DEVELOPMENT AND IMPLEMENTATION OF A SMALL SATELLITE SYSTEMS ENGINEERING WEBINAR SERIES: A COLLABORATION BETWEEN THE UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS AND THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Craig D. Burkhard [(1)], Elwood F. Agasid [(2)], Alan C. Rhodes [(3)], Julianna L. Fishman [(4)], Bruce D. Yost [(5)], Kevin C. Conole [(6)]

[(1)] NASA Ames Research Center, Moffett Field, CA, 94035, 650-604-1170, craig.d.burkhard@nasa.gov
[(2)] NASA Ames Research Center, Moffett Field, CA, 94035, 650-604-0558, elwood.i.agasid@nasa.gov
[(3)] NASA Ames Research Center, Moffett Field, CA, 94035, 650-604-4513, *alan.c.rhodes@nasa.gov*
[(4)] Technology Horse, LLC, NASA Ames Research Center, Moffett Field, CA, 94035, 650-604-0637, julianna.l.fishman@nasa.gov
[(5)] NASA Ames Research Center, Moffett Field, CA, 94035, 650-604-0681, bruce.d.yost@nasa.gov
[(6)] NASA Headquarters, Washington DC, 20024, 202-358-2052, kevin.c.conole@nasa.gov

ABSTRACT

The United Nations Office for Outer Space Affairs (UNOOSA) in collaboration with the National Aeronautics and Space Administration (NASA) established a webinar series on NASA systems engineering standards and practices for the purpose of sharing knowledge in this area. UNOOSA's "Access to Space for All" initiative provides capacity-building opportunities in space science, technology, and space applications for United Nations member states. Due to the cooperation among established space actors, the United Nations, and emerging space entities, the initiative enables students from developing countries from all over the world to carry out projects using technologies and space applications. Through NASA's Small Spacecraft Systems Virtual Institute (S3VI), the four-part webinar series was designed to cover basic systems engineering and project management skills that are fundamental to planning, developing, and implementing an experiment or a space project and that serve as critical knowledge for those engaged in space activities, whether as a designer, builder, or manager of space infrastructure and services. The first series of webinars was convened over the course of November 2023 through February 2024.

1 BACKGROUND

The National Aeronautics and Space Administration (NASA) and the United Nations (UN) have worked together since NASA's inception in 1958, most actively with the United Nations Office for Outer Space Affairs (UNOOSA) and the UN Committee on the Peaceful Uses of Outer Space. This has been a productive partnership that has allowed NASA to expand its global reach and encourage countries to behave responsibly and practice peaceful use in the exploration of outer space. In December 2020, NASA and UNOOSA signed a Memorandum of Understanding (MOU) to expand and enhance their partnership. The Small Satellite Systems Engineering Webinar Series is one of many examples of this enhanced cooperation between the two organizations. After reviewing an extensive list of areas for possible collaboration, the topic of systems engineering was determined to be an ideal initial theme as it would

fill an existing knowledge gap for many teams from developing countries while addressing a topic of mutual interest between NASA and the UNOOSA. NASA's responsibilities in this effort included developing the overall plan for the webinar series, preparation of presentation topics and content for the series, providing assistance to the UNOOSA team with the registration and selection process, arranging for relevant subject matter experts to present on the topics associated with each of the four webinars, creating a Systems Engineering Webinar Series page on the S3VI website, and a number of other administrative and logistical activities. The responsibilities for the UNOOSA team consisted of advertising the opportunity, creating and implementing the webinar series registration and selection process, working with NASA to formulate webinar series topics, setting up a Small Satellite Systems Engineering Webinar Series web page on the UNOOSA site, moderating the webinars, and linking the webinar content to the UNOOSA site.

The webinar series was segmented into four one and a half hour webinars which covered topics related to the Fundamentals of Systems Engineering, Requirements and Systems Engineering, System Assembly, Integration and Test, and Spacecraft Handling. The final webinar in the series was an introduction to the S3VI. The agendas for the first three webinars focused on addressing a number of questions relevant to each particular topic. Examples of these questions include: What is systems engineering and what does a systems engineer do? Why does NASA use systems engineering? How do you define requirements for a small spacecraft mission? Why are requirements important to space missions? How are trade studies used to determine parts selection and why are they important?

