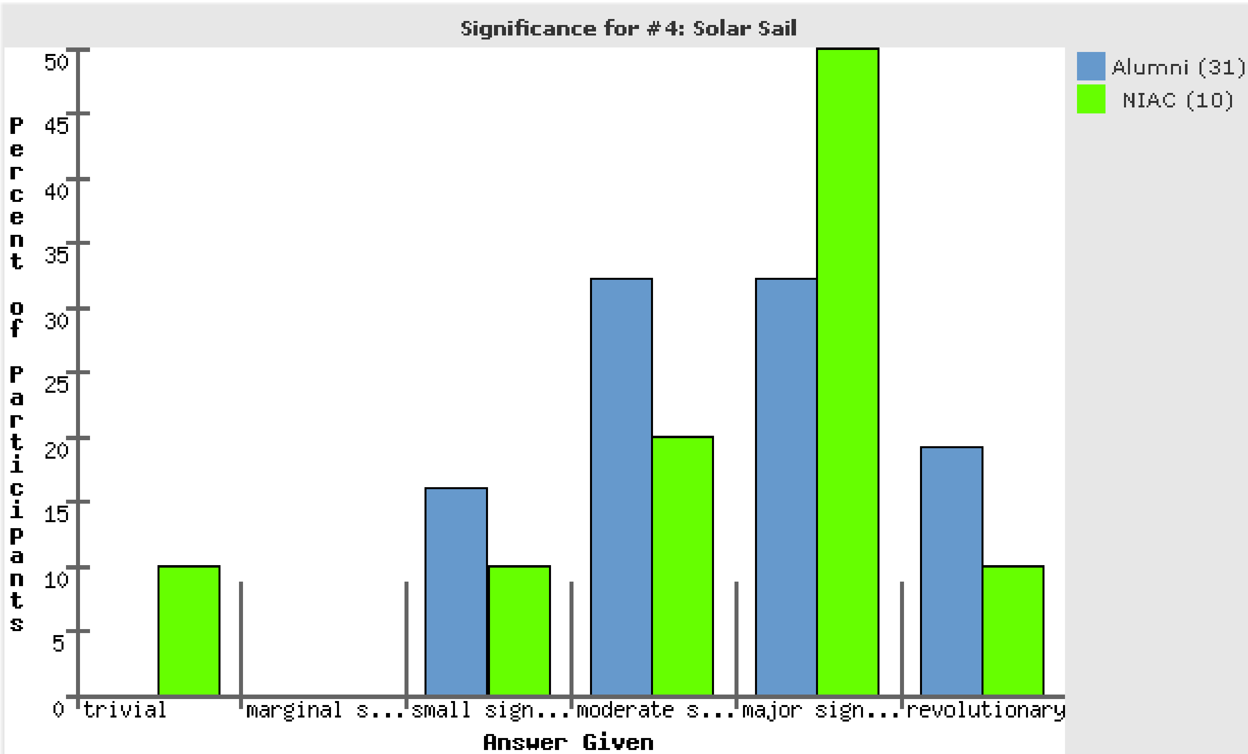



**Figure 3 -** Example Graph Showing Multiple Panels responses

This tool will also be very helpful in comparing our results to the other panels. You can choose exactly which panels you want to view on any one graph, making comparisons efficient and visually appealing. In Figure 3 you can see the initial NIAC results compared to the Alumni panel. The numbers associated with each panel in the upper right corner denotes the number of panelists in each panel.  In this case, if the trend holds up as the NIAC panel grows, the Solar Sail is a potentially much bigger deal to the experts in the field than to the more generally technically literate Alumni panel.

| Alumni | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 6.5% | 0.0% | 12.9% |
| Middle | 0.0% | 0.0% | 6.5% | 22.6% |
| Late | 0.0% | 0.0% | 6.5% | 3.2% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| Total | 0.0% | 16.1% | 12.9% | 71.0% |

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 10.0% | 0.0% | 20.0% |
| Middle | 0.0% | 0.0% | 0.0% | 30.0% |
| Late | 10.0% | 0.0% | 20.0% | 10.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| Total | 10.0% | 10.0% | 20.0% | 60.0% |

**Figure 4 -** Example Likelihood vs. Significance Graph

For more advanced analysis we will not only be able to see how each panel rated significance and likelihood individually, but also we will be able to see how the panels were divided based on *both* significance and likelihood. Figure 4 shows both the NIAC and Alumni breakdown of the panels based on how they rated significance and likelihood. In this array one can see that the Alumni really are not more skeptical than the NIAC experts about the Solar Sail. It is a front runner for a big deal breakthrough (soon) for both groups. This comparative analysis tool will be a powerful asset when the analysis phase of the study is conducted in late January and February of 2006.

# 10. Results & Analysis

The table below shows the most basic data on each of the technologies from the NIAC panel's survey. The numbers shown for significance, likelihood, and Time period are the averages of the data gather in this study. Significance and Likelihood range form low(1) to high(6), while Time period ranges from early(1) to never(4). While this basic information on the average score is not sufficient to base a full analysis on, it does give some insight into how the panel rated the different technologies. In order to do our full analysis we intended to answer several key questions.

| Technology | Significance | Likelihood | Time Peroid |
|---|---|---|---|
| Nuclear Drive | 4 | 3.9 | 1.8 |
| Ion Drive | 4.1 | 4.1 | 1.8 |
| Magbeam | 4.9 | 3.9 | 2.8 |
| Mass Driver | 3.6 | 4 | 2.1 |
| Solar Sail | 4.3 | 4.1 | 2.1 |
| Laser Propulsion | 4.5 | 3.4 | 2.3 |
| Reusable Single Stage to Orbit | 4.3 | 4.2 | 2 |
| Ram Accelerator | 3.9 | 3.2 | 1.8 |
| Space Elevator | 5.3 | 3.4 | 2.7 |
| Memory Plastics | 4.3 | 4.9 | 1.5 |
| Carbon Nanotubes | 5.3 | 5 | 1.8 |
| Electromagnetic Sheilding | 3.9 | 3.8 | 2.3 |
| Cold Plasma | 4 | 3.2 | 3 |
| Aerogel | 4.8 | 4.8 | 1.5 |
| Fusion Reactor | 5.2 | 3.7 | 2.7 |
| Roving Lunar Base | 3.9 | 3.3 | 3 |
| Bionic Leaf | 4.6 | 3.4 | 2.7 |
| Gravity Implant | 4.1 | 3.5 | 2.5 |
| LEO Compressed Air Collector | 4.4 | 3.4 | 2.8 |

**Question 1:** What breakthroughs in space technology are most considered likely by the experts working in that field in the next 50 years? Is there consensus among NIAC Researchers? Using the Web based data collection and analysis tool developed by Ellery Harrington we were able to

quickly and effectively compare the results for each item on the survey across all three measures: Significance, likelihood, and time period. For each division of the survey we selected the technology that was rated by the NIAC panel with the highest consensus in likeliness and probability, as well as the technology with the least.

