CONCURRENT EVALUATION - AN APPLICATION FOR DLR'S CONCURRENT ENGINEERING FACILITY

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ABSTRACT

So far, DLR Bremen's Concurrent Engineering Facility (CEF) is primarily used to conduct studies on Phase 0/A level and it is planned to extend this to Phase B. A corresponding approach to exploit the CE environment shall be introduced in this paper.
The Institute of Space Systems is appointed as the authoritative entity for the forward planning, coordination and implementation of the German space program. One of its main functions is to serve as mediator between the national DLR Agency and the industry. Evaluating proposals by the industry on federal tenders can be seen as part of this role. On a system-level, concerning spacecraft (not instrument) development, the System Analysis Space Segment department - operator of the CEF - is designated for this task. Domain experts, usually in charge of designing spacecraft themselves, can be appointed to assess applications. This way, similar to Concurrent Engineering studies, the evaluation process can cover all subsystem as well as Mission Analysis, Cost, Risk and overall Systems aspects.
Another area in which the CEF could be utilized in this context is when already flying spacecraft have to be re-evaluated because of new or changed mission objectives. Objectives can change due to failures in subsystem components or because of mission extensions. In both scenarios the system has to be optimized to conditions different from when the mission was initially projected. A task best suited for experts usually found in the CEF.
The experience has shown that the concurrent approach improves the productivity as well as the quality of the performed work. The same is to be anticipated for the evaluation process. In case of failing spacecrafts, the time span of CE studies as short as one week corresponds to reaction time required in such situations.
As 50% of Germany's federal funding goes to the European Space Agencies and as many German missions are also European co-operations, DLR has an interest in supporting these as well. It could therefore also offer the evaluation process to ESA or the EU.

INTRODUCTION

DLR's Concurrent Engineering Facility (CEF) was build on the basis of ESA's very successful Concurrent Design Facility (CDF) and put into operation in January of 2009. Before this, several "Design Workshops" were conducted in cooperation with ESA, to analyze and adapt the Concurrent Engineering (CE) process. While the technical implementation took a slightly different road (i.e. de-centralized computers to lower the noise level) the basic software tool – the Excel-based Integrated Design Module (IDM) – as well as the iterative proceeding were directly adopted[REF 1]. The latter is described in the Fig. 1.
Concurrent Engineering brings together experts from different disciplines (the typical constellation being depicted in Fig. 2) in one place to enable a direct communication and exchange of parameters. Besides following their domain-specific tasks in the so-called *offline work*, *all participants* are informed on the progress of their colleagues through *presentations* during each session. *Roundtables* act as global update on the pool of values to make sure that all experts use the latest set of data. With regards to space-related Phase 0/A studies these values (or *IDM variables*) are: *mass, power, temperature, dimension, cost and risk.* Complementing the CE process are *splinter meetings* and *trade-offs* in which smaller groups sit together to discuss inter-domain relationships.

