Challenges for Concurrent Engineering on Launcher Design

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Abstract

Since June 2011, Astrium Space Transportation (Astrium-ST) is implementing concurrent engineering (CE) processes, methods and tools to perform advanced project studies in the different branches of its core activities (launchers, missiles, orbital and exploration vehicles).

The interest for adopting CE lies in reducing the inherent risk of the early stages of the system life cycle (phase 0, A and B up to SRR) by rapid but complete assessments of the solution alternatives involving all the relevant disciplines from the onset of the project on.

The SPACE CODE project (SPAce Cost Efficiency & COncurrent DEsign) endeavours a company wide, transnational, multi site deployment of a CE environment and embraces the perspective of an enhanced productivity and an encouraged innovation of the multi disciplinary teams that will use it.

This paper describes the deployment of the SPACE CODE environment for the ARIANE 6 phase A and phase B.1 launcher design activities. The architectural design iterations entail system analyses and decision sequences that require the agility to explore the various alternative options. These successive trade-offs require a flexible environment to capture those analyses, decisions and rationales.

The endogenous interactions between the system elements of a launcher (control, navigation, guidance, propulsion, …) are stronger than on spacecraft because of the exogenous constraints from the laws of physics and the harsh environment the launcher is subject to. The system's measures of performance (mass, thrust, …) are indeed strongly interlinked in a multi variable optimisation problem. The time dependency of the operational conditions calls for tight multi disciplinary simulations involving the different specialty engineering domains. The required computational effort represents a challenge for the concurrent engineering approach. Another challenge resides in implementing the contingency and margin policy on the relevant parameter exchanges.

A collaborative platform (PForge), based on Atlassian's solutions, is operated to record the proceedings of the advanced project studies during the different phases of the CE campaign (initialisation, preparation, operation and post-processing), capturing the corresponding knowledge.

The Concurrent Design Platform (CDP), commercialised by J-CDS Concurrent Design Services (J-CDS), is run to build the systems engineering data model, dealing with the launcher specificities such as the large number of options (propellant types, number of stages, number of boosters, …) and the time dependency of the parameters.

The Functional Digital Mock-Up (FDMU), based on Dassault Systèmes' (3DS) solutions, is implemented to serve as the hub of the specialty engineering data repository, hovering around the geometric definition and progressing through the various specialty engineering workflows to assess the multi disciplinary launcher characteristics.

As a conclusion, this paper shares Astrium-ST's experience on the concurrent engineering processes applied for the launcher design problem in the frame of the ARIANE 6 programme (phase A and phase B.1).

1. Introduction

Since June 2011, Astrium Space Transportation (Astrium-ST) is implementing concurrent engineering (CE) processes, methods and tools to perform advanced project studies in the different branches of its core activities (launchers, missiles, orbital and exploration vehicles).

This initiative receives substantial support from the Astrium-ST management which translates in the first place in the creation of a specific entity in the company's organisation. This entity is accountable for providing support in project management and systems engineering on advanced projects, teaming up with specialty engineering domains to tackle the multi disciplinary problem solving challenges. The implementation of the processes, methods and tools for this purpose is a cornerstone of this mission and is carried out through the SPACE CODE project (SPAce Cost Efficiency & COncurrent DEsign).

The interest for adopting CE lies in reducing the inherent risk of the early stages of the system life cycle (phase 0, A and B up to SRR) by rapid but complete assessments of the solution alternatives, involving all the relevant stakeholders from the onset of the project on. Through a more efficient mobilisation of the specialty engineering domains, fostering their productivity and innovation, the inherent risk can be reduced by exploring the unknown portion of the solution space in a multi disciplinary approach.

2. Programmatics

2.1. SPACE CODE project

Astrium-ST has undertaken the SPACE CODE project to tackle the challenges of a company wide, trans national, multi site deployment of a concurrent engineering environment. It embraces the perspective of an enhanced productivity and an encouraged innovation of the multi disciplinary teams that will use it.

The iterative and incremental deployment on several pilot cases has focused on:

- implementing the best practices in project management and systems engineering to perform the advanced project studies,
- tailoring the company processes to adapt to the specificities of the advanced projects' budgets and schedules by introducing the CE approach,
- enhancing the cost awareness for the advanced projects through linking with the Cost €stimation Framework (C€F) that is developed in parallel,
- using a systems engineering data model and a specialty engineering data repository to share the consistent definition of the system of interest.