**Propulsion Consensus?**

In the area of propulsion, the Mag Beam technology was the most agreed upon within the NIAC panel. In the figure below the Mag beam is rated both significant and likely by 70% of the respondents in the NIAC panel. The remaining 30% found it Significant, but unlikely. In this case the time period was also highly agreed upon. 80% of respondents rated the Mag beam technology as occurring in the late time frame, with 20% opting for middle. None of the researchers polled found the technology to be insignificant.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 0.0% | 0.0% | 0.0% |
| Middle | 0.0% | 0.0% | 10.0% | 10.0% |
| Late | 0.0% | 0.0% | 20.0% | 60.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 0.0% | 0.0% | 30.0% | 70.0% |

0-1 Mag Beam - High Consensus

In the propulsion section the solar sail had the least amount of conformity in responses. 60% of the respondents found the solar sail significant and likely, 20% found it significant but unlikely, and the remaining 20% was spread evenly over insignificant likely and unlikely. The time period was also divided, with 40% late and 30% in both middle and early. Even though the solar sail was the least agreed upon out of the propulsion technologies 80% found it significant and 60% found it both significant and likely.

| NIAC | | | | |
|---|---|---|---|---|
| | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
| Early | 0.0% | 10.0% | 0.0% | 20.0% |
| Middle | 0.0% | 0.0% | 0.0% | 30.0% |
| Late | 10.0% | 0.0% | 20.0% | 10.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 10.0% | 10.0% | 20.0% | 60.0% |

0-2 –Solar Sail: Small spread in rating

**Launch Vehicles Consensus?**

In the launch vehicle section the “Single Stage to Orbit” was the most agreed upon in significance and likelihood. 77.8% found it to be both significant and likely. In this case the time period was not as well agreed upon. The ratings were spread across the board with 33% in both early and middle, 22% in late and 11% in never. The panelists were optimistic that it can be done, and would be important, but can’t agree on the timing.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 11.1% | 0.0% | 22.2% |
| Middle | 0.0% | 0.0% | 0.0% | 33.3% |
| Late | 0.0% | 0.0% | 0.0% | 22.2% |
| Never | 11.1% | 0.0% | 0.0% | 0.0% |
| **Total** | 11.1% | 11.1% | 0.0% | 77.8% |

0-3 SSTO: 77.8% found it both significant and likely

The low consensus within the launch vehicle group comes from the ram accelerator. As seen in the figure below, the ratings on the ram accelerator have significant spread in all three categories. With significant and unlikely taking the highest percentage with only 40% and the early time period receiving 50%, with 20% of that in insignificant and unlikely, little can be assumed form these ratings.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 20.0% | 10.0% | 0.0% | 20.0% |
| Middle | 0.0% | 0.0% | 20.0% | 0.0% |
| Late | 0.0% | 0.0% | 20.0% | 10.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 20.0% | 10.0% | 40.0% | 30.0% |

0-4 Ram Accelerator: Significant spread in ratings

**Materials Consensus?**

The materials selection had the highest level of agreement out of the technologies on the survey. The high rating went to carbon nanotubes, which 100% of the respondents found to be significant and likely. The low rating for the materials section was also rating very similarly among the NIAC panel. 100% of respondents found memory plastics to be likely, and 80% found them to also be significant. The figures for both are reproduced below.

| | NIAC | | | |
|---|---|---|---|---|
| | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
| Early | 0.0% | 0.0% | 0.0% | 40.0% |
| Middle | 0.0% | 0.0% | 0.0% | 40.0% |
| Late | 0.0% | 0.0% | 0.0% | 20.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 0.0% | 0.0% | 0.0% | 100.0% |

0-5 –Carbon Nanotubes: 100% found it both significant and likely

| | NIAC | | | |
|---|---|---|---|---|
| | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
| Early | 0.0% | 10.0% | 0.0% | 40.0% |
| Middle | 0.0% | 10.0% | 0.0% | 40.0% |
| Late | 0.0% | 0.0% | 0.0% | 0.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 0.0% | 20.0% | 0.0% | 80.0% |

0-6 Memory Plastics: Also had high consensus

**Shielding Consensus?**

In the shielding section of the survey aerogel had the highest level of consensus in ratings. 80% of respondents found aerogel to be both significant and likely. The majority of the NIAC panel considered aerogel to be a technology that would develop early in the timeframe.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 0.0% | 0.0% | 60.0% |
| Middle | 0.0% | 10.0% | 0.0% | 20.0% |
| Late | 0.0% | 0.0% | 10.0% | 0.0% |
| Never | 0.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 0.0% | 10.0% | 10.0% | 80.0% |

0-7 –Aerogel: 80% found it both significant and likely

Cold plasma has the least amount of consensus out of the possible breakthroughs in shielding technologies. 50% went to significant and likely, with the remainder being split between insignificant / likely and significant / unlikely.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 0.0% | 0.0% | 0.0% |
| Middle | 0.0% | 0.0% | 0.0% | 10.0% |
| Late | 0.0% | 20.0% | 40.0% | 20.0% |
| Never | 0.0% | 0.0% | 10.0% | 0.0% |
| **Total** | 0.0% | 20.0% | 50.0% | 30.0% |

0-8 Cold Plasma: Moderate spread in ratings

**Life Support Consensus?**

Life support is an area of the survey that did not have very high agreement among those surveyed. While 90% of the responses found the fusion reactor to be significant, the likeliness was split 60/40 in favor of likely. With our limited number of responders this 10% difference means very little.

| NIAC | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
|---|---|---|---|---|
| Early | 0.0% | 0.0% | 0.0% | 10.0% |
| Middle | 0.0% | 0.0% | 0.0% | 30.0% |
| Late | 0.0% | 0.0% | 30.0% | 20.0% |
| Never | 10.0% | 0.0% | 0.0% | 0.0% |
| **Total** | 10.0% | 0.0% | 30.0% | 60.0% |

0-9–Fusion Reactor: 60% found it both significant and likely

The gravity implant was the least agreed upon technology out of the entire survey. As seen in the figure below, the numbers are spread over every area of the chart. With numbers like these for the gravity implant it is clear that there is still much debate over the scientific possibility of a gravity implant and the practical applications of it.

| | NIAC | | | |
|---|---|---|---|---|
| | Insignificant & Unlikely | Insignificant & Likely | Significant & Unlikely | Significant & Likely |
| Early | 0.0% | 0.0% | 9.1% | 0.0% |
| Middle | 18.2% | 9.1% | 0.0% | 27.3% |
| Late | 0.0% | 9.1% | 0.0% | 9.1% |
| Never | 0.0% | 0.0% | 18.2% | 0.0% |
| **Total** | 18.2% | 18.2% | 27.3% | 36.4% |

0-10 Gravity Implant: Significant spread in ratings

**Is there Consensus among NIAC Researchers?**

For the most part the data shows that the NIAC researchers agree on their assessment of Breakthrough Space Technologies. In the areas where there was clear agreement the results strongly favored a particular rating. Even in the cases of low consensus, there was still often a similar significance and likelihood with the majority of the ratings.