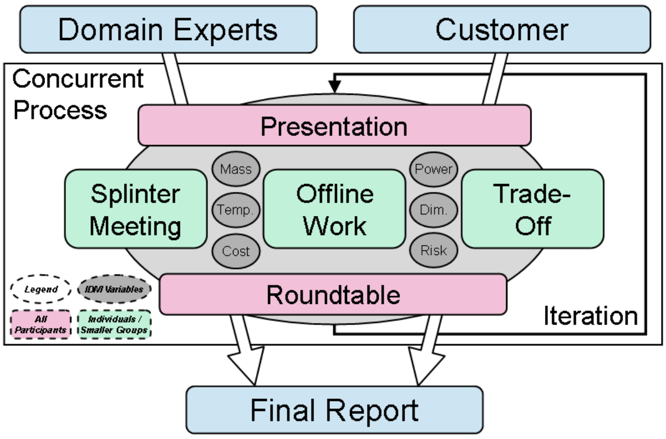

Fig. 1 Concurrent Engineering Process Elements

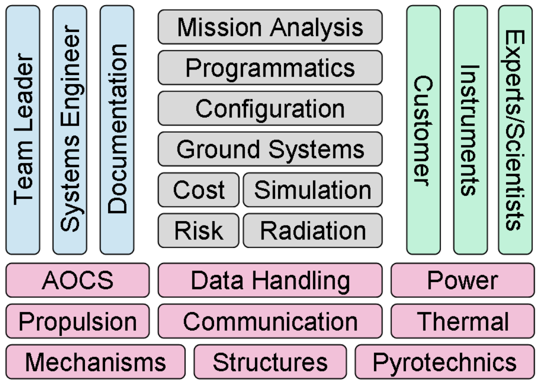

Fig. 2 Concurrent Engineering Domains

CONCURRENT EVALUATION

The basic idea behind Concurrent Evaluation is to utilize DLR's Concurrent Engineering environment - including the domain experts, usually gathered to conduct CE studies - to perform system-level evaluation tasks.
The biggest advantage of a CE study is that it speeds up the design process and creates a consistent level of understanding for all participants. The intent is to adapt this methodology to be able to use it for evaluation purposes. The following three scenarios show how the before described process can be altered for the specified assignments.

MISSION ARCHITECTURE DEFINITION

Concurrent Engineering studies usually comply with national or international space programs. Their objectives are therefore based on missions and roadmaps set by space agencies (e.g. ESA) or governmental departments. The intent of this methodology is to cooperate with the respective entities to develop advanced mission architectures with the methods known from the Concurrent Engineering approach. In addition, the proposed process shall be utilized to assess ideas for spacecraft or missions that can, but must not comply with official space programs. Examples are the European involvement in the Europa Jupiter System Mission (EJSM), a German call for a lunar mission or the idea for a "Space Weather Observation Network" (SWON), which served as test bed for the methodology. SWONs scientific goal is to enable the observation of the far side of the sun to advance weather predictions. To realize this, a network of probes was envisioned, to be established on multiple Inner-Earth asteroids to achieve full coverage.
Main focus of the assessment is the mission architecture design. With the destination typically being set, the following questions have to be answered:

- How can we get there?
- When do we want to get there?
- Why do we want to get there? What will be measured/investigated?
- Which technologies can be used and which need to be developed?
- What are the risks – environmental or otherwise – facing this mission?

The prototype study showed that the third question is of significant importance during the early phase of the study and should therefore be answered during the initial presentations. The expert team can only progress if all have a clear understanding of the mission objectives and their implications on the system and mission requirements. To support the *Introduction of Idea* by the *Customer*, possible mission scenarios as well as the intended payload are presented by the *Missions* respectively the *Instruments* domain.
In case of SWON, the introduction did not clarify why the far side of the sun needs to be monitored so that a time-consuming discussion formed around this open point.
Following the presentations is a roundtable during which all participants have to answer this question:

- What do you think of the mission?

This initial assessment is used to identify the key aspects from the experts' point of view. In similarity to brainstorming sessions, the aspects or *Discussion Points* are collected in a mind-map and linked with related mission objectives. At the end of the roundtable, all points are then weighted regarding their relevance for the study.

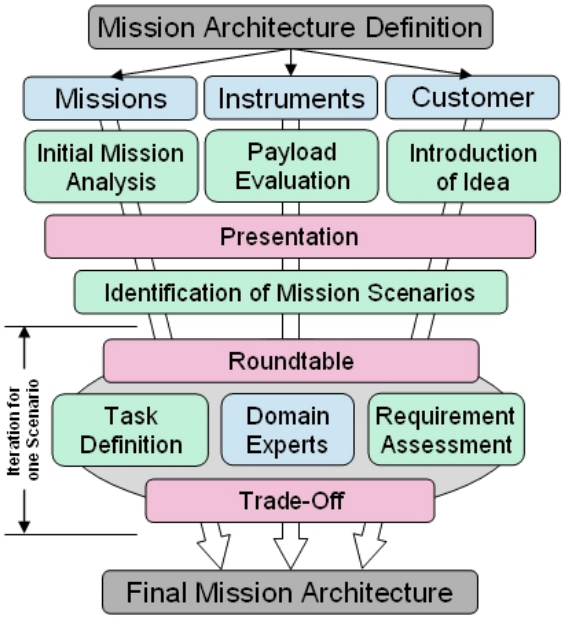

Fig. 3 Mission Architecture Definition evaluation process

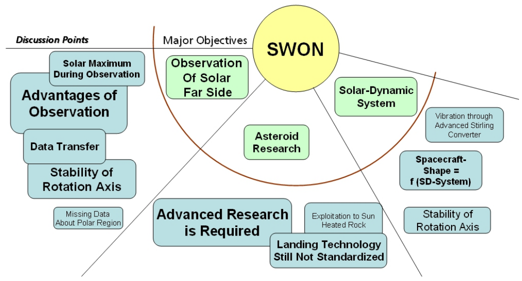

Fig. 4 Objective Weighting through Tag-Clouds

Subsystem	Thermal
Requirement 1	
Identifier	
Description	
Resulting from	
Technical Feasibility	
Socio-political Impact	
Risk Drivers	
Cost Drivers	