2.2. FDMU project

Since November 2010, EADS and Dassault Systèmes (3DS) have been teaming up in the Functional Digital Mock-Up (FDMU) project to shape the future of the multi disciplinary collaborative engineering platform provided by Catia version 6, for the mutual benefit of the end user and the platform developer.

The outcomes of the project have validated the FDMU concept on several use cases proposed by Astrium-ST. It has demonstrated the capability to expand the solution space exploration while ensuring cross discipline engineering data traceability and consistency.

This partnership towards technological innovation in systems engineering has been publicised at the Paris Air Show (Le Bourget) in 2011 and 2013. It illustrated the DMU centric approach driving the specialty engineering workflow in the collaborative engineering mode.

3. SPACE CODE

3.1. SPACE CODE environment

Astrium-ST has a recognised experience in developing, producing and operating space systems. It has grown from the consolidation of various space industrialists throughout Europe and currently has settlements in France and Germany. This geographical distribution puts several constraints on the SPACE CODE environment in terms of team composition, process alignment and tool infrastructure.

The latter is the tip of the iceberg, where appropriate Information Technology (IT) solutions provide a trans national, multi site network that complies to the entrepreneurial, organisational and military security constraints and yet allows access when requested for external partners, subcontractors and customers.

This network enables the centralisation of the information pertaining to the advanced projects that are hosted in the SPACE CODE environment. To support the exchange of information beyond the basic deposit and retrieval of data and to implement the CE approach in distributed locations, multi media assets are deployed allowing the communication between distant team members (videoconferencing, screen sharing, electronic whiteboard, …).

3.2. SPACE CODE processes

Short delays and reduced funding are two specificities of the advanced projects. They call for tailoring the managerial and technical processes that apply to large scale development programmes as found in the Business Management System (BMS) of Astrium-ST. Two inherent adaptations are the concurrent engineering processes and the design to cost processes.

Other adjustments consist in the degree of formalisation that shall balance the scale of the advanced project. This is where the best practices (INCOSE, [1]) can complement the norms (ISO, [2]) and standards (ECSS, [3] and [4]).

The life cycle cost objectives that are put on the advanced projects require a systematic cost awareness. Its integration in the processes relies on the capabilities of the C€F that is developed in parallel. The C€F gathers the data of current and legacy programme cost estimations and cost actuals, thereby providing the required calibration points for estimating the non recurring and recurring cost for the advanced projects.

The SPACE CODE processes categories are illustrated in figure 1:

- CE processes that adapt the processes below to the SPACE CODE approach,
- standard processes that follow project management and systems engineering best practices,
- generic processes that apply within the SPACE CODE environment for any type of advanced project,
- specific processes that apply within the SPACE CODE environment for specific types of advanced projects,
- design to cost processes that adapt the processes above to account for the life cycle cost of the project and/or system.

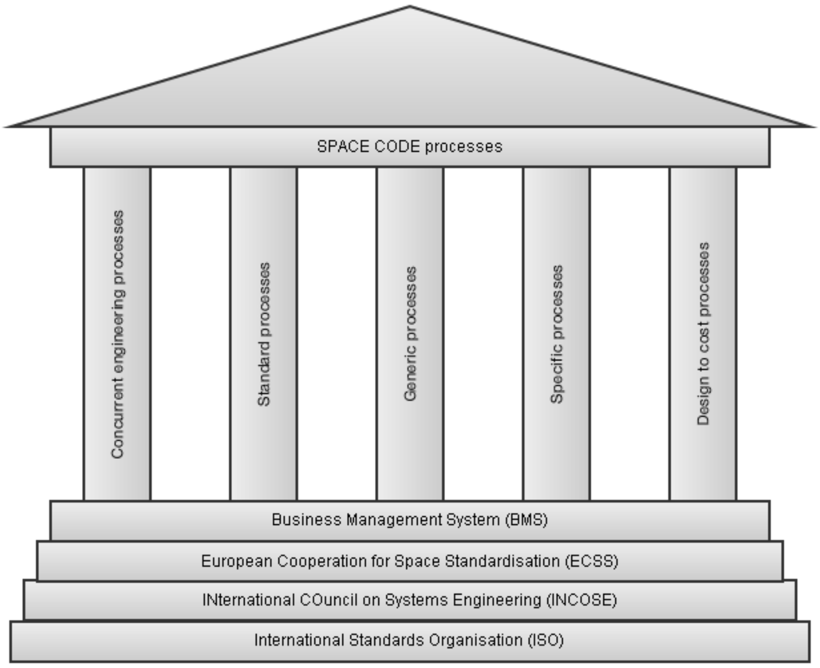

Figure 1: SPACE CODE Processes

These process descriptions are an integral part of the SPACE CODE environment and allow each team member to understand where his contribution is inscribed. The SPACE CODE processes also refer to the methods (checklists, templates, …) and tools (spreadsheets, applications, …) that support them. This allows each team member to effectively implement the processes.

