COMPASS CONCURRENT ENGINEERING LESSONS LEARNED IN REMOTE AND HYBRID ENVIRONMENTS

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INTRODUCTION

The Compass Team at NASA's Glenn Research Center (GRC) is a concurrent engineering team which specializes in conceptual spacecraft mission designs. Detailed descriptions of the team, its history, and its operating model can be found in [1] and [2]. During the COVID-19 pandemic, the team was required to move to remote (virtual) operation from their in-person model for approximately 22 months. As the restrictions began to lift and team members were able to return in-person to the Compass Lab, the team moved into a hybrid mode of operation, with some participants still tying in remotely some or all of the time. This paper discusses many of the lessons learned from these experiences, highlighting improvements, outstanding challenges and the tools and methodologies used to address both.

Throughout this discussion the terms "in-person", "hybrid", "virtual" and "remote" will be used. For the purposes of this paper, "in-person" will be understood to mean when team members are interacting simultaneously, physically within the Compass Lab. "Remote" or "virtual" will refer to when interactions are happening between people who are not co-located using only technology to interface. "Hybrid" will refer to when two or more participants are physically located in the Compass Lab and one or more participant(s) is participating remotely.

Media richness is described as "a medium's ability to communicate effectively based of four factors. They are the capacity for immediate feedback, the number of cues and channels it utilizes, the degree of personalization it affords, and its ability to communicate using natural language" [3]. This theory will be referenced and discussed in multiple of the following sections due to its relevance when choosing how to operate in remote and hybrid modes, as well as in making tool selections. The key to selecting the best mode of communication lays in how complicated the discussion is and the level of ambiguity involved. Not all conversations or interactions require media rich mediums. For example, providing information about which there is little to no ambiguity can easily be done in less rich methods - such as email. A conversation including high levels of ambiguity and/or complex information is better suited to a richer medium, such as in-person or a video call with shared screens.

TOOLS

Throughout remote and hybrid operation, the Compass team investigated a number of tools to enhance the concurrent engineering process and mitigate the challenges of the new operating paradigm.

Microsoft Teams™

The Compass Team, when required to deviate from the in-person model, migrated to the Microsoft Teams platform for live design sessions. Design sessions bring together the entire Compass team for open discussion for nearly the entire design from conceptualization to finished product. To facilitate this, design sessions are typically held for 3.5 hours, three times a week: Monday, Wednesday, and Friday. Throughout the pandemic, additional functionality was made available to NASA customers within the Teams application. The integration with other Office365™ applications, in particular, was useful for the Compass Team. In-person sessions, which historically relied on sharing information on the many screens around the Compass Lab, were replaced with the screensharing functionality in Microsoft Teams meetings.

Although this functionality was crucial to remote team operations, there were some problems with this methodology. Primarily, this removed the team's ability to share multiple screens at once with the group. This made it more difficult to view complementary information side by side and diminished the ability to note discrepancies early in the design process. This led to errors propagating farther into the design process before being recognized and fixed. Workarounds were possible. For example, the team could open multiple instances of Microsoft Teams, one in the application and one in the browser, and share different screens in each, but this required each team member to have multiple screens and more

importantly the internet bandwidth to support two simultaneous video calls. This workaround was never successfully implemented by the full team.

Whereas the physical Compass Lab space is designed to facilitate side conversations at the subsystem lead tables while the main design discussion is driven from the center of the room, as shown in Fig. 1., moving to a video call setup also meant that only one conversation could happen at a time or people would talk over each other. The Compass team compensated by transitioning to using the Teams chat functionality for side conversations. This extended the length of time required to complete a design, since what had previously been achieved simultaneously had to happen serially.

The chat functionality was implemented as a workaround, allowing side conversations to take place in text form while not interrupting the main conversation. This was not a one-to-one change unfortunately, as many team members found it difficult to monitor the chat and listen to the main conversation simultaneously. However, the chat did allow for customers to freely ask and answer questions without interrupting, which anecdotally was more comfortable for customers. Side conversations could also be achieved by using the Microsoft Teams "breakout room" functionality, which sends a subset of the participants into a separate virtual room. Although this has been implemented by the team on occasion, the primary drawback is that each conversation is now entirely isolated from each other - eliminating the ability to keep tabs on relevant information from elsewhere in the virtual or physical room.

