Integrated Concurrent Engineering Teams for Increased Efficiency in Flight Projects

Bert Pasquale, Goddard Space Flight Center, Greenbelt, MD 20771, bert.a.pasquale@nasa.gov

ABSTRACT

A highly integrated Concurrent Engineering Team (CET) within a flight project evolves in its function and has the potential to provide many benefits through the project lifecycle. The benefits include superior systems-oriented design products, as well as overall improved project efficiency and higher-performing interpersonal relationships within the project. If physically integrated, this can manifest as a Concurrent Engineering Center (CEC) centrally located within a project's physical office space. Here we discuss the process to establish and maintain a tightly integrated engineering and design team for providing highly streamlined service to the project, including a cost/benefits analysis discussion.

Keywords: Flight Project, System Engineering, Project Management, Space Telescopes, Optical Design, Concurrent Engineering, Model Based Systems Engineering, LUVOIR

1. OVERVIEW

This paper describes the functions, workings and benefits of a highly integrated Concurrent Engineering Team (CET) within a flight project. The word "integrated" is used in this paper in the context of being fully embedded in the structure, culture and physical space of a project. "Flight project" is most often being thought of by the author as scientific observatories and instruments. The structure of such an amalgamated team begins with the formation of the project and evolves as the team grows and the project progresses through lifecycle phases. **The benefits include superior systems-oriented design products, as well as overall maximized project efficiency with higher-performing interpersonal relationships**. This paper suggests various functions one can do as an engineer and/or as a project leader to facilitate this.

The three legs of any flight project can be illustrated as programmatic, design & engineering and mission assurance (see Figure 1) to support mission success. Each of these are connected with interdependencies and also have independent accountability. In a NASA project, science usually defines the mission success, and therefore drives the needed capabilities of the observatory and science instruments. As the lead systems engineer translates these capabilities into functional and performance requirements, they must then work with the design team to create architecture and instrumentation to meet the project goals. So ultimately, science drives the design, and the design must enable the science.

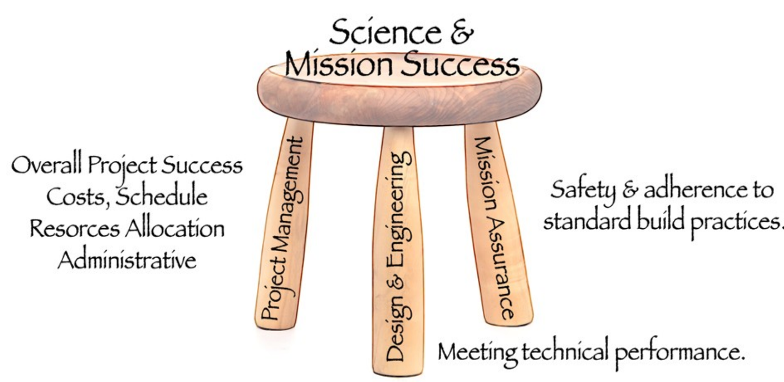


Figure 1. The Three Legs of flight projects: The balanced project functions most efficiently when each leg is equally strong.

A deficiency in the strength of any leg at best hinders the project, and at worse collapses the mission. The ideal situation for a flight project is when the designers can work as a tightly integrated part of the flight project. As NASA and industry continue to move more toward Model-Based Systems Engineering (MBSE), flight projects are adapting to how these legs work together to support the project, both organizationally and physically. This mindset can manifest as an Concurrent Engineering Center (CEC) centrally located within a project's physical office space. CET (the team) and CEC (a physical space) are used interchangeably in this paper, depending on context. This paper delves into the means to establish and maintain a tightly Concurrent Engineering Team as the basis for overall increased project efficiency. This concept is based on lessons learned from eleven years as the optical design and analysis lead on a flight project (from proposal work to Pre-Phase-A though Phase-C) and subsequent discussions with project leaders, fellow designers, and various center leaders.

2. CONCURRENT ENGINEERING TEAM STRUCTURE

A truly integrated Concurrent Engineering Team can be an essential part of a healthy and strong engineering leg, functioning with direct connection to the project-level team. To accomplish this, it should be:

2.1 Created at the Inception of the Project

Consideration for the design team's role and physical setup begins at the highest levels and at the earliest junctures. If the design team's evolving role and resources are a forethought to the mission's structure, then they can become instituted as part of the project's culture. These discussions could occur between design and proposal leaders during the proposal phase and be included in the management section writeup.

2.2 Tightly Integrated into the Project Structure

A flight project will have a Lead Systems Engineer (LSE) at the project level as the engineering technical authority for the project. The LSE has the responsibility to encourage team members to speak up, evaluate concerns that are raised and determine the appropriate response (based on technical suitability, cost and schedule) with the authority to follow through, all the way to the NASA Chief Engineer if necessary. If a project also has a Lead Concept Designer (LCD) within the development team, together they can work directly with the engineers and designers, while maintaining full awareness of programmatic concerns. This concept has been adopted in some 2020 Decadal Study proposals as shown in Figure 2.