3.3. SPACE CODE methods and tools

The SPACE CODE methods and tools depicted in figure 2 support the above processes in an integrated environment.

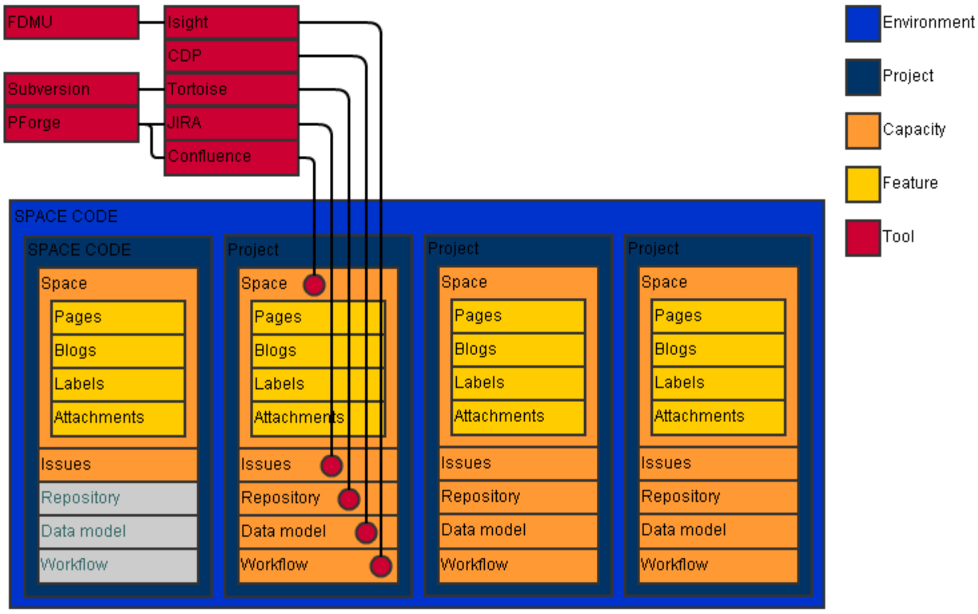

Figure 2: SPACE CODE methods & tools

Collaborative platform

A collaborative platform (PForge), based on Atlassian's solutions (Confluence and JIRA), is operated to record the proceedings of the advanced project studies during the different phases of the concurrent engineering effort (initialisation, preparation, operation and post-processing phases), thereby capturing the corresponding knowledge. The architectural design iterations performed for the advanced projects entail system analyses and decision sequences that require the agility to explore the various alternative options. These successive trade-offs require a flexible environment to capture those analyses, decisions and rationales.

While the systems engineering baseline and options are quantified in the systems engineering data model and the specialty engineering data repository, the non quantifiable exchanges between the specialty engineering domains are captured through text and graphics in a wiki (Confluence). By allocating chapters to the specialty engineering domains, every team member can contribute to writing the proceedings of the CE sessions, especially to record the discussions that lead to assumptions, decisions or rationales.

The collaborative platform also serves outside of the CE sessions to share the information on the progress and events of the advanced project.

Systems engineering data model

The Concurrent Design Platform (CDP), commercialised by J-CDS Concurrent Design Services and Solutions (J-CDS), is run to build the systems engineering data model. It supports the CE approach that consists in sharing those Measures of Effectiveness (MoE) or Measures of Performance (MoP) that are readily understood by the different specialty engineering domains and support the discussions on the concerns, constraints or issues where a multi disciplinary solution is sought. The CDP environment also supports the pacing to the CE approach of the sequence in which the specialty engineering domains perform the technical processes.

The systems engineering data model contains those MoE and MoP that unambiguously distinguish the options of the system of interest that are analysed and traded in the CE approach and ultimately define the baseline.

