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# STUDIES AND EDUCATIONAL ACTIVITIES IN A SIMULTANEOUS COLLABORATIVE ENGINEERING SETTING – RECOMMENDATIONS AND LESSONS LEARNT

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## ABSTRACT

Early 2020, the COVID pandemic spread throughout the world, disrupting the way organizations and individuals had been working until then and forcing them to rapidly adjust to a remote working environment. Given the collocated nature of the Concurrent Engineering (CE) methodology, the COVID protecting measures and protocols –such as physical distancing and the limitations on the number of people that could gather in a closed space– also heavily impacted the viability of executing CE activities in Concurrent Engineering Centers (CEC's).

More particularly, DLR's strong support to the German national containment strategy meant that, between early 2020 and 2022, conventional CE activities could not be carried out at DLR's Concurrent Engineering Facility (CEF). Faced with this situation, the desire to continue carrying out team activities (i.e., workshops / concurrent design) and providing educational activities for the University of Bremen (i.e., compulsory courses in Systems Engineering and Concurrent Engineering for the Master in Space Engineering) drove us towards an organic transition into a simultaneous Collaborative Engineering approach. At the same time, exploring these new methods is in keeping with DLR's efforts in advancing the digitization of the design processes, some of which are currently being implemented within a larger project for the German Federal Ministry for Economic Affairs and Climate Action with our participation.

By using many of the same methods and work structures we commonly apply in CEF activities and adapting them to a remote environment, we have managed to conduct some rather successful studies, workshops and courses during this time. From this work, some recommendations and lessons learnt that could be useful to other teams facing similar challenges now or in the future have been derived. In this paper, we introduce the corresponding activities, how we conduced them, and the insights we gained in the process.

## INTRODUCTION

In early 2020, the outbreak of the COVID pandemic led to an explosion of remote work throughout the world. By way of illustration, the proportion of employees working from home in the EU rose to almost 40% (from an estimated maximum of 11% prior to COVID) [1], and as many as 37% of employees in the U.S. also started to work remotely (from an estimated maximum of 5% before) [2].

Faced with this new situation, organizations around the world have needed to abruptly change the way they work, in addition to adapting to new technologies and tools. With little to no foreplaning, and without prior experience in managing a substantial amount of their staff working from home, the sudden change has not been easy.

It should be noted that the concept of remote work is not new. As early as 1976, Jack Nilles coined the terms "telecommute" and "telework" [3], and addressed the foreseeable societal impacts of telecommuting. Just a few years later, IBM experimented with the concept by having 5 employees work from home, and by 1983 it is estimated that around 2000 IBM employees were working remotely [4].

Whereas remote work has been increasingly facilitated by the evolution and expansion of Information and Communications Technologies (ICT) in the decades since, the reality is that most organisations have had limited experience with work from home (WFH) until recently – especially when working with distributed teams on medium or large-scale projects.

In our specific case at DLR Bremen, the COVID protecting measures and protocols enacted by the German government did not allow us to conduct normal operations during the years 2020-2022 in the Concurrent Engineering Facility (CEF). The reason for this is that traditionally the CEF has been used to perform workshops or Concurrent Engineering (CE) studies. But one of the main characteristics of the CE methodology is that activities are collocated, which unfortunately run counter to the compulsory physical distancing anti-COVID rules.

While DLR fully endorsed the German national containment strategy, the desire to continue carrying out team activities and providing educational activities for the University of Bremen drove us to try and adapt many of the same methods and work structures we commonly apply in CEF activities to a remote environment. This organic transition towards a simultaneous Collaborative Engineering approach was also in line with DLR's efforts in advancing the digitization of the design processes, and provided a useful testing ground to better understand the challenges of working remotely in teams, and try different strategies.

From the work carried out in the CEF, some recommendations and lessons learnt that could be useful to other teams facing similar challenges now or in the future have been derived. In this paper, we introduce the corresponding activities, how we conduced them, and the insights we gained in the process.

## EDUCATION

### Background

Since 2014 the University of Bremen (Germany) offers the "Master of Space Engineering (SpE)", a master course geared towards international engineering students. From the start, DLR has supported the program through the compulsory module "Space Systems Engineering and Concurrent Engineering", which has traditionally been held on-site at the Concurrent Engineering Facility at the Institute of Space Systems.

The course [5] covers a number of topics, including Space Project Management, Space Systems Engineering and Concurrent Engineering. After providing an overview into these subjects with a series of short introductory presentations, students would undertake a practical example by simulating a CE Study.

