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Elaboration of Ariane 6 operational concept with a concurrent engineering approach

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Abstract

In December 2014, the ESA Council at Ministerial level has decided to go ahead with the Ariane 6 and Vega-C development programmes. The overarching aim of Ariane 6 is to provide guaranteed access to space for Europe at a competitive price. ESA has the role of Procuring entity and Launch System Architect (LSA). As Launch System Architect, ESA ensures the coherence on the Launcher System and the Launch base in the elaboration of the operational concept.

The ambitious High Level Requirements of Ariane 6 Project lead to design the Launch System for efficient operations. In this frame, operations are taken "end-to-end":
- From manufacturing until end of Launch Service,
- All over the lifecycle of the Launch System,
- Encompassing the Launcher System & Launch Base & across the whole Launch System
- Including the Launch Service Customer's / payload

The operational concept describes how the Launch System will be operated all over the Ariane 6 lifecycle. This approach leads to drive the Launch System design, development, initial operations and ramp-up up to full operational capability.

Given the short development time for Ariane 6 (decision to start development in dec-2014 for a maiden flight in 2020), it has been decided to follow a concurrent engineering approach between ESA acting as Launch System Architect and the two prime contractors (ASL and CNES) in the elaboration of the Operational Concept.

The joint teams iteratively evaluate alternative solutions until convergence on the targeted recurring cost induced by the operational concept. At each step, impact on the Launch Base requirements and their running costs (operations and maintenance) are evaluated. Interface requirements are kept updated and design elements are capitalized to reduce the slack between requirements finalization and preliminary design completion. This process allows the system to freeze in parallel the requirement, the process and product design.

The paper presents concurrent engineering methods and tools applied within Ariane 6 project related to the elaboration of the operational concept with the prime contractors. Then the outcome is summarized by presenting the A6 operational concept.

Keywords: Ariane 6, Concurrent Engineering, Operational Concept, Launch system

1. Acronyms

ESR- Equipped Solid Rocket
TVAS- Thrust Vector Actuator System
CC- Common Core
BAF-HE- Final Assembly Building- Encapsulation Hall
BAL- Launcher Assembly Building
COP- Combined Operation Plan

2. Introduction

In December 2014, the ESA Council at Ministerial level has decided the launch of the Ariane 6 / VEGA-C program. The overarching aim of Ariane 6 is to provide guaranteed access to space for Europe at a competitive price. ESA has the role of Procuring entity and Launch System Architect (LSA). As Launch System Architect, ESA ensures the coherence on the Launcher System and the Launch base in the elaboration of the operational concept. [1] [2]

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Concurrent engineering methods have seen a great expansion in particular with the implantation of concurrent engineering facilities in different agencies and industries. According to the ECSS [5], Concurrent engineering is "an engineering activity taking place in the context of simultaneous design of the product, the production process and all associated product usages, in an integrated, multifunctional team, with external organizational constraints minimized"[5].

Figure 1 illustrate the concept by showing on the left side that User Requirements, Design, Operations, Manufacturing, Assembly, Tooling, Safety, Mission Assurance are considered simultaneously in the product design in order to define process engineering, production flow and operational concept.
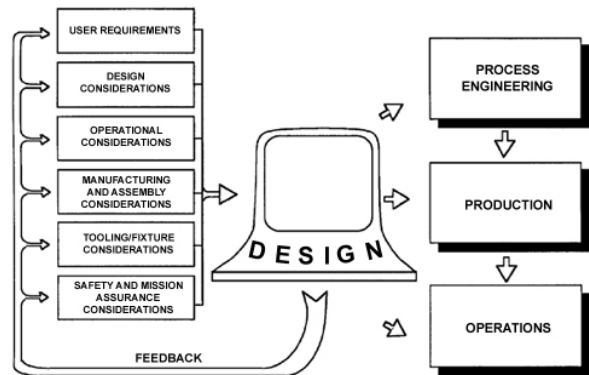

Figure 1. Concurrent Engineering Flow Diagram

Figure 1- Concurrent Engineering Flow Diagram [3]

In practical terms, concurrent engineering allows the interdisciplinary and multifunctional collaboration of all program actors through the implementation of innovative methods and processes. However, these methods are mostly used in pre-development phase up to Phase 0/A [3]. The Ariane 6 program entered into detailed design phase during the summer 2016. The real challenge is to implement such methods in a complex system development with engineers spread out all throughout Europe.

