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Investigation of Remote Work for Aerospace Systems Engineers

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Abstract. In many industries, remote work is becoming increasingly common. The global COVID-19 pandemic has accelerated this shift, which poses a particular challenge to aerospace systems engineers (ASEs). ASE work is complex, consisting of a number of tasks that are traditionally largely conducted in-person. Little literature exists to establish a basic understanding of remote work in the context of aerospace systems engineering development projects.

This paper presents the results of an interview study, where hypotheses are explored to provide initial understanding of remote work in this context, and to motivate future studies. Analysis revealed: Design reviews experienced both challenges and benefits; Remote work has complicated collaborative work with artifacts; Assembly, Integration and Testing activities experienced significant challenges; Solutions have been thought of or implemented by ASEs, in particular the use of Slack and strategies managers may use to support their team members. Several additional research questions are motivated.

Introduction

The response to the global COVID-19 pandemic has resulted in the implementation of restrictions to protect public health. In some regions, these restrictions have forced industry engineers to change from co-located work, where they are present in the workplace with their teams, to distributed work, working from home, away from their coworkers and workplace. The effect of the change to distributed work from individuals' homes, or simply *remote work,* is significant. Systems engineering organizations are facing unprecedented challenges to their traditional workflows because of remote work, which interrupt their ability to conduct design reviews, collaboratively develop documentation, interact with and test hardware and conduct day-to-day activities in-person.

The practice of systems engineering applies to fields within and outside of aerospace, where its implementation is critical to the success of complex engineering development projects in a cost-effective way (SEBoK Authors 2020). While remote work of engineers has been studied

(Lumseyfai et al. 2019), there is a lack of literature on remote work specifically for systems engineers, of which aerospace system engineers (ASEs) are a subset. Given that mobile internet, digital tools, cloud computing and storage, and video conferencing have enabled new models of work in many industries (Bailey, Leonardi & Barley 2012), it is expected there will be increased remote and distributed work by systems engineers in the future.

Collectively, this represents a significant gap in understanding the practice of aerospace systems engineering, which this paper aims to address. To generate practical insight to support remote work for ASEs this paper presents a broad exploratory study, where information on the challenges of ASEs will be gathered through qualitative analysis of interviews. This study will offer insights and solutions that can be used by these engineers and their organizations to improve effectiveness within systems engineering and beyond, in present and future remote work scenarios. The study targets experiences and challenges faced during the remote work period, which are the times when COVID-19 restrictions led to a remote work situation in the region where this study takes place.

Background

Remote Work. The concept of remote work is not new and has been studied before the COVID-19 pandemic, both within and beyond the field of engineering. Given the socio-technical nature of engineering work, relevant papers on this topic highlight a wide variety of factors which influence virtual team success, such as knowledge sharing and trust (Alsharo, Gregg & Ramirez 2017), complexity of shared mental models (Schmidtke & Cummings 2017), geographic dispersion (Gibson & Gibbs 2006) and communication (Montoya et al. 2009).

What distinguishes this paper from past work is the explicit focus on engineers in the combined aerospace and systems engineering positions, and the focus of this study on sudden and unplanned remote work driven by COVID-19. Work in aerospace systems engineering is characterized by highly complex, often safety-critical, highly innovative and technically challenging projects (Madni & Sievers 2013); this work requires high levels of collaboration, coordination and documentation, all likely to be more challenging in a remote work reality.

Previous transitions to remote work by engineering organizations have been implemented intentionally, with time and resources dedicated in advance to making it a success. These would have been undertaken with the willingness of those working remotely. The remote work resulting from COVID-19 investigated in this study features a much lower degree of intentionality and is not necessarily the choice of the individuals impacted. Another drastic difference is the scale of remote work for an organization, as the restrictions in many regions severely limit the number of employees present in the workplace, so the entire workforce is impacted. The global nature of COVID-19 further extends this scale beyond the companies in one region and has forced large swaths of the industry into remote work, generating still more impact.

This study is expected to reveal challenges and some solutions that are relevant in a number of areas: modern remote work technologies, COVID-19 restrictions to protect public health, and aerospace systems engineering.