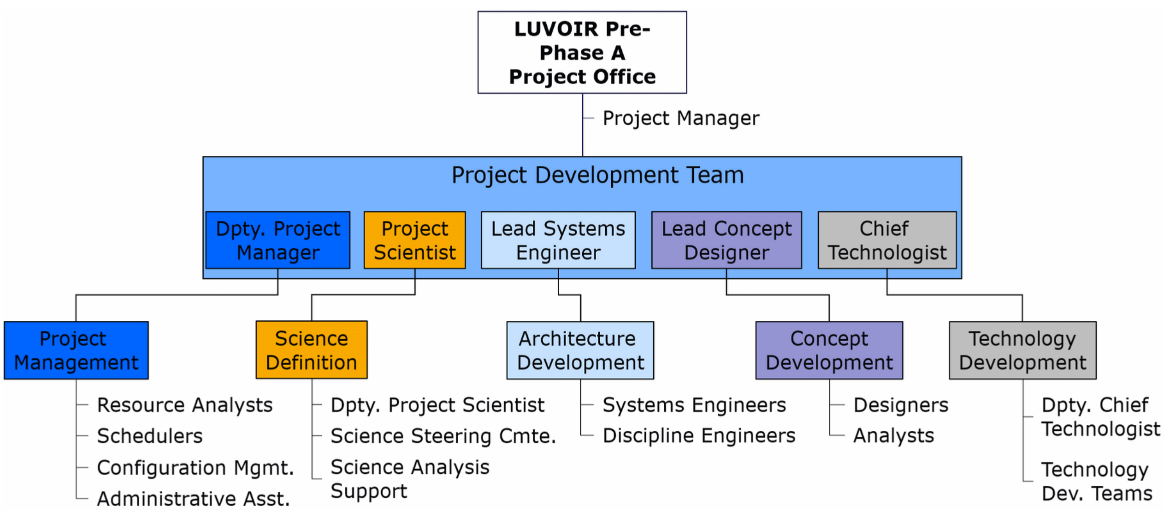


Figure 2. An example of flight project management structure. (The LUVOIR Final Report, Section 12.2.1)[2]

In the paradigm of the Concurrent Engineering Team, the LCD, or a deputy, would function as the design team director. Therefore, the designers and analysts work in a concurrent engineering environment and are tightly pulled in to keep the path as short as possible to the project, as shown in Figure 3. This allows the interdependent relationships between the three legs to be well fostered, and strengthening of the engineering inputs including systems, technology and science teams.

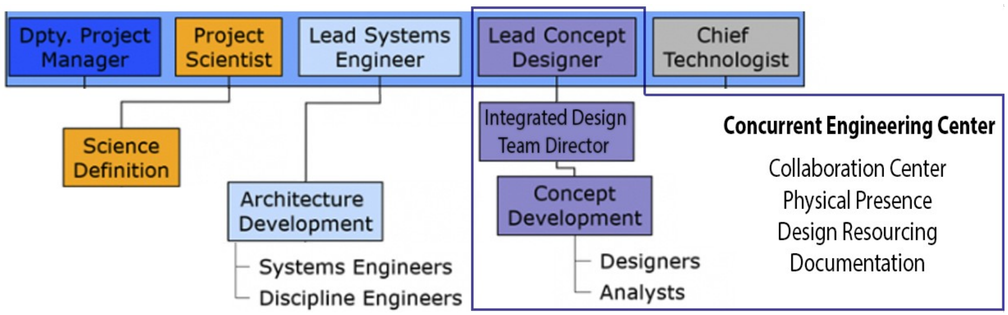
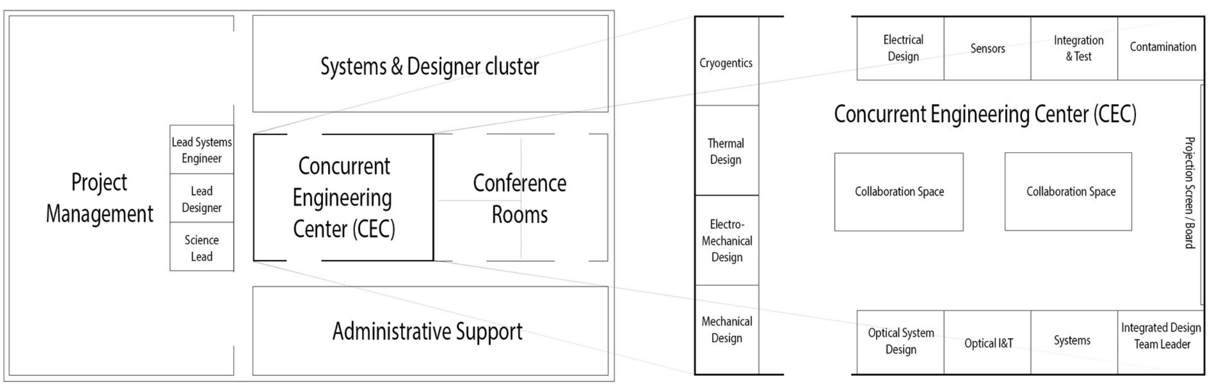


Figure 3. Conceptual CEC project integration structure.

