Systems Concurrent Engineering of a Hypersonic Accelerator Vehicle

Roberto da Cunha Follador[a,1], Andrea de Oliveira Netto Follador[b], Paloma Ribeiro dos Santos[c], Geilson Loureiro[d]

[a] Post Graduate student at Technological Institute of Aeronautics – ITA and Technologist at the Aerothermodynamics and Hypersonic Division (EAH) of Advanced Studies Institute, IEAv, (São José dos Campos), Brazil.
[b,c] Post Graduate students at Technological Institute of Aeronautics - ITA.
[d] Technologist and Professor at the Technological Institute of Aeronautics, ITA and at the Integration and Testing Laboratory, Brazilian Institute for Space Research, INPE (São José dos Campos), Brazil

Abstract. This paper presents a systems concurrent engineering approach for the conception of a Hypersonic Accelerator Vehicle (Veículo Acelerador Hipersônico -VAH) to be used in the flight test campaign of the first Brazilian Aerospace Hypersonic Vehicle named 14-X. The 14-X project objective is to develop a higher efficient satellite launch alternative, using a Supersonic Combustion Ramjet (SCRAMJET) engine for its propulsion. As it is a new technology under development and using systems concurrent engineering approach it is possible to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, for product and organization simultaneously. From the analysis, requirements and attributes are captured for the product and its organizations and the relationship among them are identified. Requirements to the early stages were based on anticipation of the needs identified for different life cycle process and then late changes are expected to be avoided, reducing development costs, avoiding delays and risks and increasing satisfaction of stakeholders over product life cycle.

Keywords. systems concurrent engineering, systems engineering, complex product, integrated product development, hypersonic.

1 Introduction

The development of the VAH is inter-dependent on the development of the 14-X, because those two complex systems will operate as a single system once the flight test occurs. In this way the approach for its development must be different from traditional systems engineering and it must take into account both product life cycle process requirements and use them since the early stages of development.

Post Graduate student at Technological Institute of Aeronautics – ITA and Technologist at the Aerothermodynamics and Hypersonics Division (EAH) of Advanced Studies Institute, IEAv, Trevo Cel Av José Alberto Albano do Amarante, n^{o} 1 – Putim; 12.228-001;São José dos Campos – SP – Brasil; Tel: +55 (12) 39475434; Fax: +55 (12) 3944-1177; email:follador@ieav.cta.br; http://www.ieav.cta.br

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This paper aims to present a systems concurrent engineering approach for the conception of the VAH. The approach is different from traditional systems engineering approach because it anticipates to the early stages of system architecting the product life cycle process requirements. It proposes to simultaneously develop, from the outset, the product and its life cycle processes performing organizations [1].

The paper is organized as following: Section 2 presents the Hypersonic Accelerator. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the VAH using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 The Hypersonic Accelerator Vehicle

A Hypersonic Accelerator Vehicle (VAH) is basically a modified sounding rocket used to provide the conditions needed to perform a test flight and to collect accurate data from the hypersonic aerospace vehicle 14-X, that is under development by the Institute of Advanced Studies (IEAv) to the Department of Science and Aerospace Technology (DCTA) of the Brazilian Air Force (FAB).

The IEAv's Hypersonic Aerospace Vehicle, named 14-X (after the 14-Bis developed by aviation pioneer Alberto Santos Dumont), initiated in 2005, is the first Brazilian project with the objective of designing, developing, constructing and demonstrating a Mach 10 wave rider in free flight with its required scramjet technology[2]. It is a product that needs tools to provide a safe development process, with compromise with quality and schedule, and at a minimum cost.

