Performance Support System That Facilitates the Acquisition of Expertise

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ABSTRACT

A performance support system (PSS) for a satellite systems crew, called the Adaptive Decision Enabling Performance Support Toolset (ADEPT), has been designed to promote performance and the continued development of operator expertise. Several characteristics of the satellite operator domain make designing a tool from this perspective particularly appropriate. For example, satellite systems crewmembers experience frequent periods of low activity and subject matter experts have indicated that better crewmembers tend to use that time to seek explanations about how the system works and how their tasks affect the system. ADEPT will support performance and foster the development of expertise by providing satellite systems crew with knowledge-based tools that offer explanation, guidance, and visualization. For example, it features a satellite visualization tool that crewmembers can use in real time to assess satellite positioning or that they can use during periods of low activity to improve their conceptualization of the remote system components they maintain. In addition, the satellite system for which this PSS is being developed is rapidly evolving. Thus, there is always more to learn, and a need to supplement formal training as it struggles to keep pace with the changes. This paper will discuss the design process and problem definition of ADEPT, outline the functions that support learning, and conclude with lessons learned from the design process and possible opportunities to generalize the concept of including learning support in a PSS.

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INTRODUCTION

To ensure that the United States retains its air superiority, the U.S. Air Force (USAF) is upgrading its space capabilities. Space technology is already a vital component of USAF defense capabilities, and the addition of the Space Tracking and Surveillance System (STSS, formerly the Space Based Infrared Low System), will help ensure the United States' military dominance. The STSS is projected to become operational within approximately five years. However, the ground systems that will likely be used to manage STSS satellites are already in place, operational, and being used to manage existing defense satellites.

The function of STSS is critical to successful military operations and to the protection of the United States. Accordingly, the proper operation and maintenance of the associated satellite constellations is of acute importance. The implementation of STSS will involve launching several low-earth orbit (LEO) satellites, possibly without increasing operational crew size. The anticipated increase in workload associated with the introduction of these additional satellites served as the impetus for developing a performance support system (PSS), called the Adaptive Decision Enabling Performance Tracking (ADEPT) toolkit.

The focus of this paper is on the ways in which ADEPT performance support functions contribute to the continued acquisition of expertise by the satellite systems crew. Specifically, in addition to supporting performance, these functions help to improve operator comprehension of their work domain and of information relevant to the tasks they are performing. The use of ADEPT to contribute to the development of satellite systems crew's expertise is appropriate for at least three reasons. First, it is consistent with the premise, also referred to as the *Janus Principle*, that performance support and training are fundamentally related and inseparable (e.g., Hoffman, 2001). The use of systems that enhance expertise in the actual work environment helps workers further develop the skills and knowledge they gained in the classroom and artificial, non-operational environments and also promotes the ability to adapt effectively to new situations and unexpected challenges (e.g. Kozlowski, 1998). Second, the focus of STSS is on advancing satellite technology, not ground systems or operator workstations. Consequently, the satellite systems crew is facing significant changes associated with the introduction of new technologies, yet their workstations are not being upgraded in ways to help them understand or better interact with those technologies. Third, the nature of STSS operation involves frequent periods of low activity, which provides an opportunity for operators to utilize an appropriately developed learning tool during their work shift. Such a tool will provide the satellite systems crew with the opportunity to learn while they are working, but not tax their performance. In addition, satellite systems crewmembers expressed interest in using ADEPT as a learning tool. Thus, there is evidence that ADEPT will be well-received on the basis of its contributions to learning as well as performance support.

At a minimum, ADEPT contributes to learning by improving the quality of the experience crewmembers gain on the job. More specifically, ADEPT will supplement operator experience with information and guidance so that what they learn is procedurally accurate and enriched with relevant knowledge (i.e. so they understand better what to do, when, how, and why). Other ways in which ADEPT performance support is designed to help build operator expertise will be discussed throughout this paper. This paper additionally provides an overview of the ADEPT design process, followed by a description of the ADEPT PSS functions that support learning. We conclude with a discussion of lessons learned and the applicability of the learning-enhanced PSS concept promoted in this paper to other domains.

