

# Developing Systems Engineering Skills Through NASA Summer Intern Project

*A pilot internship program rapidly develops undergraduate students as NASA communications systems and network engineers*

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**Abstract**— During the Formulation phases of the NASA Project Life Cycle, communication systems engineers are responsible for designing space communication links and analyzing their performance to ensure that the proposed communication architecture is capable of satisfying high-level mission requirements. Senior engineers with extensive experience in communications systems perform these activities. However, the increasing complexity of space systems coupled with the current shortage of communications systems engineers has led to an urgent need for expedited training of new systems engineers. A pilot program, in which college-bound high school and undergraduate students studying various engineering disciplines are immersed in NASA's systems engineering practices, was conceived out of this need. This rapid summer-long training approach is feasible because of the availability of advanced software and technology tools and the students' inherent ability to operate such tools.

During this pilot internship program, a team of college-level and recently-hired engineers configured and utilized various software applications in the design and analysis of communication links for a plausible lunar sortie mission. The approach taken was to first design the direct-to-Earth communication links for the lunar mission elements, then to design the links between lunar surface and lunar orbital elements. Based on the data obtained from these software applications, an integrated communication system design was realized and the students gained valuable systems engineering knowledge.

This paper describes this approach to rapidly training college-bound high school and undergraduate engineering students from various disciplines in NASA's systems engineering practices and tools. A summary of the potential use of NASA's emerging systems engineering internship program in broader applications is also described.

**Keywords**— *space; communication; networking; simulation; systems engineering; education; integration; interns*

## I. BACKGROUND

The current shortage of senior systems engineers led NASA to recognize its need for earlier training of future systems engineers [1]. As with many other aerospace organizations, a large portion of NASA's workforce will soon enter retirement. This shift in workforce threatens to leave the agency with a shortage of qualified, senior systems engineers. Because most young engineering professionals do not begin their systems engineering training until later in their careers, the agency is left with a gap that must be filled.

The complexity of today's communications systems and networks are increasing due to the agency's attempt to adopt an Internet-based approach of a layered-network paradigm while still supporting older, legacy missions. The agency's continued integration efforts, creation of system-systems and network-of-networks also contributes to the increased complexity [2]. Space Communications systems and networks are vital to the success of NASA missions. Communications systems engineers play a key role during the NASA Project Life Cycle (See Fig. 1) for each mission [3].

Systems engineering training, knowledge and skills are necessary to advance NASA's communications systems and networks. The Augustine Report, a recommendation that outlines NASA options for President Obama, reinforces the importance of systems engineering and states that:

*If NASA is to successfully execute the complex undertakings to which it aspires, it must maintain a world-class systems engineering capability, a capability that this and other reviews have deemed to be marginal in its current embodiment. [4]*

The training and development of systems engineers is typically a long and complex process. To reduce this time,

and to help combat the current shortage in systems engineers, an approach is being developed at NASA Glenn Research Center in which undergraduate engineering students can simultaneously learn systems engineering practices while earning their undergraduate degrees.

A summer intern pilot program was created for which seven interns from different engineering backgrounds were selected and trained in systems engineering under the guidance of five senior system engineers at NASA Glenn Research Center. Their disciplines varied from electrical engineering, computer engineering, computer science and aerospace engineering. During the formulation of our approach, we found that because today's youth have such an inherent ability to intuitively operate software and computers, they could be rapidly trained in systems engineering before officially starting their careers. Thus, these software tools actually enabled them to learn at such a rapid pace. The main benefit was the tool's abilities to provide visualization and immediate feedback of the affects of system changes. Out of these conclusions and observations, the pilot internship program was conceived. At the end of the program, the summer interns walked away with an advanced knowledge of NASA's systems engineering practices and their mentors with a better idea of how to shape and inspire future systems engineers.