2.3 Physically Integrated into the Project

The paradigm of a "war room" is often used in the proposal stage. Proposal teams assemble into a highly interactive (but temporary) physical environment to work out a baseline design that meets requirements and to produce proposal documentation. However, once a project begins, designers usually remain scattered in various engineering branches' respective spaces. Later, when a project has a larger dedicated space, engineers may be interspersed among the cubicles, often without line of sight to each other, nor along management walking paths. Once a project has a physical space, it behooves them to have centrally located dedicated design space (configured based on input from their design team) that fosters the direct interaction of designers and the project. This elevates the importance and expectations of the team.

As a model for this, we may look to the Goddard Space Flight Center Integrated Design Center[2] which includes the Instrument Design Lab, Mission Design Lab, and Architecture Design Lab. Each operate in a unified multi-disciplinary space with a rapid-response, quick-turnaround team, usually for a proposal effort. The respective lab director keeps the activity focused and maintains cohesion: What are today's deliverables? What sidebars are needed? Who's waiting for who's analysis? Does anyone have an agenda item for the afternoon tag-up? This results in consistent systems-driven products. A dedicated space within a flight project (example shown in Figure 4) would enables this on an ongoing basis.



(a) (b)

Figure 4. (a) A conceptual project layout with a core Concurrent Engineering Center (CEC) and (b) CEC detail concept.

2.4 Supporting Model-Based Systems Engineering (MBSE)

The goal of systems engineering is to deliver value to the stakeholders via managed data relationships. But flight projects can often have disparate paths of information for documentation and stand-alone analysis models. As systems become more complex, MBSE is the natural next step in the maturity of Systems Engineering. By managing the details of the pieces and how they communicate, MBSE enables systems engineers and designers to focus on understanding how to the pieces can best work together to build the entire system. As NASA has moved towards Model-Based Systems Engineering where the design is tied directly into the system model for the entire project (as illustrated in Figure 5 (Madni and Purohit, 2019[3])), having the Concurrent Engineering Center at the "right hand" of the LSE with the LCD directly interacting with project-level peers would more fully enable MBSE's potential.

Figure 5. A graphical representation of the data relationships and connections in (a) traditional SE and (b) MBSE. (source: Madni and Purohit, 2019[3])

3. LEVEL 1 PRINCIPLES FOR AN CET

Flight project managers make decisions based on both cost/benefit analysis and risk analysis. The concepts presented here of implementing a fully Concurrent Engineering Team are grounded in the following principles to optimize both:

3.1 The project's real resources are carbon-based.

When team relationships and working functions are cared for, the technical issues will best be resolved. Giving thoughtful attention to the needs of the team members allows the technical and programmatic issues to resolve with maximum efficiency. Aspects of interpersonal relationships, including personalities, strengths and weaknesses, resourcing, training and how team members are appreciated are all valid considerations.

3.2 The project can only progress at maximum efficiency when its design team operates at maximum efficiency.

If the stool has one short leg, the project is going to spend a lot of time, energy, and resources just catching the things that are about to fall off the edge (and fixing the things that did). The more responsive the design team can be to project needs, the more efficiently all aspects of a program can run.

3.3 Cost of better design now << Cost of dealing with issues later

Systems-oriented designs based on directed parametric studies are less likely to require major and even minor revisions, and more likely to avoid pitfalls, overcome problems efficiently and deliver more robust functional performance.

3.4 Great Documentation flows from Great Design work

Documents (e.g., Statement of Work, Technical Brief, etc.) that flow from the designers' experience and are based on vetted design trades and solutions can convey accurate representations and provide clarity. Those written based on assumptions or without guidance from the design team may require much un-tangling and leave confusion.

3.5 Face-to-face concurrent engineering prevents a multitude of delays, mishaps, and re-dos.

When the team is physically co-located, problems can often be solved in real-time, and much miscommunication is avoided. Integrated teams can develop very strong internal cross-discipline system-oriented understanding and efficiently provide robust design solutions.

4. EVOLUTION OVER THE LIFECYCLE OF THE PROJECT

This section outlines the changing roles and structure of the design and analysis team over the lifecycle of the project. Section 5 will then discuss the supporting activities and processes.

4.1 Proposal Development

A proposal team is usually led by a Principal Investigator (PI) who is seeking to achieve a specific scientific goal. During this time the PI's team will often work one-on-one with a few engineers. They may utilize the optics branch's Optical Design Lab (ODL) as a starting place for bringing a working model their system concept together. If supported by the Science Mission Directorate (SMD), they may also use the center's Instrument Design Lab and/or the Mission Design Lab rapid concurrent engineering environment to scope and cost their concept for proposal submission.

4.2 Forming & Architectural Design

After being selected as a project, the design team may just be few discipline leads. These personnel may or may not be drawn from those involved with the proposal work. This small team will span responsibilities across the full architecture, including payload (telescope and multiple instruments) and spacecraft. They will be working in tight coordination with project, science, and each other where it is imperative for them to form a strong working bonds. The foundation of a robust system-oriented design is laid by iteratively creating and testing concepts that take into account each other's inputs.

Many high-level trade studies will be performed during this phase. The designers and systems engineers will develop the foundation for a functional architecture. As requirement are solidified, the importance of coalescing analysis results, systems' and design's inputs is essential to writing clear, robust documents. This team is also responsible for creating the knowledge base system of tracking the trades made (and the motives behind) them and translating then into an accessible design Lessons Learned narrative.