Specialty engineering data repository

In complement to the systems engineering data model, a specialty engineering data repository is used to host the various data files that underlie the exchanges between the specialty engineering domains. Indeed, much of the detailed exchanges rely on these data files whose complete content is difficult to grasp by non initiated team members. In a way, the systems engineering data model is only a subset of the specialty engineering data repository, focusing on those MoE and MoP that support the way forward to the multi disciplinary solution.

A combination of a Subversion file versioning server and a Tortoise client is built as specialty engineering data repository. The server hosts the versioned instances of each data file in a central repository that is accessed by the client of any team member. Based on the update/commit scheme, any team member has the assurance of accessing the latest available and valid data file. Through the branching and tagging mechanisms shown in figure 2, configuration management constructs, such as options and baselines can be obtained.

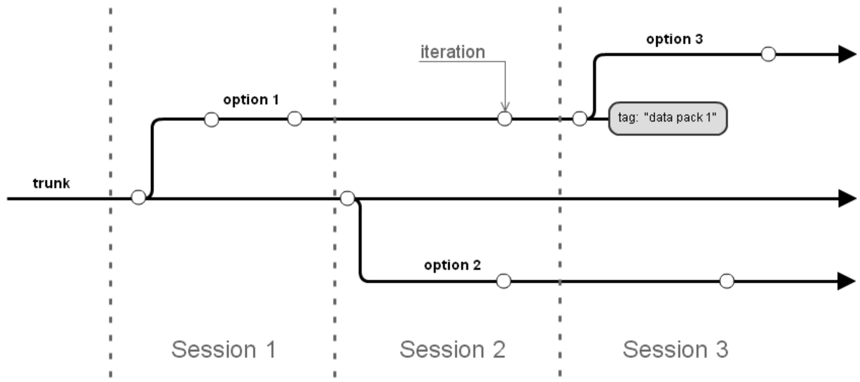

Figure 2: Options and Baselines Constructs in Subversion

Specialty engineering work- and dataflow manager

With the increasing complexity of the specialty engineering data exchanges as the project lifecycle progresses towards phase B, the need arises to augment the systems engineering data model and the specialty engineering data repository with a specialty engineering work- and dataflow manager.

The Isight solution proposed by 3DS, backbone of the FDMU approach in the Catia version 6 platform, is selected to encapsulate the specialty engineering analyses befitting the phase B launcher design activities.

4. Launcher design

The endogenous interactions between the system elements of a launcher (control, navigation, guidance, propulsion, …) are stronger than on spacecraft because of the exogenous constraints from the laws of physics and the harsh environment the launcher is subject to. The system's MoP (mass, thrust, …) are indeed strongly interlinked in a multi variable optimisation problem. The time dependency of the operational conditions calls for tight multi disciplinary simulations involving the different specialty engineering domains. The required computational effort represents a challenge for the concurrent engineering approach.

Traditionally, the launcher design focuses on the staging problem, where the team members from the aerodynamics engineering, mass engineering, mission analysis and propulsion engineering domains strive for a close to optimum solution that reaches the required payload mass in orbit performance for the targeted cost as in figure 3.

