Executive Summary

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1 INTRODUCTION

Manufacturing of high-end spacecraft parts is a process which encompasses several fields of expertise. Bringing together engineers from different disciplines is key for an efficient design of spacecraft parts. Aspects such as the general purpose of the part, functional requirements, material properties, necessary manufacturing equipment, verification & testing methods as well as assembly & integration procedures shall be taken into account from the very beginning of the design process.

For several years, OHB System has been involved in various projects with regards to Advanced Manufacturing technologies for satellite design. For instance, the GSP study entitled "System impact of Additive Manufacturing technologies design features" run by OHB System AG as Prime in 2015 showed that there is a significant amount of potential for Advanced Manufacturing technologies (as e.g. Additive Manufacturing) to impact the space sector. Potential savings in terms of mass, lead-time or costs were identified. In addition, the study concluded that a broad range of expertise is necessary to assess the benefits provided by Advanced Manufacturing for satellite system design at part level.

The main observation of the study was that a clear methodology or procedure for the Concurrent Engineering work flow is crucial for successful design of spacecraft parts. This experience was confirmed in several other studies and projects on Advanced Manufacturing with OHB System’s involvement. The capabilities and limitations of the manufacturing technologies should be defined before the start of design. All technical requirements and functions of the part should be understood and documented in a way that makes it easy to access and implement them during the Concurrent Engineering sessions.

The activity “Design of Space Hardware using a CDF like Methodology” addresses the aforementioned challenges. The main expected output is a methodology for the Concurrent Design of spacecraft parts with the possibility to take Advanced Manufacturing technologies into account.

This document summarizes the output of the activity with the focus on the developed methodology and the utilized tools & methods for the Concurrent Design of spacecraft parts considering Advanced Manufacturing technologies.

2 REFERENCES

2.1 Applicable Documents

This document shall be read in conjunction with documents listed hereafter, which form part of this document to the extent specified herein. In case of a conflict between any provisions of this document and the provisions of the documents listed hereafter, the content of the contractually higher document shall be considered as superseding.

AD	Doc. No.	Issue	Title
[AD01]	OHB-403881	1	Proposal: Design of Space Hardware Using a CDF Like Methodology
[AD02]	AO8803-ws00pe	1	Statement of Work

Table 2-1: Applicable Documents

It should be noted that all requirements listed in the documents of Table 2-1 are applicable unless noted otherwise or exceptions are identified and agreed.

2.2 Reference Documents

The following documents contain additional information that is relevant to the scope of this document.

RD	Doc. No.	Issue	Title
[RD01]	AMCDF-OHB-TN-001	01	Part Item Specification
[RD02]	AMCDF-OHB-TN-002	01	Process Applicability Matrix
[RD03]	AMCDF-OHB-TN-003	01	Concurrent Design Methodology & Preliminary Technical Dossiers
[RD04]	ECSS-E-TM-10-25A	01	Engineering Design Model Data Exchange
[RD05]	AMCDF-OHB-TN-004	01	Concurrent Design Technical Dossiers for the retained cases
[RD06]	ECSS-S-ST-00-01C	01	ECSS system - Glossary of terms

Table 2-2: Reference Documents

2.3 Abbreviations & Nomenclature

For all terms, definitions and conventions used, if available.

Abbreviation	Meaning
AD	Applicable Document
AIT	Assembly, Integration & Test
AM	Advanced Manufacturing
CD	Concurrent Design
CDP4®	Concurrent Design Platform (version 4)
CE	Concurrent Engineering
CEFO	Concurrent Engineering Facility @ OHB System
CFRP	Carbon Fibre Reinforced Polymers
DC	Demisable Cleat
PAM	Process Applicability Matrix
RD	Reference Document
RF	Radio Frequency
RFV	Requirements-Functions-Variables
S/C	Spacecraft
SRP	Structural Radiator Panel
STRB	Star Tracker Bracket
TN	Technical Note

Table 2-3: Abbreviations & Nomenclature

3 OBJECTIVES AND WORK LOGIC

3.1 Objectives of the activity

The project was aimed at establishing a structured approach to an optimized part or component by applying a Concurrent Design methods. It was meant to incorporate all necessary disciplines and competencies that are required for a potential spacecraft part. Within the activity, Advanced Manufacturing should include different novel techniques and not only the area of Additive Manufacturing. It means that the Concurrent Design approach was developed for the engineering of units to be built with a broad range of Advances Manufacturing technologies. The main technical objectives of the activity were:

- A methodology and a taxonomy for a listing, ranking & mapping spacecraft part requirements enabling a classification of mandatory requirements (driving requirements) versus those bringing an added value but not essential for the success of the mission (non-driving requirements).
- A “Process Applicability Matrix”, listing and ranking appropriateness of Advanced Manufacturing processes to selected parts including capabilities, limitations, benefits, drawbacks and risks to be monitored and controlled.
- A Concurrent Engineering approach for the “end-to-end” design of multi-functional parts taking into consideration a broad range of Advanced Manufacturing technologies and possible new materials, along with the requirements and interfaces of the parts with the system.
- The CE methodology should be run through CE sessions for which the output will be a Technical Dossier, including the “end-to-end design, manufacturing & verification strategies” to be used as baseline for further analysis for designing and manufacturing of the desired part while maximising the system performances. The mapping of requirements and the Process Applicability Matrix should be used as input data during the sessions.
- To develop, review and refine the CE approach, 3 parts proposed by ESA and 3 parts proposed by the consortium should be designed according to the proposed methodology.

3.2 Work Logic of the activity

The overall work flow that was followed within the activity is visualized in Figure 3-1.

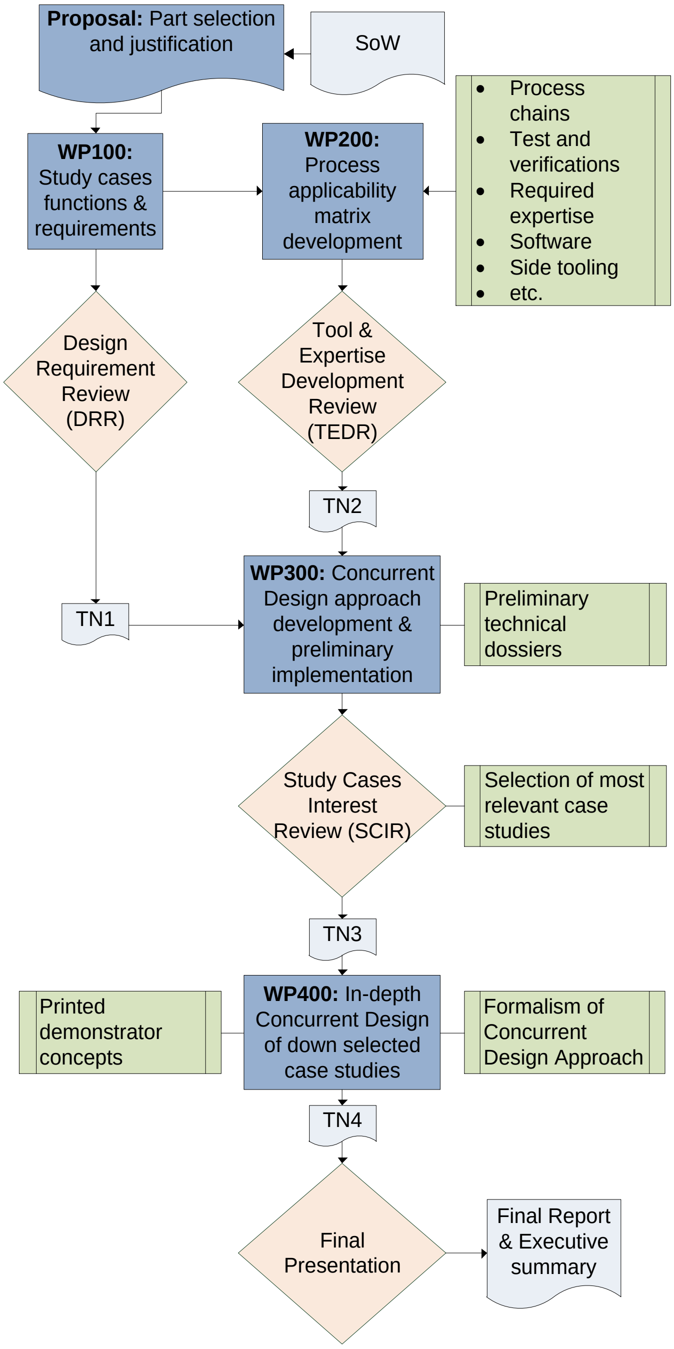


Figure 3-1: Work logic within the activity

The functions and requirements for the selected case studies will be elaborated and detailed in WP100 of the activity to achieve a listing, ranking & mapping of the requirements. In WP200, the state-of-the-art of Advanced Manufacturing technologies were investigated. Based on the results of the survey the Process Applicability Matrix (PAM) was established.

Based on the mapping of requirements and the Process Applicability Matrix within WP300, the methodology to design complex-shaped multi-functional parts was developed. The methodology was be implemented in Preliminary Concurrent Engineering sessions for the pre-selected 6 parts. The output of these sessions was documented in Preliminary Technical Dossiers. In WP400, the approach was enhanced with a methodology for the In-depth Concurrent Engineering sessions. The In-depth CE sessions were performed for the two highest ranked Use Cases. The outcome of these sessions was documented in final Technical Dossiers. The finalised design was visualised by a mock-up using a polymer-based 3D printing technology at OHB System. At the end of the study, the activity was critically reviewed and the methodology with its necessary tools & methods refined to establish a generic formalisms for proposed Concurrent Engineering approach to be applied in further development projects.

3.3 Work share within the Consortium

The members of the consortium led by OHB System were working closely together to meet the challenges related to this activity, from the definition, listing, ranking and mapping of requirements through the development of the methodology, the implementation of CDP4® and the Concurrent Design of the selected Use Cases to the critical analysis of the applied tools, resources and facilities. The activity's work share was defined as in Table 3-1.