DEVELOPMENT PROCESS

The development of ADEPT relied heavily on user and other subject matter expert (SME) involvement. First, in the problem definition phase of this effort, the performance support needs of the satellite systems crew were identified by working with SMEs and users. Then, an iterative design process involving SMEs and users proceeded. Specifically, Microsoft Visio was used to mock up screenshots of the system. These screenshots were used to help users visualize the system as it developed and thus provide better feedback and reduce time between design iterations. Below, we describe the problem definition phase of the design process in more detail.

Problem Definition

The problem definition phase involved defining the performance support (and learning) needs of the STSS systems crew and the domain characteristics that might influence how those needs would be best addressed by performance support technology.

A number of characteristics of the satellite operations domain and of the future STSS operations domain, in particular, both encourage the development of a PSS that helps build expertise and influence the ways in which that help should be provided. Some of the more influential of these characteristics are described below.

One example of an important domain characteristic is that the STSS operations environment is continually changing. Software fixes, system refinements, new lessons learned, and procedural changes require crewmembers to perpetually adapt. Currently they do so without any support other than a ground system derived from antiquated technologies. In addition, the satellite systems crew has a distinct need for performance support to keep up with the increasing workload as more satellites are brought online. The crew also needs learning support functions to help in adapting to the changing system and procedures. Further, during the period of transition when the new satellites are being brought online, the crew will be faced with an even greater occurrence of such changes. With an increase in the number of satellites maintained, the frequency and volume of procedural changes will increase as well, influencing the type of support needed by users.

In addition to the workload increase expected with the implementation of STSS, stressors such as time pressure and the awareness of grave consequences of error are domain characteristics that contribute to the implementation of performance support through ADEPT. Different anomalies reflect different levels of criticality, some of which require immediate resolution. Adding to the time pressure, crewmembers are aware that if they do not succeed in resolving the most critical anomalies the satellite could be permanently lost, representing a huge resource loss. Thus, it is important for crewmembers to recognize quickly the type of problem that they are addressing and have ready access to any information and guidance they may need to support their response to the problem.

Intra-team communications manifested as another important domain characteristic for performance support. The operations floor hosts both the satellite systems crew and the mission crew. Currently the satellite systems crew communicates by shouting, and this distracts the other members of their crew and the members of the mission crew. In fact, the mission crew often asks the satellite systems crew to stop shouting. As more satellites come online, and thus more frequent anomalies, there will be more shouting, further increasing distraction and confusion for both crews. Because crewmembers indicated that shouting serves them in ways an electronic communications tool could not, (i.e. general situation awareness from hearing verbal exchanges) the present approach emphasized development of a messaging system that will supplement, not replace, shouting.

There are also several opportunities to support satellite systems crew in responding to system anomalies. Currently, they detect and investigate anomalies by one of several means. For example, one way involves a simple alarm list. When a new anomaly is detected, the list is updated and the crewmember notified. Other ways involve a ‘drill-down’ approach in which major satellite systems are represented by a set of backlighted buttons that the operator can monitor. When an alarm occurs, the button for the associated system will turn yellow or red. The operator can click on the colored system button to view buttons representing sub-systems of that system. The operator can then click on sub-system buttons to view subsystem parameters, or *measurand* values. Then the operator can click on any measurand to view more detailed and diagnostic information. At this point, the crewmember can identify which value is out of range, and determine the appropriate course of action to follow. The list approach is more straightforward and involves fewer steps; however, ‘drill-down’ approaches are preferred by users and reveal more information about the alarm, helping the crewmembers to understand better the issue that must be resolved. With an increased workload, the drill-down approach could become too time-consuming. However, the benefit it offers, a better understanding of the anomaly, should not be disregarded. In general, the current methods for investigating and responding to alarms suggest numerous opportunities for performance support.

The prevalence of hard to decipher alphanumeric data is another aspect that needs to be addressed. Alphanumerics, or *mnemonics*, are used to represent both sub-system components and anomaly alerts, but do not clearly identify either. In the case of an anomaly, the satellite systems crew must be able to recognize the type of anomaly to determine a course of action and recognize the components involved in order to adjust the appropriate parameters. Although crewmembers become familiar with mnemonics that they encounter often, there are many with which they are not familiar. Thus, several crewmembers indicated a need for support in understanding the mnemonics.

Another area in which operators need improved support involves accessibility to various reference materials that provide guidance to the satellite systems crew in maintaining the satellites. For most reference needs, the crew currently depends on a system involving hard copies of command plans, procedures, schedules, and logs that can be found in shelved binders. To access relevant information, each crewmember must get up from his workstation, find the appropriate notebook, and then turn through the pages to find the specific information he seeks. A more accessible and easy to use reference system certainly seemed warranted.