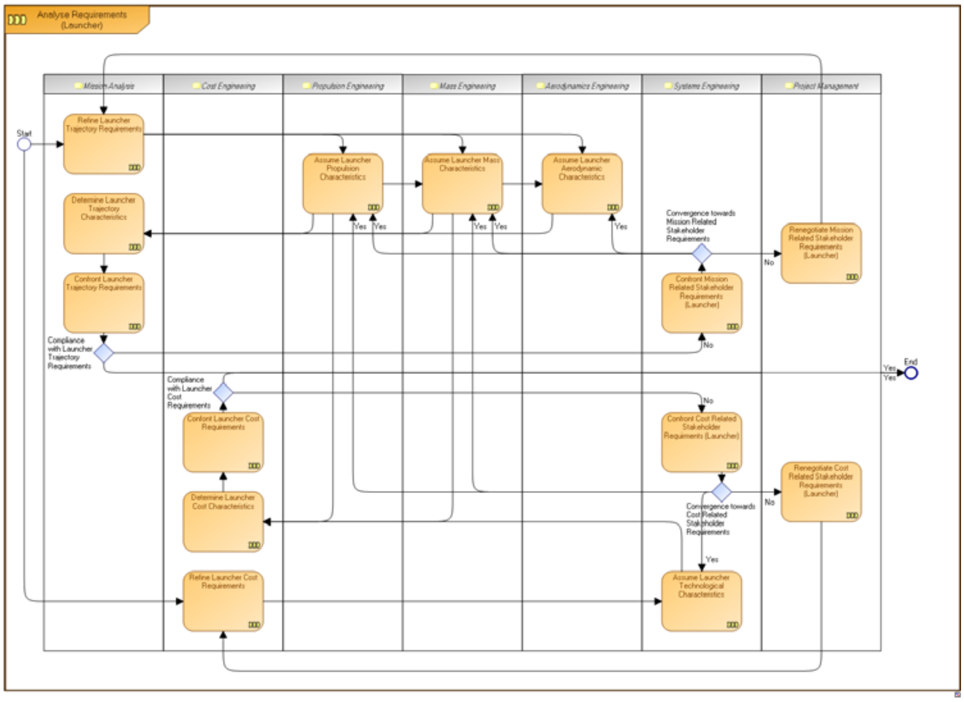

Figure 3: SPACE CODE Specific Processes - Launcher Requirements Analysis

In recent years, this process has evolved as shown in figure 4 from the collaborative engineering approach to the Multi Disciplinary Optimisation (MDO) approach whereby the contributions of the different specialty engineering domains are stowed as interconnected models that together allow computational optimisation as described in [6] and [7]. The MDO delivers good results in terms of optimisation but presents a stiff frame of applicability. Any extension of the MDO approach to innovative launcher architectures or additional specialty engineering domains needs the development and interconnection of the corresponding model. These specific interconnection and development activities for the MDO cannot be sustained anymore by the advanced projects financial and technical effort.

Nowadays, the CE approach is invoked in the SPACE CODE environment whereby the extension of the problem space to the innovative launcher architectures and the additional specialty engineering domains is performed in a straightforward fashion. The multi disciplinary interconnection of the specialty engineering analyses is performed without substantially modifying them, focusing on the data exchange process.

When the amount of detail and the level of complexity increase, the multi disciplinary interconnection of the specialty engineering analyses is performed with the work- and dataflow management in the FDMU environment. This FDMU environment furthermore recovers some of the solution space exploration and the optimisation capability.

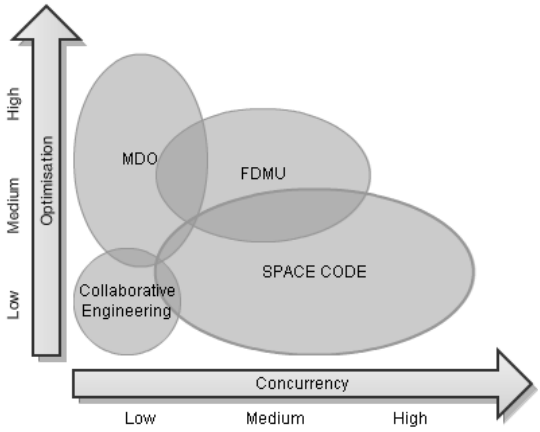

Figure 4: Combining Multi Disciplinary Optimisation and Concurrent Engineering

5. Lessons learnt

After several pilot cases on which it has been successfully experimented [9], the SPACE CODE approach is introduced for the phases A and B.1 of the ARIANE 6 programme to downselect the number of alternative configurations to a traded shortlist with clear ranking on identified selection criteria.

5.1. Systems engineering data model

The systems engineering data model has been built up in the form of a parametric integrated design model in the CDP environment much akin to [5]. The systems engineering data model in the CDP consists amongst others of the following parts:

- the domains,
- the decomposition levels,
- an activity library,
- the product tree.

The parameters (MoE and MoP) are grouped under nodes arranged the CDP product tree that follows a logical or physical decomposition as illustrated in figure 5. This tree can be built up by creating generic sets in the CDP activity library and adding these to the CDP product tree with drag-and-drop functionality in the CDP client.