Table 3-1: Work share between the project partners

OHB	• Study management & project coordination. • Definition of Use Cases and requirements. • Develop and elaborate the Concurrent Design methodology for spacecraft parts. • Run a critical analysis of the applied tools, resources & facilities proposed for the study. • Overall project documentation.
OHB CZECHSPACE	• Listing of the requirements of the selected Use Cases. • Check correct application & verification of requirements throughout the entire activity. • Structural design & analyses during the Preliminary & In-depth CE sessions. • Documentation of the design outcome in Technical Dossiers.
RHEA GROUP ENGINEERING THE WORLD WITH YOU	• Definition of the requirements taxonomy • Mapping of requirements and implementation of these into CDP4 • Support the Concurrent Design in the Preliminary & In-depth CE sessions

4 METHODOLOGY FOR THE PRELIMINARY CDF DESIGN

A methodology to formalise a preliminary Concurrent Design approach for complex multifunctional parts or part assemblies was developed and continuously adjusted throughout the experience gained in six individual preliminary sessions.

4.1 Overview

The overall objective of the preliminary Concurrent Design Methodology is to effectively assess a multifunctional part, to understand its properties and to generate and evaluate feasible design concepts for it. The methodology is specifically designed to accumulate as much information as possible in a short time. In order to achieve this, the level of detail was limited to a viable minimum, that prevents exhaustive discussions and facilitates efficient progress. Certain tools and specifications were diverted from their intended use, while established decision making processes are streamlined and adapted to fit into the methodology. The outcome of this preliminary Concurrent Design approach is designed to initiate the subsequent detailed Concurrent Design approach with a selection of promising design concepts.

The proposed methodology for the preliminary CE sessions is chronologically structured as shown in Figure 4-1. The complete time frame of a session is not specifically defined since the complexity of the part can influence it to a certain extend.

	Day 1	Day 2	Day 3
09:00	Kick-Off	Session 3: Suboption Matrix Development	Session 5: Concepts Presentations
10:00	Session 1: Requirements-Functions Chart		
11:00			
12:00		Session 4: Advanced Manufacturing Techniques	
13:00	Lunch	Lunch	Lunch
14:00	Session 2: Design Variables Definition	OFFLINE BLOCK : Concept Development	Session 6: Concepts Evaluation and Selection
15:00			
16:00			
17:00			

Figure 4-1: Chronological structure of the phases of the proposed preliminary CE approach within a 3-day session

The preparation of the sessions is the key to an organized structure and a successful approach. A centralized tool to overlook the individual steps is recommended, especially when the preparative tasks are divided in between multiple core team members.

It is of highest priority that all participants of the session are aware of the objective and where it varies from conventional assessment procedures. Therefore, the Kick-Off phase of each session is an essential part of the methodology and will be explained in the following chapter.

4.2 Session's Kick-Off

Tasks	Projected outcome
• Welcome and round table • Part Introduction • Requirements overview (CDP4®) • Open Q&A	• General session approach and target is understood • Part details and multifunctional aspects are understood

The Kick-Off session needs to be prepared thoroughly. The session initiator nominates members of the core team, which commonly consists of a session leader, a customer and a system engineer. The core team designates a part expert (e.g. technical focal point from engineering department).

- Core team & part expert:
  - Discuss first details of the part for a common understanding.
  - Define a set of functions that describe the part in its entirety.
  - Define the desired composition of concurrent design sessions participants and their specific role.
- Core team:
  - Distributes basic knowledge of the part and the general objective of the session to the participants.
  - Distributes an overview of each expert's contribution to the session.
  - Develops a functional seating arrangement that provides proximity between interdependent competencies and thus encourages a vivid exchange of information
  - Accumulates all relevant requirements and implements them together with the prepared functions into the CDP4® software. Creates and visualizes relationships between requirements and functions.
- Part expert:
  - Prepares a presentation of the part with a focus on its functionality, its difficulties and challenges.

The session leader addresses all participants and presents the agenda of the upcoming session. A focus should lie on a precise explanation of the objective for this preliminary Concurrent Design approach. Afterwards, a round table of all participants shall provide an understanding of the present competencies and help to identify potential dialog partners (e.g. structure & design) for later discussion rounds. Once everyone is acquainted and general questions are solved, the part expert gives his/her presentation on the part in focus. Questions shall be asked and a dynamic conversation should be encouraged.

This is a very important part of the entire methodology, because it provides the fundamental understanding of the part and its complexities. It was a regular occurrence that in this part of the session persistent ambiguities from one discipline were cleared up, merely by the opportunity to directly address them to other competencies concurrently.

On a different occasion, the true complexity of a part was first recognized by the participants and core team after the part expert provided the prepared presentation. After all initial questions about the part and its functionality are clarified, the prepared requirements overview is presented. In conjunction with the defined functions, the

After all open questions about the general tasks and properties of the part are clarified, the requirements overview can be presented and discussed in conjunction with the prepared functions. The core idea behind the functions is to give a complex part a simplified and clear identity that is easy to comprehend and classify. A set of functions shall be understood as the essentials behind the part that, if satisfied, attest full operability. The requirements on the other hand must have a direct relationship to one or more of these functions (marked with X in Figure 4-2). This procedure ensures that every requirement has relevance and all designated functions are properly derived serve an essential purpose. However, it is important to note that in this preliminary concurrent design setting, requirements are not utilized in the regular way. Besides potentially being prepared with quantifiable and precise values and parameters, they will be broken down and handled according to their general qualitative properties:

The projected outcome of the Kick-Off is that all participants have a clear understanding of the part, its challenges and complexities. The definition behind requirements and functions are perceived and their relationship with each other has been comprehended. The objective of the session is also understood.

4.3 Phase 1: Requirements-Functions-Variables Chart

Tasks	Projected outcome
• Review of given requirements & functions • Identification of driving requirements • Review of relationship between functions and driving requirements • Transfer of knowledge into the Requirements-Functions-Variables Chart	• Team is familiar with the driving requirements and functions of the part • Requirements-Functions-Variables Chart is established

Phase 1 is initiated with a concurrent review of the requirements, the functions and their relationship between each other. It gives every participant the chance to clarify the content of the requirements, propose changes and raise new requirements if necessary. It is even plausible to challenge the predefined functions.

This part of the methodology further increases the comprehension of the requirements and their relevance to the part. Once a general consent about the requirements-functions matrix is established, the phase continues with the identification of the driving requirements.

Driving requirements are defined as the ones that have a significant impact on potential design solutions. This part of phase 1 should be an open discussion with all participants. While there is no limit on how many driving requirements can be designated, a more condensed list facilitates the later evaluation process. However, the highest priority is a thorough compilation of driving requirements, that can independently influence the outcome of the concept generation process. In order to track and distinguish them from the regular requirements, they can be highlighted within the CDP4® software (see Figure 4-2).

	SRP-0202	SRP-0204	SRP-0206	SRP-0404	SRP-0406	SRP-0408	SRP-0502	SRP-0504	SRP-0602	SRP-0604	SRP-0902	SRP-0904
Accessibility			X								X	
Environmental Compatibility	X						X	X			X	X
Interface Provision			X	X	X	X						
Structural Strenght	X					X					X	X
Thermal Conductivity		X			X		X		X	X		

Figure 4-2: Requirements-functions relationship with the driving requirements highlighted in yellow

At this point of the methodology the established functions, requirements and driving requirements shall provide a descriptive set of parameters that facilitate an in-depth understanding of the part. The derivation from driving requirements over functions towards design variables aided with a visualization concept called the “Requirements-Functions-Variables chart (RFV-chart)” (see Figure 4-3). Thus, the last action for this phase is to transfer the highlighted driving requirements and functions into the chart.

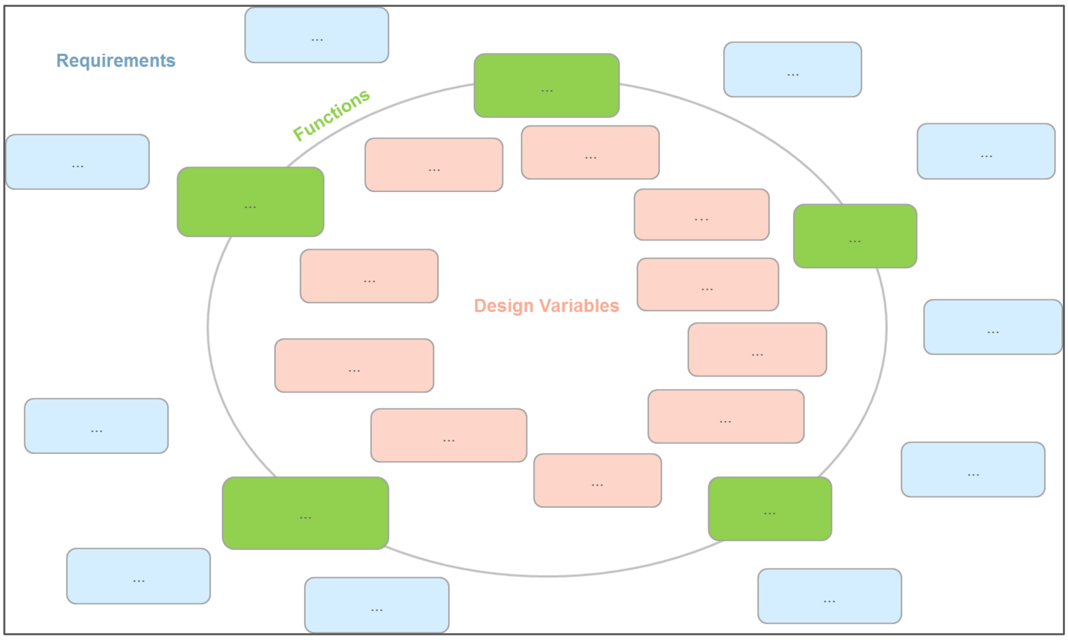


Figure 4-3: Template for a Requirements-Functions-Variables chart

4.4 Phase 2: Design Variables Definition

Tasks	Projected outcome
• Define design variables • Implement design variables into the Requirements-Functions-Variables Chart	• Requirements-Functions- Variables Chart is extended with design variables

Based on the outcome of phase 1, the RFV chart from Figure 4-3 should be filled with all relevant driving requirements in the blue fields on the outside and functions in the green fields. However, requirements and functions are not practical when generating concepts or creating design ideas. They rather provide the means to review the critical performance and compliance values, but they usually cannot provide the possibility to adjust the parameters of the part.

In this phase 2 the design variables have to be developed. A complete set of design variables shall permit a full characterization of a part and thus provide the tools to adjust its fundamental attributes. The session concludes when all participants agree that all necessary design variables have been detected and defined.