Materials had the highest level of agreement, while life support had the lowest. This is likely a result of the materials, memory plastics and carbon nanotubes, having possible applications on Earth as well as in space, while life support systems are more likely to require additional technologies before they can be applied.

**Question 2:**

**Are Experts More or Less Optimistic?**

One of the questions raised during this study was if the panel at NIAC was going to be more or less optimistic in their assessments, than previous samples. Our initial assumption about the NIAC panel was that they would be more optimistic than the previous panels about the technologies they thought likely, because it is part of their daily lives to conceder the impossible. To test if optimism was affected by level of expertise we compared the results form the WPI Alumni, the Expert panel, and the NAIC panel.

The analysis was based off of the percent of technologies rated both “Significant” and “Likely” by 50% or more of the panelists. The time period was not taken into account for this part of the analysis as we considered it an optimistic assessment if the panelist believed a technology would be possible and influential at any time.

| **Percent of Technologies rated Significant and Likely by 50% or more of the panelists** | |
|---|---|
| NIAC: | 68.4% |
| Alumni: | 47.4% |
| Experts: | 42.1% |

As can be seen in the table above, NIAC was more optimistic on a larger percentage of the total technologies than either the Experts or the Alumni. The Alumni, however was slightly more optimistic than the Experts. This calls into question the direct link between expertise and level of optimism, but through their choice of work the NIAC panel is noticeably more optimistic.

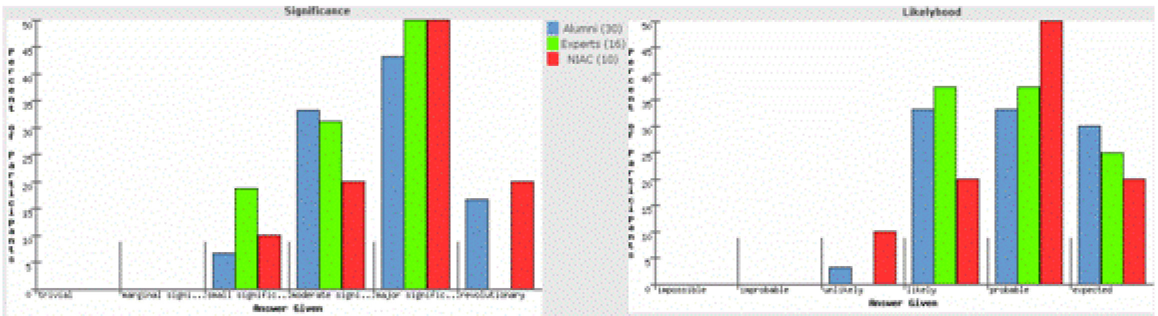
**Question 3:**

How do the NIAC Experts compare to the Expert and Alumni Panels? In the chart below we can directly compare the average likelihood assessment for each of the breakthrough technologies on the NIAC, Alumni, and Expert surveys. The ratings range from impossible (1) to expected (6). This method of analyzing the results is very similar to the process used in the previous studies and does give some useful information. However, we now have some more powerful tools and intend to do some further analysis. On the chart below we can see that the average ratings across the three panels are very similar. Aerogel is an example of a technology that got very similar results from all three panels, so we can take a deeper look at this assessment and see if it is still rated similarly by each panel. Conversely, the Space elevator is an example of the NIAC panel differing, we will also look into that case.

| | **Likelihood** | | |
|---|---|---|---|
| **Technology** | Alumni | Experts | NIAC |
| SSTO | 4.6 | 4.4 | 4.2 |
| Ram Accelerator | 3.3 | 2.7 | 3.2 |
| Laser Propulsion | 3.2 | 2.5 | 3.4 |
| Space Elevator | 2.3 | 2.4 | 3.4 |
| The Gravity Implant | 3.5 | 2.4 | 3.5 |
| Fusion Reactors | 3.3 | 3.3 | 3.7 |
| LEO CAC | 3.2 | 2.8 | 3.4 |
| Roving Lunar Base | 3 | 3.3 | 3.3 |
| The Bionic Leaf | 3 | 3.1 | 3.4 |
| Carbon Nanotubes | 4.7 | 4.6 | 5 |
| Memory Plastics | 4.6 | 4.1 | 4.9 |
| Ion Drive | - | - | 3.9 |
| Solar Sail | 4.5 | 4.8 | 4.1 |
| Nuclear Drive | 3.8 | 4.3 | 3.9 |
| Magbeam | 3.2 | 2.5 | 3.9 |
| Mass Driver | - | - | 4 |
| Aerogel | 5 | 4.9 | 4.8 |
| EM Shielding | 3.7 | 3.6 | 3.8 |
| Cold Plasma | 2.7 | 2.6 | 3.2 |
| Solid State Aircraft | 3.4 | 3.4 | - |
| Slingatron | 3.1 | 1.9 | - |

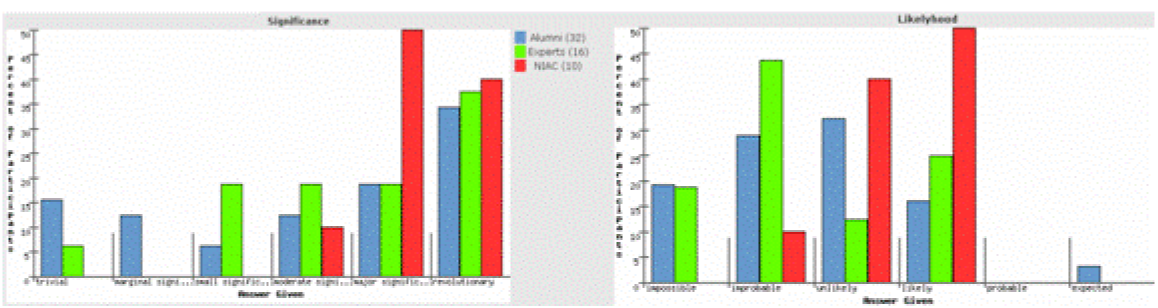
From the chart below we can see that there were very similar results on Aerogel across both significance and likelihood. Here there is little difference between the results on the three panels.