Iterative, User-Centered Design Process

The design approach was intentionally dynamic, iterative, and user-centered. Mocking up screenshots instead of constructing functional programs resulted in a more user-centric process. Although speed was a clear benefit to this method, the storyboarding technique used to engage the users and elicit their feedback also added significant value. Instead of user feedback in the form ‘this is good’ or ‘this is bad’ or ‘this would be better if...’, the storyboarding technique encouraged users to develop their own ideas of what the PSS *could* be. With the flexibility of being able to add new functionality at any point in the design process, users were able to envision the system as it evolved and contribute meaningfully to the design process.

One example of the value of the flexibility in this design approach is the development of the visualization tool in ADEPT. After most of the main functions of ADEPT had been identified, a user injected the need for a simple visualization tool to help understand satellite dynamics. For example, before a satellite enters eclipse, the crew must prepare the system to handle the different sensor readings resulting from traveling through the Earth’s shadow. The user also indicated that crewmembers sometimes forget to prepare the systems for the upcoming eclipse. As a solution, a simple two-dimensional, orthographic viewer of the Earth and the satellites was proposed to enable crewmembers to identify upcoming eclipses more easily and also to realize more quickly when current alarms are a result of an eclipse for which the satellite was not prepared. This viewer was labeled as the “SatView.”

The SatView function continued to exercise the flexibility of the design process. Subsequent user feedback collaborations and the development of SatView combined to produce a robust viewer, which was very different from the original two-dimensional concept. By presenting iterative mock-ups to users and collecting feedback, the simple viewer had evolved into a three-dimensional, medium-fidelity simulation of the satellite constellations. Later in the design process, the learning support aspect of SatView inspired the development of another performance support function. From discussing with users how they might use the fully developed SatView, it became apparent that they would use the SatView to better understand the satellite dynamics that caused anomalies and also use the capability to look ahead and determine upcoming satellite dynamics. The crew’s interest in exploring future behaviors of the system suggested the need to automate the prediction of expected future system behavior. This function is called “Orbital Attributes” and is described in a later section of this paper. Thus, the iterative, user-centered design process leveraged both performance support opportunities and learning support opportunities to inspire functionalities that support both performance and learning support.

When users were presented with the developed SatView idea, it gained immediate acceptance. Crewmembers revealed that they wanted to better understand the system, and that they wanted to use the viewer to explore satellite dynamics. Further, the SatView function also supports the crew by notifying them of upcoming satellite dynamics through the Orbital Attributes function. In addition to support performance, this tool engages users and promotes their exploration of the remote system behavior. By supporting the acquisition of expertise, SatView also promotes crew adaptability. When crewmembers understand their remote system environment more thoroughly, they will be better able to adapt to changing command plans and procedures. Thus, the SatView function became a key component of ADEPT.

During the development of the SatView functionality, users revealed that they wanted to learn more about the remote systems that they maintain. Earlier in the design process an operator indicated that the best trainees stand out because they are the ones who want to learn more and further develop their understanding. This observation strongly implied that the acquisition of expertise in this domain is influenced by the motivation level of the trainee (e.g. Hoffman, 2001).

As insight was gained concerning the use of SatView, the designers recognized the connection between ADEPT and a cognitive prosthesis design theory. This theory, called the Janus principle, asserts that knowledge-based cognitive prostheses should not force a separation between learning and performance, but rather should integrate them (Hoffman, 2001). Kozlowski (1998, p. 116) also notes that "Whereas basic skills can be developed in conventional training environments (i.e., the classroom), adaptive skills are fully developed and refined in the performance environment. This means shifting more training to the performance context and developing new training strategies and techniques that can be integrated into the work environment," further supporting the inclusion of learning support in a PSS developed for a domain such as STSS.

Based on users' interest in using ADEPT as a learning tool and the logic of the Janus principle, design objectives were adjusted. Specifically, design decisions were made based on learning, as well as performance support considerations, and the requirement to contribute to learning became explicit. Users had both the resources (periods of low activity and the SatViewer) and the need to develop and reinforce their knowledge during their work shifts. The Janus principle became an important underlying theme for ADEPT in recognizing that the PSS can blend both performance support with expertise acquisition support. The next section overviews the design solutions that reflect learning support in the ADEPT performance support system.