Office365

The greatest tool-change success story of the team from remote operations came with the NASA implementation of Office365. The primary end-product of the Compass Team is a comprehensive Microsoft PowerPoint™ chart package outlining the overall design, design path, and the detailed descriptions of each subsystem and its supporting analysis. While some of the package is built in real time, other slides are updated outside of sessions by the team members. Historically, this led to version control issues, emailing slide iterations to be integrated into the main package and needing to ensure all fixes made it into the final copy, which was then too large to be shared through standard email. Following the roll out of Office365 to NASA customers, the team transitioned to working on a shared set of slides housed in the Compass Team 'Teams' SharePoint™. This was a monumental improvement over the previous method of operation. Team members can now update their slides in the main package in real time, fix errors as soon as they are spotted and collaborate more seamlessly. Customers can also be added to the "working package" so that they can track progress outside of sessions, or when they are unable to attend. This also allows the team to make use of the built-in version control functionality through the Office365 platform.

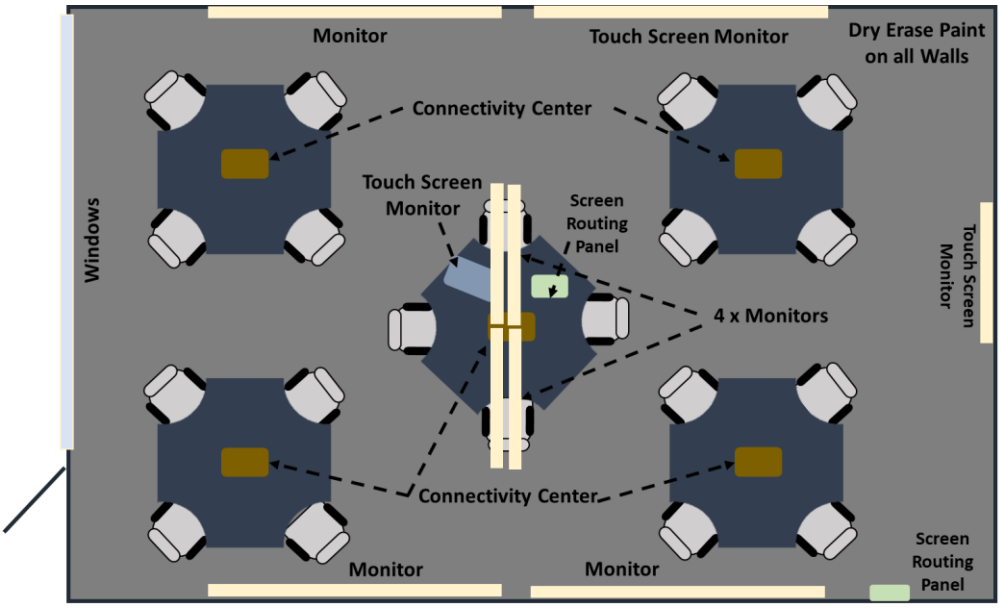


Fig. 1. Compass Lab Diagram (not to scale)

MURAL™ Virtual Whiteboarding

The Compass team also procured a license to MURAL, a virtual whiteboarding tool. Unfortunately, the team did not gain access to this software until after the transition from fully remote to hybrid operations. It would have been especially helpful in the fully remote setting but is also key moving forward in the new hybrid model. The team frequently makes use of physical whiteboards when designing in-person. In fact, the new Compass Lab has whiteboard paint which turns every wall of the lab into drawing space. This still presents a problem when virtual participants need to be able to see and participate in whiteboarding activities, however.

The solution is virtual whiteboards which give online team members the ability to participate, while allowing it to feel as "normal" as possible for lab-based team members. This is where the new lab and MURAL combine to solve the problem. The new lab features three touch screen monitors of varying sizes which can have MURAL brought up on them. The in-lab members can then draw using a stylus on the MURAL screen as if it was a physical whiteboard; allowing all in-lab team members to collaborate as normal. The remote participants bring MURAL up on their computers and can draw on the same canvas, seeing what is being added by the in-lab members and adding their own thoughts. This bridges the gap between virtual and in-person team members and allows the team to truly collaborate.