4.5 Phase 3: Sub-options Matrix Development

Tasks	Projected outcome
• Discussion and accumulation of all sub-options derived from design variables • Apply multi-disciplinary thinking to seize a broad spectrum of concepts • Generate evaluation criteria for design concepts	• Accumulated Matrix of sub-options • Evaluation Criteria

It is expected that the generation of the design variables in phase 2 already sparked first ideas and suggestions for the potential design solutions. E.g. if the material selection was decided to be an important design variable, it is common that a few material possibilities have already been discussed (e.g. aluminium, titanium etc.). Within the preliminary Concurrent Design Methodology, this is referred as a “sub-option”.

The core task for phase 3 is to accumulate all possible sub-options for each design variable. It is explicitly encouraged to even list propositions with a rather low feasibility. The matrix lays the foundation for all potential concepts that can result from this session and should be as extensive as possible. It is part of a later phase of the session to evaluate feasibility and score a concept accordingly. This phase is pure brainstorming and should be adopted this way.

At this point of the session, it is important to introduce how the later concepts will be created. Each concept proposal consists of a combination of sub-options. Some sub-options might be optional (e.g. redundancy system) while others are essential (e.g. material choice). Since the matrix provides an exhaustive accumulation of all possible sub-options, it inevitably must contain the best possible concept for the part and it is the task for the working group to track it down.

In order to rate the quality of a concept, specific trade-off criteria have to be established, which is the second task in this phase. While a higher number of criteria provide a more explicit assessment of the concepts, it also requires more time to assess. A general recommendation is to combine them as much as possible and find a common consensus how it will be graded. Since this is also very part specific, the participants and most importantly the customer have to give input what criteria are important and which might not be as relevant as others. An additional weighting factor is applied at a later stage of the session.

4.6 Phase 4: Advanced Manufacturing Techniques

Tasks	Projected outcome
• Introduce Process Applicability Matrix (PAM) • Identify potential Advanced Manufacturing techniques	• Advanced Manufacturing techniques can be included into the concept development phase

In Phase 3, the baseline for concept creation is created. Besides the composition of sub-options being a substantial part of each concept, another important factor is the selection of an appropriate manufacturing technique for it which could be a conventional or an Advanced Manufacturing technology. For this task the Process Applicability Matrix (PAM) shall serve a multipurpose role. It provides an extensive overview of current possibilities, illustrates specific capabilities and limitations while also indicating the maturity of the process (see Table 4-1).

Table 4-1: Extract from the Process Applicability Matrix [RD02]

			Process-related information					
	Manufacturing process	Processable materials (space)	Capabilities System	Capabilities Technical	Limitations Process	Limitations System	Controls, tests & verifications	TRL level**
dditive manufacturing	Laser beam melting (LBM)	Aluminium	+ design complexity + function integration + lead time	+ net shape + mass	- residual stress - distortion - geometrical dimensions - heat/pressure treatment - IF definition, - surface quality - post-processing - (raw) material	- maturity process chain - process cost	- process simulation (feasibility) - raw material characterisation - online monitoring - NDI - witness samples	7
		Titanium						7
		Stainless steel						7
		Nickel alloys						7
	Electron beam melting (EBM)	Titanium	+ design complexity + function integration + lead time	+ net shape + mass	- geometrical dimensions - IF definition - surface quality - post-processing - (raw) material	- maturity process chain - process cost	- process simulation (feasibility) - raw material characterisation - online monitoring - NDI - witness samples	7
		Stainless steel						7
		Nickel alloys						7
	Laser metal deposition (LMD) (wire feed)	Aluminium	+ design complexity + function integration + lead time, + semi-finished products + multi-metals/gradients + simultaneous machining	+ dimensions + near net-shape + mass + simultaneous property modification	- residual stress - deviation net shape - IF definition - surface quality - post-processing - (raw) material	- maturity process chain	- process simulation (feasibility) - raw material characterisation - online monitoring - NDI - witness samples	5
		Titanium						6+
		Stainless steel						6
		Nickel alloys						6

In this phase of the session the manufacturing expert shall provide an introduction to the PAM and provide answers to potential questions from the other participants. It is important to emphasize that the later concept evaluation is strongly affected by the process selection.

The projected outcome of this phase is that all participants have a clear understanding of the PAM and understand how to apply it during the subsequent concept development phase. The information stored in the PAM supports the feasibility assessment through the demonstration of design limitations and opportunities alike. It provides support to create a well-founded design concept proposal in the next phase.

4.7 Offline Block

Tasks	Projected outcome
• Derive potential design concepts through applicable combination of sub-options. • Include a manufacturing technique from the PAM	• Draft Design Concept Proposals

During the offline block each participant has time to develop their own concept(s). It should follow a definite philosophy that gives it some type of classification. Common choices are “high performance”, “low cost” or “light weight”. However, there are no restrictions in what a concept philosophy can be defined as. The focus should lie on a well-thought-out composition of sub-options that indicate a specific advantage over conventional designs. A dedicated manufacturing process has to be part of the complete draft design concept proposal.

Each participant shall prepare a brief presentation of their concept proposal that they can give to the rest of the working group in the following phase. The presentation can be aided by drawings, calculations, analyses or other supportive means to showcase their concept.

4.8 Phase 5: Concept Presentations

Tasks	Projected outcome
• Present Draft Design Concepts	• Accumulated Concepts

The concept presentations can be held consecutively. The main goal is to trigger a vibrant discussion about advantages and complications where the presenter shall attempt to sell his/her proposal as best as possible and the other participants challenge it.

The ultimate target is to concurrently decide on a selection of the most promising concept proposals to take over to the next phase where an evaluation according to the predefined criteria is scheduled. There is no specific limit on how many proposals are carried over to the last phase, but the time consumption can significantly increase with a large number.

4.9 Phase 6: Concepts Evaluation and Selection

Tasks	Projected outcome
• Rate design concepts per criterion. • Harmonize scoring over all concepts. • Final selection of the customer	• Draft Design Concept Selection

In this phase the working group shall discuss each part subsequently one criteria at a time. Each rating can rank between 1 and 5 (1 being very negative and 5 very positive) and has to be explained with a brief sentence or keyword. It is also feasible that some criteria are adjusted or added in the course of the scoring process. When all ratings are completed, each criteria is analysed once again across all listed concepts to harmonize them through a direct comparison. Hence, the scoring shall be comparable and meaningful.

As a last step, the working group can concurrently decide upon which criteria should receive a distinguished weighting over the others. In most cases certain aspects about a concept were significantly more important than others, which consequently should weigh stronger towards its total score.

The final score is determined by the summary of each criteria including a potential weighting factor. However, the ultimate draft design concept decision is being made by the customer. His/her decision for one or multiple concepts concludes the preliminary Concurrent Design approach.

5 METHODOLOGY FOR THE IN-DEPTH CDF DESIGN

This chapter describes the in-depth Concurrent Design approach as elaborated in this activity for complex multifunctional parts or part assemblies which is meant to be followed after the preliminary Concurrent Design.

5.1 Overview

The main objective for the in-depth CDF design session is to translate the established concept from the preliminary session into a detailed design solution that provides compliance to all existing requirements.

While the actual generation of the design and its analyses are mostly performed within dedicated splinter sessions, the concurrent sessions are organised to effectively allocate preparative information, clarify open questions and structure the upcoming development steps. The main incentive behind this approach is to utilize the available expertise to attain complete comprehension of the part. This includes understanding of requirements, clarification of all intended design features of the established concept solution and discipline related characteristics.

Ultimately, the development team shall enter each splinter session with a clear task definition and all necessary information at hand. This requires a comprehensive preparation before the actual design session.

In a Concurrent Design exercise, the first day should be used to prepare the splinter sessions and define the general structure of the development cycle. Each set of splinter sessions is followed by a review gate where individual milestones and compliances to requirements are reviewed (see Figure 5-1). Depending on the complexity of the part, the amount of review gates and thus the number of development cycles can vary.

	Monday	Tuesday	Wednesday	Thursday	Friday	Friday, 2nd Week
09:00	Kick-Off: Detailed Part	Splinter Session 1	Splinter Session 3	Splinter Session 4	Splinter Session 6	
10:00	Phase 1:					
11:00	Requirements Review & Classification					
12:00						
13:00	Lunch	Lunch	Lunch	Lunch	Lunch	
14:00	Phase 2:	Splinter Session 2	Review Gate 1	Splinter Session 5	Review Gate 2	Review Gate 3 /
15:00	Requirement Derivation (Class A)		Requirement Derivation (Class B)			Final Review
16:00	Phase 3: Splinter Session Organization					
17:00						

Legend

Attendance required	Attendance only if requested	Offline work - do from your own desk

Figure 5-1: Schedule proposed for the in-depth CDF sessions

5.2 Session's Kick-Off

Tasks	Projected outcome
• Welcome and round table • Detailed Session Structure • Requirements overview (CDP4) • Open Q&A	• The team understands the focus of the session's objective. • The team understands how requirements shall be treated (class A & B). • The team understands how the design process will be carried out.

As the detailed session shall be conducted in direct succession to the preliminary session in the frame of this activity, the approach is designed create a seamless transition without specific preparation needed.

During the session's kick-off the established concept from the preliminary session is presented. In an optimal scenario, the time interval between the preliminary and detailed session is very small, which makes a reintroduction of the concept redundant. However, a brief discussion about the concept's characteristics shall support a general understanding of its specifics and where each discipline becomes relevant.

A description of the detailed session structure shall underline the importance of information transmission and that the overall target of the session is to provide complete comprehension of the part to the development team. Furthermore, the requirement handling is described to the team. An explanation on how the distinction between class A and class B requirements during the subsequent phases shall emphasize the focus on rapid and controlled development progress.

Class A & B requirements:

The incentive behind this is to initiate the development process with a clear prioritization of the important aspects of the part (class A). Having a condensed overview of well understood and relevant constraints and objectives greatly facilitates the effectiveness of initial development and design creation. Once the design becomes more mature, more requirements are being considered and worked into the part (class B).

In addition, the actual design process shall be addressed to the entire team to further demonstrate how the development approach is structured. It shall be avoided to initiate a discussion about the general concept decision. It was decided in the preliminary session and shall be treated as an input rather than a variable for further discussion. Consensus on this shall be achieved before progression and reminded by the team leader. Lastly, there shall be room for open Q&A at the end of the kick-off.

