Engineering Success & Successful Engineering: A West Point Cadet Project with NASA Illustrates the Value of Diversity

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Abstract: As part of their senior year capstone experience at the United States Military Academy, five Systems Engineering and Engineering Management cadets are working with NASA on enhancing ways to more safely land autonomous space landers on other planets and more reliably guide autonomous surface rovers through our largely un-navigated solar system. Despite the apprehension the cadets had when they first discovered they would be working on such a daunting task, after a semester of getting to know one another and assessing their individual and collective strengths and weaknesses, they have developed into a cohesive team that has gained both an improved understanding of our nation's space exploration program and greater insights into how NASA engineers are currently approaching the problem. Even though the cadets did not come equipped with any noteworthy qualifications or specific background on space or sensor technologies, they acknowledge that their undergraduate courses have prepared them for dealing with the challenge. As a result, they are putting into practice much of the theory that they have been learning. The capstone project is also providing the cadets with an opportunity to experience first-hand what leadership and teamwork are all about. In this paper, the cadets describe what they have learned during their capstone experience, and they explain what it took for them to successfully engineer an engineering success. Recognizing that in order to produce a value-added solution to a complex problem, the cadets needed to gain as many insights as they could from differing perspectives. Through their own diverse backgrounds and unique insights into the problem, the cadets were able to apply a systems engineering problem-solving methodology to help advance NASA's current design and approach. While portions of the cadets' work and results on the project will be highlighted, this paper focuses primarily on the learning outcomes and educational goals realized through this capstone experience.

Introduction

As part of our senior year capstone project at the United States Military Academy, we are working with NASA on enhancing ways to safely land autonomous space landers on other planets and more reliably guide autonomous surface rovers through our largely un-navigated solar system. Despite the apprehension we had when we first discovered that we would be working on this daunting task, a semester of getting to know one another and assessing our individual and collective talents has allowed us to develop into a cohesive team that has gained both an improved understanding of our nation's space exploration program and greater insights into how NASA engineers are currently approaching their challenges.

Even though we did not come equipped with any noteworthy qualifications or specific background on space or sensor technologies, we believe that our undergraduate courses have adequately prepared us for dealing with this experience. As a result, we are excited about putting into practice much of the theory that we have been learning. Furthermore, our capstone project is providing us with an opportunity to experience what leadership and teamwork really mean. In this paper, we describe what it takes to successfully engineer a solution to a real-world problem. Recognizing that in order to produce a value-added solution to a complex issue, engineers must gain as many insights as they can from differing perspectives. In this paper we will highlight portions of our work and describe our methodology for tackling this project, but we will focus primarily on the learning outcomes and educational goals realized through our capstone experience.

Stakeholder Analysis and Problem Definition Phase

Early last semester we were introduced to our capstone project via a teleconference with Jon Paterson and Tom Bryan, two of NASA's engineers working on advanced sensor technologies at the Marshall Space Flight Center. About a month later we finally got to meet both in person as well as various other stakeholders involved with the project to refine how our cadet team could contribute to the mission. At first we were very worried about how we were going to provide any value to NASA. Fortunately, through our discussions with our stakeholders, we discovered that we would be able to provide a different approach to NASA's current methodology for determining the most appropriate sensor suit to be placed on-board automated space landers and surface rovers. By leveraging the Systems Design Process that we learned in our systems engineering undergraduate courses at West Point, we believed we could introduce NASA to our interdisciplinary approach for enabling the realization of a successful system.[1]

At first, NASA presented us with two very distinct problems they were struggling to resolve. The first problem dealt with how NASA could best implement a crew launch vehicle that would eventually replace the current space shuttle program by the year 2010. This problem deals with engineering a system that would effectively launch astronauts into space and allow them to re-enter earth in a more efficient and effective manner. The second project that NASA proposed to us dealt with developing a system that could detect and avoid hazards while landing on the moon or any other planet. NASA called this project its Object Detection and Avoidance Capability (ODAC) program. Our team decided to pursue the ODAC project because it seemed to better fit our skill sets and appeared to more closely resemble some of the engineering class projects we had completed in the past.

Mr. Patterson and Mr. Bryan also provided us with a list of ten concerns for the ODAC project (see figure 1). These concerns are unique to every mission depending on the mission's goal but at the same time significant trade-offs exist when attempting to account for all ten concerns simultaneously. These stakeholder concerns helped us think about what key issues NASA wanted to solve and gave us insights into what it wanted as a potential final solution. We eventually realized that NASA appeared to be focused more on existing alternatives, which we believe our systems engineering expertise could help improve upon.