This collaborative environment could be further enhanced by implementing a touchscreen-like feature for the virtual participants, who are currently constrained to the difficult task of drawing with a mouse. Using a tablet and stylus or purchasing laptops with integrated touchscreen features are potential solutions the team intends to investigate further.

Global Integrated Design Environment [5] Enhancements

The final piece of the puzzle, although still under development, will be useful for team members who tie into the Compass sessions remotely. As previously mentioned, the main drawback to the screen sharing through Microsoft Teams is the inability to share two separate screens at the same time side-by-side. The most common use of this for the team is having the Master Equipment List (MEL) visible next to either the working charts or the computer-aided design (CAD) model. The team uses the GLobal Integrated Design Environment (GLIDE), an in-house software package, to share technical parameters with each other in real-time [5]. At the suggestion of the GLIDE development team, work has begun to create a web-based, real-time Master MEL viewer on the GLIDE website. This would allow team members who are virtual (and eventually customers) to view live updates to the Master MEL and follow along with the side-by-side view from outside the lab.

REMOTE OPERATION

Although the Compass team was able to leverage a variety of tools to help mitigate the shift to remote work, there were other challenges the team faced, such as training and team building, innovation, efficiency, and burnout.

As the team transitioned to remote-only operations in 2020, members were able to leverage pre-existing relationships during the design sessions. At the time, some members had worked for the team since its inception over a decade ago, most for at least three to five years, and a couple for closer to one year. Regardless, cross-team relationships and familiarity had been established, which made switching to different modes of communication easier. This is not to say this transition was easy. Changing from real-time, in-person communication to video calls coupled with email and asynchronous chats was, and remains, a challenge.

During the pandemic however, the team needed to add new team members to replace others who retired or had competing commitments. This is where the change from in-person was made even more evident. Training in the Compass environment typically consists of shadowing a more senior engineer for at least a full study (usually several), observing and participating, and then being able to lead future studies with back up from the trainer. Without the in-person model, the ability to "look over the shoulder" of the senior engineer and see what they are doing in the larger context was extremely diminished. Although some subsystems did have success training new engineers in the environment, those success stories required significant time spent outside of the sessions in one-on-one training. This took a concerted effort on the part of the subject matter expert (SME) and cut into time that would normally be spent on supporting other NASA projects.

As discussed in [6], forming a connection which can withstand disagreement and misunderstanding is best done in a media rich and personal environment. As the team moved to remote operations, the in-person connections previously

taken for granted were not available. Additionally, as was the case across the new virtual workforce, team members were hesitant to make use of cameras in meetings. Removing this channel of non-verbal cues not only made communication more difficult with people talking over each other, it also removed passive communication (nods, furrowed brows, etc.) and undermined the ability to foster connections. The cumulative effect of this was that team members were less willing to reach out to each other directly. With the loss of the personal relationships, many team members switched to using the lead systems engineer as a liaison to other team members, rather than reaching out directly. This created an unnecessary choke point which the team had not previously experienced and created a virtual "telephone" scenario, rather than fostering direct collaboration. Additionally, many of the design discussions which had happened organically between SMEs when they were seated near each other, now only took place at the direction of team leadership. This meant designs were more directed than generative; inhibiting innovative thought.

The inability to share multiple screens side by side, to have simultaneous conversations, to train in real time, and to make use of non-verbal cues combined to have several effects. Errors persisted longer in the design process, necessitating the additional rework ideally avoided by concurrent teams. Design runs took longer and therefore cost more for customers. The Compass timeline of approximately two weeks with six to seven official design sessions moved to a timeline of four weeks, with 12 official sessions and many "splinter sessions" to work through the conversations that would have historically happened simultaneously throughout the room during regular sessions. Another effect of this was the need to overlap design studies to meet deadlines. With the longer run times, designs were sometimes open concurrently. This made it more difficult for the team to focus entirely on one thing and required extra mental effort to switch back and forth. The added effort and lack of "down weeks" between sessions contributed to burnout of team members.