Design Reviews. The NASA Systems Engineering Handbook (NASA 2016) provides a widely adopted framework for the phases and milestones in projects undertaken by ASEs. This process model was chosen for the study because of its ubiquity in aerospace and systems engineering. The

handbook breaks a project into seven life cycle phases, designated Pre-Phase A, Phase A, Phase B, etc, ending with Phase F. Phases A and B take place early in the project before any major fabrication of components or detailed design. Phase C is the period for detailed design and the start of fabrication. Phase D is where the overall system is integrated, tested and finally completed. In the context of this study, the result of Phase D is the construction of just one final device or vehicle, referred to as the system. Multiple copies are typically not produced, nor is there any mass manufacturing. This is typical of space systems engineering, where the design is highly tailored to the requirements and use. Phase E is the operations phase which occurs after the project has been successfully developed and put into flight operations. Phase F is the closeout phase, when the system is taken out of operation. In summary, the authors would expect that the effect of remote work on an ASE team would depend on the phase in which they are working, and so it is important to place the findings of this study in the context of phase.

The handbook also outlines project milestones referred to as Key Decision Points, and when in the project those typically occur (NASA 2016). These milestones are checkpoints in the project between customer and contractor and may determine if the project moves forward to the next phase. They have a variety of possible names but, for simplicity, will be generally referred to as design reviews (DRs). There are over a dozen DRs in the handbook, but those that are relevant in this study are the System Requirements Review, (SRR) which occurs during Phase A. The Preliminary Design Review (PDR) which takes place near or at the end of Phase B. And finally, the Critical Design Review (CDR) which in the middle or end of Phase C. While the NASA Systems Engineering Handbook is widely adopted, exact definitions of both project phases and DRs can vary between engineering companies. What is outlined here is consistent with this study.

DRs are crucial in aerospace engineering programs as they represent key progress points along the development project (Schmidt, Sarangee & Montoya 2009). DRs occur in each stage to ensure that the customer is satisfied with the project's direction, used to assess progress and verify the quality of the work (Huet et al. 2007). It is the responsibility of the company to provide a convincing and thorough presentation of the status of design work to the client and demonstrate that the project is progressing. Traditionally, design reviews rely on group familiarity and information sharing to succeed (Wetmore, Summers & Greenstein 2010). The results of a poor design review vary, but can range from delays in the projects at the cost of the company, to the customer canceling further work with the company in favour of their competitors.

When it comes to remote work, DRs can be viewed as a type of meeting that can be conducted fully remotely or in a mix of remote and in-person (often called a hybrid meeting). Hybrid meetings and presentations are common and have even been studied recently (Saatçi et al. 2019), however their usage and effectiveness for a DR run by ASEs is unclear based on the literature.

The aspects of DRs to highlight for this study are their importance to the project being undertaken, the importance of communication, and their traditionally co-located elements. Taken together, remote work must have an impact on DRs, and likely creates challenges for both company and client worthy of investigation. Hypothesis 1 aims at exploring this.

Hypothesis 1: Design reviews will experience challenges due to remote work.

Artifacts. A major component of systems engineering (SE) is the development and sharing of artifacts, also known as work products. The definition of *artifact* can vary by context and source,

so this study provides a definition for clarity. An artifact is defined as a representation of work done, used or produced during the systems engineering process, generated internally or externally, and created as a deliverable or to support other work. This definition is chosen to be broad and is consistent with the literature, e.g. (Fernandes & Machado 2015) and (Broy 2018).

Based on the definition, artifacts vary widely in format and formality, including text documents, spreadsheets, block diagrams, schematics, 3D models, slide decks, and requirements tracking software. It is expected that artifacts may exist in physical or digital form. Some artifacts require specialized tools to interact with and create, like computer-aided design (CAD) software to generate digital 3D models, or simply a particular printer to create hard copy engineering drawings on large sheets of paper. Given the significant range of possibilities for artifacts, some artifacts will likely have been impacted by the change to remote work (Jarrahi, Nelson & Thomson 2017).

In addition, because remote work has changed the nature of collaboration, the process of creating artifacts may have changed during the remote work period. It is not known at the outset of this study which artifacts are collaborative and which are not. Artifacts that were worked on synchronously may now be worked on asynchronously. Remote work may have also resulted in the creation of new artifacts to support those working on projects. Hypothesis 2 captures the intent of this study with respect to artifacts:

Hypothesis 2: The creation and use of artifacts will have changed due to remote work.