DESIGN SOLUTIONS

The following section will describe design solutions, explaining how each responds to the problem definition and to learning support. It is important to note first, however, that the application of the Janus principle here is not a blending of *training* and performance support, but the enhancement of performance support with continued learning opportunities.

SatView Function

As described earlier, the SatView function evolved from a request by a user to incorporate a basic visualization tool. The development of this tool further revealed the users' motivation to learn more about the remote systems that they operate.

The purpose of the SatView, then, is to promote a better understanding of the remote system and why anomalies may be occurring. For example, if a satellite is about to enter the Earth's shadow, its subsystems need to know that values such as temperature are going to drop drastically, quickly, and that this is not cause for alarm. The crew prepares the sub-systems to deal with these types of atypical situations. In the eclipse example, if a crewmember does not prepare the temperature control subsystem in time, alarms will be triggered. An unaware crewmember may be unaware that the alarms do not indicate failure and attempt to resolve them. The operator could consult the SatView after receiving the alert and easily recognize that the satellite is in eclipse. After adjusting the appropriate parameters, the operator could also utilize a period of downtime and return to SatView, rewinding and fast-forwarding through simulated time, to further investigate the satellite dynamics of the eclipse. Other such anomalies can also be better understood through the visualization capability offered by the SatView functionality, promoting an improved understanding for the operator. Further, crewmembers could also utilize the SatView to explore possible upcoming situations, such as eclipse. This idea was further developed and implemented in a function called "Orbital Attributes."

Orbital Attributes Function

In the eclipse example described above, crewmembers are actually alerted of upcoming eclipses well in advance. Because there are several steps involved to prepare each satellite for its eclipse period, crewmembers receive advance notice and then work to prepare a satellite for the eclipse over a period of months, but the step of preparing the systems for the change in data may still be overlooked. A reminder function, Orbital Attributes, was therefore added to the SatView concept for predicting potential anomalous situations. Reminders generated from the SatView simulation data are displayed in a list underneath the alarms list, for significant visibility. Although primarily a performance support function, the Orbital Advisory tool includes a link to the SatView to encourage crewmembers to explore the satellite dynamics in the context of their remote environment, and thus represents another means of enhancing learning through performance support.

AWE Display Function

Because resolving anomalies successfully is one of the primary tasks of the satellite system crew, the most significant performance support function of ADEPT is the alarm display. Due to the constraint of being able to use read-only data from the operational system (a discussion of this constraint is outside of the scope of this paper), the alarm display uses only the Alert, Warning, and Event (AWE) information already available to the crewmembers. The advantage of the ADEPT alarm display is that it optimizes the information based on what crewmembers need to see when they are dealing with an anomaly. This provision includes links to checklists and information that they previously had to find based on their own memory. In the current system, although the present list display is more concise, crewmembers prefer using the present drill-down display to find the incorrect parameters, as mentioned earlier. Thus, to provide an alarm display that is more useful than the present individual displays, attributes from both the current approaches were incorporated.