The details of the approach are given below:

- Introduce college-bound high school and undergraduate engineering students in NASA's communication systems engineering processes and practices
- Expose future, multi-disciplinary engineers to a possible career path in communications systems engineering
- Train NASA engineers on successful mentoring techniques
- Generate new ideas and fresh perspectives for NASA

Glenn Research Center and student intern participants

- Expose NASA Glenn's overall missions to the academic community
- Prepare students for future Space Communication and Navigation (SCaN) work

## II. APPROACH AND PROCESS

The approach is based on several observations from past summer intern experiences as well as suppositions about the upcoming generation of future engineers. First, we have found that with past programs, summer interns were mostly assigned to a single mentor on one very specific engineering task. We also observed that past summer interns had a very limited opportunity to truly understand and engage in NASA systems engineering processes. Through our experiences we have also discovered that the current generation is able to operate computer software tools intuitively. Today's youth feel comfortable learning new software; they do not feel intimidated. In addition, current students are adept in social networking tools, allowing them to work quickly and naturally in a collaborative environment with both their peers and mentors. Lastly, we found that the communication analysis software has matured to the point that with the proper training and guidance, students can quickly and effectively apply the tools themselves. Having the ability to perform knowledge discovery, rapid communication analysis and to apply system design tools with such tools directly from their own workspaces allows the students to participate in an actual NASA's systems engineering project environment.

The approach introduces summer interns to NASA Communications Systems Engineering Practices within the NASA Project Life Cycle (See Fig. 1) progressively over the course of their four-year undergraduate education. The

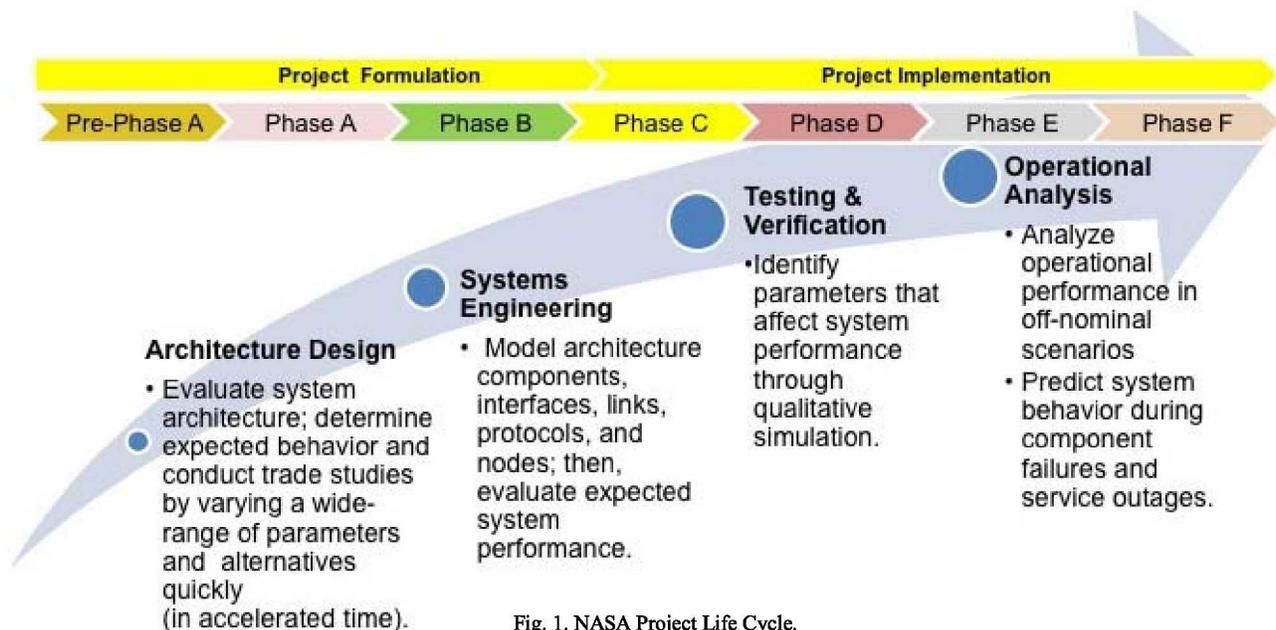


Fig. 1. NASA Project Life Cycle.

students' skills are developed through the challenging task of performing each of the systems engineering steps required during the project life cycle (See Fig. 2).