HYBRID OPERATION

Beginning in early 2022, the team was able to move to hybrid operations in which two or more team members participated from the Compass Lab. The new Compass Lab, built during the pandemic, is designed to better accommodate remote participants, as shown in Fig. 1. The team continues to experiment with how work will be performed in this new paradigm. Many of the positive lessons learned during remote work can be applied to this new environment, including better remote tie-in of customers and SMEs from other NASA Centers and universities, as well as the ability for team members to join remotely when schedule, illness, travel, or weather would otherwise have prevented them from participating meaningfully at all. Given the effects of winter weather on travel in northeast Ohio, this will undoubtedly continue to be useful. There has already been evidence of positive effects - allowing fully remote team members or those quarantining to participate actively in the sessions without the need to pre-plan.

One of the greatest improvements for hybrid operation over the old Compass lab is the integration of microphones which cover the entire room. Previously, all online audio was routed through a single speaker phone at the center of the lab to avoid audio feedback issues resulting from multiple open microphones. This isolated the virtual participants from meaningfully engaging in design discussions happening throughout the room and made them more like "observers" than "participants" since much of the input from SMEs on the room's perimeter was inaudible. Now that the audio (both into and out of the lab) is more robust, team members, customers, and advisors can participate more fully when they are unable to be onsite.

MEDIA SELECTION

Compass sessions are run primarily through three different mediums: real time conversation and problem solving, Excel™-based master equipment lists (populated through GLIDE), and a comprehensive working PowerPoint chart package which includes all trades and design evolution (and eventually the final design point). These tools and their implementation are discussed above. However, selecting the correct medium for the correct task can be challenging.

The following quote from [4] describes the challenge of selecting the correct mediums for communication based on the type of information being discussed. *(emphasis added)*

> "On the theoretical front, media richness theory posits that **richer communication channels**, such as in-person interaction, **are best suited to communicating complex information and ideas**. Moreover, media synchronicity theory proposes that **asynchronous communication channels** (such as email) **are better suited for conveying information** and **synchronous channels** (such as video calls) **are better suited for converging on the meaning of information**. There is also a rich body of empirical research

that documents the myriad implications of communication media choice for organizations. For example, previous research has shown that establishing a rapport, which is an important precursor to knowledge transfer, is impeded by email use, and that in-person and phone/video communication are more strongly associated with positive team performance than email and instant message (IM) communication."

Concurrent engineering, in general, is an excellent example of an activity which relies on multiple mediums of communication for different aspects of the process. At an overarching level, the team starts with top level requirements and must distill them down into a functional spacecraft design - beginning with something ambiguous and converging on a design is a process that is well suited to media choices which are both rich and synchronous. However, there are aspects of the process which rely on sharing well-understood pieces of information, for example sharing mass and power for components in the design. This does not require much discussion, but instead that the information be accurate and available to whoever needs it. The team completes this part of the process with GLIDE and the master equipment list, neither of which requires a rich media source or synchronicity.

A graphic depicting the general functions of the Compass Team scaled by complexity and ambiguity versus the communication methods available to the team is shown in Fig. 2. The band of effective communication is intended to illustrate the appropriate selection of media for each particular task. It is worth noting that the Compass team uses most of these media choices concurrently during a design session but can tailor what is being discussed in each stream of communication. Fig. 3. also illustrates the modes of communication available to the Compass Team, from rich to lean media, by decomposing the media choices into the four components which define the richness of the media.

An example of the effect of the loss of rich media sources for concurrent engineering when operating remotely was difficulty defining the lines of demarcation for responsibility between SMEs. Deciding who would design which parts of the system and ultimately held the responsibility for them was something taken for granted in the in-person environment. People could raise their hands or nod yes or no to indicate whether they felt comfortable taking on the task. Defining these lines remotely was very challenging - often needing to be done multiple times because not everyone had understood the lines of responsibility the same way and, in many instances, had to be repeated when SMEs were engaged in other discussions. This illustrates needing rich forms of communication to converge on understanding, whether it be for the design itself or the team dynamics.