For Ariane 6 program, this is translated into three aspects:
- Implement incremental development process, (in opposition to sequential engineering)
- Supported with collaborative tools
- And Bringing people together

This paper presents first the tools and methods used within the Ariane 6 Program to support concurrent engineering at launch system level in the elaboration of the launch system operational concept. Then the current status of this work will be presented in the form of the A6 operational concept. Last, the paper will develop, which methods have been used/ will be used at which step of the development. For each method, one practical example will be given on a specific study.

3. Concurrent engineering tools and methods used within the Ariane 6 Program

The following chapter presents concurrent engineering tools and methods used within the Ariane 6 Program. It is translated into three types:
- The incremental process in comparison with the classical V model
- The use of collaborative tools
- The incentive in bringing engineers from traditionally segregated expertise areas together.

3.1. Incremental process

The classical development process is the so-called V-Model described by Figure 2. The sequence is the following: Definition of the operational concept, design of the system, design of the subsystem, integration, test and verification of subsystem, system verification and validation and finally the system enters in operation. The limit of this method is that it leads to long cycles with sequential loops between system-stages-products. In addition, the consistency between Products design and System optimization is quite difficult to assess. Finally, it leads to cost and planning overruns.
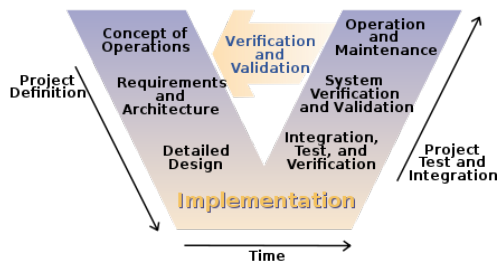

Figure 2- V development model [6]

In Ariane 6 development life-cycle, Launch system studies are performed in parallel with Launcher System Design analysis Cycle and Launch Base preliminary definition and are fed by the results of trade-off's performed in co-engineering session.

From the launcher system perspective, the development is led by the production pull logic [7]. The program logic for Ariane 6 is based on the one successfully implemented for Airbus A350 airplane. It is based on one single launcher definition which demonstrates the compliance of both product and manufacturing/operational process with respect to its requirements in 3 incremental qualification steps:
• Step 1 (S1): Development Launcher
• Step 2 (S2): Serial Launcher for Entry Into Service and Ramp-Up

• Step 3 (S3): Serial Launcher for Full Operational Capability
Each step is associated with a product and process standard for the Launcher System, qualified during the step. The target is to do right the first time especially on product design and hence minimize the definition evolutions between each step. These evolutions, mainly on processes, (S1→S2, S2 → S3) are introduced by batch in order to avoid having a series of prototypes (especially for S2). [7]

Based on this logic, alternative solutions are iteratively evaluated until convergence on the recurring cost target induced by the operational concept. At each step, impact on the Launch Base requirements and their running costs (operations and maintenance) are evaluated. Interface requirements are simultaneously updated and design elements are capitalized to reduce the slack between requirements finalization and preliminary design completion. This process allows the system to freeze in parallel the requirement, the process and product design.

For each trade off, a particular attention is paid on optimizing the processes with an end-to-end vision to avoid local process (manufacturing integration or test) optimisation. The whole life cycle of the affected products are being considered:
- The procurement cost at partner level.
- The integration and test processes at subsystem level
- The logistics and maintenance costs.
- The launch system set up costs prior to launch

3.2. Collaborative tools

Collaborative tools are necessary to support iterative development logic with a parallel achievement of requirement, process and product design. They shall support the requirement definition, the process and the product design.

These tools secure and ease the development and qualification phases of the launch system. They will secure the transition phase from the development phase up to the full operational capability and simplify the hand-over to the entities in charge of the Launch System exploitation.