4.3 Pre-Phase-A: Design Maturation and Trade Studies

As the team adds on new personnel, each engineering discipline has the potential to add several supporting members. It is essential to have developed a "systems orientation" narrative to the project. New team members can be briefed on the history of how we got here, potentially raising new thoughts that can immediately be built on. Trade studies will move away from large architecture questions and towards more detail studies. Math Models standards are confirmed, including software and file formats. The design leads may also be acting as Product Development Leads (PDLs) responsible for managing their cost & schedule. Relationships with outside institutions can creating new interfaces. As design cycles continue (sometimes as quickly as 6-12 month intervals), the robust systems-oriented foundation can enable a quicker convergence to Phase-A-level quality of analysis to support the Mission Critical Review.

4.4 Phase-A: Flight Designs

In Phase A, the project would likely go through one or two more design cycle releases to solidify the flight design. This again necessitates the design team continue to work in tight coordination with the project disciplines. Also, the design teams for instruments may now be "breaking off" from the original core (in essence starting their own CETs), with new engineers and designers joining on these teams. The original core members are entrusted to impart a full system history to the new members as teams divide up. New PDLs may join the team, or designers are pulled into full time PDL positions. As formal vendors studies ensue, it is again imperative to have a cohesive design team to interface with requirements and design parameters. All this is done as requirements flow from and results flow back to the project. Correlation of modeling and analysis inputs from disparate teams will require careful coordination, as illustrated in Figure 6:

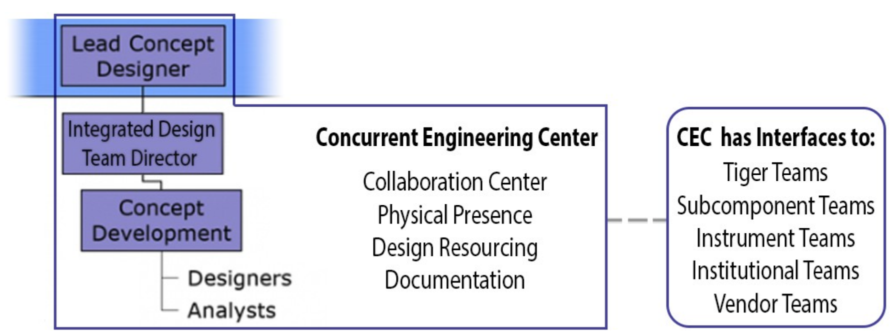


Figure 6. Representation of CEC coordination with other design teams under the project purview.

4.5 Phase-B: Prototypes and Final Design

In Phase B, separate instrument teams are now well established, potentially in distributed spaces. The continued growth of new personnel will require cognizant heritage members to continue knowledge transfer. The CET would continue to maintain a continuity between teams, including newly established vendor contracts. Multiple team analysis results can continue to flow back through the Systems and Design Center teams for checks and correlations, with the results and activities coordinated with project-level interrelationships (e.g., systems, technology, science and management).

4.6 Phase-C/D: Building and I&T

During hardware build, the CEC may continue to operate as aggregator of results for top-level correlations. The fast response of the concurrent engineering teams would mitigate the risk of hardware failures. Activities would include modeling of the I&T processes, providing correct sensitivities of the test setups and running "realistic" Monty Carlos of the instruments and test setups. This allows problems to be caught, and processes improved before and during I&T. The CET would work with the LSE to support Mission Ops for development of commissioning and in-flight calibration plans.

4.7 Phase-E: Commissioning & Operations

After possibly a decade or more since initial design concepts were traded, maintaining a continuity of cognizant design team members into flight operations could be of value to the project. As Level-0 data comes from the observatory, the Space Operations Center (SOC) has the responsibility of calibration, processing and generation of Level 1-N (1, 2, 3…) science products. The CET can contribute calibration artifacts (e.g., test-informed and validated engineering models behind the processing) to support the SOC. For example, correlations to wavefront sensing and simulated field images can be used to rapidly create on-orbit optical and environmental models which feed back into calibration and data processing.

5. CONCURRENT ENGINEERING TEAM ACTIVITIES

To support this project lifetime cycle, there are many activities and functions to consider in the implementation of the Concurrent Engineering Team for a flight project. These are broken these into five general categories (Figure 7).