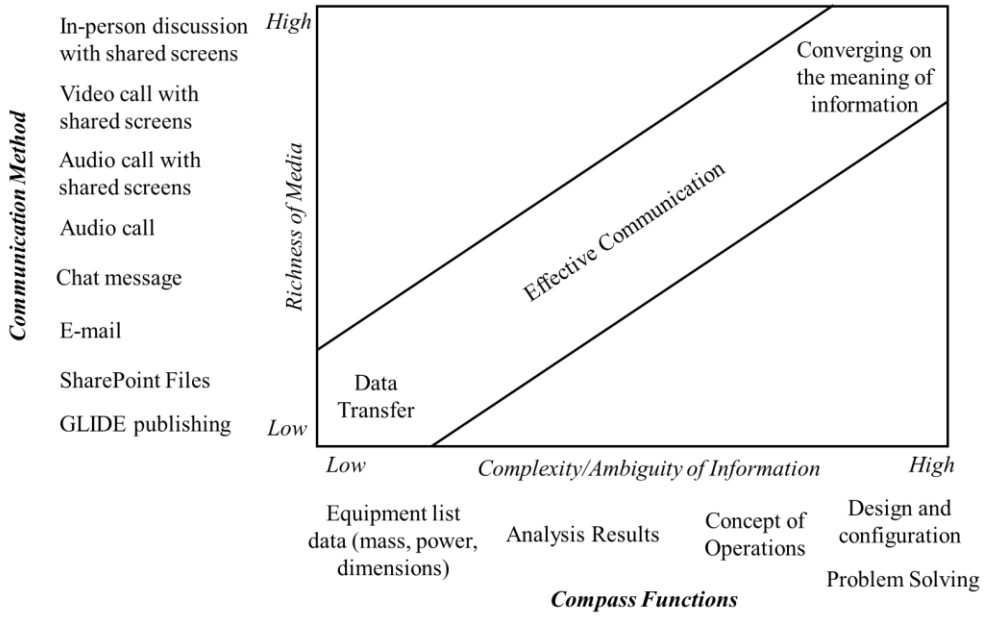
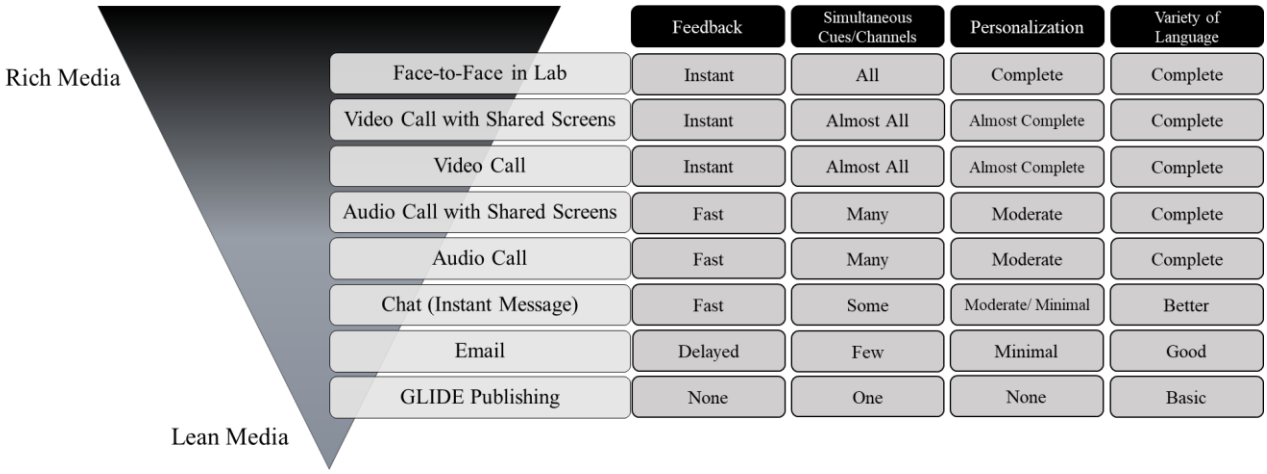


Fig. 2. Representation of Compass Communication Methods and Functions based on Richness of Media and Complexity of Information