Launch System tools shall be made accessible by ESA to the Launcher System and Launch base design authorities (ASL and CNES).
System engineering tools are the following:
- Requirement, Verification & Validation Database to gather links from Launch System Level down to Product Level.

- System Engineering Model to cover the launch system (launcher system + launch base) engineering data involved in different domains.
- Exploitation model to describe the operations part of the launch cycle as in the Operational concept

This suite of tools is currently under construction and will allow the technical teams, while not collocated, to work concurrently and to exchange data.

Finally, one of the main expected achievements from the collaboration between launch base and launcher system prime contractors under ESA management is a single digital mockup integrating the launcher and the launch base elements. This will grant the capability to prepare in advance the cost critical launch system procedure such as:
- Central core integration to the solid rocket boosters.
- fluidic ground/board connection.

Indeed, thanks to virtual reality tools, both launch base and launcher system engineers will be able to validate their own deployment procedure. Thus both combined tests and launch system operations in exploitation phase will be secured in term of cost and schedule.

3.3. Bringing people together

Above all tools and methods, the people of the A6 program are the one making concurrent engineering possible. ESA, CNES and ASL experts meet under the steering action of ESA Launch System Architect that manages to set working session objectives consistently with its work-plan that is agreed upon by ASL and CNES.

These activities gather interdisciplinary/ multifunctional engineers from design experts to operational engineers getting people thinking "out of their boxes" and think in parallel about the operational concept and the impact on the launch system requirements.

4. The Ariane 6 Launch system operational concept

The previous chapter presented examples of concurrent engineering methods. Before presenting how these methods are used within the A6 Operational concept elaboration, the following chapter will present first the drivers of the launch system operation and then the A6 Launch System operational concept.

4.1. Definitions

The Launch System Overall Life Cycle (Launch System macroscopic time scale) is defined as being the complete life cycle of the A6 Launch System from the start of its development up to the end the A6 Launch Service.

It is necessary to distinguish the different phases of this overall life cycle since the characteristic of the Launch Cycles required to be performed by the A6 Launch System as well as the external environment and associated operational constraints induced on the A6 Launch System by the other Launch Systems at CSG (e.g. Launch rates and Launch distribution scenario) differ.

The Launch System Launch Cycle is defined as being the cycle relevant to the execution of a Launch Service from Customer's request up to the end of the Launch Campaign (Launch evaluation report delivery to the customer).

One Launch Cycle includes:
- The Launch Service activities from Customer's request up to the signature of the contract
- The Launch Service activities for the execution of the Launch service contract (from contract signature up to the delivery of the Launch evaluation report delivery to the customer).

The Launch Campaign begins with the first destocking of a launcher element in the frame of a specific launch mission, and includes the following activities:
- Ariane 6 Launch Base (Launch Complex and Launch Range) preparation
- Launcher vehicle preparation and integration
- Payload/Launcher Combined Operations (COP)
- Launch Operations covering Ariane 6 launcher, Launch Complex and Launch Range operations (including Flight Data Gathering).
- Launch Complex revalidation.

4.2. Drivers of the launch system operations

In the perspective of serving both the Launch Service Customers & efficiency/profitability of Ariane 6 exploitation, drivers and guidelines are considered for the definition & implementation of operations.

The Ariane 6 Launch system operations will fulfill customers' requirements in particular:
- "Destination" & date of launch are a must
- Fulfillment of RAMS requirements & « fast track » to launch (i.e. the shorter is the path for the Customer's from arrival in Kourou to the Launch, the better).
- Attractive launch service prices
- On the top of committed Launch Service quality & date of delivery, the Launch System will provide the necessary flexibility and

adaptability to Customer's requests and constraints.

The Ariane 6 Launch System will be reactive and flexible:

- 11 launches +/-1 per year, i.e. the Launch System will be capable of delivering and sustaining this yearly processing capability;
- 8 launches capability over a 6 months period, i.e. the Launch System will be capable of clocking-up to this high launch rate capability during a limited period of time;
- Capability of adjusting to unforeseen events and late Customer's requests (avoid domino effects) and of catching additional/late Launch contract opportunities.