Assembly Integration and Testing (AIT). AIT refers to tasks that take place in Phases C and D, and also consists of the final work done on the project before completion and the beginning of operations. The development of complex systems involves an extensive set of tests (Eppinger et al. 2014). Each of the three aspects of AIT places different requirements on members of the project to interact or interface with hardware. Assembly requires extensive interaction with the hardware whereas integration and testing may be accomplished through simulations or remote access to hardware components (for software) though this varies case by case. For the context of this study, it is well established that numerous aspects of AIT require the in-person use of facilities and equipment, some of which are very specialized (Larson & Wertz 1999; Fortescue, Swinerd & Stark 2011). With the in-person requirements of AIT, it follows that the constraint of even partial remote work will create challenges in this aspect of projects. For this study, verification and validation (V&V) of requirements through testing is also being considered a part of AIT findings during remote work. Hypothesis 3 summarizes this study's expectations with respect to AIT:

Hypothesis 3: AIT activities (including V&V testing) will experience challenges due to remote work.

Solutions. The final aspect of this study reflects the authors' intent to produce practical insight and solutions on the topic of remote work for ASEs. The goal of this investigation is to collect and understand the adaptions thus far by ASEs to address changes during the remote work period, which are referred to simply as 'solutions.' At the launch of this study, the region in which the study would take place had been under restrictions requiring remote work for around seven months. Based on the time elapsed, it is reasonable to expect adaptations for remote work have been implemented, and more still may be moving towards implementation. The final hypothesis of this study captures this expectation and the goal to investigate solutions:

Hypothesis 4: Solutions have been thought of or implemented by ASEs to address working remotely.

Summary. The following is a summarized list of the hypotheses developed in this section, which were investigated so far in this study:

1. *Design reviews will experience challenges due to remote work.*
2. *The creation and use of artifacts will have changed due to remote work.*
3. *AIT activities (including V&V testing) will experience challenges due to remote work.*
4. *Solutions have been thought of or implemented by ASEs to address working remotely.*

Figure 1 graphically shows the approach used in this study, starting with the fundamental research questions leading to the development of hypotheses and finally the results. Emphasis is placed on the use of additional analysis beyond simply proving or disproving individual hypotheses.