5.3 Phase 1: Requirements Review & Classification

Tasks	Projected outcome
• Review and classification of existing requirements into Class A & B: • Class A: Requirements that need to be clarified and derived in phase 2 • Class B: Requirements that will be clarified and derived after Review Gate 1 • Potential adjustments of requirement definition	• All requirements are adjusted in terms of wording and applicability. • Classification of all requirements into either class A or B

In order to facilitate an efficient development process, the initial step is to review the existing requirements. Unlike the preliminary session where requirements were approached in a simplified and generalized way, in this phase each requirement shall be addressed specifically. In concurrence with the present experts, each requirement shall be assessed, if needed it shall be rephrased and ultimately understood by the development team. In addition to a general comprehension of a requirement it is often helpful to quickly brainstorm on exemplary design and analysis measures that could lead to successful compliancy.

At the end of each assessment the team assigns a classification (class A & B) which ultimately defines at what point of the development the specific requirement becomes relevant. The challenge for this approach is to carefully place the requirement into their appropriate category. It shall be avoided of having a decisive requirement being considered too late in the development cycle and potentially having to change core aspects about the established design.

5.4 Phase 2: Requirement Derivation

Tasks	Projected outcome
• Review list of class A requirements • Identification of potential actions to ensure compliance to specific requirements	• Condensed list of class A requirements including information on how to achieve compliance

Phase 2 is designed to investigate the complete list of class A requirements on its potential to be enough input for an initial design development. Each expert shall comment on his/her individual discipline and confirm that the condensed list of requirements provides adequate opportunity to ultimately provide full compliance. However, if the current list of class A requirements needs adjustments and/or additional requirements, the changes shall be made.

The target is a discussion with individual disciplines about their specific demands and expectations for the upcoming part design. Ultimately, it shall come to an agreement between all experts and the development team that the list of class A requirements is sufficient to provide promising potential of reaching full compliance.

This phase shall also give the development team the chance to discuss potential actions to ensure compliance to specific requirements with the related experts.

Finally, a condensed overview of the class A requirements shall be created. It shall incorporate additional information and guidelines for each requirement on how compliance can be achieved (options for trade-offs). This list will also serve as a checklist for Review Gate 1.

5.5 Phase 3: Design Phase Organisation

Tasks	Projected outcome
• Design phase structure and schedule • Scheduling of potential expert meetings for additional clarification and/or analysis	• Work schedule for the upcoming splinter sessions

The final phase for the first day of the detailed session is planned to give structure to the upcoming splinter sessions. The development team shall present their approach and how they plan on conducting the tasks in front of them. They shall also give a broad estimation on what can be expected at the next review gate and how they plan on demonstrating it. This can also be an opportunity for the experts to comment and give pieces of advice on how the development cycle could be carried out. Additionally, necessary meetings with certain experts can be scheduled if specific topics could not be clarified within the concurrent session. Ultimately, this phase 3 concludes the session and shall assure that all participants are fully aware of the upcoming actions, the expectations for the next review gate and potential support meetings that are planned for the splinter sessions.

5.6 Splinter Sessions

Splinter sessions are dedicated for the iterative design process described in Figure 5-2 as a "Design iteration process". This process consists of an iterative loops between the design and the analysis teams (e.g. structural analysis, Thermal, AIT) working closely together in terms of doing the design optimization and verification loops to come up with a design which complies with all requirements defined in the Requirements Derivation Phase. The Splinter Sessions concerning different domains (e.g. Structural, Thermal) can run in parallel.

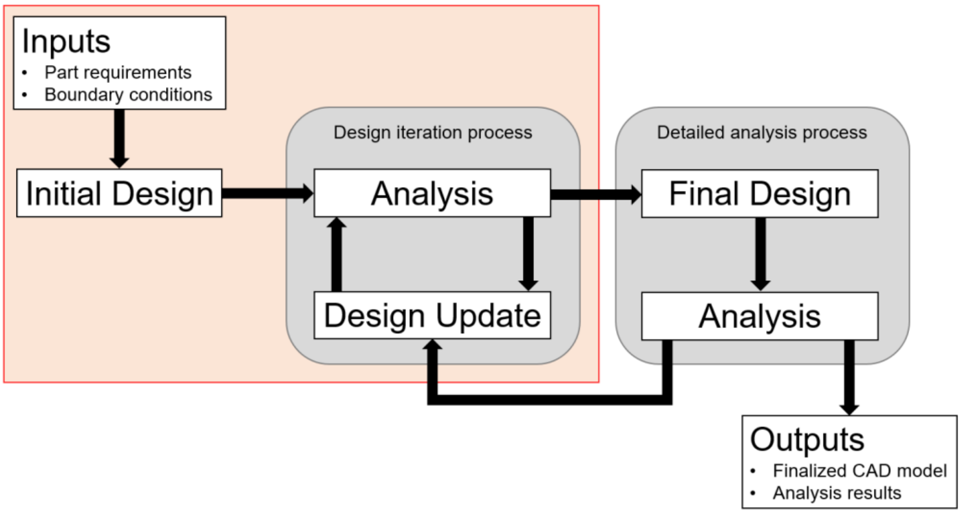


Figure 5-2: Detailed CEFO Session work flow – Design iteration process

These requirements are used as an input for the Splinter Sessions together with an initial CAD design based on the final concept chosen for the Detailed Session. The baseline models (e.g.

FE, Thermal) with the boundary conditions, reflecting the given requirements, is prepared and the first analysis loop is provided. Based on the analysis results, the design change is communicated between the design and the analysis teams. Every loop follows the same pattern:

Design Update → Analysis → Verification → Design Change Proposal

As the outcome from the Splinter Sessions for the Review Gate meeting, a short summary presentation is prepared with the conclusions and the proposed following steps.

5.7 Review Gates

Review Gate meetings are dedicated to the discussion about the results from Splinter Sessions within the CEFO team. The summary of the design optimization and analysis results are checked against the requirements and the outcomes from the individual Splinter Sessions are harmonized. Any possible design difficulties are also discussed with corresponding experts.

The outcome from the Review Gate 1 is the summary of additional information and inputs needed to go forward with the design optimization and structural verification. The future steps are defined to fulfil all the requirements.

After the first Review Gate meeting the design process continues through additional design iteration loops to investigate the inputs from the Review Gate meeting. At the end of the second block of Splinter Sessions, the Review Gate 2 meeting takes place to summarize the achieved results. Conclusions are discussed within the CEFO team and fulfilment of all requirements is checked. Any possible future tasks are defined to be performed in a given time frame before the final closure of the project.

5.8 Design Finalisation (after the CEFO session)

The Design Finalisation phase is dedicated to the final loop of the design update and the analysis and verification, described in Figure 5-3 as a "Detailed analysis process". During this process all the remaining requirements should be satisfied. The design is frozen and the final conclusions are made based on the structural analysis results. The output from the Design Finalization phase is its presentation including the final design of the part along with the analysis results. The model is provided in CAD data format.

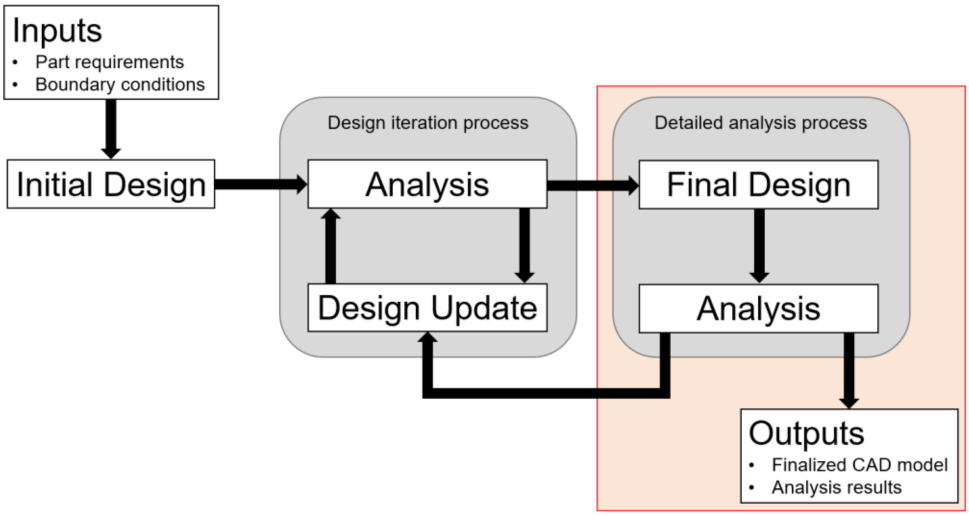


Figure 5-3: Detailed CEFO Session work flow – Detailed analysis process

6 TOOLS APPLIED FOR THE METHODOLOGY

The means and tools that were developed and used during the preliminary and in-depth Concurrent Engineering sessions are listed, described and critically analysed. In the list below they are divided into tools that were used in all session and tools that were only developed for a certain part design.

The tools that were used in all preliminary CE sessions are:

- Centralized Information Encyclopaedia for knowledge management
- CDP4® for requirements documentation and review
- Requirements-Functions-Variables chart (RFV chart)
- Process-Applicability-Matrix (PAM)
- Morphological box
- Spreadsheet for scoring of design concepts

Further tools that were applied during the in-depth CE sessions:

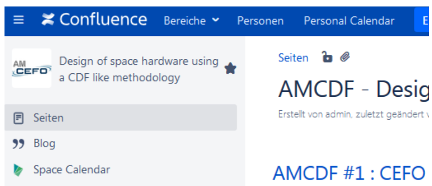
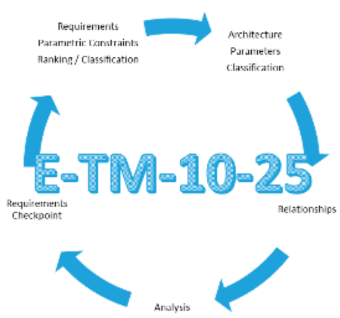
- CAD Software (*Siemens NX*)
- Structural Analysis Software (*Altair HyperMesh*)
- Action Item List (Excel spreadsheet)