The details of the approach are given below:

- Introduce communications systems engineering to students during their undergraduate education of electrical and computer engineering, computer science, and physics. This introduction will be comprised of individual and group assignments, as well as a series of supplementary lectures, referred to as the "Summer Lecture Series", on topics relevant to the students' systems engineering assignments. A knowledgebase will provide additional learning resources and reference material including the NASA Systems Engineering Handbook and other relevant systems engineering project examples and guidelines.
- Leverage the students' computing and IT intuition in the early phases of their systems engineering education. Today's college and university students are very adept with computer hardware and software, which allows them to quickly learn systems engineering software tools and become immediately productive in collaborative team environments.
- Focus on the practical aspect by engaging them in a real-world systems engineering project. The emphasis is to use realistic mission scenarios as reference models for the students' systems engineering assignments; otherwise the concepts and processes of systems engineering, as presented through lectures and reference material, may be difficult for the students to grasp. Additionally, real-world examples serve to illustrate the impact that systems engineering has on design and mission success.
- Define the project for future years of summer intern participants. As described in the following section relating to the systems engineering training process, the students' summer work assignments will follow a progression corresponding with their related coursework at a college or university. Students in the early years of undergraduate study will focus on early phases of the NASA project lifecycle (Pre-Phase A and Phase A, for example) as shown in Fig. 1. As the students' academic studies progress, their corresponding work assignments will begin to focus on the later phases of the project lifecycle - including design, followed by integration and testing. By senior year, the students will have had the opportunity to explore most phases of the project lifecycle.
- Monitor performance and progress throughout the years of systems engineering training. During each term of internship, the students will be given systems engineering assignments commensurate with their education and experience, and the students will work closely with mentors and other senior engineers for proper guidance.

- Build and maintain key relationships among mentors and students during the summer program and throughout the academic school year through the use of various social networks.

The approach described above was translated into a strategic process to train future systems engineers progressively through their four-year undergraduate education. In many cases, students would begin the summer intern program immediately after high school graduation.

Their summer internship training and activities were intentionally designed to coordinate with their engineering education discipline and level. This tactical process is illustrated below in Fig. 2 where "KD" stands for knowledge discovery, "Comm Sim" for communication simulation, "Net and Sim" for network and simulation and "SW and HW" for software and hardware.

The process begins by the mentor team briefing the interns on the NASA systems engineering processes and practices currently being carried out at the agency. Then, using a designated visualization tool, the students begin to carry out their hypothetical communication analysis assignments in a collaborative team environment. This serves as a valuable lesson in two ways. First, the interns gain important knowledge by actually operating the tool themselves and secondly, through the feedback and critiques provided by the mentor team.

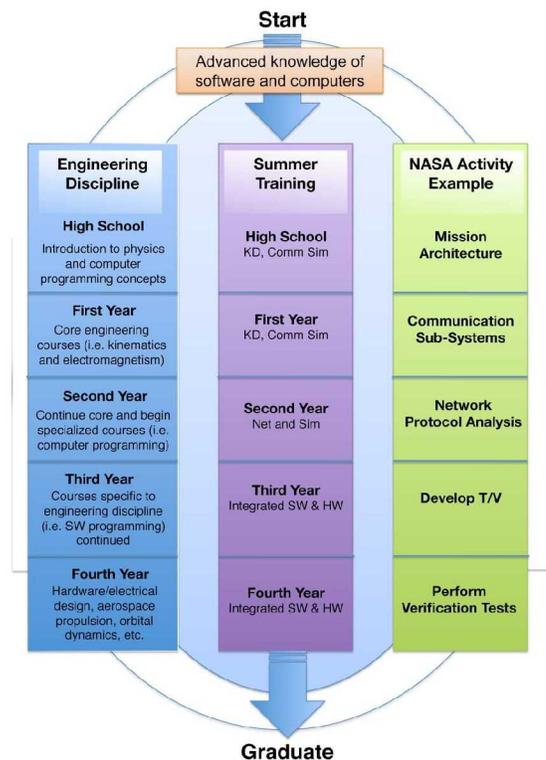


Fig. 2. The intern's path from the beginning of their engineering education, throughout their NASA systems engineering training and up to college graduation.