The final webinar of the first series provided interactive discussions and demonstrations of the S3VI tools; shared information on additional webinar opportunities offered by the S3VI; and reviewed databases curated by the S3VI that include the Small Satellite Reliability Initiative (SSRI) Knowledge Base Tool, Mission Design Tools, Small Spacecraft Information Search, and the State-of-the-Art Small Spacecraft Report.

Future webinar series will be conducted with topics directly relevant to participants in the various Access to Space for All opportunities. The particular topics for these webinars are to be determined. The presenter will discuss details related to the first webinar series and future plans for additional series.

2 APPLICATION and SELECTION PROCESS

UNOOSA advertised the webinar series via its network with the intent to create a diverse, equitable, and inclusive application pool. In order to facilitate an interactive classroom environment, NASA and UNOOSA aimed to select 50 to 75 applicants. The registration announcement also specified that eligibility specifications included the ability to commit to attending all four live webinars, and applicants were required to either be currently enrolled in a university or have a degree in a space-related discipline. The registration also noted that applicants would be chosen based on relevant professional or academic experience as well as information related to how they intended to use the information and knowledge obtained. Priority would also be given to participants from government organizations, research institutes, universities, and other public and not-for-profit organizations of developing economies and economies in transition that are Member States of the United Nations. The country classification list of developing economies and economies in transition that would be used to assess applications was linked to the registration form.

UNOOSA received 888 applications from individuals around the world, with a wide variety of backgrounds ranging from undergraduate students to directors of research entities with advanced degrees in systems engineering. In consultation with NASA, UNOOSA selected the final 75 applicants to participate in the live webinar and informed those not selected that they would still be able to view the webinar recording a few weeks after each live event. UNOOSA also balanced the final selectees by gender and geographic region.

In the end, a large percentage of applicants who indicated they would attend all four webinars did not do so, which limited the ability to maintain a cohesive and consistent cohort. However, recordings were posted after each webinar and were accessed 191 times, demonstrating that the public was interested in accessing the content. Also to increase accessibility, NASA provided closed captioning in English of each webinar.

3 WEBINAR SERIES

The first webinar covered the specifics that comprise the fundamentals of systems engineering and project management to provide the audience with a high-level overview of systems engineering in preparation for the subsequent webinars. The topics that were discussed included a broad scope overview of systems engineering and how it plays a vital role in the design and implementation of a small spacecraft mission. The importance of having a systems engineering knowledge base and how acquiring various aspects of systems engineering knowledge helps to ensure success as a systems engineer. Attributes important for those considering systems engineering as a career and the roles systems engineers play within a project were also presented. The process flow from an idea to an operational system was discussed as well as the individual steps taken from the development of an original idea to production of the final operational system. The presentation also covered overall project management and included the following topics: project management activities as they relate to the systems engineer, program project and control (PP&C) and the common areas between the two; elements of managing a small spacecraft project; project life cycle phases, reviews and requirements; and the roles and responsibilities of a systems engineer.

Content for the second webinar focused on the importance of requirements for any space project. Explanations on requirements for NASA missions were followed by an interactive case study during which webinar participants listed the requirements for building a typical coffee cup. During the thought process, the participants provided a list of ideas, needs, questions, and finally requirements. The presenter discussed how to define requirements and how they are the first steps in the process. A discussion of the concept to plan to project which led from idea development through to a successful mission included a review of the verification and validation process and the associated V-graph. An example of the requirements creation process was presented. The example was based on the Apollo Lunar Excursion Module (LEM) which provided an actual case to explain the development of good requirements. The presenter shared how creating requirements assists with telling a story and how to use guidelines for writing good requirements through example requirements and questions that may be asked during the requirement writing process. A second case study was examined to engage the participants in thinking about developing requirements for a mission to explore Europa. A few key areas of focus for requirements development in this case included ground systems, launch systems, spacecraft systems, and the science/payload systems. The webinar concluded with a discussion of trade studies and how they are performed. An overview of the concept of operations (ConOps), what they are, and their importance was also presented.