Fig. 5 Proposed IDM Adaptation Structure

The participation of the customer in this phase and the direct interaction with the experts through the concurrent approach assures that the architecture "responds" to the customer needs. As the discussion points serve as baseline for the next step, their proportional importance (compared to each other) has to be clarified. Instead of using numbers to express the relationship, so-called 'Tag-Clouds' are adapted for this purpose. Tag-clouds are usually applied to ease searches and consist of two elements: a 'Topic' and 'Tags', which are common for the specific topic. An exemplary topic could be 'Moon' and related tags 'Apollo', 'Vacuum' and 'Cheese'. The three tags are arranged around their topic and to depict that Apollo is much more important than Cheese (when researching the Moon), Apollo is displayed with a greater font. Fig. 4 shows how this methodology was implemented for the SWON study. Resorting to the already existing mind-map, the relative importance of each objective and each discussion point is expressed through the size of the box and font. This visual representation allows for a much better and quicker comparability of different objectives.
During an iterative process the discussion points are now used to evaluate different mission scenarios one by one. In case of the SWON study, three possible options were examined:

(1) A mission to Lagrange Point 3
(2) A Technology Demonstrator Mission to a single asteroid
(3) An Observation Network with probes on multiple Inner Earth Asteroids to achieve full coverage of the solar far side

Based on the demands due to payload and environment, the experts assess the domain specific tasks for each mission scenario and define subsystem and system requirements. These requirements correspond to the IDM variables, compiled during typical CE studies, and are presented at the end of one session. As multiple factors characterize the significance of a requirement, they can not be expressed through the combination of a mind-map and tag-cloud. Rather, an adapted version of the Excel-based IDM is applied (compare Fig. 5), replacing the IDM variables *mass*, *power*, *etc.* with specific assessments of the *technical feasibility*, *socio-political impact* and possible *risk* and *cost drivers*.
After all mission scenarios have been iterated and based on the IDM input, the team can decide on the most promising mission architecture in a final *Trade-Off*. In case of SWON, the expert team decided that scenario (2) was the most promising as it combined two fields of science, namely asteroid and solar science, and also includes a challenging but manageable technology demonstration, i.e. landing on an asteroid.
The outcome of this type of assessment – a 10-15 pages long report – shall serve as foundation for future CE studies.

RISK ASSESSMENT

Besides the traditional spacecraft subsystems - e.g. *Thermal* or *Propulsion* - the IDM also contains workbooks for the domains *Cost* and *Risk*. These two IDMs are presently not utilized during Concurrent Engineering studies (at DLR) and both, cost and risk are assessed outside of the CE environment. The following chapter will introduce a methodology to adapt the concurrent approach to perform risk assessment studies.

While the IDM offers the possibility to enter the reliability of components, thus enabling a bottom-up analysis, a complete system can be better analyzed through top-down approaches. Two methodologies are commonly used here: Failure Modes and Effect Analysis (FMEA) and Fault Tree Analysis. System level risk analyses during early phases of a project are of particular interest as they can still influence the spacecraft design. Therefore, the risk assessment either needs to be performed after an initial system design study (Phase 0/A) or in between later CE sessions when a complete spacecraft design is available.

Despite all risk reduction efforts, subsystem or component failures sometimes do occur and endanger the whole mission. The combination of complex spacecraft systems - worth millions of Euros – and the harsh space environment result in unavoidable failures. Famous examples are Galileo, whose high-gain antenna failed to unfold, SOHO's AOCS shut-down and the Hayabusa engine failures. The three also have in common that, in spite of the major component breakdowns, the spacecrafts could be saved. In each case, immediately after the error occurred, special task forces were established to analyze what happened and to look for solutions. Because of the already described advantages of Concurrent Engineering it is proposed to utilize the CEF (and similar facilities) for these task forces, as well.