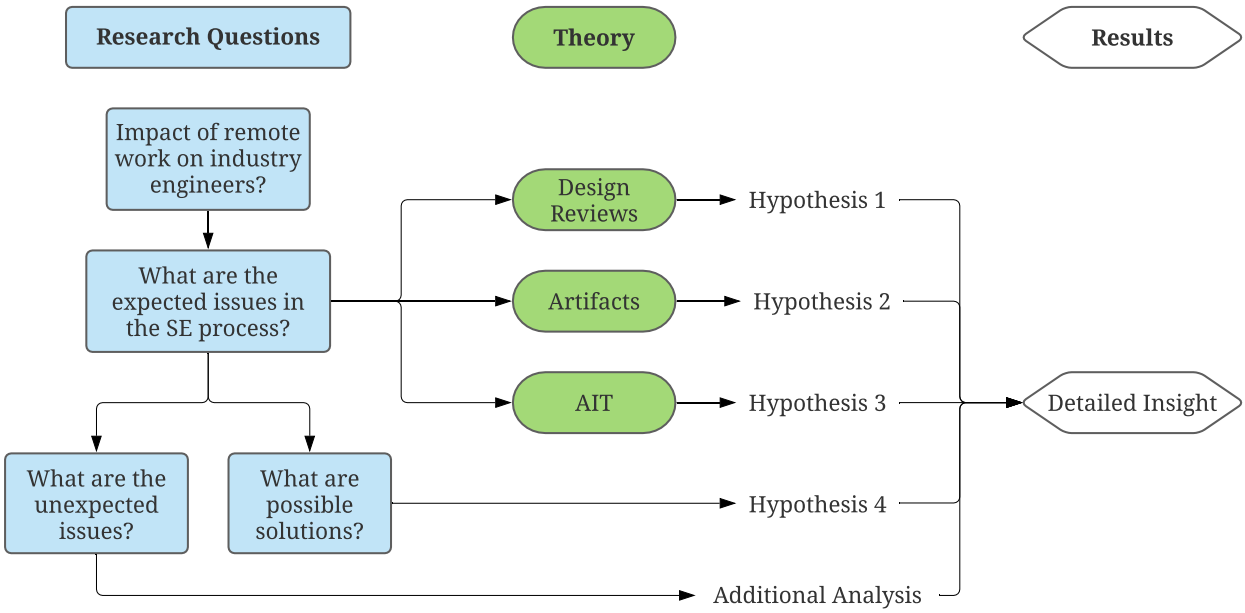

Figure 1. Study Approach

Methods

Research Contexts. Interviews were chosen as part of a qualitative approach to this study. Qualitative research originates from the social sciences (Babbie 2015), yet is suited for the purpose of conducting research in the domain of systems engineering (Szajnfarber & Gralla 2017). Based on the standards outlined by Szajnfarber & Gralla, the approach is well suited to the goals of this study because of the lack of research on the remote work situation created by COVID-19, and the lack of literature tailored to remote work of systems engineers. This approach also permits deep exploration of the topic to uncover insights not captured in the hypotheses generated at the outset owing the inductive nature of qualitative methods (Szajnfarber & Gralla 2017).

Data was gathered through semi-structured interviews with one participant at a time lasting at least one hour. Interviews were conducted via Whereby, a video conferencing software (Whereby 2020). Interviews roughly followed a predetermined set of questions covering the topics of: systems engineering project phases (which includes DR milestones), AIT, and lastly artifacts.

The interview sample comprised six participants at a single engineering company. Participants were chosen based on the recommendation of their department manager at the company, with whom the researchers have an ongoing relationship. All recommended individuals participated in the study. The study was approved by the University of Toronto Ethics Review Office.

Of the six participants, five were male, and one was female. All have at least ten years of experience working at the company and can be considered senior in their roles. Three participants manage others as part of their role. The age distribution of the participants is as follows: three are in the range of 30-39 years old, two are 40-49 years old, and one is 50-59 years old.

The set of interview questions was relayed to participants in advance per the department manager's request. This was done to ensure no questions would lead participants to reveal sensitive information or company intellectual property. Transcriptions of the interviews were also provided to the company for review, so redactions of sensitive information could take place if needed before the researchers analyzed and published findings. It should be noted that in the review of the proposed questions, none were flagged as a problem and had to be changed. In review of the interview transcripts, only two of six required redactions, and these were relatively minor and not directly related to the topics of the study.

Data Analysis. Analysis was conducted with the approved interview transcripts using the qualitative research software, NVivo (QSR International 2020). The analysis began with an initial set of hypotheses, consisting of those presented in this study, and others. Statements made by participants were assigned or *coded* to that hypothesis and placed into subcategories based on how the statement compared to the hypothesis (true, false, neutral, or simply contextual information). The unit of analysis was at minimum a sentence but often consisted of a paragraph or more.

Instances of the same code were collected into *nodes* by the software. After all transcript content had been coded, the nodes for each hypothesis were investigated to determine the truth of the hypothesis. This part of the process involved iteration between data and the theory driving the hypothesis, which is characteristic process of qualitative research analysis (Corbin & Strauss 2008). For example, an initial hypothesis surrounding V&V produced limited results and was difficult to distinguish from a hypothesis about AIT, and so these were combined to create what is now hypothesis 3 in this study. The goal of analyzing the nodes in the study was to identify evidence for or against the hypothesis, determine the holistic results, and seek additional nuanced insights for discussion. Memorable quotes from the participants were also noted for use in presenting the results. During the process, some hypotheses were removed from the scope of the study to ensure those with the most valuable results could be presented in detail.

Results & Discussion

The company from which participants were interviewed experienced remote work for approximately seven months continuously at the start of interviews. During this time, the number of employees working remotely was estimated to vary between 80% and 95% of the total workforce.

Those that were on-site followed safety precautions and health guidelines set out by the regional government. The extent of remote at this company therefore impacted all employees. The company had never experienced a remote work situation of this nature before.

Participants from the company were willing and even eager to share their perspectives, insights, and experiences in remote work with the researchers. They were all attentive to the impact of remote work on themselves, others, and their workflow. One participant emphasized the importance of this study well: "How we do what we do is as relevant from a process perspective as the work itself, and often something that is given less attention than is warranted."