4.3. Presentation of Ariane 6 operational concept for one launch campaign

Figure 3 presents the flow of launcher (including its upper part) assembly activities. The integration of the launcher is performed horizontally in the BAL. The target for integration duration is 5 days. The Central Core (CC) is then transferred to the launch zone, erected in vertical position and assembled with the ESRs on the launch pad. In parallel, the combined operations will be performed in the BAF-HE, with duration target that will be half the one of Ariane 5 today. The P/L will be mated on the launcher on the Launch zone at D-2.

Conventionally, the launch cycle is made of the following phases (list not in a chronologic order, see the details flow of operational phases of the launch cycle is shown on the flow diagram in Appendix 1.):
1. Mission Preparation (including Customization)
2. Transport and arrival in KRU of launcher elements
3. Launch Complex preparation until start of launcher N operations
4. Launch Range preparation until start of launcher N operations
5. ESR operations up to arrival on Launch Pad
6. Central Core operations until out of BAL
7. Central Core transfer to Launch Zone, verticalization and set-up on ESR
8. ESR assembly to Central Core
9. Central Core Ground/Board interface connections & tests
10. Encapsulation of Payloads
11. Transfer of Upper Part (UP) to launch pad
12. Launcher Readiness review
13. Handling & integration of Upper composite on the Launcher
14. Payload Customer Tests
15. Preparation of the Launch System for Countdown
16. Launch readiness review
17. Launch Countdown
18. Liftoff and flight
19. Post-flight data Evaluation
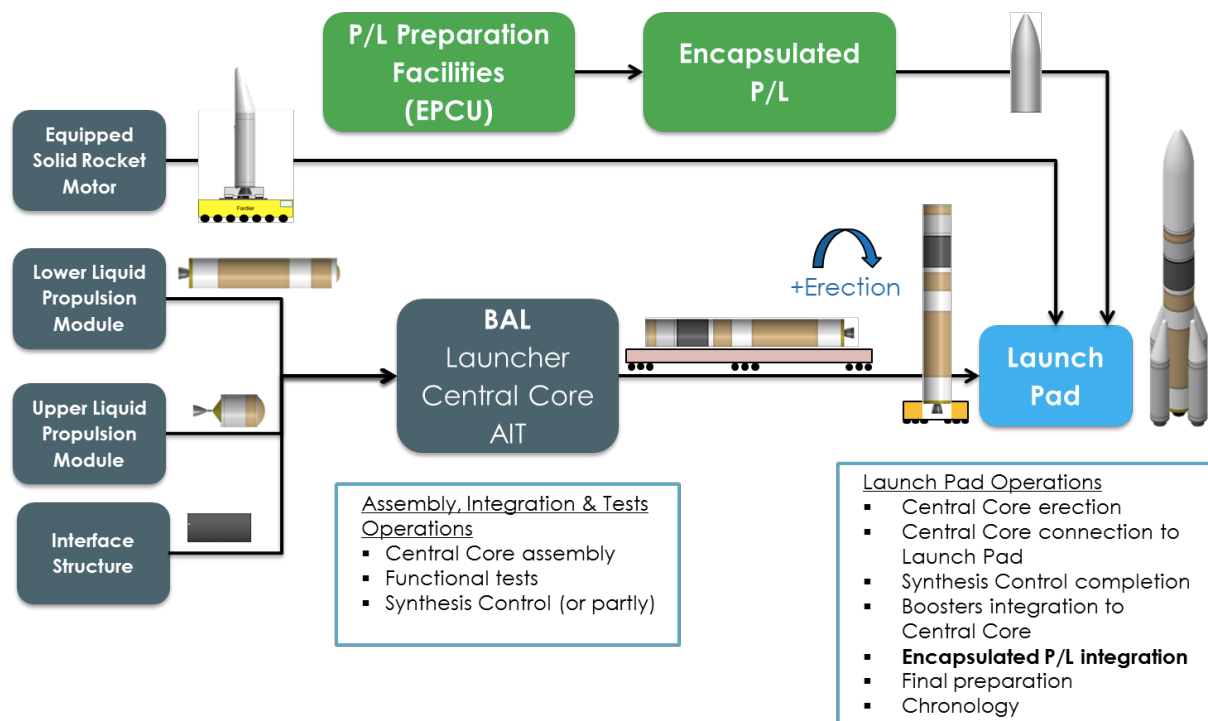20. Launch System Post-Launch revalidation
21. Launch Scrub and Abort

Figure 3- Ariane 6 operational concept targets

The details flow of operational phases of the launch cycle is shown on the flow diagram in Appendix 1.