After assigning all the students (usually in pairs) to one of the conventional domains –such as Mission Analysis, Communications, Structure, or Systems Engineering–, and the lecturers guide the following sessions in a similar fashion to how CE studies are conducted at DLR. Starting by defining a small mission that can be performed by a 3-unit CubeSat, the study focuses on having the students design a 3U CubeSat that can satisfy the mission objectives by the end of the one-week course.

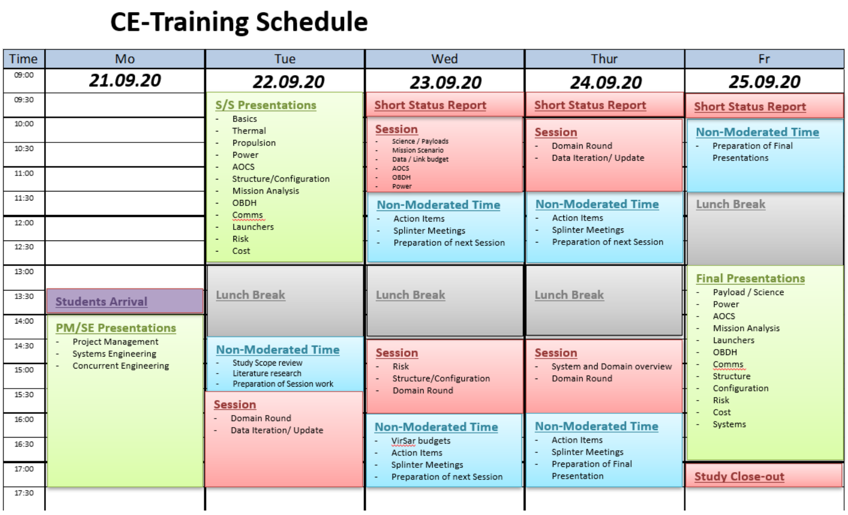


Fig. 1. Example of training schedule for on-site CE course

While DLR implemented COVID restrictions in the first trimester of 2020, we were able to conduct an on-site CE course in the second semester of the year since –at that time– we managed to set up an alternative location in a larger meeting room which allowed for enough social distancing. With the use of masks and a policy of open windows, we performed one last CE course in a similar manner as to the way we conduct them in the CEF, but based on the experience and the ever-adapting level of restrictions, we decided that moving forward we would need to move the course on-line.

Immediately a primary issue arose: Concurrent Engineering is, by definition, a simultaneous *collocated* activity. Moving it online would require us to consider the activity in the light of Collaborative Engineering (CoE), and assess how to best provide an experience that would be as close as possible to a CE study, while acknowledging the particularities of a simultaneous, distributed activity.

**Initial Considerations**

Moving an on-site course online is, in theory, not all that complicated. Lectures can be presented on a cloud-based video conferencing service (e.g., Zoom, Skype, Microsoft Teams, Adobe Connect), or simply recorded and either shared or hosted on the cloud. Discussions can also be held via video conferencing, and many tools today offer the possibility of creating virtual "rooms" to divide up teams for splinter activities. In practice, though, things are not as clear cut:

1. Videoconferencing lectures, while possible, can be a technical challenge. With a large number of participants, issues of bandwidth and lag are common – not to mention audio or video-feed malfunction, which can happen to anyone. A safer alternative is to record the lectures in such a way that they can be downloaded or streamed by the students at their convenience but, on the other hand, video lectures deny students the option to formulate questions or make comments in real time.
2. Human interactions are significantly more complex than we tend to assume, and current videoconferencing tools –although immensely useful– create artificial barriers to communication such as: (1) diminished body language perception, (2) limitations on non-verbal feedback due to the difficulty of tracking 15-20 participants on a screen, and (3) lack of verbal backchanneling. These hurdles –and others– make the experience of engaging with a team on-line considerably less effective than direct face to face communication, and "talking rules" will add to that.
3. Given that the new format of the course required students to use their own laptops, we also faced the need to support them with necessary software which would normally be pre-installed in the CEF – specially our MBSE tool of choice, Virtual Satellite [6][7].