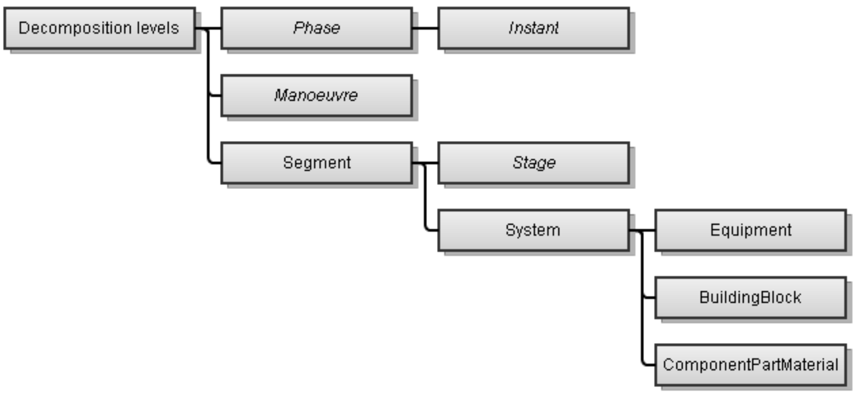

Figure 5: Decomposition Levels

The physical decomposition follows the ESA Generic Product Tree as proposed in [8]. It provides a shallow decomposition that can if required recursively be deepened. This allows to balance decomposition depth and span of control to the advanced projects.
The logical decomposition along the stages captures the time dependent architecture, providing a collating frame that allows correctly tallying the jettisoned, separated and remaining masses.

The logical decomposition along the phases (launcher ascent, payload injection, …) and the instants (waiting on launch pad, 1st stage ignition, maximum dynamic pressure, …) captures the time dependent parameters (longitudinal acceleration, dynamic pressure, …) with a granularity that remains compatible with the CE approach. The logical decomposition along the manoeuvres captures the transition parameters (ΔV, propellant mass, …) between the phases.

These logical decompositions allow handling the dynamic behaviour of the parameters in the current implementation of the CDP with an implicit link between the different parts of the static parameter tree that is clear to the team members. An explicit link, as proposed in the J-CDS roadmap for the CDP, will in this respect drastically improve the readability of the systems engineering data model. It will provide the capability of modelling the dynamic behaviour of the system and managing the different varieties of parameter values (best estimate value, uncertainty, clearance, …). This will allow implementing the contingency and margin policy more legibly.

5.2. Concurrent Engineering

The CE approach has been applied for the phase A of the ARIANE 6 programme. Four sessions spread over two weeks have allowed the specialty engineering teams to consolidate the MoE and MoP of the two top ranked alternative configurations.

The team members acknowledged that in the given timeframe, a traditional collaborative engineering approach would not have produced the same depth of analysis and level of consistency. It has to be conceded that the CE approach was also more demanding on the team members.

5.3. Specialty engineering work- and dataflow manager

The implementation of the FDMU approach for the phase B.1 of the ARIANE 6 programme is anticipating the need of the systems engineering and specialty engineering teams to strengthen the Architectural Design and Information Management processes by providing a global vision on the launcher design activities.

Two successive increments are planned, starting with the encapsulation of the workflows of those specialty engineering domains required to perform a launcher staging analysis taking the recurring cost into consideration.

The subsequent increment concerns the encapsulation of the workflows of:

- the MAIT engineering, ground engineering and RAMS engineering domains, even though their level of interaction with respect to the work- and dataflow is limited,
- the GNC engineering, thermal engineering and transient phases domains, required to analyse the launcher controllability, cryotechnic propellant management, stage separation and dynamic environment issues.

The N^2 diagram in figure 6 illustrates the data interactions between the specialty engineering domains for both increments 1 and 2, represented in the mint respectively orange coloured cells. The mint and orange hatched cells illustrate the increase in data interactions when the specialty engineering domains from increment 2 join those from increment 1.