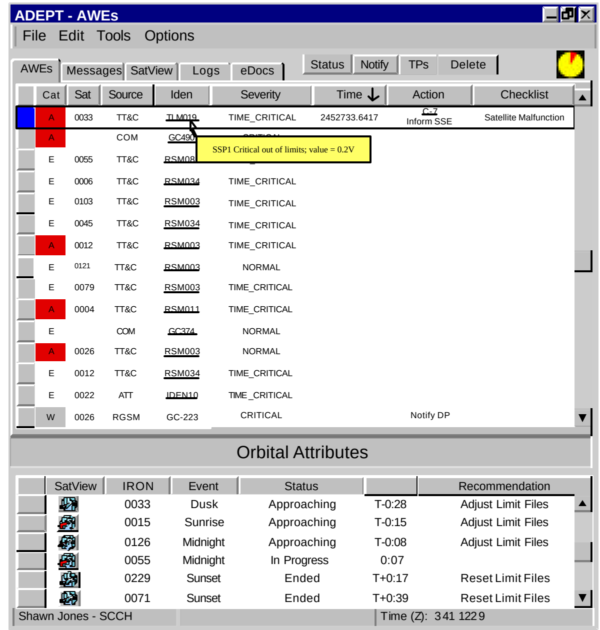

Figure 1. AWE Display with Orbital Attributes

The resultant alarm display (Figure 1) concept was a hybrid of the current system's list and drill-down architectures. The list structure serves as the basis for the current alarm display and is enhanced by pertinent information, such as that obtained through the current drill-down process. Additionally, information about a mnemonic in the alert list display is presented by mousing over an individual mnemonic, adding learning value to the display. Previously the crewmembers merely associated cryptic mnemonics with courses of action. Now they have the opportunity to more quickly recognize the type of problem that they are resolving. Although the alarm display primarily serves as a performance support function, it also offers valuable learning support.

Messaging Function

In response to the need for performance support to improve communication, an online messaging system was designed. Crewmembers wanted something that would be as easy to use and as effective as shouting, but also would reduce interference with the mission crewmembers. The layout of the operations floor is such that crewmembers can be far enough away from one another that nothing short of a shout would be effective without additional technology. Also, crewmembers develop a significant amount of situational awareness by overhearing other shouting. That is, there is a natural sort of eavesdropping that occurs with the shouting system that promotes better awareness for all crewmembers. A system was needed that would enable crewmembers to be aware of other crew members' communications, would be easy to use, and not add more work or further distraction.

The communication problem posed a challenge for system design. Voice-based communications systems were beyond the scope of this effort. So, an online text-based messaging concept was introduced. Concepts that reflected both a more traditional email format and the newer instant messaging format were explored. An instant-message-email hybrid was finally adopted (Figure 2). The design not only allows for chat-style communications between two or more crewmembers, but also reflects the benefits of stored emails by offering an archiving function. In this way, communications can be stored and retrieved by searching for one or more of several features such as date, crewmembers, keywords, and topic. Crewmembers can use the sort function to find messages that could help them better understand a current anomaly or one that they recently resolved but would like to understand better. Overall, the messaging function reflects the Janus principle in that it provides the opportunity for crewmembers to refer to old communications to leverage, and thus learn from, previous situations.

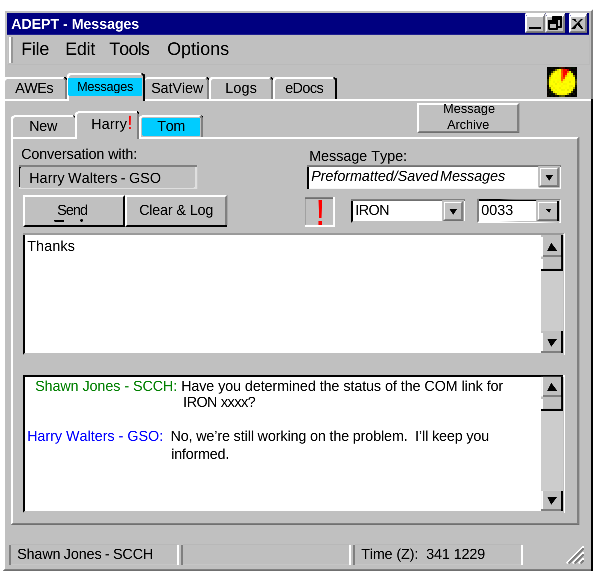

Figure 2. Messaging Display

eDocs Function

Another opportunity for performance support lay in the shelved, binder-based reference system. The types of information stored in this system were identified and then made available in ADEPT through a reference tab (Figure 3), called "eDocs." Crewmembers will be able to find documents in eDocs representing the changing procedures (there's also a shortcut in the alarms window that keeps crewmembers apprised of the most current procedure), local procedures, and educational background material. All of this information is currently available to crewmembers, but is contained mostly in a shelved binder system. The educational material provides another opportunity for crewmembers to engage in exploratory learning during a period of low activity. Although visually less engaging than the SatView, the robustness of the information in this reference document promises to be of considerable value to users of ADEPT. The eDocs function also serves as an easily adaptable tool to which other learning support resources may be added.

Although there are several functions and sub-functionalities that add significant value to the ADEPT system as a performance support tool, many are beyond the scope of this paper. The ones outlined above demonstrate the underlying theme of the Janus principle: learning support and performance support are inseparably coupled.