An example of how the CE process could be adapted for all introduced scenarios is shown in Fig. 6 and described in the following:

As initial step, all domain experts compile a general analysis of the spacecraft by characterizing the subsystems at hand. First objective is to establish a map of the spacecraft system to be able to identify functions and dependencies of subsystems and components. Examples are power cycles, sensor-actuator relationships and data handling or transmission. To establish a consistent level of understanding of the spacecraft and its mission, the initial step is concluded by presentations of all participating domains.

During the iterative phase, the domain experts assess virtual (in case of FMEA and FTA) or given errors. In case of an intrinsic failing system, directly and indirectly affected subsystems have to be identified. In parallel, the Missions domain develops an overview of the mission scenario and the current situation of the spacecraft. The next step is to assess the spacecrafts capabilities. Depending on the already passed mission duration, failure un-affected subsystems need an update on their state of degradation (i.e. battery efficiency or rest-fuel). For all affected S/Ss it has to be evaluated which functions can and which cannot be executed. In case of FMEA, critical components or 'Items' are related to one or multiple 'Failure Modes'. These modes are described through their 'Effect' and 'Observable Symptoms' and possible solutions for 'Recovery or Compensation' are proposed. FTA concentrates on evaluating how a component failure propagates through the whole spacecraft. As for FMEA, failures can either impact the overall functionality of a components or isolated functions.

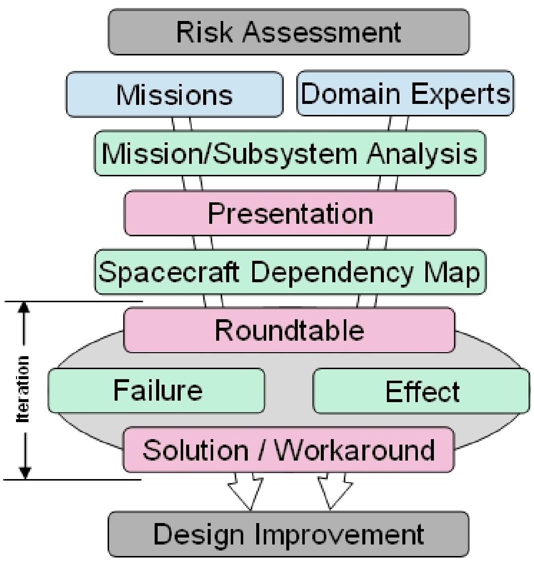

Fig. 6 Component Failure evaluation process

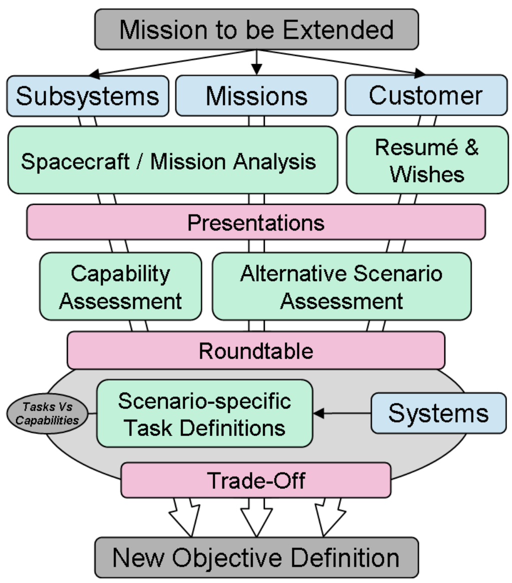

Fig. 7 Mission Extension evaluation process

For all three cases, roundtables are regularly held to give an update on the progress of each domain. Especially in the examined case of (simulated or genuine) failing systems, an error in one subsystem can lead to malfunctions of other S/Ss. By engaging all participants in the evaluation process of each domain, the roundtable averts this effect. 'Outsiders' add new angles to an assessment, thereby completing the picture. As for most CE processes, the cooperation leads to a whole that is more than the sum of its parts.

The results from FMEA and FTA can be used to identify critical components and bottlenecks on which the overall function of a spacecraft depends on. The concurrent approach could streamline both methodologies, thus allowing a faster execution. As mentioned before, these analyses should be performed as early as possible to be able to improve the spacecraft design while it is still only "existent on paper".

Regarding the failure of already existing spacecrafts, the results from the roundtable are combined with the possible mission scenarios identified by the Missions domain in consultation with the spacecraft operator in a final trade-off. During this, all participants will decide on the best solution and how to proceed. For instance, the Galileo mission team identified the spacecrafts low-gain antenna as capable alternative[REF 2]. While still on its way to Jupiter, new flight and ground software was developed so that all science data could be transmitted at a lower rate.