80% of NIAC found it both Significant and Likely
81.3% of the Experts found it both Significant and Likely
90% of the Alumni found it both Significant and Likely




In the case of the Space elevator the results differ. The Alumni and Expert panels have a less optimistic view of the Space Elevator than the NIAC panel does.

50% of NIAC found it both Significant and Likely
25% of the Experts found it both Significant and Likely
19.4% of the Alumni found it both Significant and Likely




How do the NIAC Experts compare to the Expert and Alumni Panels? The three panels of increasing expertise were very similar, more so than we would have originally thought given the difference in expertise. This calls into question if higher expertise gives better results, as the results were so similar. When there was a difference, NIAC was somewhat more optimistic, but over all they were similar.

# 11. Summary

The technology assessment conducted in this project focused on forecasting the future of space technology. Through conducting our Delphi-type study with a panel of carefully chosen NIAC experts, we have been able to assess several possible breakthrough technologies and conduct a comparative study with previous technology assessment projects. Through our analysis of the NIAC panel data and our comparisons with the Alumni and Expert panels, we were able to come to some interesting conclusions.

From the survey results we were able to see that the NIAC panel had a high level of agreement in their ratings of the technologies. This is as we expected. There is likely a combination of factors contributing to the similar ratings among the panel, including the level of expertise and the panels cognitive type makeup. With further information on the MBTI scores of the panels forthcoming, a clearer cause for this consensus in results will be seen.

We were also able to conclude that the NIAC panel was notably more optimistic than the alumni and expert panels when it came to the possibility of breakthrough technologies being developed and the significance of their development. This trend in the data was likely the result of the area of expertise shared by the panel. Each panelist was an expert involved in proposing and developing technologies that would be considered breakthroughs, and even some that would be thought of as purely science fiction, by the general public. With this focus the panel was likely in the mindset too see the possibilities that other panels would have over looked. This area of the analysis would also benefit from the addition of MBTI data. Analysis comparing the panelists who share cognitive types between the NIAC, Alumni, and Expert would allow us to come closer to seeing just the result of the level of expertise, without the impact of cognitive type. This would be a recommended addition to the analysis when the data becomes available.

Through a direct comparison of the NIAC, Alumni, and Expert panels we were able to see that each of the panels had very similar ratings for the technologies shared across the three surveys. When there were differences, the NIAC panel tended to have their results shifted in the direction of a more optimistic assessment. This finding runs counter to the thought that having a more “expert” panel would result in greater accuracy in the forecast, and speaks well for the Delphi process. Accentually, it follows that when using the Delphi-type process, as was done in this series of technology assessment projects, it is not necessary to go through the difficult and time consuming process of assembling a panels consisting of experts. A panel of the general population will result in similar findings more efficiently.

# 12. APPENDEX

**A1: Letters**
**Initial Contact Email:**

October 7, 2005

Dear Robert Cassanova,

This is a continuation of a study of "breakthroughs" in space technologies begun by WPI students last year. We understand from our advisor that you said that a panel of experts drawn from the ranks of NIAC project researchers was a possibility. This is an especially exciting possibility since the survey used in the previous project included several technologies that are currently being researched in studies funded by NIAC, including Space Elevator, Solid State Aircraft, and Magbeam technologies.

With our project we intend to improve upon the previous survey, possibly adding or removing items from it based off of results from last year and possible recommendations from NIAC. We have noted the changes on the attached list of possible technologies. We will develop new items for those to be added, but will probably cut an item for each one added so that the survey stays about the same length. We want to be careful about changing the items on the prior survey because the NIAC panel results will be more valuable when they can be compared to last year's survey results assessment.

We would like to arrange a meeting or conference call with you, and discuss our view of this project and how involved NIAC would like to be. We have attached a document outlining the breakthrough technologies that are possibilities for our survey as well as the survey used last year. If you could get back to us with your thoughts we would appreciate it.

Thank you for your time,

Dustin Gillis
DustinGillis@gmail.com
Paul Stawasz
pstawasz@wpi.edu
Tsung Tao Wu
TsungTao@gmail.com

## Group Lead Contact Email:

November 14, 2005

Dear NAME,

Dr. Cassanova of NIAC has reviewed our* proposal for improving a Delphi Study on space breakthroughs begun last year and recommended you as a potential panelist in the "expert" wave of the study to be carried out this year. He may have already contacted you about this study to explain why he would like to see this carried out. Whether or not you can participate, he wants to be sure that 2-3 people associated with the ____________ research group participate, and he hoped that you would recommend others to us whose judgment you value to represent you groups perspective.

The space technology Delphi study on the importance, likely hood, and possible time frame of breakthroughs in this field is a continuation of a study begun last year with a study of two panels of respondents, totaling 46 people. Though one of the panels is currently considered the "expert panel" the participants were not typically specialists in pioneering space technology. Hence, you would be a member of the "NIAC Expert" sample.
The study will be conducted in three waves, over the next four weeks:

- Wave One is the initial survey, which we have attached to this email.
- Wave Two will show the participants the distribution of responses and give the outliers a chance to defend their positions.
- Wave Three will be a survey on the likely hood of 4 or 5 scenarios using the technologies based off of the initial survey results.

While it is not required, we will also be asking NIAC panel participants to complete the MBTI measure of cognitive style online so that we will be able to compare responses to the person's cognitive type. In last year's study one of the panels had completed the MBTI and the results were so interesting that we are re-contacting the other panel to ask them to do the same.

We would be grateful for your involvement in our study, as well as your recommendation of one or two of your colleagues whom you believe would be willing to participate in this study. Please do not distribute the attached survey, as we are trying to track the response rate. If you could fill out the attached survey and return it, as well as any recommendations, to DustinGillis@gmail.com . If you decide not to partake in this yourself, we would still ask that you recommend others. Thank you for your time, we look forward to hearing from you.

Sincerely,

Dustin Gillis
DustinGillis@gmail.com
Paul Stawasz
pstawasz@wpi.edu
Tsung Tao Wu
TsungTao@gmail.com

**We are a team of engineering students completing a graduation requirement worth 3 courses each, called the IQP in WPI parlance. It is taken very seriously and advised by a sociologist with experience in technology assessment and forecasting.*

**Panelist Recommended Contact Email:**

December 1, 2005

Dear NAME,

You have been recommended by ____________ as a potential panelist in the "expert" wave of a study on Space Technology Breakthroughs. This space technology Delphi study on the importance, likely hood, and possible time frame of breakthroughs in this field is a continuation of a study begun last year with a study of two panels of respondents, totaling 46 people. Though one of the panels is currently considered the "expert panel" the participants were not typically specialists in pioneering space technology. Hence, you would be a member of the "NIAC Expert" sample.
The study will be conducted in three waves, over the next four weeks:

- Wave One is the initial survey, which we have attached to this email.
- Wave Two will show the participants the distribution of responses and give the outliers a chance to defend their positions.
- Wave Three will be a survey on the likely hood of 4 or 5 scenarios using the technologies based off of the initial survey results.