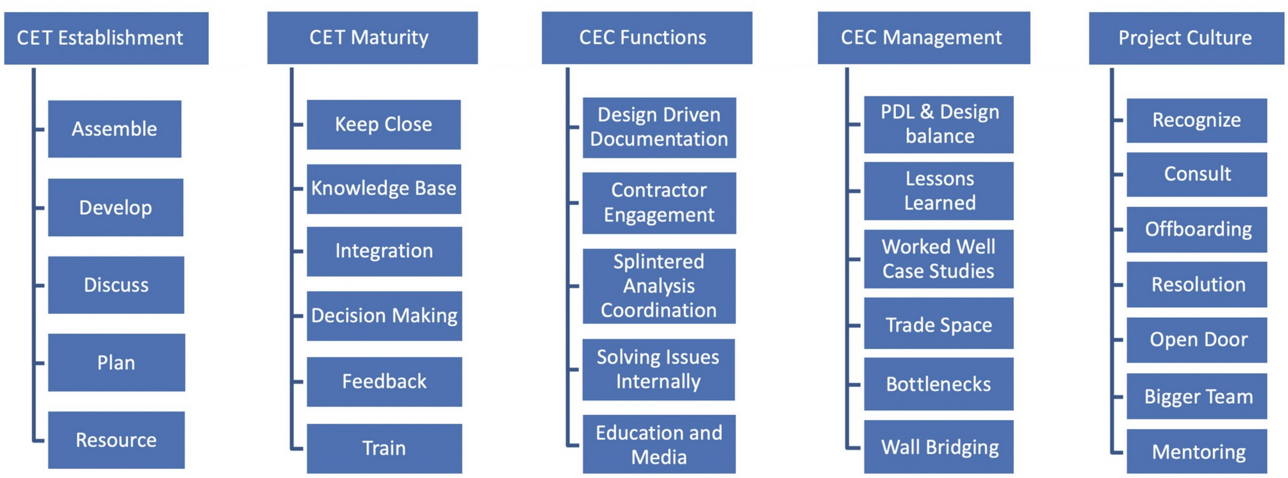


Figure 7. Breakout of various CET activities.

5.1 Design Team & Center Establishment

The early phases of development set the technical and cultural foundation for both the team and the larger project.

Assemble the right team.
The basis for developing a high-functioning team includes not only the right technical skill set, but also the right mix of other strengths such as experience, interpersonal skills and leadership capabilities.

Develop the design team, both internally and with the project.
To be effective, all CET discipline leads must work together with a multi-discipline systems mindset. By understanding the other disciplines' first-order constraints and drivers, they can mitigate against re-designs later. The parametric trade studies of the CET will set the foundation for the flight system.

Beyond the technical, the project can employ the use of assessment tools (CliftonStrengths®, DiSC®, etc.) and coaching resources to bring awareness of the project and team's dynamic interplay from the beginning. Self and mutual understanding will make a huge difference to the long-term unity and culture of the project. The entire project could have coach-led discussions on regular intervals, with break-out sessions for leadership and sub-teams. On-boarding of new members can include said assessment tools and reviews with team leaders. When break-out teams are formed, this assessment can be repeated on a smaller scale (perhaps just a discussion) to quickly bring cohesion to the group.

Discus & Plan CEC development with team members.
The first step in design optimization may be the optimization of resources, which are *always* limited! Having learned how the members "move" as their strengths allow, and by exploring solutions with the CET, the project can implement processes and working environment optimized to the team's unique way of working. The risk exists of creating inefficiencies when resources are allocated without any consultation with the team members. This planning may apply to a small group of cubicles now, or years away when the project moves into dedicated office space or begins I&T.

Proactively act to resource an CEC.
Resources and space will always be constrained, so the project buy-in of an CEC prior to acquiring new space is essential. The lead designer up to the project manager needs to champion the establishment of the Concurrent Engineering Center and make the case "up the ladder" (to the flight directorate level) from the beginning. No one can assume resource decisions will be made based on optimal function. The CEC Leader must stay active in resourcing decisions or risk leaving the team under-resourced. The engineers and CET should not have to look elsewhere for their resources to optimize their workflow that otherwise could have been provided by the project.

5.2 Team Maturity

The team "matures" as the project progresses. Many programmatic, technical and sociological influence will be in play as it does so. These functions may assist both the team's and the project's growth.

Keep the team at the project's right hand.
A main utility of the physical proximity of the CEC is to enhance the communicative flow. Having the Lead Concept Designer and Systems Engineer working together at the project level allows the apropos application of the design team to solve the systematic problems. The establishment of the ICD supercharges this, allows for designers to remain fully involved in and supportive of the project progress. Having "linchpin" members (those with the most intimate understanding of the systematic drivers the design) close by enables both management and the LCD to be "in the know" on a daily basis. There is a disconnect that naturally occurs with physical distance, with the risk that design is brought in as an afterthought to an evolving issue. The resulting inefficiencies can be avoided if the project develops a culture where designers are part of the initial discussions.

Treat Knowledge Base as gold
The value of CET members who had slugged through the work of establishing the systems-oriented design should always be appreciated. These "highly cognizant" engineers carry the knowledge to prevent potential errors. They are valuable at all junctures and can be key to train and integrate new members. If your key members love working on the project, they will stay on to pass their knowledge, and loyalty, to others.

Integrate new additions thoughtfully
As previously mentioned, onboarding can include strengths assessment and time to get to know and be known by the team. This promotion of assimilation and unity is just as important when members join in later phases. It is essential to be sure new members fully interface with heritage members for some time while they learn the systematic drivers of the design.

Another caution during onboarding is to not displace heritage members who have been integral to specific meetings or interfaces. The new member may bring a new or specialized skill, but not possess the knowledge base to understand the issues. Not maintaining the heritage member's connections may cause very costly delays or errors.

Keep the CET members fully engaged in decision-making
When there are project-level decisions which touch on design issues and/or designer's functions, it should be regular practice to have full LCD and/or CET Sr. representative participation. Having to provide refutation of a decision made by management after-the-fact is counter-productive all around.