Fortunately, malfunctions are still rare and point to an even better solution: simulated spacecraft failures. By simulating a component or subsystem breakdown, a Concurrent Evaluation team exercises worst-case scenarios for active spacecraft. The intention is not to replace existing FMEA or FTAs. Simulated malfunctions shall rather be used to improve future design processes. As the spacecraft are already finalized, the engineers are forced to utilize the system at hand (designed by others) which leads to "out of the box" thinking. A design improving question could be: Why not always use a low-gain antenna with improved software instead of an additional, more complex high-gain pendant?

MISSION EXTENSION EVALUATION

One finding of the analysis *Historical Technology Evolution of Space Systems* conducted at the System Analysis Space Segment department was that exploration spacecrafts rarely "just" execute on their predefined mission. Instead they either fail or – in the most cases – outperform their mission goals. Considering only the last 30 years, 53% exceeded their initial purpose, while 18% performed as planned and 29% failed[REF 3].

Fig. 7 depicts a suggested Concurrent Evaluation process to be applied for the 71% that survive the set operation live-time and are assessed regarding a possible *Mission Extension*. The procedure is similar to the before described ones:

After an initial analysis of the spacecraft and its mission (and a referring presentation), the domain experts assess the spacecraft regarding their capabilities. As the team might consist of members who did not participate in the earlier phases of the project, all capabilities and functions should be introduced in a roundtable. Main variable of the analysis is the state of degradation.

In contrast to the risk assessment, the customer (e.g. the operator or a space agency) resumes an important role in this type of evaluation. As the spacecraft was only intended to operate during its predefined mission life-time, financial resources have to be reallocated. In most cases, the scientific value justifies the mission extension and the concurrent approach assures a consistent view on this matter by both scientists and operators. In close cooperation with the Missions domain, the customer analyzes whether the mission scenario should be altered to cover new fields of interest or whether the operation should be maintained as before. Possible scenarios are then related to the subsystem capabilities and the specific tasks to be performed by the subsystem. A trade-off concludes the mission extension evaluation opposing the assessed scenarios to be able to decide on a final mission profile.

CONCLUSION

The three introduced cases demonstrate how the advantages of Concurrent Engineering can be adopted for evaluation purposes. These advantages or most important attributes are:

- The consistent level of understanding for all participants
- A streamlined, fast-executable process
- An improved result that is more than the sum of its parts

This paper describes how these attributes can be combined with already existing methodologies (Risk Assessment) and processes (Mission Extension Evaluation) and how they can be applied to new fields (Mission Architecture Definitions). DLR's existing CEF as well as similar Concurrent Engineering facilities can be utilized in this regard, thereby extending the concurrent approach across other phases (compare Fig. 8). The conducted SWON study serves as example on how evaluation studies can be implemented but further studies need to be conducted to improve the described processes even more.

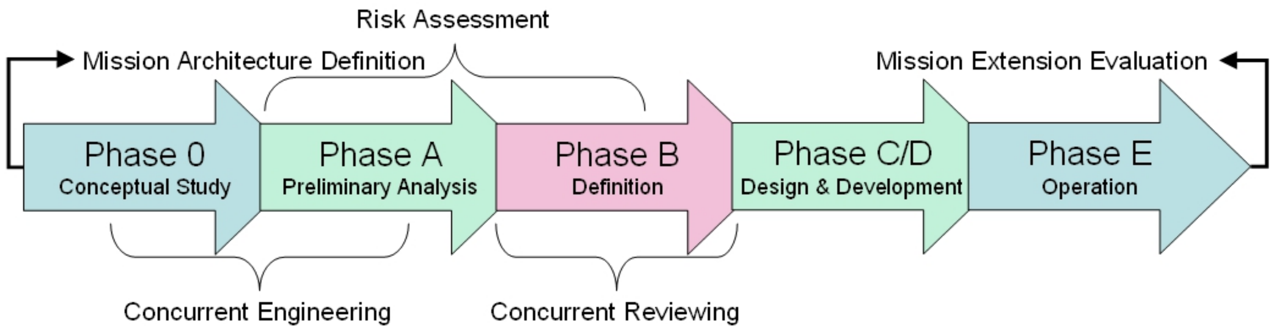

Fig. 8 Phases of a Spacecraft and Intended Concurrent Evaluation Intervals

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