5. Concurrent engineering throughout A6 development

Chapter 3 presented the concurrent engineering tools and methods used within A6 program and Chapter 4 presented the overall operational concept. The following chapter will develop, which tools and methods have been used during different phase of the program, and therefore present example of studies which output serves to the elaboration of the operational concept.

5.1. Phase A/B (Up to PDR-like level)

During the first phase, main trade-offs were driven by the decision to be taken in terms Launch Base infrastructures needs. Concurrent engineering task tackled end to-end system optimisation. To illustrate such activity, this chapter will focus on the trade-off performed between a full horizontal, mixed horizontal/vertical and full vertical operational concept. The outcome of this session driven by recurring cost objectives is the 1st version of the launch operation concept including the priority design topics.

The three scenario investigated are full Horizontal, Horizontal/Vertical and Full Vertical.

The Full Vertical is an Ariane 5 Like scenario as presented in Appendix 2 while the Full Horizontal scenario relied on the hypothesis that both launch launchers and P/L would be integrated in horizontal position.

The Horizontal/Vertical scenario is a smart mix of both scenario, meaning that most of operations are performed horizontally but the P/L will be integrated vertically and assembled at a later stage on top of the launcher on the launch pad.

For the trade-off, the following phases have been studied concurrently:
- ESR Integration
- P/L Integration
- Control policy
- BAL concept
- Transfer and verticalisation concept and device, Launcher connections
- Horizontal integration of launcher elements.

For each phase, the following criteria are applicable to for the assessment and trade-off:
- Recurring Cost (end-to-end, over exploitation lifecycle)

- Time to market (Maiden flight 2020, Full Operational Capability in 2023) and fit to the NRC
- P/L Customer's satisfaction criteria
- Flexibility to meet launch manifest dynamics (P/L customer's requests); launch date, launch rate, 8 launches in 6 months
- Robustness to contingencies
- Adaptability

For each phase, there was no showstopper for the horizontal integration logic. However, it was found not be optimal in terms of service to the customers.
Therefore the outcome of this workshop lead to the decision to have a horizontal/vertical scheme as depicted on Figure 3.

5.2. Detailed design phase (up to CDR-like level)

Throughout the detailed design phase, each life phase will be consolidated individually based on the convergence on recurring cost and results of concurrent engineering activities. The encapsulation phase in the Final Assembly Building – Encapsulation Hall (BAF-HE) is presented as an example of already performed optimisation.
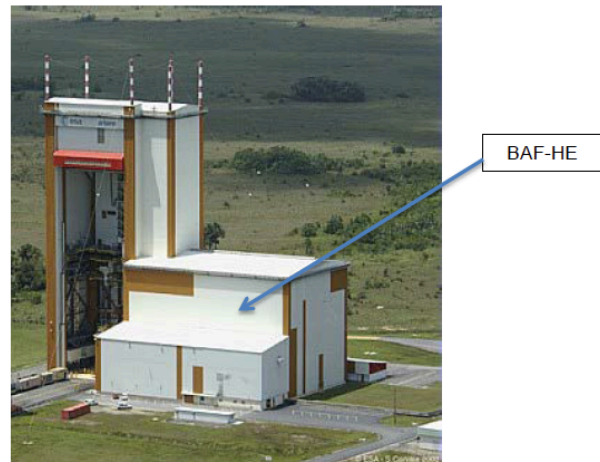

Figure 4- Upper Part Composite Assembly Hall (BAF-HE) in the Ariane 5 Final Assembly Building

The goal of the working group was to consolidate A6 operational scenario (for Pre-COP and COP phases) in BAF-HE and to confirm its compliance with A6 launch rate requirements and with A5 exploitation during transition phase. Then the group identified, if necessary, the improvements to be implemented by A6 Launch System to meet the launch rate requirement. Finally it identified the impacts/constraints on A5 Launch System and A6 Launch System during transition phase.