Weight	Micro-meteoroids
Size	Radiation
Power & Power Sources	Vibrations
Cost	Visibility
Thermal Capability	Durability

Figure 1: NASA's Key Concerns for Object Detection Sensors

Based on our initial analysis, we defined our problem statement as follows: *Develop a model to help NASA determine which sensor or combination of sensors will be best suited for autonomous landing and roving on lunar and planetary surfaces.* The greatest benefit we believe our team will provide NASA is introducing it to a value-focused thinking (VFT) approach versus its current alternative-focused thinking (AFT) design. VFT tends to be a different way of focusing an organization's goals and objectives into an action plan. Values are what people really want, and VFT is markedly different than choosing alternatives and going with the one that fits the best. Oftentimes, when organizations rely on AFT, they fail to take the time to reflect on what is really important to them. Ralph Keeney, a pioneer in the field of VFT, introduces the concept of Constraint-Free Thinking: "thinking about values is constraint-free thinking . . . it is thinking about what you wish to achieve or what you wish to have."[2] By introducing VFT to NASA, we believe we can offer NASA a new paradigm for approaching how it researches, develops, and designs sensor technologies for autonomous space missions. Rather than merely selecting the best set of sensor technologies currently available, we believe a VFT approach will provide NASA with a more unconstrained view of examining what sensor capabilities and requirements it values as being the most critical for future missions. In doing so, we believe can leverage our systems engineering education and help NASA come up with a systematic way of better articulating what it values most and considers to be mission critical for space exploration.

Solution Design Phase

In order to create an effective solution for NASA, we realized that our model would need to address a number of NASA's key concerns: 1) pattern recognition, 2) range detection, 3) orientation, 4) altitude, 5) integration of sensors, 6) facilitate autonomous & manned missions, 7) conserve fuel, and 8) hover time. These functions are important for all missions and will help in determining the final solution because the sensor or combination of sensors must be able to accomplish all these functions. If a sensor is incapable of adequately satisfying these functions then it is not likely to be a final candidate. To help us better visualize our system of concern, our team developed the following functional hierarchy:

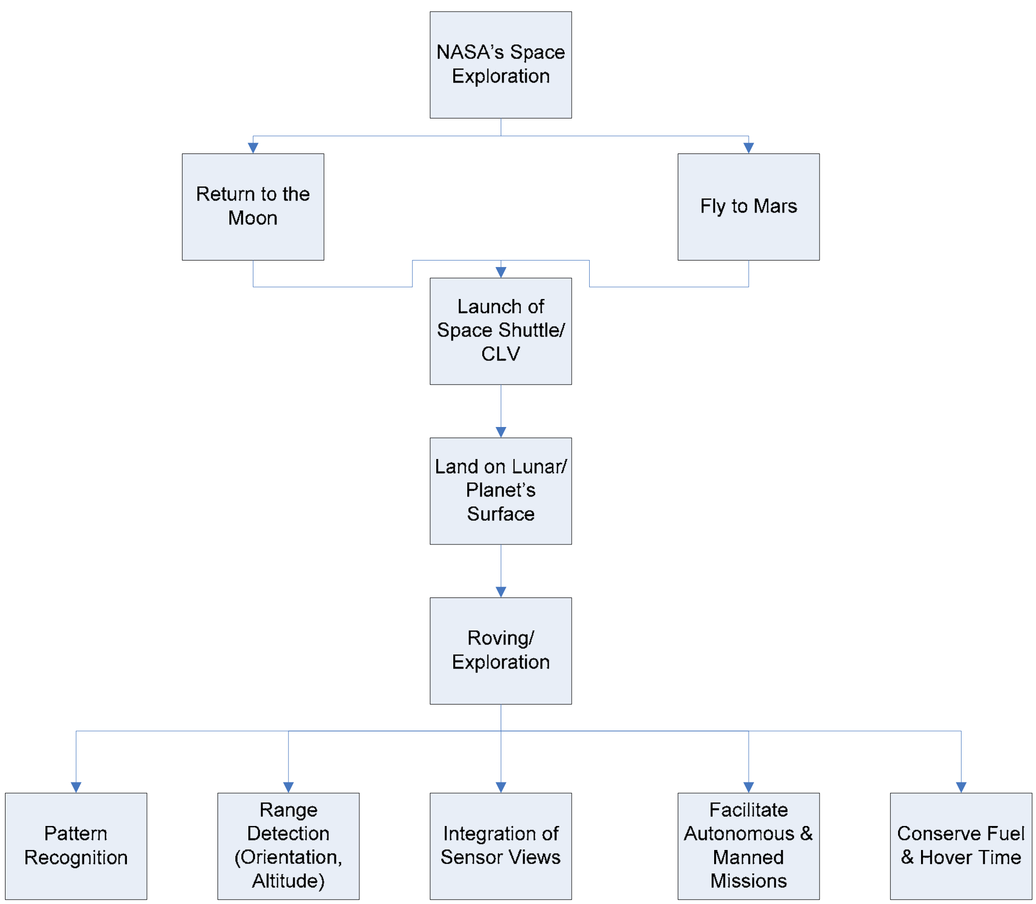

Figure 2: Functional Hierarchy of NASA's Autonomous Space Exploration Mission

This functional hierarchy shows how the ODAC project is a critical component of NASA's overall space exploration mission.