The third webinar in the series comprised topics related to systems assembly, integration and test (AI&T) in addition to spacecraft handling and all aspects associated with these areas. The presenter utilized common examples of objects that are used each and every day such as an automobile to a NASA small spacecraft mission to convey what is meant by systems assembly. In addition, the NASA project life cycle and associated phases were well covered, including key reviews and how the various phases play vital roles in the steps for systems assembly, integration and test, and spacecraft handling. Small spacecraft subsystem components were clearly defined and how each plays in the overall design of a spacecraft. The purpose of the System Integration Review (SIR) and the role it plays in the AI&T phase of a mission were described. A number of other elements related to this topic were explained to include a review of spacecraft systems and subsystem elements, key resources, examples of integration and test roles and responsibilities, and key personnel. The webinar continued with discussions related to spacecraft integration and testing listing the elements and providing some examples. The presenter shared the different types of testing, outlined the various integration phases of a spacecraft (subsystem or instrument, spacecraft bus, observatory or payload, and launch vehicle), plans and procedures, outlined the purpose of the Test Readiness Review (TRR) and its function, provided examples of component subsystem level tests, and functional and comprehensive testing of fully integrated spacecraft. This webinar concluded with discussions on thermal vacuum environmental tests and vibration environmental test parameters and function.

The final webinar in the series offered an introduction to NASA's S3VI which provided the participants an overview of the institute's purpose, products, and activities. The resources that the S3VI provides benefit the overall small spacecraft community which is comprised of individuals and organizations from sectors to include academia, industry, and other government agencies. In this webinar, descriptions and demonstrations of several products were provided to the participants. The knowledge of the type of resources that are available and where it can be found are important to systems engineers and those managing projects as they develop their own particular mission concepts and eventually design and build flight hardware for either ground experiments and/or spaceflight missions.

4 SURVEY RESULTS and FEEDBACK

At the conclusion of the Small Satellite Systems Engineering Webinar Series a survey questionnaire was sent out all the participants to obtain their feedback on the four webinars, the overall structure of the series and thoughts for future webinars. A total of sixteen participants responded to the survey questionnaire. Figure 1 shows the compilation of responses to questions that addressed the overall series. The responses for the entire series were extremely positive.