As shown in Fig. 2, each year of their education coordinates with the systems engineering tools and respective NASA-based project activities that they are exposed to throughout the internship program. Students having completed their senior year of high school will begin their internship with a basic understanding of physics and engineering concepts and will focus on high-level mission architectures as a project activity using communications simulation and appropriate software tools to complete their assignments.

Upon completion of the students' first year within their respective engineering disciplines at a university or college, the students will have a more thorough understanding of math and physics which allows them the additional capability to explore in further depth their work related to mission architectures from the previous summer. The students will select one or more systems within the architecture and decompose the system into sub-systems and formulate conceptual designs of the sub-systems. As an example, the students may complete the conceptual design of a communications sub-system using communications simulation tools to assist with their link budget calculations.

As students progress through their academic studies, their corresponding work assignments during summer internships will progress commensurately. Second and third year students will begin to have a more thorough knowledge of core course material within their respective engineering disciplines. Consequently, the students' assignments for these summers will transition beyond the physical layer of the Open Systems Interconnection (OSI) reference model and advance into an analysis of network layer protocols and related their application within the communications system design; additionally, the students will begin development of preliminary test and verification plans for their designs in an effort to meet technical requirements.

Upon entrance into the fourth year of academic study, the students will have likely specified an area of specialization and will have completed a portion of the corresponding coursework. During the summer internship, the students will use an integration of hardware and software to perform verification testing in accordance with the plans as established in their previous summer's study.

During the process, particular attention was paid in identification of what systems design and analysis tools the students would use. Details on the toolset used is described below:

The interns were trained on a commercial, off-the-shelf software simulation tool called Satellite Tool Kit (STK). Its robust physics engine coupled with powerful visualization capabilities has made it one of the most popular tools in the aerospace industry. The physics engine can model and simulate mission objects such as communications satellites, spacecrafts, ground-based antennas, and even human extravehicular activities. With the ease of using STK's Graphical User Interface (GUI) to model system parameters coupled with STK's robust visualization capabilities, the interns were able to generate consequential data during their 10-week tenure.

Although the interns did not have an in-depth knowledge of orbital mechanics or communication analysis, using STK allowed them to view the higher-level conceptualization of the mission without delving too deeply into the rigors involved with such missions. Without such a tool, the mathematical complexities of communication analysis may have discouraged them from pursuing a career in this field before undergoing the adequate hand-on application of real systems. One key is the visualization component of STK. Each of the interns expressed how helpful it was to view their models and scenarios in rich 3-D graphics. Hence, after teaching them the basic physics of communications analysis, the students could readily apply and apprehend the real-world application. At least two of the students expressed that they were inspired to study communications in their undergraduate programs because of this experience.

As for their lunar mission project, the interns were given a set of requirements that were then turned into actual objects in a STK environment for further modeling and analysis. Their analyses involved analyzing communication link budgets, orbital trajectories, and specific plausibility of mission objectives – all of which were easily accessible through STK. The mentors played an important role in educating the interns about model parameters. And by performing this hands-on work themselves, the interns gained a better understanding of the analysis results and were subsequently able to make changes to the mission as needed to meet the requirements. Without a powerful and user-friendly tool like STK, this process would not have been possible.

### III. SUMMER INTERN PILOT PROJECT

An educational platform to learn the NASA systems engineering processes and apply it in the design and analysis of future lunar and earth science missions was introduced to the intern team. The mentors conducted "Friday Talks" in which various systems communications topics were addressed allowing the students to interact one-on-one with their mentors and peers. The students also participated in facility tours to see first-hand the work being done at NASA Glenn Research Center. An eRoom Web site was created for the students to interact and collaborate among themselves as well as store data and research results in one central location. The experience provided a unique opportunity for peer networking among participants.