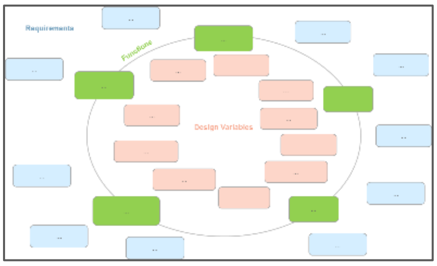
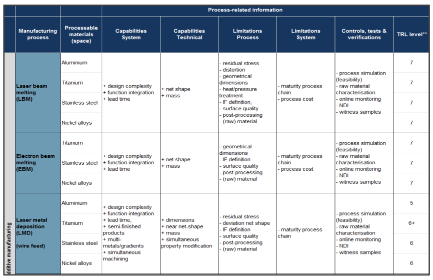
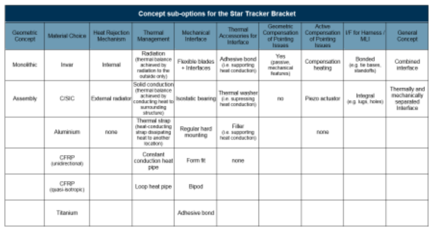
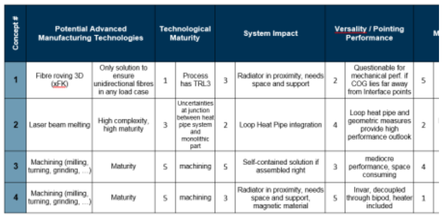
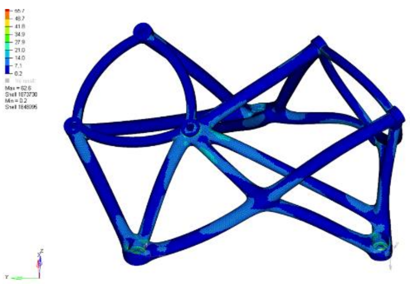
Tools that were developed particularly for a certain parts design in the in-depth sessions:

- Adhesive Stiffness calculation model (Excel spreadsheet)
- Adhesive MOS calculation model (Excel spreadsheet)

Table 6-1 summarizes the tools and its purpose that were developed during the activity for the proposed methodology for the Preliminary and the Detailed CE sessions. The tools are described in detail in the following chapters.

Table 6-1: Tools to be applied for the proposed methodology

Tool	Purpose	Preview
Centralized Information Encyclopedia	Knowledge management Sharing organisational details for the sessions as project timeline, latest schedule updates	
CDP4®	List, adjust & categorize requirements to be prepared for preliminary session Check compliance to requirements during detailed design	

Tool	Purpose	Preview
Requirements-Functions-Variables chart (RFV chart)	Review relationship between driving requirements & functions from CDP4® Derive design variables	
Process-Applicability-Matrix (PAM)	Provide background info on Advanced Manufacturing Identify potential Advanced Manufacturing processes	
Morphological box	List all sub-options for each design variable Make participants aware of the full range of potential combinations and thus demonstrate the diversity of concepts	
Scoring table for design concepts	Rating of identified design concepts against each other	
CAD & FEM	Design & Structural Analysis	
Action Item List	Action tracking during Review Gates	No preview

Centralized Information Encyclopaedia for knowledge management

For knowledge management for both the preliminary and the in-depth CE sessions the Software *Confluence* from *Atlassian* was applied which is a Centralized Information Encyclopaedia. Through Confluence the organiser of the CEFO could easily share all required information regarding the project schedule and other organisational details for the sessions.

Requirements-Functions-Variables chart - RFV chart

The purpose of the Requirements-Functions-Variables chart (RFV chart) is to review the relationship between the given requirements and functions from CDP4® and to identify driving requirements that can be translated into variables for the design. The RFV chart provides a visualization of all driving and non-driving requirements, functions and design variables that facilitates an in-depth understanding of the part.

Process-Applicability-Matrix (PAM)

The Process-Applicability-Matrix (PAM) was established in preparation of the preliminary CE sessions with the aim to support the CEFO participants in selecting an adequate manufacturing process. Originally, it was meant to contain all required background information on conventional as well as Advanced Manufacturing Technologies including process-related information (as capabilities, limitations, maturity level, controls & verification methods) and part-specific information (as added value, required expertise, drawbacks, identified gaps & risks).

Morphological box

In the preliminary CE sessions, the concept sub-options were generated on the basis of a morphological box by means of an Excel spreadsheet. The aim of the morphological box was to ease the identification of the most promising design solutions. It supported the CEFO participants by visualising all potential options for the established design variables derived from the RFV chart. Its compact overview helped to identify feasible combinations of design options that in conjunction make up a concept solution.

Spreadsheet for scoring of design concepts

The identification of the most promising design concepts was done through a spreadsheet. The spreadsheet included a rating for part-specific criteria as e.g. maturity level of the foreseen manufacturing technology, costs (divided into recurring costs and non-recurring costs), mass, robustness, system impact, versatility, and others. This enabled the CEFO team to trade-off and select the design solution with its adequate manufacturing technology for the in-depth CE sessions.

CAD Software and FEM Software

For CAD and FEM the commercial software packages of *Siemens NX* and *Altair HyperMesh* were applied.

Action Item List

An Action Item List is essential to streamline all action that need to be done during or in parallel to the splinter sessions.

CDP4® for requirements documentation and review

The CDP4® is an implementation of E-TM-10-5 [RD04] that supports modelling and near real-time data exchange/sharing between the stakeholders of a Concurrent Design activity. The CDP4® can be used to model and quantify both the problem statement (requirements) and the solution (architecture).

In the context of current activity the CDP4® has been used to model and classify the requirements, the identified functions and the relationships between them. E-TM-10-25 [RD04] and the CDP4® support an iterative multidisciplinary process illustrated in Figure 6-1.

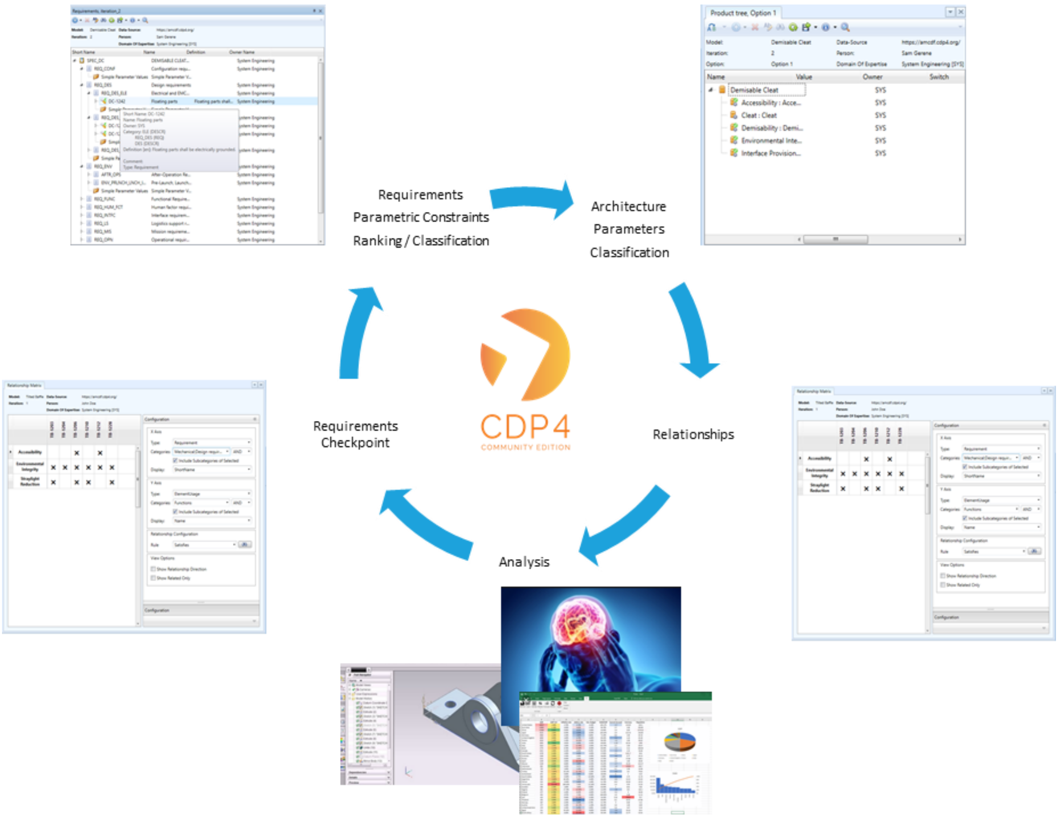


Figure 6-1: Illustration of using E-TM-10-25 & CDP4® in an iterative process

The CDP4® provides multiple view-points on the same modelled data (for this activity the requirements, functions and relationships). The following have been extensively used during the preliminary in-depth concurrent engineering sessions:

- Requirements browser: provides the means to create a structured overview of the requirements, their associated properties as well as parametric constraints.
- Element Definitions browser and Product Tree browser: provides the means to create a structured overview of the solution, i.e. an architecture, consisting of functions and products characterized using so-called parameters.
- Relationship matrix: provides the means to create a structured overview of the relationships between any two kinds of things. In the case of the activity relationships have been created between functions and requirements (e.g. function satisfies requirement) and between requirements (e.g. requirement derives from requirement)

During the course of the activity a taxonomy has been created, based on the ECSS glossary of terms [RD06] and ECSS Technical requirements specification [RD04]. This taxonomy is modelled using CDP4® on the basis of E-TM-10-25 categories. The taxonomy (categorization) is used to classify requirements, building blocks (functions and products) and the different kinds of relationships between them. The taxonomy adds the necessary semantics to the model so the Concurrent Engineering team can reason about them and supports the decision making process. Figure 6-2 provides an overview of the taxonomy system that has been used, where a E-TM-10-25 model items can be categorized using multiple categories.

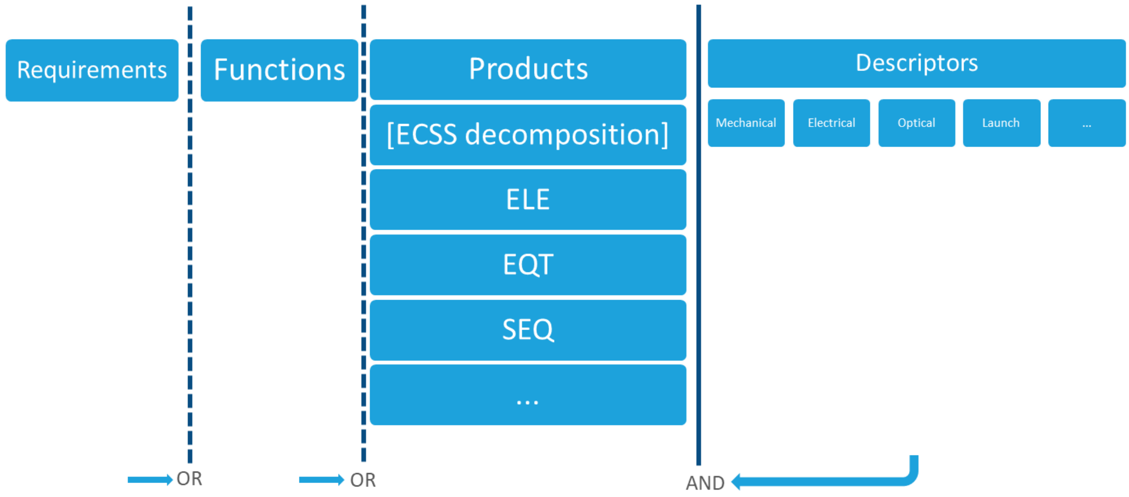


Figure 6-2 Taxonomy using ECSS-E-TM-10-25

Next to adding semantics to the model, the categories are also used to provide a filtering mechanism in the CDP4®. The relationship matrix makes extensive use of categories to provide focussed views on relationships between modelling items. Figure 6-3 shows the Relationships Matrix, the functions (building blocks categorized as *functions*) are displayed along the y-axis; the requirements are displayed along the x-axis. On the intersection between a function and a relationship an arrow is shown in case a relationship exists between the function and requirement, in Figure 6-3 *satisfies* relationships are displayed.