Given these considerations, we decided the following:

1. While video lectures do not allow for questions or comments straightaway, we considered them to be the best option available to us. Since the course has a strong practical orientation, we encouraged students to ask questions at any point during the practical part of the training, and we also tried to emphasize the different aspects of the theory as they apply to specific practical elements or situations (e.g., when discussing different possible solutions we encourage students to make sure that they are satisfying the requirements, and remind them to be critical of both the formulation and the reasoning for the requirements they have been provided).
2. To account for the loss of efficiency in communication, we spaced out the schedule into 2 weeks (see Fig. 2), adding days off for the students to have more time to work and to talk with their partners (i.e., when they are more than one student working in the same domain) or other domains (e.g., for discussions that require various subsystems or domains to reach agreements, but do not affect the entire system/team). In addition, we included an additional short status report at the end of every moderated day on the second week, right after the non-moderated sessions. This allowed us to touch base as a team, get back on the same page, and make sure that any questions within the team could be formulated before the end of the day. This also ensured that students could address any issue that might have come up during the non-moderated session, not having to find themselves blocked and unable to continue working until the next session.
3. When conducting the course in the CEF we can provide the students with all the software needed to conduct a CE study, as it is already installed in the workstations of our facility. This includes tools such as CATIA for modelling/configuration, STK for mission analysis, and instances of Virtual Satellite. Since students do not always have access to licenses for CATIA or STK, in the new format we need to be more flexible with the tools used, but this has not been a problem since they either have other licenses (e.g., SolidWorks) or can make use of a number of free alternatives. In the case of Virtual Satellite, as it is a DLR open source software there is no licensing issue, but given that it is essential for our activities in this course, we require all the students to install and set up the model in their laptops/home computers. To facilitate this, we developed a step-by-step tutorial,

and provided additional support throughout the course through "VirSat Consultancy" on-line sessions, where students could directly consult with our DLR Braunschweig colleagues who develop the software.

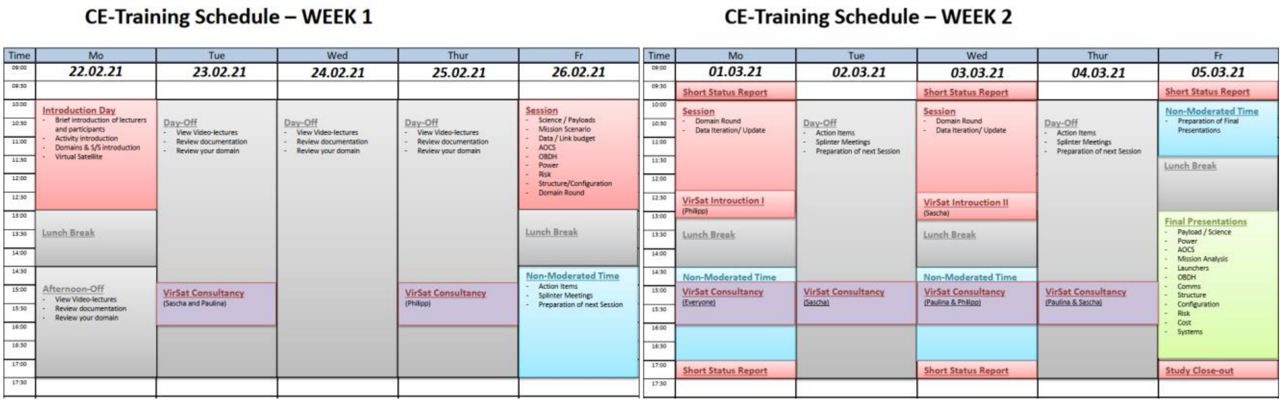


Fig. 2. First training schedule for on-line CE/CoE course (1st semester 2021)

**First Outcomes**

While the course was successful, and we managed to roughly emulate the process and results of previous on-site iterations of the SECEF course, we did find that the number of iterations of the design were subpar. We concluded that this was due to:

1. The Payload and Science domain took too much time to close their specific mission requirements, and then to complete their payload design (i.e., select and configure their instruments and equipment) when working online.
2. The inefficient communication seemed to lag progress more than anticipated.

In real CE studies we normally either have a pre-defined payload, or at least have the necessary information to consider the payload a "black box" from the point of view of the satellite bus or the spacecraft. For the students, we have always wanted them to create their own mission. While this seems to be generally well received, it adds a certain level of extra stress since the payload and science domain needs to (mostly) complete their tasks within a day or two, or the rest of the team will have insufficient time to design the rest of the bus. While this seemed to work in on-site iterations of the course, we learnt that additional time is required when doing this online.

Even though we were aware of the problem, we failed to fully understand the level in which having all the students working remotely would slow down their work. During this first online course we realized that besides the communication barriers, other factors affected the pace of work. In particular, working online can result in a certain lax attitude in some students. When working with a team on-site, and with the lecturers' present, a certain level of "peer-pressure" is felt which is lost when working in a distributed manner. This translates into delays in work, some partners being forced to taking a larger amount of responsibility, and lower team cohesion.