	Feedback	Simultaneous Cues/Channels	Personalization	Variety of Language
Face-to-Face in Lab	Instant	All	Complete	Complete
Video Call with Shared Screens	Instant	Almost All	Almost Complete	Complete
Video Call	Instant	Almost All	Almost Complete	Complete
Audio Call with Shared Screens	Fast	Many	Moderate	Complete
Audio Call	Fast	Many	Moderate	Complete
Chat (Instant Message)	Fast	Some	Moderate/ Minimal	Better
Email	Delayed	Few	Minimal	Good
GLIDE Publishing	None	One	None	Basic

Fig. 3. Representative Matrix of Compass Communication Methods by Robustness of Media Richness Sub-Components

An innovative team thrives on maintaining a diversity of viewpoints and having the psychological safety to share those ideas. One interesting note from the employees studied in [4] during the switch from in-person to fully remote was how their connections to other employees changed. They began to replace connections outside their organization with connections inside their organization. The danger is that people outside a person's home organization are more likely to be able to provide a different viewpoint and different information. As groups become more insular and siloed, it is not hard to believe that innovation could be stifled. A team, such as Compass, could see this affect its ability to be innovative as well, if it has a less diverse and varied pool of ideas from which to draw. The authors of [4] do caution about overgeneralizing their results past the confines of similar jobs and the United States; however, the experience of the Compass Team (a group of United States-based, information workers) experienced qualitatively the results that the authors described quantitatively.

OUTSTANDING CHALLENGES

Although the hybrid functionality is much improved over the fully remote setup, team leadership still feels that in-person work is better. Without camera use, it can be difficult to tell if virtual participants are actively engaged or if they needed to step away for a moment - something taken for granted in person. Facility with technology can also cause issues. Not all forms of virtual communication have been embraced by all team members and that can lead to miscommunication and missed communication. A communication plan, detailing how different methods of communication should be used can be helpful, but there is a concern about becoming too prescriptive and undermining the ability to communicate in whatever way is best for the team members involved. Additionally, a team wide expectation of when to use cameras in conversation should be reached since there are multiple schools of thought as to their use. Some team members prefer to never use their cameras, while some are comfortable being on camera all the time. At a minimum, the Compass Team has tried to implement a practice of being on-camera when participating in the main conversation. This allows everyone to communicate more clearly by choosing the richest possible media.

As discussed above, knowledge transfer and training remain a challenge. For the team members able to attend sessions in-person, the hope is for this to remedy itself naturally. However, as remote work becomes more commonplace, there will be a need for SMEs to dedicate additional time for one-on-one training sessions for those new to the Compass environment. The organic method of training will need to be augmented with a more planned effort and developing these training materials will be an added effort.

Each of these challenges has led Compass leadership to advocate that fully remote team members be the exception, rather than the rule. There is evidence that proactive virtual team members can participate actively by engaging with the rest of the team through the many available mediums. However, not all employees are well suited to this type of engagement and it still removes them from the richest form of design communication. Additionally, participation in Compass studies

affords members vast exposure to leadership in both the project and center realms. This career advantage may inadvertently be diminished by the reduced visibility of virtual participation.

There are still some outstanding challenges beyond the scope of the Compass team to fix. These include internet bandwidth issues, especially when using the virtual private network (VPN), and outages of the tools being implemented. Even delays in video sharing can complicate matters when trying to collaborate in real time. As the hybrid working paradigm becomes more common place, it is likely that the IT infrastructure will become more robust and provide solutions to these challenges.

CONCLUSION

Although the Compass Team continued to produce valuable results operating remotely, and now in a hybrid fashion, the best results are achieved when working in-person. In-person operations improve collaboration, team dynamics, innovation, and efficiency. However, there have been lessons learned from the experiences that the team will continue to incorporate which give the ability to better tie-in virtual participants, such as customers and remote SMEs, making the team robust to challenges like weather, illness, and travel. Additionally, as the agency experiments with hybrid work, the team leadership recognizes that team members may not be available in-person for sessions held outside of the standard Compass calendar (Monday, Wednesday, and Friday afternoons). Therefore, the plan in the near term is to expect most Tuesday or Thursday sessions (usually held due to holidays shifting calendars) and splinter sessions to be either hybrid or virtual.

The workplace of the future will continue to shift in the coming years and the lessons learned through remote and hybrid work necessitated by the pandemic will aid in preparing teams for this future.

ACKNOWLEDGMENTS

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