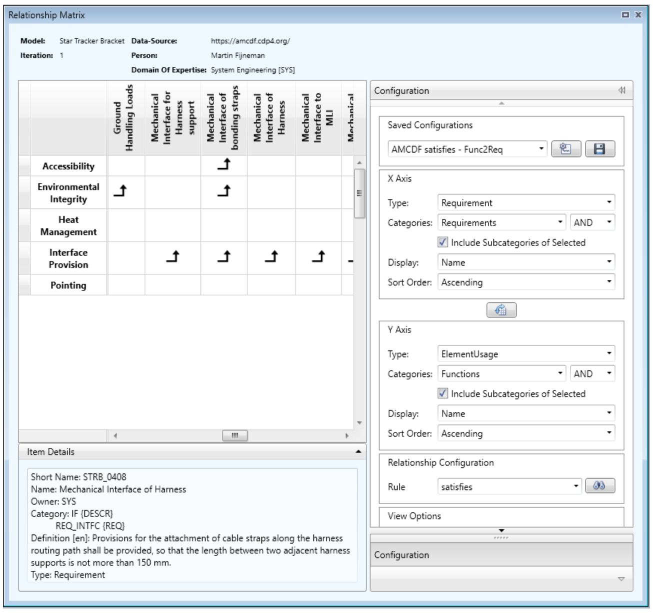


Figure 6-3 Relationship Matrix in the CDP4®

Next to a means to display relationships, the relationship matrix also supports the creation, editing and removal of relationships. During the CE sessions it has proven to be a versatile tool to support the analysis and decision making process.

The functionality of the Relationship Matrix has been improved based on feedback from the CEFO team and how it could support them better during the process presented in Figure 6-1. CDP4® is an open source application hosted on GitHub. GitHub is therefore also used to collect bug reports and feature requests. The following issues have been resolved during the course of the activity:

- #53: Toggle visibility of SimpleParameterValues and ParametricConstraints in the Requirements browser.
- #156: Improved filtering capabilities in the Relationship Matrix
- #158, #179, #180: Improved sorting capabilities in the Relationship Matrix
- #159: Improved access / display of detailed information of the selected item in the Relationship Matrix.
- #181: Highlighting of items in the Relationship Matrix
- #182: Automated requirements verification based on relationships between parameters modelled in the solution and parametric constraints modelled in the requirements
- #188: Requirements export to an Excel spreadsheet.

Next to the issues reported on GitHub more features have been discussed such as the possibility to support model-based reviews by means of Review Item Discrepancies (RIDs), annotations (model notes), etc. The CDP4® provides a partial implementation that will receive the focus of the CDP4® development team in the near future.

In order to make a complete requirements model, E-TM-10-25 and the CDP4® will need to support the inclusion of images and other types of media in a requirements specification. Currently it is not possible to insert images and tables in the requirements. This has been identified as a shortcoming and will be resolved in the near future.

7 PRE-SELECTED USE CASES

The Use Cases to be investigated during the preliminary Concurrent Engineering sessions to test the proposed methodology based on three parts proposed by ESA (RF Filter, Structural Radiator Panel, Optical Baffle) [AD02] and 3 parts proposed by the consortium (Star Tracker Bracket, Demisable Cleat, Pressure Management Assembly) as shown schematically in Figure 7-1. The pre-selection of Use Cases was focussed on complex multi-functional assemblies and aimed at providing a wide range of parts with different fields of applications, challenges and objectives. This ensured that the developed Concurrent Design methodology was challenged by all Use Cases and demonstrates its adaptability and universal applicability to create an optimized design for a multitude of component types.

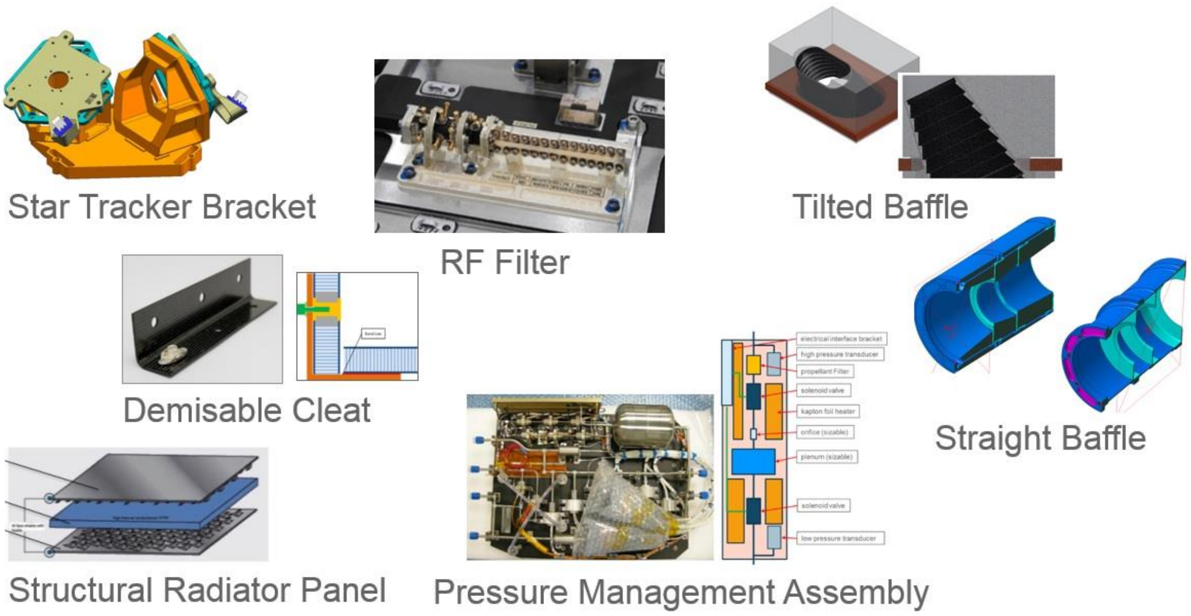


Figure 7-1: Use Cases investigated in the Preliminary Concurrent Design sessions

The requirements for all parts are listed, visualised and described document TN1 [RD01]. The document also contains a ranking and mapping of requirements including its taxonomy.

8 TECHNICAL DOSSIERS

The outcome of the Preliminary CE sessions of all six preliminarily investigated Use Cases was documented in Preliminary Technical Dossiers (see document TN3 [RD03]). The outcome of the In-depth CE session on the Demisable Cleat and the Start Tracker Bracket was summarized dedicated Technical Dossiers for each part (see document [RD05]). In the following the final design of both retained Use Cases is summarized.

8.1 Final Design for the Demisable Cleat

The cleat was designed as a small sub-assembly of one L-profile and two flanges bonded together. The flanges have holes for bolts connecting to satellite panels. The cleat is to be placed outside of the panels, enabling unrestricted access to bolts and respecting the defined design volume. The illustration of the Demisable Cleat assembly is shown in Figure 8-1 together with the dimensions of the final design.

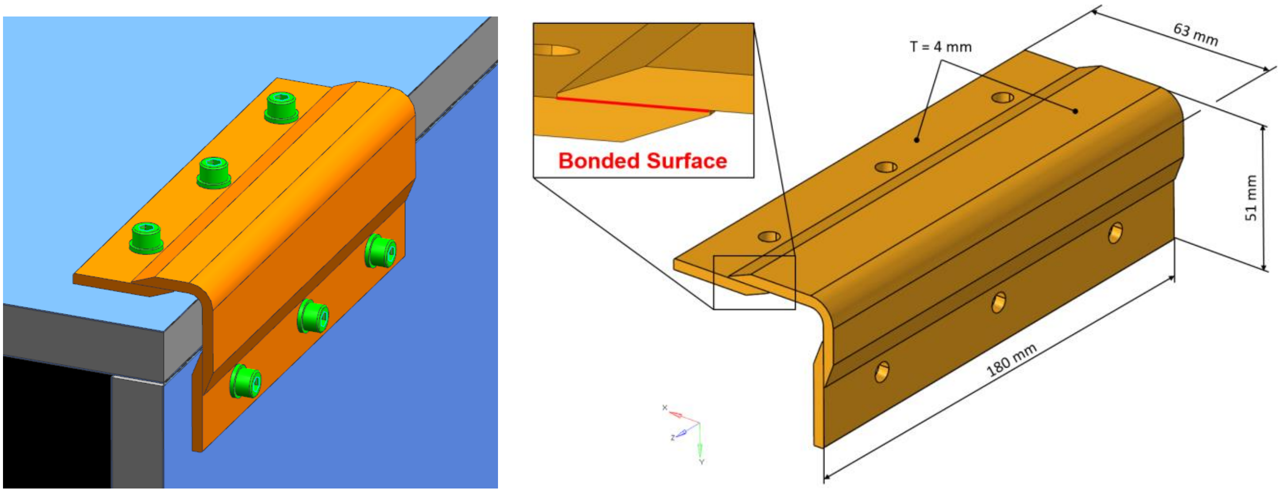


Figure 8-1: Detail of connection of panels using the Demisable Cleat

The overlap of bonded parts is driven by the required strength of the bonded joints. Edges of adjacent bonded parts are gradually chamfered to eliminate stress peaks and peeling. The thickness of parts is also an outcome of structural optimization.