**Schedule Evolution**

Based on our findings, we updated the schedule:

1. Because of the need to have the mission requirements and the payload design completed as soon as possible –as the bus design cannot proceed much without it– we added an additional Payload Specific session. During this session, we conducted a brainstorm of ideas to identify an interesting mission, and guided the team to achieve as close to a mission concept as possible. The payload and science team were then responsible to make their research and design their payload within the next couple days, and strongly encouraged to finalize by the end of Monday at the latest.
2. In order to account for the slow progress evidenced in the previous iteration of the course, we also included an additional session on the second week, with the idea of adding a final opportunity to iterate the design before final presentations. We also reasoned that while on off-days it was up to the individual participants to be engaged with their team members, in days where we conducted sessions they compelled to be fully involved.

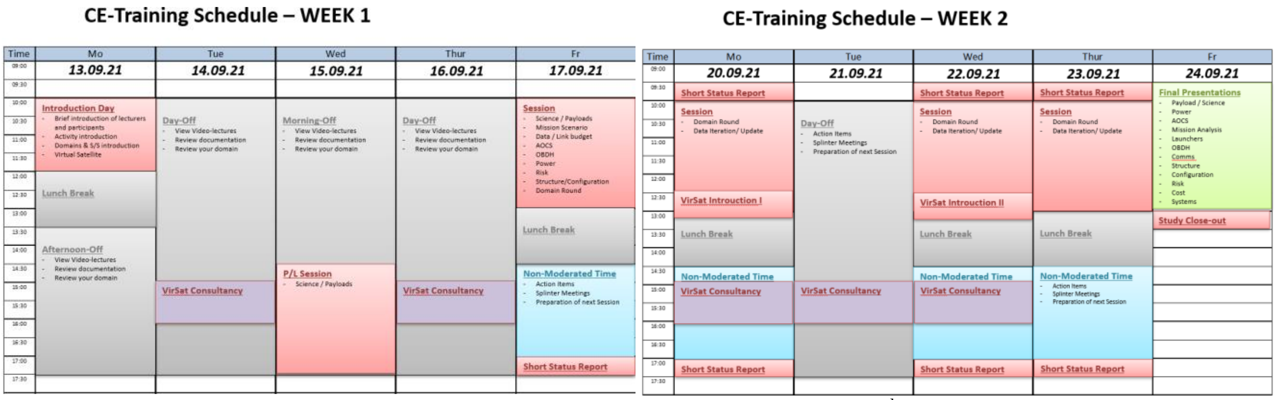


Fig. 3. Second training schedule for on-line CE/CoE course (2nd semester 2021)

**Final Outcomes**

The results in our second iteration of the on-line course were much better. The payload session worked well, and helped move the first part of the work along in a more streamlined way than in the previous course. The additional session at the end of the second week also helped to iterate the design and have a more finished product at the end.

In view of these results, we maintained the same training schedule in the following course (1st semester 2022), which turned out even better. The main reason for this was the high level of commitment from the students. In particular, the payload and science group was composed of very motivated participants who set a high bar from the start. They were able to provide a remarkably good –and close to complete– payload design by the end of the first week. They also made the effort to continuously work in a presentation format to share their information with the team from the very first day. This energy and method seemed to rapidly spread into the rest of the team, and positively impacted the final outcome of the course.

**Lessons Learnt**

- **Encourage presentation of results from the start**: Considering the frequency of technical issues with audio and other human communication issues when using video conferencing systems, providing frequent visual presentations of any results or critical information can be key in improving remote collaboration.
- **When certain tools or tasks are important to the course, ensure their use by making them part of the evaluation**: In spite of stressing the importance of installing and using Virtual Satellite, a number of students did not have the software installed when the first session was conducted on the first iteration of the course. Furthermore, a few avoided to work with it throughout the course, letting their partners assume responsibility for their subsystem's model. To ensure an equitable distribution of responsibilities and that everyone experienced the use of Virtual Satellite to understand what MBSE is about, we set a deadline at the end of the first week for the installation and set-up of the software. The students who did not do so incurred an automatic penalty to their grade. We also asked students to distribute the elements within their subsystems between themselves, and kept track of their work and progress, which we then evaluated for the engagement part of the grade.
- **Emphasize the importance of engagement, and if it is lacking, reduce "off days" and add more moderated sessions:** While "off days" are important for students to work on their tasks and self-organize, be aware that working online can result in a certain lax attitude from some of the students. If it seems like the team is not following through, it might be a sign that there are some members/groups inside the team that are not as focused as they should be. It may be a good moment to add additional sessions, as that will force most passive students to participate.
- **Don't underestimate the impact of inefficient communication:** Remote working tools and video-conferencing tools have substantially improved since the start of the pandemic, and many interesting functions are now available which can improve the effectiveness of remote communication within teams. In spite of this, good teamwork hinges on good communication, and communicating online still falls short from face to face communication. When intending to work remotely under a similar model as you work on-site, **expanding the timeframe is almost a necessity**. This gives the team the flexibility to adjust to any changing circumstances and to add additional time to communicate separately. Also, finding the best way to conduct group discussions in an effective way with your specific team is important. Consider aspects such as:

a. Define your remote meeting etiquette: Should everyone have the cameras on during discussions, or only the person speaking? Do you implement a “raising your hand” approach for questions/comments, or assign a comment-moderator and ask participants to write their questions/comments in the group chat?
b. Determine your own online meeting tool stack: What engagement tools work best? Virtual whiteboard? Interactive polling? Shared text document?

## WORKSHOPS

### Background

In 2019 the CEF was contacted internally, and we were asked to provide support to a project for which the DLR was carrying out the System Engineering lead. This project, at the time in a Phase 0 stage, has been ongoing in the last years and, what started as a collocated workshop in 2019, became a yearly online workshop in 2020 and 2021. These separate activities built upon the results from the first workshop and the work carried out by the team throughout the rest of the year.

The objectives to be carried out by the project revolved around a complex exploration mission, requiring multiple independent elements each of which were to be developed by independent contractors. Each of these elements was a complex system on its own right, including items such as surface support equipment, an autonomous vehicle, or a special type of probe.

While some of these elements had been under development for some time, they had been designed independently and with little interaction between the different contractors. At the time, the project was being conducted without a control for integration, interfacing, and overall general system engineering practices (e.g., no functional analysis of complete system, no joint mission & system level requirements). Wanting to close the gap between the work being carried out and their own vision, the customer decided to bring DLR in to support the project by introducing the principles of systems engineering to the team, and supporting their efforts as System Engineering lead.

As this project is confidential, we cannot disclose details in regards to the mission objectives, participating organizations, and other comprehensive information, but we will introduce the objectives of the workshops, explain the main execution steps taken, and our lessons learnt.

### Objectives, Execution and Results 2019

The original 2019 workshop objectives revolved around three major aspects:

- Team building.
- Integrating a System Engineering viewpoint into the team.
- Closing the gap between the customers vision for the mission and the work that was being carried out.

More specifically, the support of the CEF was requested to help the team to integrate the different concepts, define the interfaces between the elements, and assist the team so they could produce a documented case for the mission, covering the science case and technology case, the mission design, and the scientific & technological payload design.

The workshop was conducted on-site, for a one-week period. After introductions of the previous work by the different contractors, and a system view presentation by the Systems Engineer, a number of issues arose. There was conflicting terminology, different assumptions on how the mission would be conducted, as well as insufficient understanding between contractors of their interfacing and interaction with other elements of the system.

On top of that, there seemed to be a general feeling in the team that following a system engineering process was burdensome and unnecessary. In particular, the importance of a functional analysis was played down, as in the view of some team members this seemed to be purely documentation of things that they believed they had tackled on their own or their element was already further in development with regard to their project life cycle already including hardware.

After some deliberation, we decided that the most productive way forward would be to re-focus into taking the team through an analysis of the desired mission scenario, dividing it into activity segments, and identifying the steps and elements involved at every stage. This opened up avenues of discussion regarding interfacing and design considerations (including functions) that had not been considered previously.

By the end of the workshop the team seemed satisfied with the results, actions were set for future work, and there seemed to be a grudging acceptance of systems engineering installed in the team.

**Objectives, Execution and Results 2020**

On this first online workshop the general objective was to continue working on the team building aspects, on the integration of the system engineering viewpoint, and to perform a complete functional analysis.

The major issue when performing the functional analysis though was that each contractor continued to look at the project as an integration of systems where they only needed to focus on their "own system". This view limited the analysis as it did not consider the system level functions which impacted multiple elements.