NASA asked us to consider these possible solutions: Infrared, Tactical Arial Navigation, Light Detection and Ranging, Three Dimensional Imaging, Night Vision Devices, Outpost Guidance System, Stereo Video, and Video Camera. By doing so, NASA has indicated to us that it is approaching the problem via an AFT methodology. Our approach to the project, on the other hand, will be based on a VFT methodology, which we believe will benefit NASA in the following ways:

- Thinking outside the box for current sensor technology
- Limiting cost and expenses on unnecessary or non-critical capabilities
- Identifying gaps with existing sensor technology and improving upon key existing requirements
- Generating ideas for new solutions that NASA has not yet considered

Through our VFT approach, we are helping NASA find and articulate its values and then incorporate them into an optimal action plan. Furthermore, the approach that we use will not be limited to NASA alone, but can be easily incorporated into other organizations as well. As a team we really didn't realize this point until late in the project, for the beauty of our model we are creating is that fact that it can be customized to help decision-making on a wide-range of problems. Our model will make complex problems more manageable by providing decision-makers with a systemic way of identifying where they ought to focus their available resources.

Conclusion and Our Path Ahead

In 2004, President George Bush articulated a number of key milestones for NASA to accomplish: "Our goal is to return to the moon by 2020 . . . [By] establishing an extended human presence on the moon [we] could vastly reduce the costs of further space exploration, making possible ever more ambitious missions"[3] While the President's speech has helped to galvanize renewed interest in our nation's space exploration program, it has also forced NASA to adhere to an accelerated timeline that attempts to balance both current concerns (retirement of the space shuttle program, completion of the international space station, etc.) with future opportunities (return to the moon, mission to mars, etc.). Consequently, NASA's interest in autonomous landers and rovers has received greater attention and research in the area is helping to lay the foundation for future projects.

In concert with the its 2006 strategic goals, our team plans to create a Microsoft Excel spreadsheet model that will assist NASA in determining what capabilities ought to be considered for a variety of sensors being developed.[4] Our model is a decision support system that will examine space exploration as a series of sequential phases, each with a distinct set of requirements and constraints. We believe the Interactive Decision-Making Architecture featured in our model will allow experts at NASA to input their own parameters that we know will inevitably change because of different mission requirements and advances in technology.[5] Our decision support system will help to better link NASA's strategic goals to its operations and thereby increase the probability of success for future space missions. Furthermore, we believe our model is robust enough that it can be easily transferable to a wide range of military applications, such as acquisitions, mission analysis, and capabilities assessments.

Our team's biggest goal for last semester was ensuring that we had a well defined problem statement and a good plan for how to implement a solution using value focused thinking that would be useful to NASA. We have made significant progress in our project as well as come closer as a team and this experience should be very rewarding. Diversity has been evident through the workings of our team and the diverse nature of our product. While our team may not be composed of the most diverse set of individuals (we are all cadets who wear the same uniform, are all a part of the Systems Engineering Department, are all seniors about to graduate, and are preparing to join the Army as second lieutenants). At the same time we are all very different. Each member in the team has different ideas on how to accomplish the project at times this can be a problem. It was a challenge trying to work together, but through group dynamics such as working on a complex project like this we became closer and more efficient. We believe our contribution to the project will be introducing NASA to a value-focused solution that we believe can be used for a diverse range of future problems associated with space exploration. Furthermore, we believe our model can be used for a whole host of additional problems including life-cycle planning, equipment procurement, and financial analysis. From complex problems facing industry to life-threatening issues facing our military, we believe our model can be tailored to fit any decision-making environment. As a result, we believe we successfully engineering an engineering success that will satisfy any number of diverse problems.

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Biography

Maj. Ernest Y. Wong is an assistant professor with the Department of Systems Engineering at the U.S. Military Academy. As a military intelligence officer, he has served in a variety of assignments around the world. He holds a B.S. in Economics from USMA, and both a M.S. in Management Science & Engineering and a M.A. in Education from Stanford University. His recent NASA fellowship with the Exploration Systems Summer Research Opportunities program at the Marshall Space Flight Center has made it possible for him to provide a similarly rewarding experience for cadets whom he advises at West Point. He can be contacted at USMA DSE, 646 Swift Rd., West Point, NY 10996, 845-938-4756, ernest.wong@usma.edu.