M6 bolts are proposed for connection of the panels. The respective holes in the flanges have a diameter of 6.6 mm + 0.2 mm to allow for a compensation of certain misalignment of holes in the panel and cleat. Both parts are machined from EN AW-7075 T351 of raw material. Chromate conversion surface treatment is required for corrosion protection and creating a defined surface for bonding. Scotchweld 9232 two-component epoxy adhesive is used.

The part list for the Demisable Cleat is shown in Table 8-1. For visualisation the Demisable Cleat design was printed in polymer via Fused Deposition Modelling (FDM). The 3D printed demonstrator is shown in Figure 8-2.

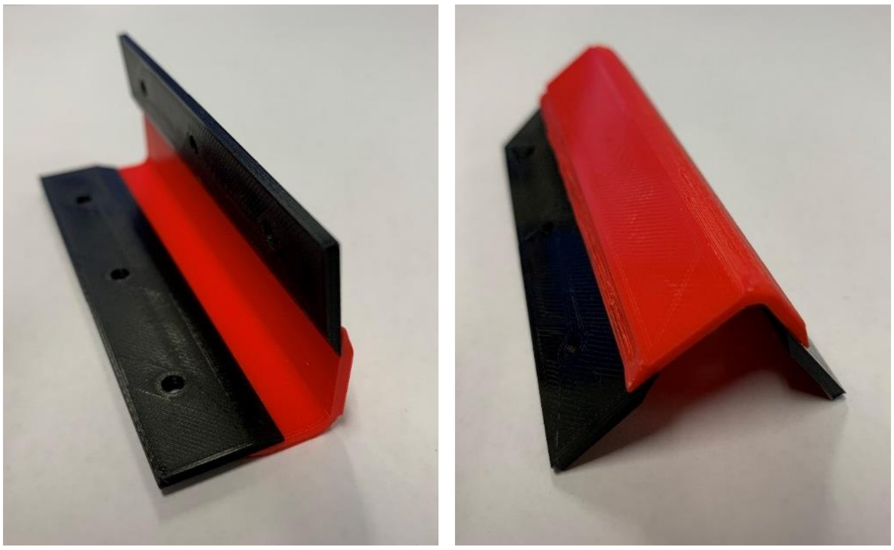


Figure 8-2: 3D printed demonstrator for the Star Tracker Bracket design

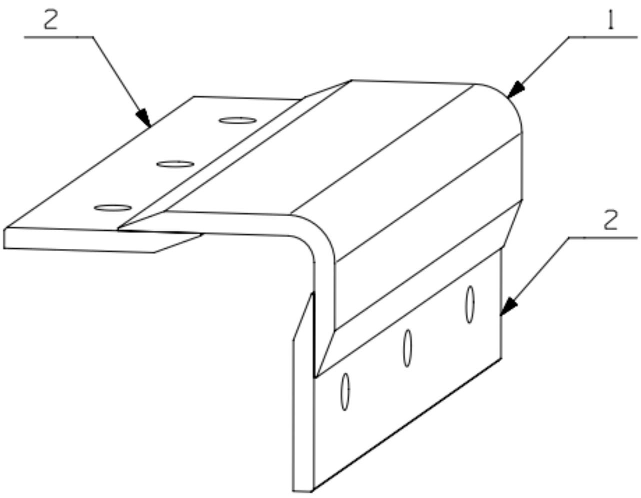


Figure 8-3: Final Design of the Demisable Cleat – Definition of Parts

Item no.	Part	Material	Mass [g]	Quantity
1	DC L profile	EN AW-7075 T351	117	1
2	DC flange	EN AW-7075 T351	67	2
Total Mass			251	
Total Mass with margin 20%			301	

Table 8-1: Demisable Cleat: List of Parts

8.2 Final Design for the Star Tracker Bracket

According to the selected conception the STRB is designed as an assembly of structural part (titanium bracket) and two aluminium radiators as shown in Figure 8-4. Dissimilarity of thermal expansion between the two materials is mechanically compensated by flexible blades as integral elements of the radiators. The assembly also includes ISO 4762 and LN9136 bolts, ISO 125 washers and GFRP thermal washers for decoupling the STRB from the SC structure.

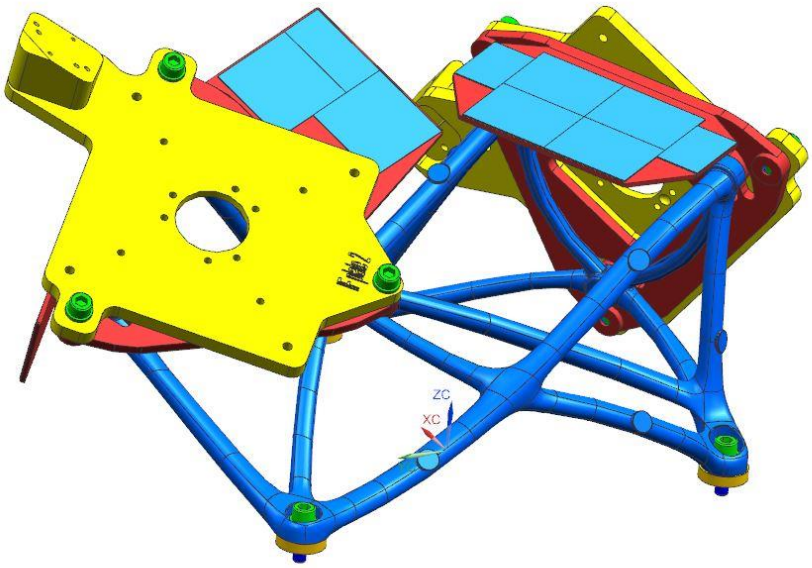


Figure 8-4: Final Design of the Star Tracker Bracket – complete view with IF plates

The pre-defined design volume and interface points are respected as shown in Figure 8-5.

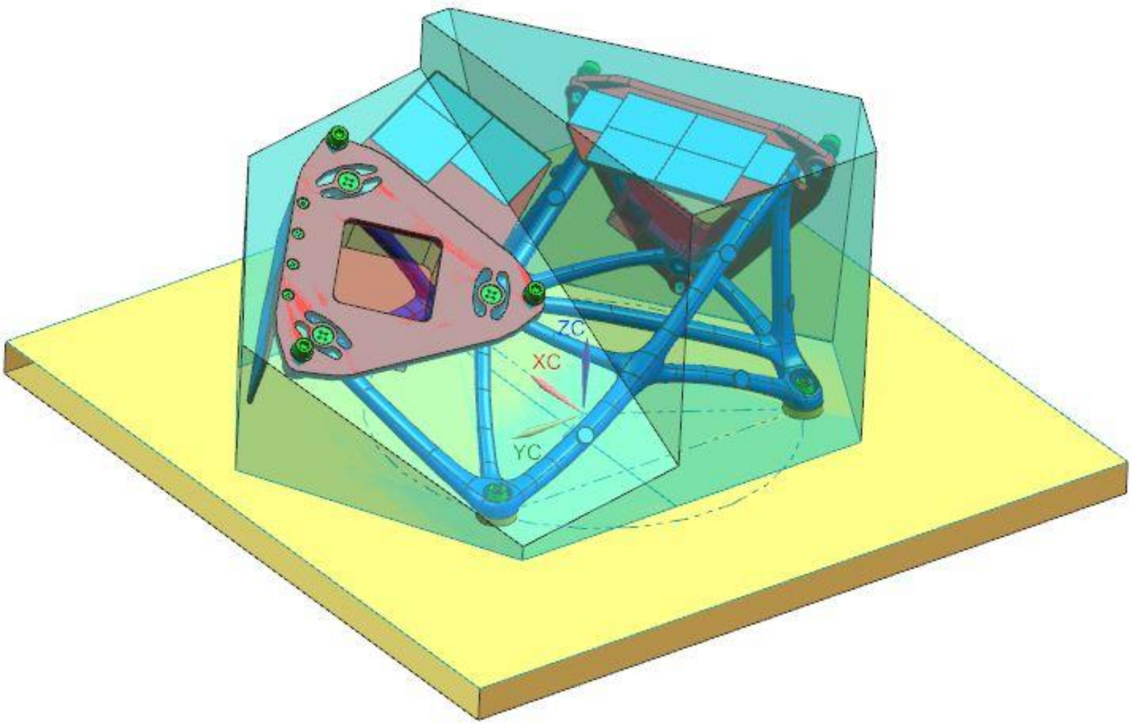


Figure 8-5: Final Design of the Star Tracker Bracket including design volume

The bracket structure allows for an easy access to bolts, also considering tools. The Star Tracker harness shall be routed along the branches and strapped to them.

The titanium bracket is a bionic structure composed of several "branches" connecting the pre-defined interface points. The first idea of the shape an outcome from the topology optimization with the goal of minimizing the mass and maximizing the stiffness under the given mechanical loads. Several manual iteration were then carried out with modified shape and cross-sections of the branches to improve thermal behaviour, stiffness and reduce local stresses. Several flat round interfaces for MLI standoffs were created at the end. The part will be additive manufactured with post-processing (machining) so that the required geometry and tolerances is achieved on functional faces. Self-locking bronze thread inserts are used to secure bolts.

The radiators are designed as aluminium machined parts providing mechanical interface between the structural titanium bracket and pre-defined Interface plates. The area of the radiators is designed with respect to the heat rejection requirements, several OSR tiles are implemented for better heat rejection. The heat-radiating areas are either integral or separate parts joined by screws. For these parts a good contact of parts is necessary which is reflected by definition of flatness and roughness of surface and by the number of bolts which is higher than necessary for structural reasons. Maximum dimensions of the raw material is also respected. For threaded holes the self-locking bronze thread inserts are used as well.

The lower side of radiator is flat and can be used for accommodating the heaters and sensors if requested. Information on tolerances, surface condition, thread inserts, tightening torques for bolts and AIT that cannot be derived from the CAD model would be covered by drawings in real project.

However, the restrictive definition of the boundary conditions (design space) led to the non-ideal position of the radiator plates. Ideally the radiators should be placed directly on the Interface Plates, where the Star Trackers are mounted. In the real project, the radiators should be placed outside of the design space defined for the CEFO session. The exploded view is illustrated in Figure 8-6 and the part list for the Star Tracker Bracket is shown in Table 8-2.