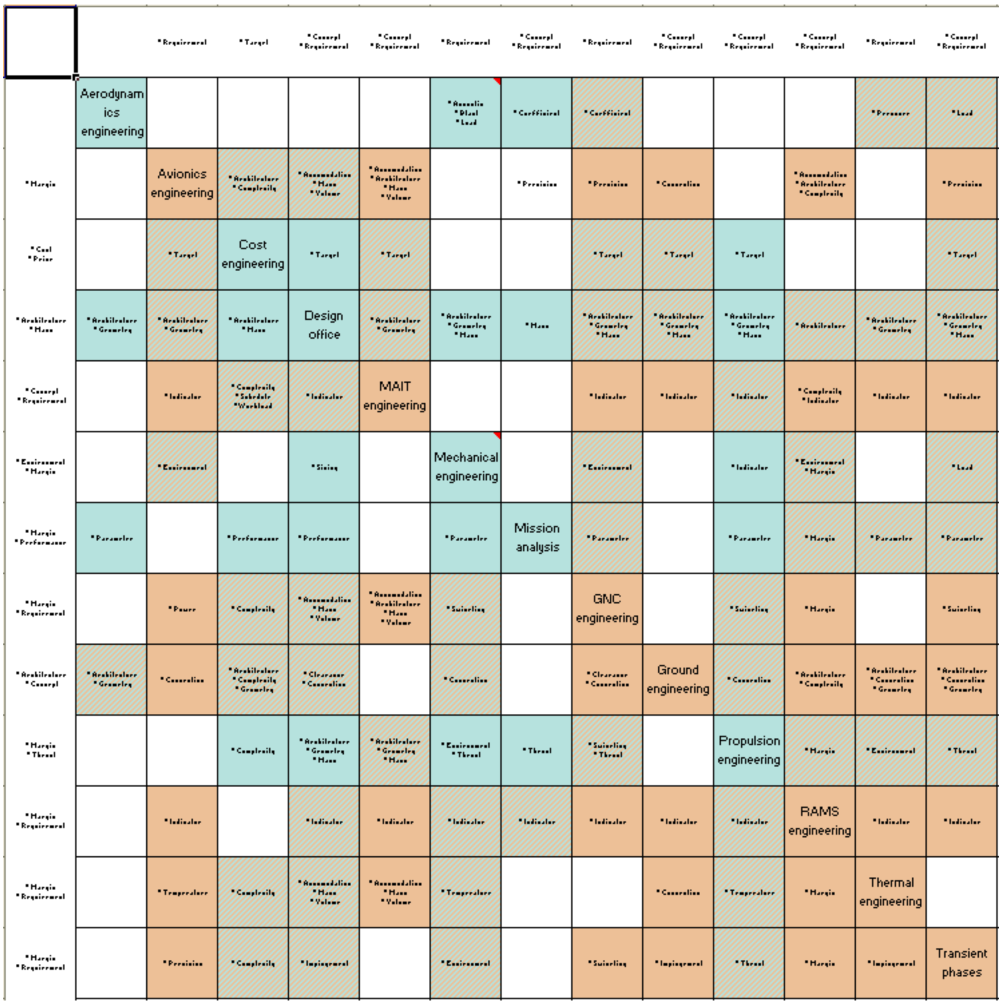

Figure 6: N² diagram for increment 2

To foster the buy in of the specialty engineering teams for the FDMU approach and increase the proficiency of the domain engineers, an encapsulation laboratory is opened. There, the domain engineers encapsulate their work- and dataflow themselves under the guidance of the FDMU team. A visual management approach is adopted in order to:

- optimise the occupation of the encapsulation laboratory,
- encourage the information exchange between the domain engineers and the FDMU team,
- create the emulation towards the objectives of the phase B.1 of the ARIANE 6 programme,
- measure and steer the progress of the encapsulation activities.

An encapsulation process has been devised in figure 7 to sequence the different tasks focusing on:

- agreeing on the objectives of the encapsulation activity and the purpose of the encapsulated workflow (prepare and interview),
- inserting the different execution steps in the workflow manager, checking that they correctly execute in the desired circumstance and identifying the input and output parameters (sketch, wrap and parse),
- connecting the input and output parameters between the different execution steps and making them available for or fetchable from the other encapsulated workflows (map),
- verifying and validating the correct and precise performance of the encapsulated workflow before delivering (verify, validate and deliver).