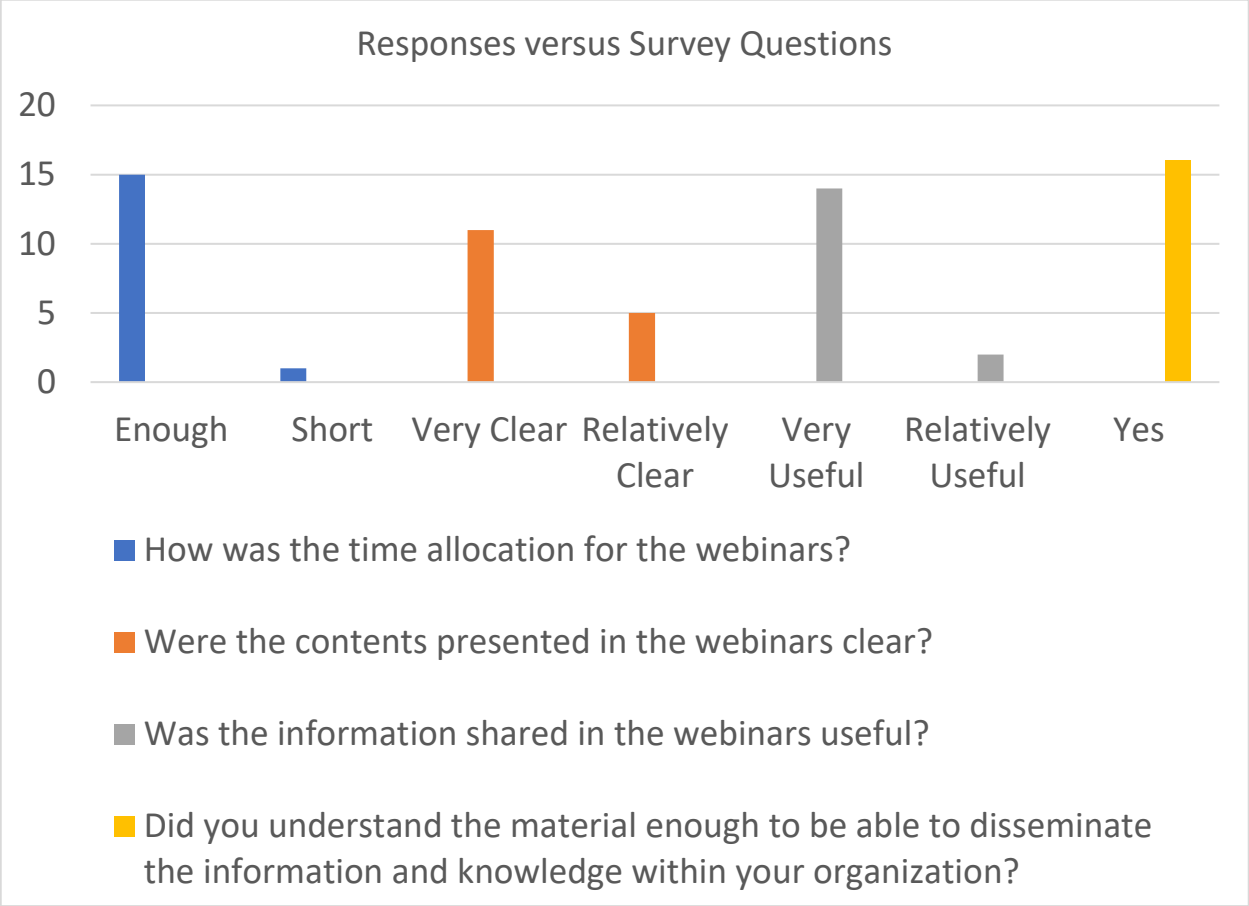


Figure 1. Responses obtained from the webinar series questionnaire.

The feedback obtained from the questions related to overall time allocated, content presented and delivery of the material to the participants to disseminate within their particular organizations was extremely positive. This is a clear indication that the webinar series was very successful.

A number of additional questions were prepared and answered by webinar series participants. These include:

- What did you learn through the four sessions?
- What other activities and/or themes for webinars would you like to see from UNOOSA and NASA?
- What did you wish to learn that was not covered in the webinar series?
- Do you have any overall comments/recommendations/observations about the webinar series?

A few responses received for "What did you learn through session one?" include the following:

- "I got an understanding of Systems Engineering, Systems Engineer, and his role during project life, the elements of managing a small spacecraft project, the project's life cycle phases and project elements, experience from NASA and systems engineering implementation for the success of each and every project that will allow me to implement systems engineering principles for my projects with my institute."

- "The processes of mission planning, development, integration and testing were explained in a clear way that can be applied to future nanosatellite missions from South America."

- "We were focusing on the fundamentals of systems engineering, provided me with a solid foundation in key principles and methodologies. I gained a deeper understanding of the systematic approach to designing and managing complex systems. Learning about requirements analysis, system architecture, and the importance of interdisciplinary collaboration was particularly enlightening."

Reponses received for "What did you learn through session two?" include the following:

- "I think that it was a good talk to clarify a series of fundamental steps to make an optimal requirements definition and I will use this topic to perform new schemes of requirements in the fields of spacecraft operations."

- "This has helped me streamline just what I need to understand and know before commencing any project."

- "The second webinar focused on the following: How do you define requirements for a small spacecraft mission? Why are requirements important to NASA missions? How trade studies are used to determine parts selection and why is it important? What is a concept of operations (ConOps) and why is it vital to a NASA mission? Through learning about requirements, I've realized how important it is to have clear, specific requirements before designing a system. I've learned how to collect, analyze, and verify requirements to make sure they accurately reflect what stakeholders want the system to do. I plan to use this knowledge in the future, especially when planning projects and developing new products. By following a structured approach to requirements engineering, I hope to avoid problems, make stakeholders happy, and build solutions that are even better than people expected."

"What did you learn through Session 3?" responses include:

- "Insights from the System Assembly, Integration and Test, and Spacecraft Handling webinar, I'm enhancing my project approach. Applying best practices in assembly, integration, and testing, I aim to ensure seamless systems functionality. This knowledge will not only elevate project efficiency but also contribute to educating future STEM professionals. Excited to implement these principles and foster collaborations for advancement in engineering practices globally."

- "During this session, I gained valuable insights into the intricacies of system assembly, integration, testing, and spacecraft handling. The discussions on best practices, quality control measures, and the importance or precision in these processes were particularly enlightening. I plan to adapt this knowledge by implementing a more systematic approach to systems assembly and integration in my future activities, ensuring through testing protocols and meticulous spacecraft handling. This newfound understanding will not only contribute to the efficiency of our projects but also enhance the overall reliability and success of future endeavors."