Each summer intern was assigned ownership of one system in the scenario and its associated communication links. The student's assignments were open-ended and reflected the realistic nature of architecture assignments. The seven students shared five senior mentors to help guide them through the process of creating a sortie lunar communication network design. The same students will return for the next 2-3 years for continued education and will work on a different project each summer.

Important lessons learned from the pilot program were as follows:

- The students learned how to work effectively in a collaborative team environment to achieve project goals
- The students were able to overcome many challenges through open discussions, dialogues and working meetings which yielded optimal results
- The efforts of the student team allowed NASA to develop an unprecedented model for creating a NASA-related mission environment which may serve as a benchmark for future integrated team environments
- Students learned valuable presentation and documentation skills that will help them in future jobs and academic courses

#### IV. LUNAR COMMUNICATION NETWORK DESIGN

The intern team was tasked with performing high-level design and analysis of communications for space systems deployed in a plausible, scaled-down NASA Lunar mission scenario based on the latest concepts developed by NASA lunar architecture teams [5]. The Lunar Architecture Team (LAT) study selected the rim of Shackleton Crater at the South Pole as a reference architecture, and the envisioned outpost consisted of habitable elements connected to form one pressurized habitat as well as power units to provide continuous power through day and night operations. Small Pressurized Rovers (SPR) enabled human crews to venture hundreds of kilometers from the outpost to conduct extra-vehicular activities (EVAs) for science-related and other purposes.

Due to budgetary constraints, however, NASA's plans to establish a permanent outpost (including the construction of a large habitat) on the moon are likely to be scaled back, along with plans to deploy a constellation of dedicated lunar communication satellites in orbit around the moon. The reference scenario for the intern team's design included the Constellation Orion vehicle, the Constellation Altair lander, an SPR, ground stations on the Earth, and a lunar science satellite with a secondary communications payload which provided a communications relay capability for lunar surface and orbiting systems. The intern team produced the architecture [5] and associated detail shown in Fig. 3. Similar to the architecture envisioned by the LAT team, the architecture of Figure 3 includes the Altair lander, which serves as a habitation element for the human crew. The SPR allows the human crew to perform sortie missions, venturing hundreds of kilometers across the lunar surface for science-related purposes. Communications between elements on the surface (e.g., Altair, SPR, and the In-situ Resource Utilization [ISRU]) and lunar orbiting elements (e.g., the Orion spacecraft and the Science/Communication Hybrid Orbiter [SCHO]) are accomplished via access links as shown in green in Fig. 3. Communications between elements in the lunar vicinity (including assets both on the lunar surface and in lunar orbit) and the Earth are accomplished via long-haul links, as shown in red. Short-range communications between surface assets

are accomplished via the IEEE 802.16e wireless protocol standard, which NASA has considered for use on the lunar surface.

Within this reference scenario, each summer intern was assigned an individual space element for which they were tasked to develop a conceptual communications system design. As a first step in the design process, the students performed knowledge discovery to gain a better understanding of the requirements and concepts of operations associated with their respective elements. To best capture the results of their knowledge discovery, each student formulated what the mentors referred to as "baseball cards", which allowed for a more formalized documentation of their findings and served as a quick reference for use in the analysis and design phases of the process. Next, the students performed communication link analyses between their systems and other systems within the reference scenario using documented NASA communications parameters to achieve the data rates and bit error rates as defined by their respective system requirements. Finally, the students formulated conceptual master equipment lists (MELs) and other deliverables including sub-system architecture/interface diagrams for their respective communication system designs.

The interns used various software tools to assist with their communications systems designs. The MindMapper software was used to assist with the knowledge discovery process. For communication link analysis and communication system design, the Satellite Tool Kit (STK) software was applied. Microsoft Excel was used to compile the master equipment lists for the communications system.