The results of the interviews have been broken down by topic area and the corresponding hypothesis as introduced in the Background section: Design Reviews for hypothesis 1, Artifacts for hypothesis 2, etc. Each of the following sections provides evidence for or against the hypothesis and elaborates on additional related insights.

Design Reviews. Hypothesis 1 was found to be not strictly true. Interviews showed there is a mixture of both challenges and benefits mentioned for conducting DRs remotely. Five of six participants provided input to this effect as they had all participated in one or more DR during their remote work period. One participant was heavily involved in planning and running two DRs during this period, and summarized that there were "no major downsides."

The participants unanimously feel these remote DRs were successful and that the online format flowed well and had no impact on the programs. They determined a solution to run DRs that worked well and used this methodology for a PDR and a CDR. Typically, DRs at this organization are mostly in-person events. While the company is familiar with meetings that are a hybrid of remote and in-person, such as conducting a telephone conference call from a meeting room, it is unclear that the company has any experience with conducting events like a DR fully remotely. As a result, the methods to conduct this DR were mostly new to the company.

When not remote, DRs take place over a period of two days. They are a presentation style where team members walk through slides and the customer asks questions throughout. Minutes are kept of the questions and any discussion, and action items are recorded. These are summarized at the end of the second day. A third day is reserved for any additional smaller meetings. DRs typically consist of over 50 people, and are located either at customer site or the company site depending on the original contractual agreement.

The video platform Zoom was used for the remote DRs. A core group of around eight people from the company were gathered safely in a meeting room at the office, while everyone else was remote and off-site. This core group was responsible for delivering the presentation orally and hosting the Zoom session. This group gathered to enable easy internal conversations to take place during the review. The use of this core group on the Zoom call is similar to a hybrid-style meeting. However, it differs in that the core group is small compared to the total number of individuals in the call, and conversations within the small group were not meant to be shared with the client or everyone in the call. A communication channel on the company-wide Slack platform was created and used by those at the review for internal conversations. The Slack channel was used to "keep people inspired and interested" and featured a range of conversations, including technical, motivational, and humorous. The Slack channel was used constantly throughout the reviews.

At the beginning of each day in the DR, the program manager went over etiquette and expectations for the session. These were for everyone to stay muted unless they were presenting or there was a question. This etiquette is similar to practices found in hybrid meetings studied in the literature, and seems to be common practice. The customer made use of the chat for questions that were less pressing or for other non-urgent comments. For these DRs, the cameras of individuals from the company and the customer generally remained off, though this was not required by etiquette.

There were three benefits found because of remote DRs taking place as described. The first is that there are no travel implications. As mentioned, DRs sometimes take place at the customer site, which requires traveling to this location (in the case of this company this would involve air travel) and accommodations for all those attending for several days. Travel and accommodation have cost and time implications, and can create a limit on the number of people from the company that can attend. Remote DRs avoid any of these issues. The second benefit is that a remote DR allows productive work on other tasks for those just observing. Not everyone at a DR has to participate to the same extent, and in-person, it would be expected that those attending would be paying attention to the presentation but this expectation is not the case for remote DRs. This benefit could also be considered a drawback if participation and attentiveness of everyone at the DR is a goal. A third benefit is that the DR can be easily recorded, which allows minute takers to go back and review discussions to capture important points.

The challenges associated with the DRs are not issues that were directly faced but rather are elements that were missing compared to the in-person event. The challenges primarily stem from changes in communication.

The remote set up removes visual cues of facial expressions and body language that can be helpful when trying to find an appropriate time to ask a question. DRs are also noted as one of the few opportunities to meet the customer in-person and build relationships, which is a lost opportunity in the remote configuration especially as most people on the call keep their videos entirely off. One participant warned that a potential risk of remote DRs is impeding the ability to be clear and convincing when presenting, which they noted is critical: “The engineering can be good, but if you can’t explain how you got to that point, then it will be to your detriment. And at these reviews, they will basically eviscerate you in front of everybody.”

A key condition on these findings is that the participants and the reviewers (their customer) had spent time working together in previous phases on this project, before the remote work period, which included in-person interactions at DRs. One participant stated that as a result of this preestablished relationship, the customer had a high level of confidence going into the DRs. Mutual respect and rapport were emphasized as being a very helpful precondition to the remote work collaboration between participants and the customer, such as DRs.