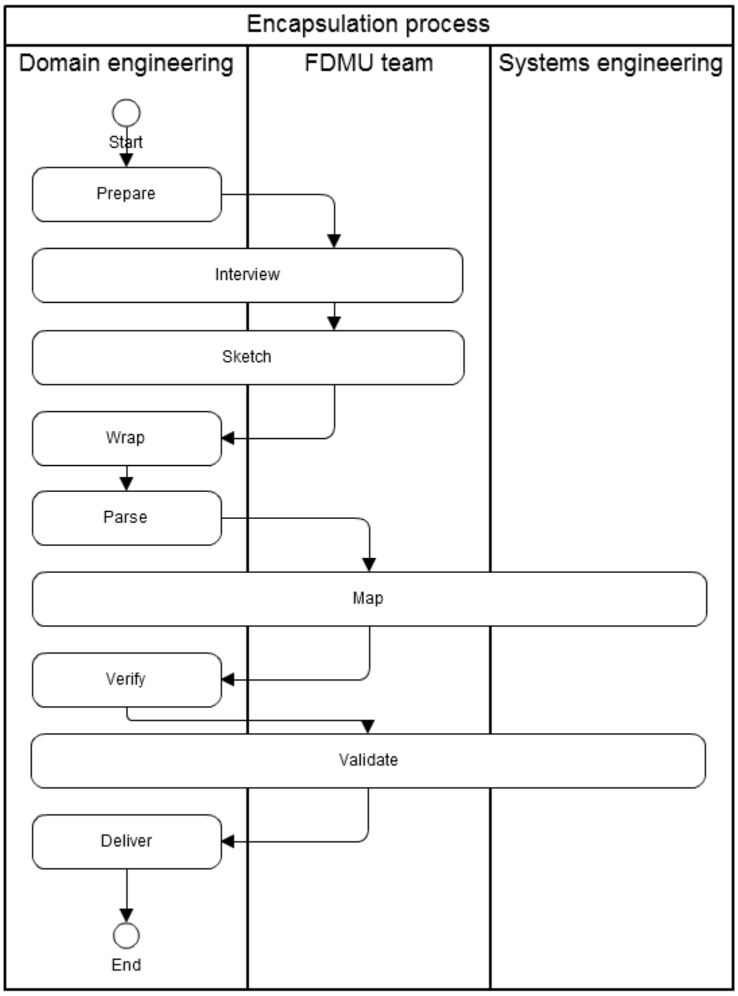

Figure 7: Encapsulation process

6. Conclusion

The SPACE CODE approach is introduced for the phases A and B.1 of the ARIANE 6 programme and positively accepted by the contributing project management, systems engineering and specialty engineering teams. It benefits from the long lasting practice of collaborative engineering that has allowed Astrium-ST to tackle the complexity of the space systems in the different branches of its core activities.

The increasing complexity of the specialty engineering data exchanges as the project lifecycle progresses towards phase B.1 calls for the implementation of a specialty engineering work- and dataflow manager under the FDMU approach.

To foster the buy in of the specialty engineering teams for the FDMU approach, the domain engineers encapsulate their work- and dataflow themselves under the guidance of the FDMU team.

This allows to lift the apprehensions of the stakeholders regarding their perimeter of activity and responsibility.

The first returns in terms of efficiency, schedule and cost on the ARIANE 6 programme using the SPACE CODE approach confirm the interest to proceed with improving the current increment of the SPACE CODE environment, in particular with the FDMU approach.

References

[1] C. Haskins, K. Forsberg, M. Krueger, D. Walden and R. D. Hamelin, “Systems Engineering Handbook - A Guide for System Life Cycle Processes and Activities”, INCOSE-TP-2003-002-03.2.2, issue 3.2.2, October 2011

[2] ISO, “Systems and Software Engineering - System Life Cycle Processes”, ISO/IEC 15288-2008, issue 2, February 2008

[3] ECSS, “Space Project Management - Project Planning and Implementation”, ECSS-M-ST-10C, issue 3.1, March 2009

[4] ECSS, “Space Engineering - Systems Engineering General Requirements”, ECSS-E-ST-10C, issue 3, March 2009

[5] ECSS, “Space engineering - Engineering design model data exchange (CDF)”, ECSS-E-TM-E-10-25A, issue 1, October 2010

[6] F. Lemaire, G. Collange and S. Reynaud, “GOAL - An Industrial MDO Platform Used to Design Expendable Launchers”, 3rd International Conference on Multi Disciplinary Design Optimization and Applications, June 2010

[7] G. Collange, N. Delattre, F. Lemaire and I. Quinquis, “Different Approaches to Multi Disciplinary Optimization for Preliminary Design of Expendable Launch Vehicles”, 3rd European Conference for Aero Space Sciences, July 2009

[8] I. Alonso Gómez, “ESA Generic Product Tree”, TEC-SGH/45, issue 1 revision 1, November 2011

[9] D. Haerens, G. Collange, A. Huet and A. Matthyssen, “Implementation of Concurrent Engineering for Launcher Design”, 5th International Workshop on Systems & Concurrent Engineering for Space Applications, October 2012