While it is not required, we will also be asking NIAC panel participants to complete the MBTI measure of cognitive style online so that we will be able to compare responses to the person's cognitive type. In last year's study one of the panels had completed the MBTI and the results were so interesting that we are re-contacting the other panel to ask them to do the same.

We would be grateful for your involvement in our study and appreciate your timely response. Please do not distribute the attached survey, as we are trying to track the response rate. If you decide to assist us in this study please fill out the attached survey and return it to DustinGillis@gmail.com . Thank you for your time, we look forward to hearing from you.

Sincerely,

Dustin Gillis
DustinGillis@gmail.com
Paul Stawasz
pstawasz@wpi.edu
Tsung Tao Wu
TsungTao@gmail.com

**We are a team of engineering students completing a graduation requirement worth 3 courses each, called the IQP in WPI parlance. It is taken very seriously and advised by a sociologist with experience in technology assessment and forecasting.*

**Reminder Email:**

December 1, 2005

Dear Steven Dubowsky,

I hope you had a good holiday and also that you had a chance to go over the survey for our study. We greatly appreciate your participation and your recommendations of interested colleagues. We ask 20 minutes of your time to fill out the attached survey and return it to DustinGillis@gmail.com Thank you. We look forward to seeing your results.

Sincerely,

Dustin Gillis
DustinGillis@gmail.com
Paul Stawasz
pstawasz@wpi.edu
Tsung Tao Wu
TsungTao@gmail.com

**A2: Survey:**

**WPI Space Technologies Survey**

# *Possible Breakthroughs*

*Dear Panelist,*

Below is a list of possible breakthroughs. Under each breakthrough there is a set of drop down menus to help you gauge each breakthrough's significance on the future of space travel should it occur, the likelihood that such a breakthrough would occur, and the time frame that would occur in. Beneath each breakthrough there is also room for some brief comments, should you wish to elaborate on your opinion. Once you complete this questionnaire, please return it to *DustinGillis@gmail.com*

| **Please enter your name:** | |
|---|---|

**A)** **Propulsion In Space**

*The following section includes possible means of moving through space without the use of conventional chemical rocket drives. Look over the advantages and problems besetting each and rate them in terms of what system or system you think is most likely to be available to space craft designers and space mission planners 25 or 50 years from now and which would be the most significant breakthrough, if it occurred.*

**Nuclear Drive –** Thermal nuclear drives are based primarily on nuclear reactions causing high temperatures, which are then used to heat water, or a similar liquid, to vapor. The vapor is then used to generate power directly for use in propulsion, or to power other systems, some of which propel the craft. For direct propulsion, the vapor is forced out an exhaust port to create thrust. However, the use of nuclear power is controversial due to fears that an aborted launch will spread radiation in the Biosphere. Thus, it is more likely to be used as a drive leaving from LEO rather than launching from Earth.

In space, high temperatures of 2000K are needed to have an acceptable thrust to propellant ratio (3000K would be close to optimal). However, in space, excess heat cannot be readily dissipated, and so far no one knows how to radiate more than 1000K. The lack of particles to transfer the energy to limits the ability to radiate heat.

A breakthrough in our conception of how to radiate heat is needed to use this drive effectively. Alternatively, some means of gathering, attracting or finding existing concentrations of particles in space has to be found to make existing radiators more effective.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

| Comments: |
| --- |
| |

**Ion Drive –** In 1955 Dr. Ernst Stuhlinger presented a theory at a Vienna convention that described ion propulsion and promised a far more favorable fuel to thrust ratio than a chemical rocket. An Ion Drive is a type of spacecraft propulsion that uses beams of ions to accelerate. He worked under NASA contract from 1958-1968 but never solved the key problem, which was that ejecting the positive charged particles left the craft with a negative charge and it just attracted most of the particles back canceling most of the thrust. Though a failure from the standpoint of a drive that could launch a vehicle from the Earth to orbit, its value as a propulsion and control system for crafts already in space was recognized. The problem is that while one could theoretically accelerate to speeds that were a substantial fraction of the speed of light, the rate of acceleration is very slow.

How slow is the acceleration? The ESA's SMART-1 lunar mission was ion driven and took 15 months to reach the moon. However, the drives are very fuel efficient. In 1998 JPL's Deep Space 1 probe was successfully powered by a xenon Ion Drive. On Deep Space 1, 72kg of xenon gas resulted in 16,000 hours of runtime for the Ion Drive.

A breakthrough that results in faster acceleration is needed to realize the promise of this technology. Current speculation focuses on coupling it with another source of propulsion in order to "kick start" it.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
| --- | --- | --- |
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**Magbeam –** Proponents, such as Professor Winglee of the University of Washington, claim that Magnetized-beam plasma propulsion technology promises a round trip to Mars in 90 Earth Days. "Magbeam" works by separating the power source from the spacecraft. The power source is kept in stationary orbit and it "fires" a focused plasma beam to accelerate a vessel in a particular direction. The beam shuts down when the desired velocity is reached. This technique requires another stationary source at the destination point to decelerate the ship in the same fashion.

The advantages to magbeam technology are quite significant. First, one power source can be used to power several vehicles. Second, the power station can be powered using solar panels and the vessels' fuel requirement is drastically reduced. The drawback is that the second stationary source must first be placed at every destination by another means. With current rocket technology, it is possible to reach Mars (with such a set up) within 2.5 years.

Alternatively one could utilize magbeam to go one way quickly (say to Mars orbit) and then use traditional fuel to enter and leave the Mars atmosphere and return home. A breakthrough in the engineering of a full-scale "magbeam satellite" that is easily placed into orbit at popular destinations would be needed to use this propulsion system effectively for round trips.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**Mass Driver –** Mass Driver prototypes have existed since 1975, most of which were constructed by the Space Studies Institute. It is a form of spacecraft or cargo propulsion utilizing a linear motor to accelerate payloads up to high speeds. Payloads would be placed in a "bucket" which is fitted with an electromagnetic coil. This "bucket" is then accelerated by a series of electromagnetic drive coils spaced a certain distance apart forming a tunnel. The "bucket" is reusable and remains with the mass driver while the payload is sent on its way. Due to the thick atmosphere and high gravity of Earth, this is not currently suitable for Earth based launches, however ship and moon based configurations would not be as subject to these forces making them ideal. The mass driver requires no fuel for propulsion and instead can be operated solely on electricity from a local nuclear power plant or solar array. A breakthrough in this technology would come from providing the necessary power, possibly from solar or nuclear means.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**Solar Sail –** The Planetary Society has invested in an experimental mission that is being launched by a Ukrainian rocket this year. Solar sails work by capturing light pressure within large metal film sails, and using the force to push a "ship" through space. The advantage to this is the theoretical speed that could be achieved, which is some large fraction of the speed of light.