Based on this finding, the authors would expect there to be more challenges for remote DRs without existing customer relationships. The sample in this study is not sufficient to investigate this hypothesis, so this has been highlighted as an area of future work.

There is no clear decision on if DRs will continue to be done remotely if there is no longer a requirement to do them remotely. The decision is likely to be a joint one between the participant company and their customer, and may vary by customer, program, and DR. Should a decision need to be made, the authors suggest that DRs in the early phases of a program, such as System

Requirements Review (SRR), be conducted with an in-person or hybrid remote and in-person format to promote establishing strong relationships and rapport.

Artifacts. Hypothesis 2 was found to be true, but the specific changes vary by the artifact in question, how it is used or created, and the individual doing the work. Aspects that have not changed are what artifacts are created, and the way these are created. More than ten different categories of artifacts were mentioned by participants, including simple Word documents, spreadsheets, block diagrams, and technical engineering schematics. Most of these can be worked on remotely the same way they would be in the office because they are computer based. As one participant put it, "one of the things that we do very well here is generate paper and I don't think COVID has severely impacted our production of paper."

New artifacts that did not exist before the remote work period were not found. This suggests that existing artifacts were sufficient to continue the project with remote work.

However, a few challenges related to artifacts were mentioned due to working remotely. One participant strongly prefers printing mechanical engineering drawings for review and sign-off, which cannot be done from home at the desired larger paper sizes suitable for the drawings. Another issue is the remote connection to CAD software. While it is possible to access CAD tools in the office remotely, this was found to be slow and awkward to use, which discouraged its use for quick and easy reference for the previously mentioned participant.

An aspect of artifacts that has changed is the collaborative act of getting input from others when creating or reviewing. Not all artifacts are collaborative, but some individuals may create their artifacts collaboratively, out of need, or to be more efficient. As one participant, a systems engineer, explained, generating requirements is easier to do both collaboratively and co-located, "going through [artifact creation] collaboratively with all the different experts you need in one room is a lot easier than trying to do that, either on a Zoom call or just sending like marked-up documents out."

For these collaborative artifacts, the time to get input from others or to reach out is slower when working virtually. For artifacts that capture system requirements, these are normally generated through workgroups like the one described in the previous quote. With remote work, it is necessary to wait for a reply or to schedule a meeting to get the same level of input.

Also, for the generation of design specifications, it was typical for the systems engineer to go to a designer's desk and go through a CAD model together, making requests for images and cross-sections needed for the artifact. Now this activity must be done over a scheduled video call with screen sharing. Participant comments generally pointed out that with remote work, individuals cannot go down the hall, visit a neighboring cubical, or go to the labs to immediately speak with who they need. It was found this is the source of the slowed communication, and this finding extends to beyond artifacts as well.

A challenge associated with the collaborative aspects of artifacts is the limitations of some of the tools. One participant expressed, "I really wish you could track changes in a spreadsheet like you can in a word document." Tools like MS Word offer the ability to add comments, and "red lines" with the track changes feature. This makes reviewing and providing feedback on an artifact easy to do remotely. However, the frequently used MS Excel spreadsheets do not support any analogous

feature, which makes it more challenging to provide feedback. While other tools that could better support this collaboration exist, a key limitation found was the restrictions on what platforms are permitted owing to the regulations on data used in aerospace programs like those worked on by the participants. Collaborative tools must be secure and often cannot involve storing or sharing data with services hosted on external servers located outside the company building.

In summary, remote work has not fundamentally changed or led to the creation of new artifacts. Remote work has complicated the process for individuals who generate and review artifacts collaboratively. These challenges in collaborative work extend beyond just artifacts, and relevant to communication in general during remote work. Further investigation of communication for ASEs working remotely is area for future work.

Assembly Integration & Testing. Hypothesis 3 was found to be true. Five participants mentioned challenges to do with AIT, and the sixth participant's program was in Phase E, with all AIT work completed before remote work. It was found that there are far more references to challenges of AIT due to remote work than to a lack of changes, or benefits. One participant whose program is in Phase D and whose role involves overseeing the mechanical work elaborated extensively on challenges throughout their interview, stating that "I don't see that as a viable way of being able to work remotely now or moving forward."