The outcome consisted in design requirement for LaS, LB, and Interface, a first sequential of the operations to be performed and a consolidation of tools and means equipment list.

The A6 operations' planning in BAF-HE has been built based on Ariane 5 duration target to be divided by a factor of 2 wrt Ariane 5 standard operations

The Ariane 6 operations planning in BAF-HE consists of carrying out the following operations as described in Figure 5.

Table 1. A6 Operation in BAF-HE

	Venus
D-7	BAF-HE, unpacking of Dual Launch Structure and Launch Vehicle Adaptor
	EPCU for Lower S/C, unpacking of lower Payload Adaptor on S/C transfer vehicle pallet
	EPCU for Upper S/C, unpacking of upper Payload Adaptor on S/C transfer vehicle pallet
D-6	BAF-HE, unstorage of the 2 half PLF
	EPCU for Lower S/C, S/C mating on Payload adaptor and S/C transfer vehicle transfer to BAF-HE
D-5	BAF-HE, Payload adaptor-Lower S/C mating on Launch vehicle adaptor
	EPCU for Upper S/C, S/C mating on payload adaptor and S/C transfer vehicle transfer to BAF-HE
D-4	BAF-HE, Sylda mating onto launch vehicle and payload adaptor-Upper S/C mating on Dual launch structure
D-3	BAF-HE, Fairing horizontally assembly

The outcomes of the working group have been re-injected in the nominal design works of each partner (venting options, control logics e.g.).

In that way, requirements are being consolidated simultaneously with the design of the launch base and the launcher. Each step of the design takes the operational constraints and cost aspects into account and evolution/optimization can be integrated in the overall concept until the latest point.

6. Conclusions

The overall goal of Ariane 6 Launch System is to achieve the full operational capability by 2023 with a Maiden Flight in 2020. To cope with this challenging calendar, concurrent engineering is being implemented to develop in parallel the launch vehicle, the launch base and the associated operational concept.
The incremental development approach allows the parallel engineering work on different subsystems. For that, system-engineering tools are currently under development to allow real-time update of Launch System reference data in short time. In addition, multidisciplinary and multi-functions workshops are done allowing simultaneous trade-off including design-to-cost and design-to-operation aspects.
These methods and tools are being applied all over the operational concept development. First, during the Phase A/B the overall operational concept has been defined and the trade-off from a full horizontal concept to a full vertical concept was performed. The outcome was an optimised Horizontal/Vertical integration concept enabling in particular simplification of ground means. The choice of the vertical integration of the Upper composite at the latest was driven by the concern to to avoid as much as possible hazardous operation on the launcher system while the Payload is integrated and to provide maximum flexibility to the customers. Then in Phase B/C, concurrent engineering methods will be applied to the operational concept maturation in a life phase analysis approach. Each operation are studied and impact on the design are then integrated respectively in
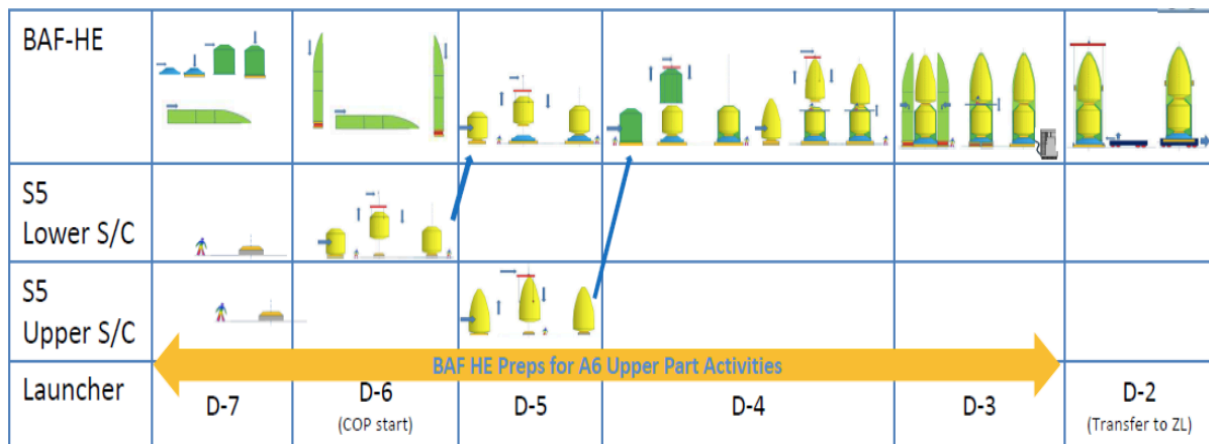