- "During the 3rd webinar, I learned about a small spacecraft project, subsystem components of a small spacecraft, and the systems assembly, integration, and testing with the AITS, test plan and

types of tests, as well as how to use safe spacecraft handling and the different steps involved. The importance of a space mission. It was also included with experience shared from NASA's projects has big implications for my future careers and project implementation."

The responses for the question "What did you learn through Session 4?" include:

- "Gaining insights from the NASA Small Spacecraft Systems Virtual Institute introduction, I'm refining my approach. By assimilating key principles, I aim to enhance project strategies, fostering efficiency, innovation, and collaboration initiatives. Excited to apply these learnings and contribute to the advancement of small spacecraft systems through collaboration, particularly with fellow African countries."

- "In this session, I will mention the State-of-the-Art (SoA) Small Spacecraft Report. This is really amazing material. Also, I'm impressed by all the resources available that can support the design and development of small satellite missions. Finally, with all the knowledge and material available, it is a matter of commitment and effort to purse a small satellite project."

- "I learnt how to access different resources for small satellite systems. I will apply this in my ongoing research of improving the reliability of space-to-ground optical communication using small satellites."

Responses received in answer to the question, "What other activities and/or themes for webinars would you like to see from UNOOSA and NASA?" include: on-site training, practical, and hands-on experience sharing; collaborative robotics/other STEM related topics, possible practical collaborations and mentorship programs; and more training and even, if possible, the opportunity to visit NASA sites especially for individuals from developing countries.

A few responses were captured from the question, "What did you wish to learn that was not covered in the webinar series?" These include: "Learning some real demo from initial design up to the launching stage, how to apply Model Based Systems Engineering (MBSE) techniques in small satellite systems engineering, and would like to know more about the processes that ended with a spacecraft project proposal," and "a session more focused on the engineering design process and risk management and reliability identification."

Responses to the question, "Do you have any overall comments/recommendations/observations about the webinar series?" included: "It was perfect, good learning opportunity; it was very interesting, wonderful, interactive and I look forward to the next upcoming webinars; "found the webinar series to be informative and well-structured, the presentations were clear and engaging, providing a solid foundation on the subject matter, I would suggest incorporating more interactive elements such as Q&A sessions, live demonstrations, or panel discussions to enhance participant engagement. Additionally diversify the content with real-world case studies and practical examples could help bridge the gap between theory and application. Overall, I appreciate the effort put into the series and believe these enhancements could further elevate the learning experience for participants"; and "I want to thank NASA and UNOOSA for offering this great opportunity to close the gap for developing countries that want to establish their own space programs; and very helpful source of training and awareness on small satellite systems engineering, keep it up!"

5 SUMMARY and CONCLUSIONS

The development and implementation of the Small Satellite Systems Engineering Webinar Series between UNOOSA and NASA was successfully accomplished. Through the registration process a total of 888 applications were received from individuals interested in attending the live webinar series. Out of the total applicants, 75 were invited to participate live in the webinars. The four webinars in the series were recorded and have been posted to the S3VI website along with the presentation charts. These materials may be found:

- S3VI website: https://www.nasa.gov/smallsat-institute/systems-engineering-series/
- UNOOSA website: https://www.unoosa.org/oosa/en/ourwork/access2space4all/NASA.html

6 FUTURE WORK

Currently, there are ongoing discussions regarding the continuation of the Systems Engineering Webinar Series. Future series will similarly be available for all UN member states to participate. The plan is to have two series of four webinars each that are an hour and a half in length. The first series is tentatively planned to be held in the fall of 2024, spaced three weeks apart (September-October-November) and the second series will be in winter (January-February-March), also spaced three weeks apart. Potential topics include but are not limited to: configuration (documentation) management; the various reviews in a project lifecycle from Preliminary Requirements Review through Acceptance Review (explanation of what is required for each review); a deeper look at how to define Requirements; and Testing when means available are limited. The UNOOSA and NASA teams will also review the list of topics proposed by the participants from the first webinar series to determine topics of interest to advance their learning in the design and development of future small satellite missions. Participation will likely not be limited as in the initial webinar series in order to broaden access to the live sessions.

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