In light of this we divided the experts by domain (e.g., communications, power, structure) and asked them to work on the functions pertaining to their domains but for the overall system. Once this was done we divided them again, now into their system elements, and carried out the functional analysis at that level.

Dividing the experts and keeping track of multiple sub-teams online was a challenge. We could provide separate virtual rooms for each sub-team, but following all the discussions was impracticable, and having discussions with the whole team would have been tremendously inefficient. As a strategy, we decided that the best way was to set clear step-by-step tasks, and let the team organize itself in whatever way they preferred. We offered continuous non-moderated slots of time, with short update sessions in the middle so we could keep track, and move onto the next step as soon as every sub-team was done.

This seemed to work remarkably well: the clear focus on what was expected next allowed the team to focus on technical aspects, rather than on methodology and the reason behind the need for the step itself. This provided good results, and seemed to help in team building as discussions were carried out in small groups rather than the whole team. It also seemed to make the experts feel more comfortable with the process, and they were more engaged and accountable, as they felt in control of their design decisions (as it should be) – we asked them for deliverables that they could develop as they saw fit, instead of feeling that we were telling them what to do on the technical front.

After performing these two analyses, we finished the exercise by integrating them into a "functions matrix". From this document, the team evaluated the functions across domains for their system elements, and identified the internal and external interfaces they needed to consider for their element to satisfy the needs of the system.

**Objectives, Execution and Results 2021**

The third workshop took place when Covid-19 restrictions were slightly loosened. It was possible to meet again on-site but keeping social distancing, which lead to the following set up: A core design team of ca. 14 engineers were seated on spaced out tables in a conference room equipped with a room microphone, a projector and a webcam; because of the upper limit of allowed people for the conference room, the costumer together with the systems engineer and the moderator participated from the CEF (same building but two floors below the design team); the remaining c.a. 17 engineers from the project team together with the moderator backup participated remotely, online only.

Based on the effort invested in the upfront workshops, early phase systems engineering was continued leading after a 5-days CE approach to: a list of sensors, a mission sequence, a mapping of functions to hardware, a concept of operations and autonomy, the basic visualization of the involved elements and a product tree including first budgets and interface definitions within a data model.

Issues and findings:

- Bad audio quality, mostly due to equipment (e.g., inadequate microphones and speaker systems).
- Hard to involve remote participants due to audio quality and a lack of mechanisms to integrate them better into our ad-hoc setup.
- Direct communication between moderator, systems engineer and customer proved very helpful for fast decision taking and study planning.

- CEF-team felt disconnected from conference room design team while working in separate spaces; this led to lower acceptance of guidance, proposals and action items. We tried to correct this by having the CEF-team visit the conference room from time to time in person (whilst opening windows for Covid-19 regulations); this made a positive impact.
- Some IT open minded participants made the acceptance of Virtual Satellite core version (more complex in comparison to standard CE version) significantly easier.

**Lessons Learnt**

- **For online workshop activities, setting clear step-by-step tasks, and letting the team organise itself in whatever way they prefer seems to work very well**: While team discussions might be necessary at points, the work progresses much faster if it is broken down into tasks, each task and its deliverable is provided sequentially to the team, and non-moderated, self-organised time slots are provided for the sub-teams/individuals to work independently. In our experience, people familiar with the CE process and/or CE studies can make this process more effective by taking the lead of the changing groups.
- **Different team configurations are very successful in providing different perspectives inside the team**: When dealing with systems of systems, or very complex systems, dividing the "System Element" teams (e.g., autonomous vehicle team, probe team) into Domains (e.g., Thermal, Data Handling) can help make the team to see the complete mission system and find themselves asking system level questions, instead of focusing on "their system". In our experience, this seemed to help with the integration of the "Systems View" for the team.
- **The threshold for the minimum equipment and communication software in CoE activities is very high:** While it is obvious that equipment and software is necessary for remote collaborative working, the minimum threshold seems to be frequently underestimated. Continuous access to microphones needs to be at the individual or 2-people level minimum, and audio speakers need to be powerful; if such a setup is not possible, headsets with microphones might be the best alternative, although they interfere with natural communication with the people around you – this is especially ture for comfortable, well-cushioned high-performance models; one ear headsets with microphone might reduce the negative impact.
- **While it is possible to perform good work in remote collaborative conditions, in-person communication remains superior**: While full-remote work has been necessary in the last years –and will remain necessary at lest to some degree in the future–, hybrid activities with the key personnel on-site, using the CEF as a nexus between local participants and online participants will provide better results when remote participation is indispensable. When possible, traditional CE should be used.

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