Create a culture of open, solicited feedback
There is a huge ROI on developing a culture that invites and rewards open feedback. This is directly embodied in identifying issues that could potentially otherwise go unresolved and cause problems later. All projects naturally endorse the free and open reporting of risks, issues, and failures as a fundamental part of any project culture. But it doesn't fully happen without proactive measures that take both the technical and human dynamics into account. All weekly status meetings or reports could include the question: "What resistances to your work did you face this week? If they were resolved, how so?" On the technical side, to keep issues from slipping through the cracks, the CEC manager should keep a running list of issues brought up and if/how they were resolved.

Train members on reporting procedures
In is ultimately the engineer's job to proactively call out issues. But there is always the human factor. Realize that members may be holding on to an issue because they have the belief it will be resolved in due course or another entity will eventually take the desired action. (In retrospect, certain resistances should have been bigger red flags than I realized at the time.) The use of coaching assessments can bring out issues that members have been reluctant to raise, and more importantly uncover the cultural issues driving the reluctance. Likewise, conducting "stay interviews" with those who continue on the project will enhance the understanding of what works well and communicate that team members' opinions matter.

If a culture of rewarding feedback has been developed, the vast majority of issues will be resolved directly. But many designers and engineers will not fully grasp how the internal and independent reporting paths function and how they can be properly (or improperly) used. Clear reporting chains that make it possible for everyone to report up as far as needed within a project are just an org chart away. Actually coaching members how to do this communicates that their concerns will be taken seriously.

5.3 CEC Functions

An Concurrent Engineering Center enables many technical and project functions to run smoothly. These could include:

Creating design-driven documentation.
There's a saying "where you sit is where you stand." Project managers, scientists and engineers may each have a different perspective of how the documentation, design and science interplay. In the CEC, the designers can work in concert with the project and science to support the creation of documents as they need to be produced. This could be hardware requirements, procedures, or presentations. Inter-disciplinary reviews can allow documents to be edited in real-time with full technical consensus. There is a danger of documentation being written without full participation by designers that contains erroneous technical interpretations. Communication is key to prevent errors. For example, writing hardware requirements documents in concert with the designers can prevent errors that would lead to a swirl of confusion and the tedious revision work of rooting out the misunderstandings.

Preparation for contractor engagement.
How hardware requirement SOWs for vendors contracts are structured will vary. They are written as per legalities and the work is governed by FAR. This becomes trickier and more important where there is tight dependence between vendor and NASA hardware or even other vendors. Writing an Interface Control Document (ICD), carries the basic requirement for the cognizant designers and relevant stakeholder to contribute input and review the product, as an error here could cause multiple delays and re-works across multiple vendors and institutions. The CEC can provide the context to efficiently generate and vet ICDs. This provides the contractors with better guidelines and streamlines contractual issues.

Collating splintered analysis back to top-level requirements
As the project grows, additional internal teams will develop for instruments, discipline breakouts and/or other "tiger-teams" as well as and external institutional and vendor teams. The CEC can act as a collator of analysis from these sources and work with the LSE to maintain continuity to top-level requirements. The CEC can also check work and plans against references such as NASA GOLD Rule 5.11: "Instrument System Performance Margins" and 5.12: "Instrument Alignment, Integration and Test". The CEC can centrally integrate vendor models into project models, enabling the designers to quickly asses design products from the contractors. If necessary, they can do parallel analysis to support validation activities, and be instrumental in resolving conflicts. If needed, the CEC designers can work as "badgeless teams" with the vendor to settle design issues (to certain level given contractual regulations and while respecting their autonomy).

Understanding design issues internally before discussing widely.
Design issues and problems are, by definition, expected. Sometimes there are issues that need to be (or already have been) brought to project management, or beyond. Impromptu meetings to discuss design issues with management and/or customers prior to having an internal understanding of the technical issue and a proposed plan forward, carry the danger of increasing confusion and misunderstanding. In the CEC, a project manager or team member can first consult the core team and those involved to gain understand the issue, perhaps with additional analysis or documentation being produced. Once understood, the message and proposed solution if applicable can be propagated clearly and in unity.

Supporting educational and outreach media.
Project outreach and educational materials are very important for the general public's support of NASA's mission. These materials can greatly benefit from products supplied by the CEC. These could include graphics, animations and technical text copy. Many online communities are very tech-savvy and if errors find their way into public material, they are quick to either point out errors or draw incorrect understanding of the systems NASA builds. With CEC storyboarding and products, project media can portray and describe the systems correctly to the public and carry a high scientific gravitas.

5.4 CEC Management

The CEC supports management by a variety of functions.