It is important to provide context about how participants and their company have handled AIT during the remote work period. AIT still occurred in-person in the building, as it was believed that it simply cannot be done otherwise. Programs would halt or be delayed if in-person work was totally blocked in this respect. So remote work in this sense is not totally remote and is better understood as limiting people on site. Those on-site were typically technicians, while the engineers and technical staff (which encompasses the participants in this study) have been mostly working remotely, with exceptions on a case-by-case basis. Because of this situation, there are challenges associated with AIT, but its core function remains fundamentally unchanged.

One aspect of AIT that has not changed is the use of testing protocols. At the company studied, there is a set corporate process for conducting tests, and a group of personnel required that has not changed with remote work. Other AIT tasks that do not require in-person work also have not changed, such as review of relevant documents and the creation of test. Meetings to address assembly issues known as "Material Review Boards" are also able to proceed over video call in the remote work situation.

It was found that many challenges with AIT taking place in the remote work period center around how it is difficult to communicate features of physical hardware when not in-person. One participant described the challenge of remotely conducting the process used to solve assembly issues on the production floor on site, which involves referencing several sources of information and working with the technician: "You're like sitting at a problem, looking at hardware, looking at a reference hardware, looking at the drawings and looking at a CAD model and to share that via Zoom, it's just impossible. There's no way."

This challenge has impacted the production of hardware from external suppliers. The participant highlighted that explaining mechanical drawings in-person at a supplier is important because there are many possible interpretations, and it is difficult to communicate physical features even with drawings and CAD. During the remote work period, it has not been possible to visit the suppliers

producing the hardware to explain the hardware, or to perform the inspections before final shipment, both of which are normally done. The company had to change the quality clause in their contracts, and resorted to using photos of the hardware for inspection. The use of photos however was not as effective as an in-person inspection, and as a result, there have been "big glaring errors that would not have made it through the chain if we were allowed to be onsite and inspect properly." This issue raises the question of new methods or process for remote inspection of physical hardware features when working with suppliers.

This challenge also extends to mechanical work outside the AIT phase, and into conceptual work earlier in projects. Working remotely, there is no easy means of drawing to share ideas, like on a whiteboard, no reference hardware to support explanations, and using CAD comes with difficulties like computer lag and connection issues. In summary, AIT activities have experienced significant challenges as a result of remote work.

Solutions. Hypothesis 4 was found to be true, in line with researchers' expectations. There were many solutions mentioned by participants throughout the study that cover a wide range of aspects of remote work. This section limits itself to two solutions found that might be of the most use to the company participating in this study.

Slack is a platform for organized instant messaging either directly between individuals, or in channels with a number of individuals (Slack 2020). This study has found this platform to be well-suited to the work undertaken by the participants. Participants indicated it is suitable for quick and informal conversation and is regarded as an efficient means of communication, both when working remotely and when in the company building. A downside of Slack is it does not provide the same form of written records of decisions like an email chain can. A perhaps more significant limitation is that documents, data, and sensitive communication must still be sent via email to follow theregulations on data security for aerospace programs. The need for secure file transfer is somewhat unique to aerospace projects, and creates an additional challenge to overcome with remote work.

This study found Slack to have been adopted to different degrees by different groups within the company. Participants from two teams in the disciplines of software and mechanical adopted it and used the platform heavily. Others have not adopted the platform and prefer more traditional email. A participant from one of the previously mentioned teams expressed frustration that other groups outside of their own did not also use Slack, "A lot of the support groups don't use it, which is a little frustrating." This study recommends a more standardized adoption of the platform across groups that frequently interact to make the most of the benefits. A prerequisite for achieving this may be addressing barriers created by the previously mentioned regulations on data security.

This study found helpful suggestions that managers can use to help manage their team's time. The first suggestion is that managers limit the number of team meetings to the same as what was done before the remote work period. This is driven by the observation that people are scheduled to attend a much larger number of meetings in the form of calls during remote work. This in-turn, is because meetings are the core way people synchronously communicate now that informal and at-desk chats have been removed. The increased number of meetings has a detrimental effect on the ability for individuals to focus and get work done, hence this suggestion.