The limiting factor is material. It must be light and strong enough to create a sail many times the size of the space craft that could withstand the solar forces. Also, due to the rate at which solar energy declines as you move away from the Sun (within the solar system anyway) it's more attractive for travel in the inner solar system than beyond Jupiter.

Research on the idea began in the 1950's and now NASA has a science team looking into carbon fiber as the most promising material at present. A breakthrough in solar sail material has potential to radically reduce onboard fuel requirements and dramatically change space travel time and distance limitations.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**B) Launch Vehicles**

*The challenge of how best to escape the Earth's gravity is a separate question from that of how to move around in space. Missions to other celestial bodies would depart from a Space Station. Let's assume this for the moment and consider the alternative concepts that would compete with the ELV and Shuttle concepts over the next 25-50 years.*

**Laser Propulsion –** Dr. Leik Myrabo at RPI is doing research in laser propulsion. His laser propulsion works by applying a high power laser to a surface in two stages. The first pulse of the laser is short, and is designed to vaporize a thin layer of the surface material. The second, longer, pulse is applied a few microseconds after the first to let the vapor from the first pulse expand, and then the longer pulse sends a shockwave to the surface projecting it away from the laser. After the second pulse, the process waits until the vapor clears, and then repeats 10 times per second. While launching in the atmosphere, water could be used as the "surface" held in a sort of sponge. As water vaporizes from the surface of the sponge, more water seeps through the sponge to the surface to get hit by the laser. The strongest Air Force laser that Myrabo received access to lifted a small prototype 75 ft. Clearly to carry a heavier payload to low earth orbit will require a breakthrough in laser technology. Freeman Dyson speculated that with a powerful enough laser it would take about 6 minutes of powered flight to reach LEO from a mountain top with such a system.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

| **Comments:** |
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**Reusable Single Stage to Orbit (SSTO) –** The use of a SSTO as a launch vehicle has been abandoned by NASA since 2001 when the X-33 project was put on the back burner. However, since such a launch vehicle is still capable of reaching Low Earth Orbit (LEO), the only major problem is its fuel capacity. If the vehicle was redesigned so that it could be refueled in orbit, then fuel capacity would not be an issue when traveling beyond LEO. The rocket would launch as it has in the past, from a tower on Earth, and once it reaches LEO it would rendezvous with fuel canisters or a refueling station in orbit. These canisters could be launched into LEO by the Ram Accelerator described in the next item in this section. Due to the extreme g-forces in the Ram Accelerator launch, transport of materials and supplies is the only viable use of this launch system. People and fragile cargo would go up in the SSTO vehicle. The two in tandem would create a capability worthy of being called a breakthrough.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
| --- | --- | --- |
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**Ram Accelerator –** The ram accelerator concept was developed by Abraham Hertzberg at the University of Washington in Seattle. It works as a stationary ram-jet engine by accelerating a launch vehicle inside of a steel pipe. The pipe would be built into the side of a mountain, measure about 750 feet long, and be filled with a yet-unknown combustible mixture of gasses. When the gas is ignited, it projects the launch vehicle upward at about 30,000 G's. The launch capsule must be designed long and slender to prevent drag in the atmosphere, and have a sharp point at the top to prevent the force of the launch from igniting the gases above the launch vehicle in the pipe. To prevent friction against the pipe, the launch vehicle is slightly smaller in diameter then the pipe, and uses the gas in the tube as a cushion. The extreme g-forces make this style of launch impossible for humans, but could be used to transport various types of cargo and especially fuel to LEO.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
| --- | --- | --- |
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

| Comments: |
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**Nanotube Polymer Space Elevator -** The space elevator is a 60,000 mile, three-foot-wide ribbon anchored on one end to a platform on Earth and to a counter weight in space on the other. First an initial spacecraft will have to be launched with the ribbon into geo-synchronous orbit. Once in orbit, the ribbon will uncoil as the spacecraft moves higher to keep the center of mass at the same point. When the ribbon reaches the Earth's surface, the craft will unroll the last 10,000 miles of ribbon, moving up to its geo-synchronous station. Once constructed, 13 tons of cargo can be moved up the "ladder" at a time. The vehicle that moves the cargo would use a couple of tank-like treads that tightly squeeze the ribbon. It will take about a week for cargo to reach geo-synchronous orbit at 22,300 miles up. The ribbon will be constructed out of carbon nanotubes (explained below), which are lighter and seven time stronger than steel. Currently the longest nanotube ever made is just a few feet long. However, if a nanotube-polymer breakthrough occurs, it will be possible to build the 60,000 mile ribbon.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| <u>**Significance**</u> | <u>**Likelihood**</u> | <u>**Time Period**</u> |
| --- | --- | --- |
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**C) <u>Materials</u>**

*In this section Materials and Shielding and other support technologies are addressed. Please assess them in terms of your view of their significance to the space program as well as the likelihood that they will emerge in the period before 2050.*

**Memory Plastics –** Memory Plastics are deformable materials that regain their original shape when subjected to a transition temperature. Basically, it is a polymer capable of 'healing' itself through the rupture of embedded microcapsules containing some healing element. Possible breakthroughs with memory plastics would be in the resealing of life support structures and suits that had failed. Inflatable habitat units are planned for the Moon and Mars, at least initially. The NASA plan is to construct them in LEO and transport them to the Moon. This development would increase the structural resilience and durability of such units and allow them to stay in service longer. The reduced risk of catastrophic failure of a life support or greenhouse system is attractive.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| <u>**Significance**</u> | <u>**Likelihood**</u> | <u>**Time Period**</u> |
| --- | --- | --- |

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|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**Carbon Nanotubes**- Carbon Nanotubes are fullerene-based materials with extraordinary strength-to-weight ratios, and variable conductivity. Possible breakthroughs include translation of properties from nanoscopic fibers to macroscopic materials; use of nanotubes within polymer composites that would offer variable conductivity for thermal management, etc. Carbon Nanotubes could prove to be an important material is the production of a space elevator as well. They just might be strong enough to produce a solar sail as well, if they can be woven like fibers.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**D) Shielding**