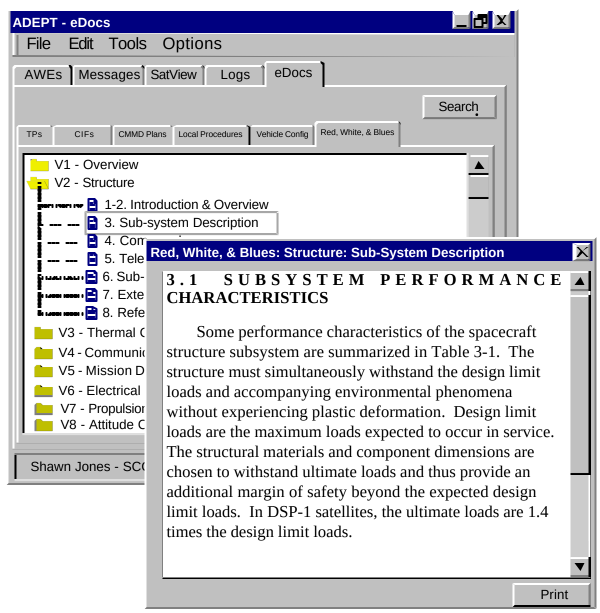

Figure 3. eDocs Display

DISCUSSION

The overarching idea behind ADEPT is to help crewmembers develop a more robust understanding of the systems that they operate and the anomalies that they resolve. Although not all crewmembers will become experts, ADEPT should assist more crewmembers in acquiring expertise than is possible in the current system.

Lessons Learned

One lesson learned from the ADEPT design process reflects aspects of modern innovative product design philosophy. A product should be not only usable, but *desirable* by the user as well (e.g. Cagan & Vogel, 2002). Field users gave very positive feedback to the matured ADEPT concept. This positive feedback, particularly the users' interest shown in the SatView function, demonstrates the desirability of ADEPT to its intended users. Aiming to include desirability in design is important because it ensures that users will not only be able to benefit from the use of the product, but also that they also want to use it.

Further, desirability contributes to ADEPT's facilitation of expertise acquisition. By making the satellite systems crew's experience more enjoyable, desirability encourages the crew to learn more about their responsibilities and the remote systems that they operate. Users' acceptance of the ADEPT concept promises that they will want to use the learning functions provided, and thus facilitates the acquisition of expertise.

Finally, the users' positive feedback to the ADEPT concept serves as its own lesson. The design process facilitated the development of a concept that concisely responded to users' needs. The positive feedback received in response to the concept demonstrated the success of the functionalities of ADEPT. Considerations of how the concept of a PSS that supports learning can be generalized across domains follow.

Generalizability and Future Directions

The PSS described in this paper represents solutions derived in support of a very specific domain, satellite operations. However, designing PSSs so that they contribute to learning is an objective that can be pursued across other domains as well.

One example is another remote operation domain, unmanned aerial vehicles (UAVs). As in the case of satellite technology, UAVs are remote systems that may have important consequences for the future of warfare. As the use of this technology is still evolving, it is especially important to note ways in which the crewmembers may benefit from a PSS that can help them simultaneously build domain expertise. The importance of a user-centered design approach in UAV operations has already been introduced by Mouloua et. al. (2003). Building domain expertise while operating the system is one important way to contribute to more robust user-centered design of UAV operator interfaces.

Another example of potential generalization is to the medical command and control (C2) domain. This domain is very knowledge intensive and refresher training provides a significant and necessary opportunity for learning support to be coupled with performance support. Further, the increased accessibility of expertise provides considerable potential for improving performance by coupling learning and performance support.

CONCLUSION

The Janus principle asserts that learning support and performance support should not be separated, but rather integrated. ADEPT followed a user-centered, iterative design process that incorporated the Janus design principle. Coupling learning support with performance support promises to return improved results and, as in ADEPT, may even provide the opportunity to improve desirability. Finally, this design principle can be applied throughout other domains such as unmanned aerial vehicles and medical command and control.

ACKNOWLEDGEMENTS

The authors wish to thank AFRL/HEA and SMC/MTMG for their sponsorship, continued support and feedback, and help in gaining access to our invaluable subject matter experts. The authors also wish to recognize Mr. Alex Cole for his invaluable assistance as a subject matter expert. Additionally, the authors would like to extend thanks to the USAF satellite community for providing valuable feedback and support to this effort.

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