The other related suggestion derived from this study is for managers to host regular "office hours" where they are on a video or conference call, and any of their team is welcome to join at any time,

but it is not mandatory. It provides a designated time for team members to talk to the manager or have side discussions with other team members. The motivation behind this approach is that it emulates the informal side chats that occur in the office, again without increasing the number of meetings scheduled. The participant who implemented this saw success, as they and their team have had several good discussions during these periods. This study suggests managers consider both these strategies for their teams.

Future Work

The findings discussed in this paper result from in-depth interviews with a limited pool of participants in a single company. Six additional interviews are planned to expand the participant pool, including interviews with a broader variety of ASEs to increase the generalizability of the findings. In particular, the current participant pool lacks diversity of gender; under-representation of identity in this dimension may have a real impact on the reality of remote work, and therefore it is important to include additional voices of women in future work. Additionally, the participants represent a limited number of all the project life cycle phases (Pre-Phase A through F), so the results may not apply to all phases. Future studies should aim for a more uniform distribution of design phases to clarify how findings pertain to the phase being worked on by an ASE team. Given that this paper represents the first step in describing the remote work reality for ASEs, the authors expect that future qualitative and quantitative studies will continue to uncover salient results.

This study motivates a number of important areas of research; one example is to explore appropriate alternative technologies to traditional whiteboards. Further, the role of existing relationships, formed during in-person work, during a transition to remote work warrants investigation; the authors imagine that a long-time systems engineer who shifts to remote work after years of established good-will established in-person will have a smoother transition to working in a remote team than someone who was onboarded directly onto a remote team. A related question motivated by findings on DRs suggests that DRs will be more effective for teams where there is an existing relationship with the customer that was developed in-person. Lastly, the findings on AIT work motivate a focused investigation on the impact to the whole supply chain for hardware components. In particular, there is space to search for existing or novel solutions to the remote inspection of hardware that was highlighted as a challenge in this study.

One participant's statement notes the challenge of building relationships during remote work: "I'm a huge fan of people participation on teams and to do that, you need to build team spirit. You need to have people in the same room, eating cookies. It's very hard to do that remotely."

A common theme found in the analysis of the hypothesis is communication. Communication is in fact embedded in the results and discussion of all four hypotheses in the previous section. This is not entirely unexpected to the researchers due to the nature of the systems engineering discipline. A participant captured this particularly well when responding to an interview question:

Researcher: "Would you say that big picture thinking and the need for information flow between humans is characteristic of systems engineering in general?"

Participant: "That is systems engineering."

This presents an area for future work that could produce many insights, whether through different interview questions or the reframing of the research analysis. Subject literature would have to be consulted to determine what findings might be most valuable and relevant to this study's focus on systems engineering in aerospace.

Another interesting finding is the disparity in individual sentiments on remote work. Participants often highlight both positives and negatives to remote work compared to the previous co-located work. They had a variety of personal feelings that varied both individually and between individuals. Some participants wished to continue to work remotely while others made it clear it was not suited for them. Comments from 3 different participants show this:

"To answer your question on a personal level, I wasn't too happy about [the transition to remote work] and it wasn't my cup of tea."

"I'm way happier. I'm [financially] better off. I have more time for my family and myself, if we're happy and we're getting our work done, why do we need to come back to the office?"

"So supporting things remotely is certainly a well-proven capability from our line of work."

Future work in this area could involve determining the factors that contribute to personal views on remote work, such as role requirements, personality traits, length of commute, team composition, and project design phase.

Conclusion

Remote work is an increasingly important, yet understudied, topic to study in the context of aerospace systems engineering. Deepening the understanding of challenges and solutions of remote work will lay the foundation for new methods, technologies, and processes to improve ASE projects and products. This study presents evidence that:

- Design reviews experienced challenges but also benefits due to remote work.
- The creation and use of artifacts changed due to remote work; remote work has complicated the process for individuals who generate and review artifacts collaboratively.
- AIT activities (including V&V testing) experience significant challenges due to remote work.
- Solutions have been thought of or implemented by ASEs to address working remotely, in particular, the use of the communication platform Slack and strategies managers may use to support their team members without consuming too much of their time

These findings suggest that though remote work presents challenges to the traditional ASE process, it is possible to learn and develop best practice for this work, ultimately leading to more efficient and effective engineering design processes.

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Biography

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