Find an optimal balance between PDL and designer tasks.
Having The functions of an CEC potentially consolidates the management of the engineering disciplines, requiring less non-engineering overhead. Product Development Leads (PDLs) are in essence a mini project managers, responsible to a set and manage schedule and budget, and also to assemble the needed team (designers, technicians, schedulers, etc.) to deliver their product to the project. The more the designers are empowered to design, the better they serve their PDLs and the project. While experienced engineers can (sometimes) make great PDLs, there is a risk of pulling away of cognizant engineers from ongoing design and analysis. With the CEC, the PDL overhead could be reduced while keeping the designers in direct line through their management. Since they aggregate discipline leads' inputs on an ongoing basis, the

ICD material can be provided to PDLs for use in their monthly reviews. One alternative scenario is if PDLs from Code 400 (who are trained in resourcing) could work in tandem with IDL discipline engineers. Another option is to provide or even include resource analysis & scheduling to the CET Lead to help with the management aspect inherent to the role.

Keep a list of lessons learned and trade results
The CEC can centrally update design "lessons learned list" after significant deliverables/milestones. These could even be physically posted on a designate portion of the wall, to emphasize its importance and invite discussion from all involved. The list would not be to name names but rather highlight the actions. There should be an open invitation for all members of the project to contribute.

When something works particularly well, understand why, and allow it to happen again.
It's natural to examine, discuss and document when something goes wrong. But rarely does someone write up a case study when things go very well. This risks losing knowledge base and future efficiency. When a team produces amazing results, it behooves the project to not constrain them to move only in a specific the way (without clear explanation as to the drivers behind the constraint). It benefits the project to allow members to "move" in the way they are most productive.

Perform directed design trade space studies
The parametric trades conducted in the early phases can lead to even more streamlined analyses later when schedule is the more precious commodity and do-overs are more costly. Within the CET, considerations for programmatic and systematic constrains can guide these trades. When inter-disciplinary systems-oriented connections are understood by the team, trades can be done "to the left and right" of the baseline parameters. (e.g., "What would be the design freedom gained by loosening the nominal design residual, and what would be the overall effect on the final system?") These parametric studies could translate to a more robust design with higher performance margin and translate to substantial cost savings in development progress, schedule and simplified integration and testing. This also protects against a "design spiral" where design iterations are not part of a controlled burn and the benefits of continuing are not parameterized.

None of these trades matter if they are not communicated well. In the CEC, the team can have the freedom to "speak design" in an environment to allow them to develop and present a clear message to the project. When the project sees the CET can include programmatic constrains in the technical decisions, trust is built rather than worn away.

Mitigate against bottlenecks and delays
Delays often occur, both on a large and small scale. An analysis could take longer to complete than anticipated, or a pandemic can cause a critical design review to slip. A "No bad news late" culture means that delays or other problems are communicated to stakeholders as soon as they are known about. In the CEC, the disciplines are in constant communication with each other, and the CEC Leader can quickly convey status changes to the PDLs, team leaders and/or the project.

Mitigate against artificial walls between engineers
If feasible, the CEC leader can coordinate the discipline efforts of the "engineering pool" across multiple tasks and coordinate back to the project-level program/system-level modeling that individual teams don't have. The Concurrent Engineering Center can thereby act as a bridge between internal design teams that have been divided due to work breakdown structures (WBS). If the CEC is functioning centrally, the resources (the engineers) are able to be used most efficiently with full cross-WBS understanding. It behooves the project to treat productive relationships like gold bars – because that's what they're worth to the project. When apropos, the CET members could work across tasks when there is payoff to the project. This analogy also applies to creating "badgeless" contracting engineering teams and being able to work team-to-team directly, whether virtually or in-person.

5.5 Team and Project Culture

Beyond the design teams, the project-wide culture is passed down from above and so has to be deliberately modeled. There are many moving parts of a project involving soft skils.[4] The following apply not only within the CET/CEC, but to the wider project.

Recognize specific accomplishments of both individuals and teams.
Within the CEC, the specific accomplishments and contributions of both individual designers and teams can be tracked and recognized. While all members are "just doing their job," when they are specifically acknowledged, the team benefits. Within the CEC, the leaders can regularly solicit input and keep a file of praise points, special accomplishments and other noted efforts of the team members. These can be kept handy to regularly write nominations for project, division, directorate or center awards, even if these are internal or "non-official". When giving group awards, attention can be given to also highlight the significant contributions of members with leadership awards.

Make decisions which affect team members after soliciting input and discussing.
There will be many fork-in-the-road points in a project's lifecycle, with dissenting opinions on the proper course of action. The danger exists of decision made without transparency and soliciting input can breed contempt, contention, mistrust and ultimately, disunity. Most people want to feel heard above "getting their way". The CEC could provide a forum for meetings with project leadership, rather than just the design leader meeting with the project. This allows a more inviting forum to have honest discussion about concerns or simply get clarification for issues. Sometimes it may be as simple as taking the time to explain governing rules and methods (e.g., Flight Directorate policies).

Don't leave negative feedback unresolved.
A big red flag for any team is when one member harbors negative impressions of another team member, but it has not been discussed with the team member. The impression could be accurate or a misimpression, so working through the issue is imperative. Leaving issues unaddressed is a setup for reoccurrence and/or creating new issues. For example, having a devalued view of a team member could affect how they are treated and hinder overall progress. Unresolved conflict is an indicator of underlying problems which eventually result in increased dysfunctional relationships over time.