*Temperature extremes, reentry frictional heat, asteroids and radiation are hazards in the space environment that lead to concerns about shielding and insulation. However, lead, steel, and other heavy materials used on Earth as shields to these types of elements are unsuitable for space applications where minimizing weight is a primary concern. In this section, you are asked which, in your view, "materials" research or "electromagnetic fields research" offers the greater promise in dealing with the shielding and/or insulation challenges of space.*

**Electromagnetic Shielding -** Electromagnetic fields can be used to repel radiation and shield against smaller objects in space. A limitation of the technology is that it may not be able to assist in atmospheric reentry as a result of a planet's magnetic field. Robert Youngquist, a physicist who leads the KSC-Applied Physics Lab at Kennedy Space Center in Florida, is leading a team that is betting on electromagnetic fields as the solution to many of NASA's manned and unmanned problems with radiation in space. "Youngquist's team envisions a spacecraft equipped with what's called a multipole electrostatic radiation shield, a radiation guard made up of three, electrically charged spheres set in a line along the axis of the ship. The center sphere, set close or even attached to the crew module, would be positively charged, while two outrigger spheres on either side would carry a negative charge. Together, the combination should be enough to repel both high-energy protons and electrons that would otherwise penetrate a spacecraft (Malik 1)."

As for stopping incoming objects, the electromagnetic fields of the strength currently used in containing the materials in a fusion reactor would stop a cannon ball or a bullet, but that is about it for now. The breakthrough in EM fields would require a larger supply of energy to the electromagnets. This would probably allow for a sufficiently large and strong bubble of protection to be created.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| Significance | Likelihood | Time Period |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

**Comments:**

**Cold Plasma -** Cold plasma is based on a phenomenon that scientists witnessed in space around 30 years ago, but had no way of creating on earth. Now, with more recent developments in technology, creation of this substance is possible. The main benefits to cold plasma are that cold plasma stop electromagnetic pulses and so can be used to absorb radar, microwave and laser energy. The radar absorption effectively makes a spacecraft invisible to a whole class of sensors and the military implications are obvious, but other space applications are less obvious. This is the stuff of science fiction though, cloaking devices and warding off hostile attacks from laser or beam weapons. The breakthrough that would allow cold plasma to realize its promise would be an energy source light enough to carry and as powerful as a nuclear reactor. There may be natural threats in space to which it is applicable as well.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| Significance | Likelihood | Time Period |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

**Comments:**

**Aerogel -** Aerogel is an ultra light solid also known as "solid smoke." It is the lightest known solid, (90-99% air) with abnormal levels of heat absorption. Aerogel has the ability to protect crayons from melting when aerogel is placed between the crayons and a butane torch. Aerogel has the same heat insulation in a 1" pane as a 32" thick pane of a normal, air insulated window. The downside to aerogel is that creating aerogel can be difficult, and expensive, as it is best done in microgravity, but it has been used successfully to insulate the Mars Rover and Space Lab 2.

As of January 13, 2004, NASA announced that Aerogel is the new insulation of choice. An attempt is likely to be made to use it to replace the ceramic heat shield tiles on the Shuttle that are so vulnerable to chipping and costly to replace. Aerogel can be used as a heat shield simply by ejecting it out along the surface of the vessel as the spacecraft prepares for reentry. The gel is expendable, it would be burned away, but will prevent heat damage to the aluminum hull as it burns away. The Aerogel breakthrough that is needed involves its ease and cost of production" on the fly", since in space shielding applications it tends to get used up and requires replacement.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

D) Life Support

*As Freeman Dyson so eloquently puts it, the movement of mankind into space will have as much to do with the bio-technology advances as space technology per se. Our plants have to be able to come with us, we ourselves will have to adjust to a radically changed environment and the whole thing has to make sense economically. People have to be able to make a living in any place that is colonized. Your assessment of the implied trade relationship between Earth and the Moon would be appreciated.*

**Fusion Reactors -** To make a future moon base profitable, something on the Moon will have to be profitable. Currently, the only identified resource so compact and rare on Earth that it would be worth importing from the Moon is helium-3, a potential fuel for nuclear fusion. However, at the moment, fusion energy is impractical since to get a reaction, one must generally put in more energy than comes out of the reaction. (There are few reports of breakeven experiments.)

Hydrogen fusion is easier to achieve than helium since it takes less energy to get the smaller nuclei to fuse. Unfortunately, helium fusion is even more difficult to get started (takes more energy) than fusing hydrogen. In order to use the more challenging, but potentially higher yield helium-3 as a fusion reactor fuel, a major breakthrough is needed in the field of nuclear energy

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

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| 1 (Trivial) | 1 (Impossible) | Early (2020) |

| **Comments:** |
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**Roving Lunar Base -** The Roving base is a mining colony gathering Helium-3 for the powering of fusion reactors. Helium-3 is not highly concentrated at one site like a vein of gold or uranium on Earth. Hence, a roving nomad habitat is needed to do a kind of strip mining in areas where the right beta "signature" is found in the regolite.

The "morphlab" base, as proposed by Albritton et al. of the University of Maryland, is composed of multiple parts that allow it to be disconnected and driven or towed from one site on the Moon to another. Once set up in a promising mining area, robotic/remote controlled harvesters would be sent off to collect the nearby Helium-3. The habitat modules will provide life support systems for the occupants of the base. The robotic harvesters will gather Helium-3 in a 50 mile radius and then the base will be disassembled and the separate modules "driven" or "towed" 100 miles to a new mining area.

The necessary breakthrough will be in the devices that locate, gather and safely transport the precious fusion reactor fuel, assuming that there is a related breakthrough in the fusion reactor field on Earth before its oil supplies run out in 50-75 years. Overall, think of the mobile base as a conceptual breakthrough.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |
| **Comments:** | | |

**The "Bionic Leaf" -** One of the breakthroughs that could make a moon habitat productive enough to be self sufficient in agriculture is the bionic leaf. The idea was inspired by Freeman Dyson who has been commented about the need for a silicon black leaf that would be 15% efficient in using solar energy rather than the paltry 1% of Earthly green tree leaves. What is needed for lunar agriculture is a cyborg half plant- half machine hardy enough to "grow" on the moon mostly outside of a greenhouse.

The "bionic leaf" is made of black silicon and aluminum honeycombed with fine hair-like tubing that is the outside part of the plant situated on the lunar surface. It can synthesize carbon dioxide and water into a carbohydrate in direct or indirect (reflected from a satellite) sunlight. Inside or underground (in a protected area) the tubers, ears of vegetables and fruits store the resulting sugar coming in from the leaves in tubes as in normal agriculture they travel through the stem or trunk of a plant. So, the key to lunar agriculture is to supply this system with Carbon Dioxide and Water. Oxygen can be mined from lunar rocks, so Carbon and Hydrogen are the elements in short supply that must be “imported” to kick off the system and then be recycled without serious loss.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

**Comments:**

**The “Gravity Implant" -** Mankind did not evolve with the right biochemical feedback system for space. So, to avoid the disorienting impacts of low or no gravity giving the body all the wrong signals (about where to put the calcium, when and how hard to tense the muscles to exercise them and which antibodies to maintain etc.) an implanted translator is put under the skin and along the spinal cords of most Astronauts toward the end of their training.