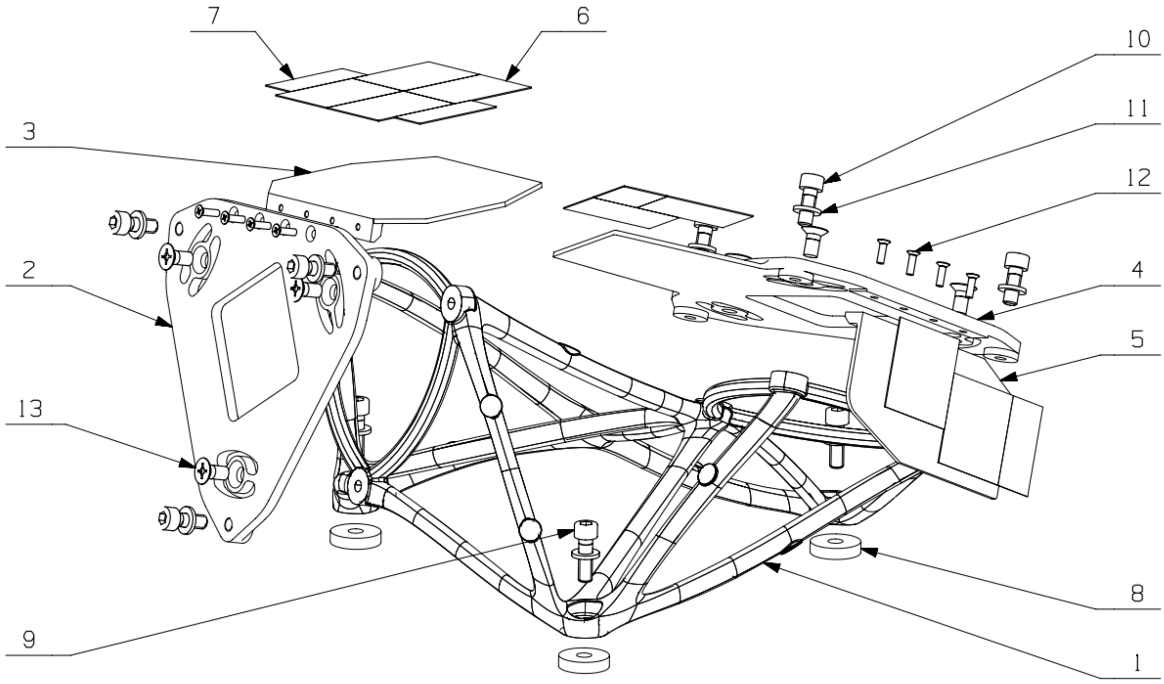


Figure 8-6: Final design of the Star Tracker Bracket – exploded view

Item no.	Part	Material	Mass [kg]	Quantity
1	Structural bracket	Ti6Al4V	1.192	1
2	Radiator Base 1	EN AW-2024 T851	0.155	1
3	Radiator Plate 1	EN AW-2024 T851	0.063	1
4	Radiator Base 1	EN AW-2024 T851	0.188	1
5	Radiator Plate 2	EN AW-2024 T851	0.039	1
6	OSR tile 40 x 40 mm	OSR	0.002	8
7	OSR tile 40 x 20 mm	OSR	0.001	4
8	Thermal washer	CFRP	0.004	3
9	Bolt M6 x 20 DIN 912	1.4401	0.003	3
10	Bolt M6 x 16 DIN 912	1.4401	0.003	6
11	Washer 6.4 DIN 125	1.4401	0.001	9
12	Bolt M3 x 10 LN9136	Ti6Al4V	0.0004	6
13	Bolt M6 x 12 LN9136	Ti6Al4V	0.002	8
Total Mass			1.723	
Total Mass with margin 20%			2.068	

Table 8-2: Star Tracker Bracket: List of parts

The 3D printed demonstrator for the is shown in Figure 8-7 including the bracket (1), the Radiator Bases (2 & 4), the Radiator Plates (3 & 5) and the flexible interface connectors.

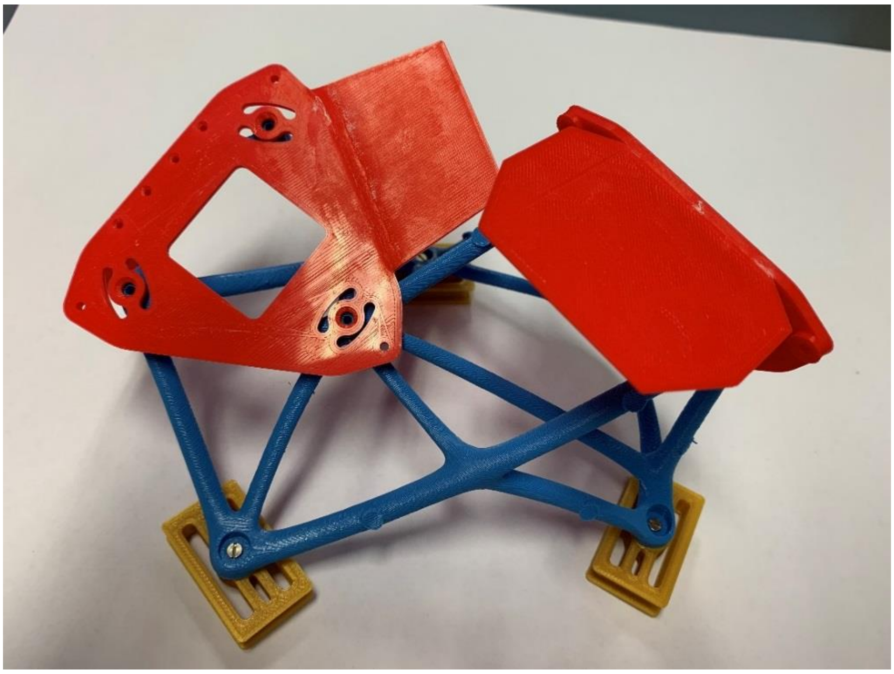


Figure 8-7: 3D printed demonstrator of the Star Tracker Bracket design

9 LESSONS LEARNT

The Lessons Learnt from the activity can be summarized as follows:

- The sessions should always have clear boundaries. Its range and scope shall not deviate or cross over its intended frame. This could lead to an unstructured sequence and cause confusion within the session. One of the strong attributes of this methodology must be its organized workflow that provides easy comprehension throughout.
- Transformation of information shall be done with care in a Concurrent Engineering setting, since otherwise disconnect between the requirements' author and the engineer that attempts to provide compliance to it may occur. Having part experts in the sessions that can provide descriptive examples on how compliance can be demonstrated for a specific requirement greatly support the outcome of the session.
- Some parts may require extensive amount of development time which can be driven by the complexity of the part or by the technology applied on the part. Therefore, the overall complexity of the part should be considered in the scheduling of time and resources for the CE sessions.
- The outcome from the Review Gate meeting should be presented in the form of an Action Item List in which should be clearly stated what will be the next steps, what are the inputs needed and who is responsible for each task.
- The outcome from the Design Finalization phase should be provided in a form of a summary presentation of the design iterations including the reasons for which the particular design was not acceptable against the given requirements.
- Time schedule and the man power allocation for Splinter Sessions should be estimated based on the specific part and its complexity. Definition of a third Review Gate for more complex parts is recommended.

10 CONCLUSION

Within the activity “Design of Space Hardware using a CDF like Methodology” a methodology for the Concurrent Design of spacecraft parts was developed. The Concurrent Design was divided into a Preliminary CE sessions and an In-depth CE session. The methodology was especially established to design complex and multi-functional parts with the possibility to take Advanced Manufacturing technologies into account.

The proposed methodology was successfully performed and tested exemplarily for the design of a Demisable Cleat and a Star Tracker Bracket. The outcome of the design sessions was documented in Technical Dossiers and demonstrated by 3D printed mock-up for both parts.

With the feedback of the CEFO participants and the Lessons Learnt documented during the sessions, the methodology was adjusted and optimised. In addition to CDP4® for requirements management and the necessary CAD & FEM tools, easy-to-use spreadsheets were developed and applied effectively. Valuable tools elaborated as an essential part of the methodology are the Requirements-Functions-Variables Chart (RFV chart), a Process-Applicability-Matrix (PAM) for background information on manufacturing technologies and the Morphological Box to ease the identification of the most promising design solutions.

11 OUTLOOK

An outlook on potential follow-up activities to further develop the proposed methodology as well as the Use Cases that were investigated in the preliminary and the in-depth CE sessions.

Integration of tools with workflow into a dedicated Design Suite

For the proposed methodology several self-developed rather easy-to-use tools were developed using conventional spreadsheets. Although handling these tools is rather simple, professional tools with more flexibility might be helpful to work together concurrently on the same data and thus could reduce the required time and resources during the CE sessions. Thus, the consortium recommends to work on the integration of the developed tools with the proposed workflow into a dedicated Design Suite. The Design Suite might contain a database to work on the design concurrently.

Introduction of simulation/AR/VR of manufacturing processes into the methodology

The proposed methodology and workflow might be enhanced and linked to a simulation tool using Augmented Reality or Virtual Reality. The simulation might be used to ease the decision making process regarding the identification of design solutions in the sub-options matrix or to find potential options for adequate Advanced Manufacturing processes.

Demisable Cleat

An optimization of the cleats spacing on the panel can be provided in terms of compensating the exceeded mass of the current Demisable Cleat design. For repeated production the L-profile and the flanges can be made of custom rolled profiles with optimized cross-section. Information for the adhesive material is required to estimate the lifetime performance of the bonded joints. It is proposed to test the adhesive material to cover the whole range of required temperatures and to define the radiation ageing.

Star Tracker Bracket

The pointing requirements were still not met with the current design of the STRB. The structure optimization still needs to be performed to improve the pointing performance. A further topology optimization is recommended with considering flexible interface points between the STRB and the S/C and considering the thermal conditions. The interfaces may be designed as a panel inserts to reduce interfaces and mass. To fulfill the thermal rejection requirements, the interface plates require a design update to accommodate the OSR Tiles. A buckling analysis should be performed. Through holes and bolts with nuts should be implemented instead of threaded holes for fixing IF plates. Nevertheless, the current results show a positive trend in achieving the compliance in all requirements. It is promising for further development.

Tilted Baffle

Due to the promising results from the preliminary session, further investigation on the use Advanced Manufacturing for the design of Optical Baffles is recommended. It may provide performance benefits, reduced lead times or cost reduction. Tools to simulate and predict and measure the straylight of the AM surface and the overall baffle after is mandatory.

ACKNOWLEDGEMENT

The activity “Design of Space Hardware using a CDF like Methodology” was performed in the frame of the ESA Contract No. 4000125906/18/NL/GLC/as.