Offboard members thoughtfully.
People leave or sometimes do have to be moved off a project due to performance, interpersonal or organizational factors. Exit interviews can reveal issues that had gone undiscussed and convey that the person's value regardless of the reason. A smooth transition could occur by including moved personnel in the plan if possible. It could be presented as, "Here's the situation, what would you do?", or "We have three options, which do you prefer?" Unceremoniously removing someone with a history in the project risks a strong negative ripple effect on morale in the project.

Foster an open door policy.
An "Open Door" policy means that anyone should feel the freedom to discuss an issue with any other project member. Some buildings have a physical "C-Suite" layout where the uppermost management have a doored-off area; the Open Door policy helps mitigate against all types of barriers at all levels of leadership, between themselves, designers and other project members. If project members feel the leadership is cliquey, it is, but when effort is made at all levels, this can be avoided. By regularly introducing project leadership with new team members and taking opportunities for interaction (social or work-related), an appropriate amount of familiarity can be fostered. The bond between management and designers can be strengthened when the design team holds discussions and debriefs in the CEC.

View your project as part of a bigger team.
Every project is a piece of the whole of NASA's mission. While some instruments or components are explicitly technology "demonstrators" or "pathfinders", flight projects are not inherently technology development vehicles. In either case, defining the necessary technology maturity levels is critical to managing cost and schedule. As projects cannot justify the expenditure of resources beyond direct project interests, technology spin-off should be handled in a way that attempts to preserve the investment. When a project has invested in a technology it's not going to carry further (due to scope change or other factors), it should be assessed for potential agency technology and science payoff.

The CEC may be a powerful resource to brainstorm how the technology could be leveraged elsewhere. Collaboration with the Science Mission Directorate and/or the Engineering and Technology Directorate could then find a funding source for finishing development. Having the technology in-hand could be a key catalyst for component qualification and/or developing a robust science collaboration for a future proposal.

Mentor for the big picture.
NASA's commitment to mentoring is well represented in flight projects, from funding summer internships to including junior members working on teams. It is difficult to truly learn from a class how systems, design, science and technology function together to create something that the nation, in fact the whole world, sees as a pinnacle of achievement. In the ICD, a younger engineer can get a view of "the big picture" of a flight project and how a high-functioning design team serves a project. This also plants the seeds for the next level of thought for future design team efficiency. Developments in technology and techniques should be propagated via branch discussion, papers and presentations. Missions far in the future may be inspired or enhanced by what a young designer or future manager gleans from the mentor's experience.

6. COST/BENEFITS ANALYSIS

In many past flight projects, the design team's structure and role may not have been given this much forethought. If the case for core design team integration is accepted, then it follows that **the efficiency of the project can only be optimal if project has kept the design team healthy, equip and fully engaged**. This efficiency shows up in various ways:

6.1 Financial Impact

The core members of the CET are senior designers, engineers and analysts. If they have taken the steps to develop the understanding and definition of the system together, they can potentially move with great agility through the design process. This team can take the design to maturity on an accelerated schedule, shortening the path to CDR. Beyond the engineering advantages of an CEC within the project, having the team and all it embodies as a central component of the culture can greatly mitigate against project schedule and cost overruns. This could potentially include:

Reducing the number of cycles and re-dos. (Mid to high cost)
Reducing the number of design fixes. (Significant cost)
Reducing the number of missed opportunities for streamlining. (Unquantifiable cost)
Reducing the contractual delays and bring clarity to negotiations. (Potentially huge cost)

Avoiding these errors can speed the development cycles while maintaining or increasing project margins.

6.2 Design Impact

The obvious advantage that comes from systems-oriented design processes is potentially superior performance with increased margins. Conversely, not being able to make correct design conclusions early can have negative impacts on the final product. While a problem may have been corrected, the time lost (now causing urgency and pressure), and possible compromises made can constrain future choices in unforeseeable ways. Degraded science capability or reduced observatory performance may be traceable to early errors that went unaddressed.

6.3 Morale Impact

One trait common with all designers: they take immense pride in their work. If the designers are treated as ancillary to the project, at best this results in a situation where there is sense of division between the project and the designers. At worst there are cliques formed and other dysfunctions where communication is severely hindered both ways, costing the project schedule, money and diminished workplace satisfaction. Providing "designer space" for them to work together in the environment they designed allows them to build a community where their contributions can have a continual, significant impact. They can flow that respect to their discipline teams and to the project.

6.4 Costs and Potential Risks

There are plenty of challenges and costs associated with establishing the CEC infrastructure. Physical space, or funds to configure the space, may ultimately not be available and creative solutions may be needed. A pandemic could cause all work to become virtual (a concept to be addressed following the lessons of the COVID-19 quarantine). There are the potential risks of bottlenecking of work if the CEC is overwhelmed or creating groupthink and missing potential solutions. These are mitigated by fostering the culture of open communication and dialog, with the understanding, from the flight directorate on down to each member, of the Concurrent Engineering Center functions outlined here. If implemented from the start and guided through the wonderful and crazy life of a project, this is achievable, and will result in many more innovations beyond those described in this paper.

7. SUMMARY

If embraced by project management at inception and fully supported by the directorate, the flight project Concurrent Engineering Center design and analysis functions can provide an elevated level of service throughout the project lifecycle. This can result in superior engineering products and improved internal and external relationships.

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