As mentioned briefly, each student individually produced several deliverables related to their design efforts, including:

- Systems overview
- Concept of operations diagrams
- Communications subsystem design
- Architecture/Interface Diagrams
- Communications link analysis
- Design optimization and recommendations
- Technology infusion study

Deliverables related to the architecture of the system (e.g., the systems overview, architecture/interface diagrams, and concept of operations diagrams) were completed using architecture frameworks such as the Department of Defense Architecture Framework (DoDAF) as well as others.

The students performed communications link analyses with the assistance of their respective mentors, and used realistic communications parameters such as those documented by current NASA programs. The communications systems designs were completed with input from related Subject Matter Experts (SMEs) and under the guidance of their respective mentors.

As a whole, the team deliverables included:

- Communications architecture model and simulation
- Sensor system design
- Earth science architecture

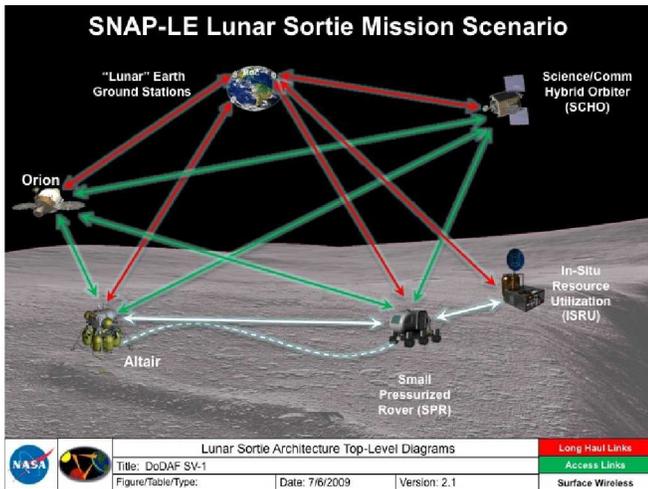


Fig. 3. Top-level architecture diagram of the Lunar sortie mission.

Throughout the project, the students continually integrated their individual elements into a STK scenario of the reference architecture. This allowed the students to analyze the predicted performance of each of their links given their respective communication payloads. If the students found that there was excess margin in their links, it would allow them to investigate the possibility of reducing the transmit power or antenna size of their communication payload to save on mass or energy. The students also utilized the integrated scenario for visualization and collaboration on concept of operations, design trade-off, and coverage analysis.

## V. CONCLUSION

During the course of this project we found that today's undergraduate engineering students are quite comfortable learning powerful software tools because of their general computer and technology acumen. These tools played a vital role in helping the interns digest the technical complexities of communication systems engineering. The interns displayed exceptional abilities in Internet and IT-based communication tools, which allowed them to learn and produce truly innovative systems engineering products.

Initially, the first summer of the project was planned only to be a learning and training experience. It was found later that the student work products and analyses were useful as a first "spiral" in the development process. With a successful program like this, NASA can proactively combat the current shortage of qualified systems engineers. NASA Space Communication and Navigation (SCaN) Program plans to continue these activities in order to build a summer intern model for training future systems engineers for years to come.

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## REFERENCES

- [1] L. Guerra, and W. Fowler, "Space Systems Engineering for Aerospace Undergraduates," *AIAA Aerospace Sciences Meeting and Exhibit*, Reno, Nevada, January 2008.
- [2] K. Bhasin, and J. Hayden, "Communication and Navigation Networks in Space System of Systems" in *Systems of Systems Engineering*, Wiley & Sons, pp. 348-384, 2008.
- [3] NASA, "Systems Engineering Handbook," December 2007, p. 6.
- [4] N. Augustine, et al., "Review of U.S. Human Spaceflight Plans Committee – Seeking a Human Spaceflight Program Worthy of a Great Nation," p. 113, October 2009.
- [5] M. Flanagan, et al., "NASA's Lunar Communication and Navigation Architecture," *AIAA SpaceOps 2008 Conference*, Heidelberg, Germany, May, 2008.
- [6] K. Bhasin, et al., "Lunar Communication Terminals for NASA Exploration Missions: Needs, Operations Concepts and Architectures," *AIAA International Communications Satellite Systems Conference*, San Diego, CA, 2008.