It senses changes in gravity and compensates for them by essentially intercepting and changing the bio-chemical and electrical neuro-signals that help the body stay in equilibrium in the Earth environment. The Astronauts call it being "reprogrammed" for space and they worry about what else the re-programmers might change to make the mission more likely to succeed at their expense. However, they volunteer for it anyway after they see the films of what the Russian Cosmonauts looked like after 500 days in space.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

**Comments:**

**LEO Compressed Air Collector and Processing Plant -** Two important resources that a self sustaining lunar base will need to start or expand agricultural production are water and carbon dioxide. Lifting these bulk resources from the surface of the Earth is expensive. One alternative to this problem is the use of a vehicle that collects water vapor and carbon dioxide as part of a load of compressed air taken from the upper atmosphere. This collection vehicle would "swoop" down into the upper atmosphere and collect air, compressing it as it went back out of the Atmosphere for delivery to a separation and processing plant in LEO. The necessary breakthrough is in the design of a large hollow ended skimming vehicle that can repeatedly withstand reentry stresses and then close its nose and escape back into space on orbital momentum or with a short "burn".

The orbiting processing and compression plant that separates water, carbon dioxide and oxygen etc. from compressed air is also going to be a challenge. It must not only separate these resources but also convert them into a compact solid form. Carbon dioxide and water can be readily frozen into solids, but then they must be wrapped in a protective layer to avoid dissipation into space. One wants a block of dry ice or water ice ready for transport to the Moon. Some of the oxygen must be left in a liquid form (LOX) so that can be used to power a rocket to give it a "push" in the direction of lunar orbit or wherever else it is needed. On arrival it needs to slow down, requiring another "burn" for insertion into lunar orbit or to be delivered to an agricultural production facility.

Once charged with thawed Earth atmospheric products, the agricultural plant will recycle the precious delivery of Hydrogen and Carbon endlessly. These are rare elements on the Moon and essential to human and plant life. Oxygen can be mined out of the oxide rocks on the lunar surface. Water is to be found mainly in a deep crater at the South Pole. Setting up for agricultural production anywhere else will require imported water as well as carbon dioxide.

*Select the significance, likelihood, and time period from the gray shaded drop down menus:*

| **Significance** | **Likelihood** | **Time Period** |
|---|---|---|
| 1 (Trivial) | 1 (Impossible) | Early (2020) |

| Comments: |
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# Scenarios

**A3: Scenarios**

**Scenario 1: Interplanetary Travel**

Breakthroughs Needed: Fusion Reactor, Magbeam, Ion Drive

Purpose: This scenario makes possible dependable interplanetary travel

With the development of fusion reactors, a sufficient power source would be available to power mechanisms such as the magbeam. With this power, the magbeam would be capable of propelling crafts at high speeds to distant destinations. Two possibilities could then follow. If the destination planet does not have a counterpart magbeam, a ion drive could be used to both slow down and accelerate the craft for a landing an subsequent return journey. This would also allow the setup of a counterpart magbeam at this planet for subsequent journeys. If the planet already has a magbeam, the ion drive could be used in a similar fashion for travels to other non-magbeam equipped planets. Having these three breakthroughs would result in a dependable transport system and backup system so that interplanetary travel could be both relatively simple and safe.

**Scenario 2: Colonies on Other Planets**

Breakthroughs Needed: Fusion Reactor, Electromagnetic Shielding, Bionic Leaf

Purpose: This scenario makes possible colonies on planets other than the earth

In order for a colony to be set up on a remote planet, several breakthroughs must be accomplished. A significant amount of power will be necessary to allow both research and life support systems to run in a remote environment. A breakthrough in fusion reactors would provide sufficient electricity to power these systems and any other systems that may be required. One of these systems is the electromagnetic shielding system. This system would protect the colony against radiation and objects what could potentially destroy or damage the colony. With enough electricity, it is possible that temporary environments could be set up to facilitate the growth of plants and vegetables. With a temporary environment set up, a bionic leaf could be used to produce oxygen from carbon dioxide and produce sugars in the form of fruits, vegetables and tubers. This could sustain colonists and allow the colony to be more self sufficient rather than rely on outside sources for sustenance. With these three breakthroughs, the possibility of colonies on other planets is significantly increased.

**Scenario 3: Cargo Transport**

Breakthroughs Needed: Fusion Reactor, Mass Driver, Magbeam

Purpose: Makes possible the long distance transport of materials through space

Delivery of materials from one place to another without the need of a manned craft would be ideal in a time where space travel, and exploration and colonization is common. With the development of a fusion reactor, sufficient electricity could be available to operate a mass driver and magbeam. A mass driver could be mounted on a planet or craft to propel objects through space at high rates of speed. Once the objects reach their destination, a magbeam could be utilized to decelerate the cargo to a speed where it could be safely collected. This system would not involve direct fuel or the need for personnel on the journey, so speed of delivery would not make as large of a difference. Also, due to the ability of the mass driver to constantly launch cargo, a steady line of materials could be sent continuously with relatively low energy consumption compared to a scenario where spacecraft are used. With these three breakthroughs, a dependable and continuous cargo transport system could be developed.

**Scenario 4: Lunar Material Collection Facility**

Breakthroughs Needed: Fusion Reactor, Roving Lunar Base, Mass Driver

Purpose: Makes possible a material collection facility that can attain its own fuel and send materials back to earth or an orbiting facility

The moon holds a material crucial for the powering of a fusion reactor. Because of this, a method for collecting this material (Helium-3) must be developed. The major breakthrough needed to make this scenario both necessary and possible is the development of a fusion reactor. With this reactor operational, a means of collecting the necessary materials from the moon will be facilitated in a roving lunar base. This base will travel along the moon's surface collecting Helium-3 as it goes. The rational method for powering the base would be by fusion reactor. Doing so will permit the facility to be self powering. A method for transporting the crucial materials must then be developed. In this scenario, a mass driver would be mounted on the roving facility. The mass driver would be powered by the fusion reactor powering the base and could propel the Helium-3 canisters to a collection facility in orbit around the moon or earth. This Helium-3 would be used to power other fusion reactors in operation both on earth and in space. With these three breakthroughs, a self powered Helium-3 collection and distribution facility can be made possible.

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