Figure 5- BAF-HE Operations

the launcher vehicle and the launch base technical specification and validated by cost optimisation. Finally, in Phase C/D, concurrent engineering associated with the system engineering platform accessible by all contributors to the project will allow fast local optimisation loops.

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Appendix 1- Flow of operational phases of the launch cycle
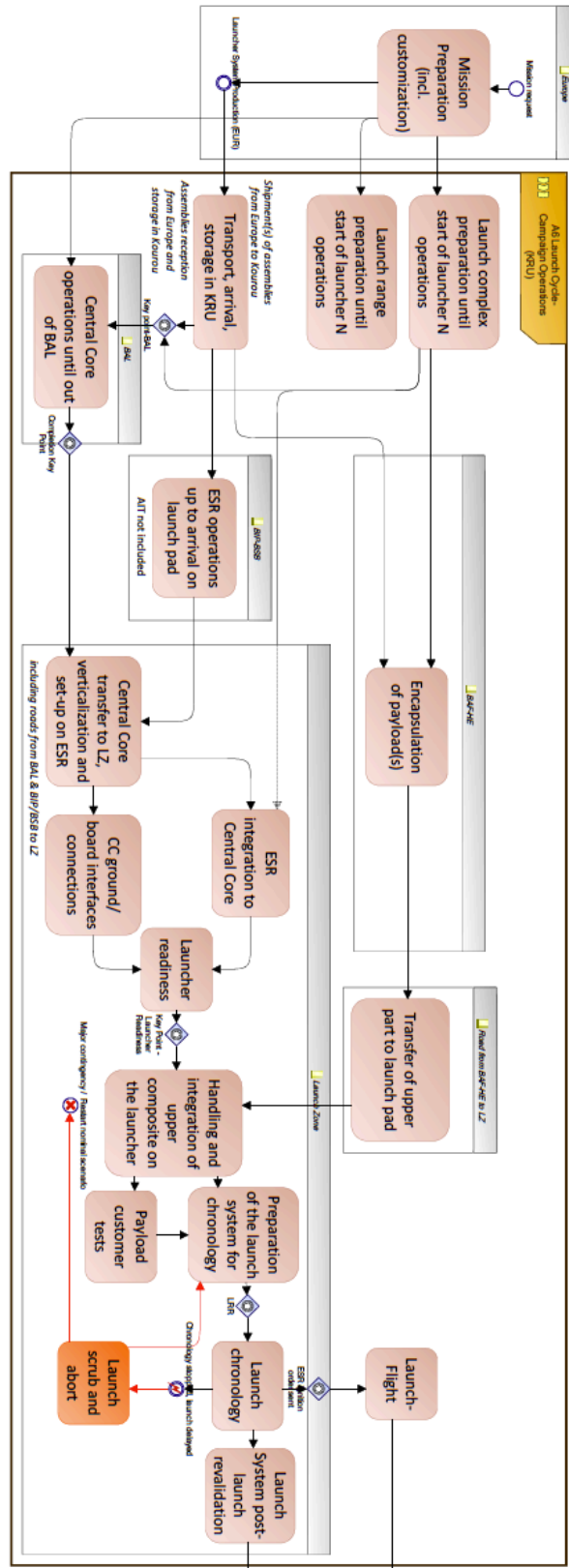
Appendix 2 : Reference scenario- Ariane 5 Integration [8]