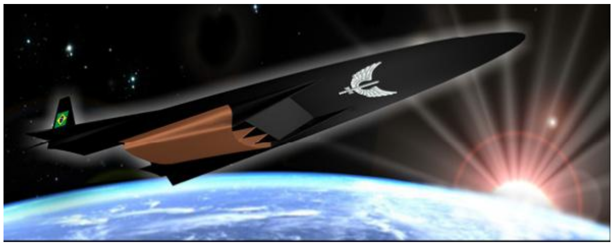

Figure 1. Artistic conception of Brazil's Hypersonic Aerospace Vehicle 14-X (Source:[2])

Aerospace and hypersonic vehicles are complex products. During its development process, one of the greatest concerns is safety all over its life cycle. A failure in the design of a safety requirement can lead to problems that may involve the loss of a huge amount of financial resources or even human lives. In the case of a flight test for the development of a new technology, it must be guaranteed the return of flight data, which will provide the information necessary to the continuous development process of a future product. The development organizations need a clear view of the whole life cycle process in order to understand the requirements for a successful and safe test flight that will take place after, at least, six years of development effort. There are many opportunities to improve safety, economy and chances of success over VAH life cycle if a concurrent engineering approach takes place from the beginning of its design stage.

3 The systems concurrent engineering approach

The development of complex products has in systems concurrent engineering a powerful tool. Hitchins [3] states that complexity can be understood by what he calls complexity factors. These factors are variety, connectedness and disorder.

Loureiro [4] presents a framework to address complexity in product development – the Total View Framework presented in figure 2. It has three dimensions. Each dimension addresses one of the complexity factors mentioned above. The analysis dimension addresses the variety factor. Along the analysis dimension, it is deployed what must be analyzed in order to develop a complex product. A systems engineering process consists of stakeholder analysis, requirements analysis, functional analysis and implementation or physical analysis. The integration dimension addresses the connectedness factor. It defines what must be integrated along an integrated product development process: product elements and organization elements. Organization here refers to the organizations that perform product life cycle processes. Product elements and organization elements are the system elements. The structure dimension addresses the disorder factor.

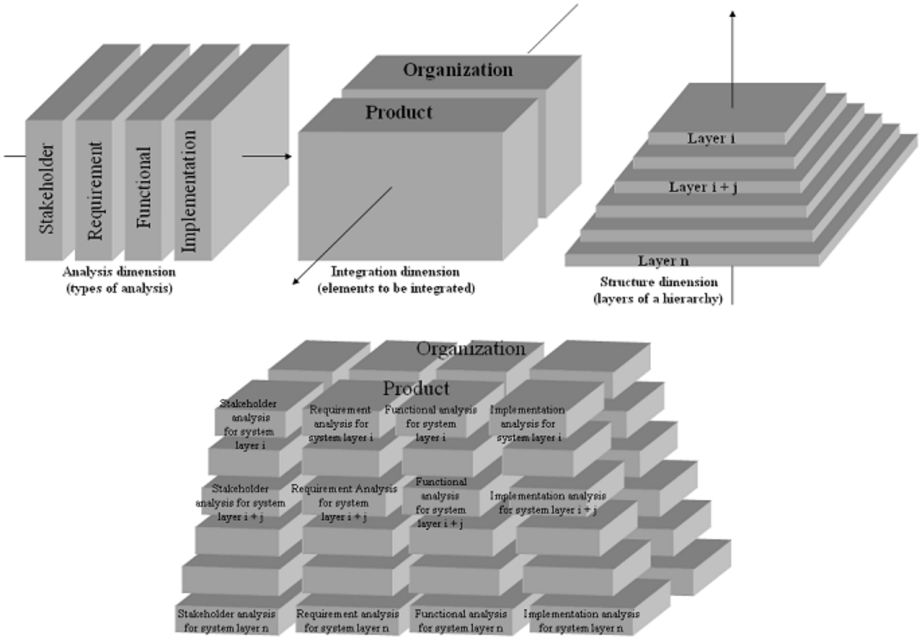

Figure 2. A framework to address complexity in complex product development – the total view framework (Source:[4])

The method within the total view framework is called Concurrent Structured Analysis Method evolved from Loureiro [4]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis are performed, for the product under development and its performing organizations simultaneously.

Figure 3 details the concurrent structured analysis method showing the steps to incorporate the concurrent engineering concept in the systems engineering process. The analysis processes are performed at each layer of the system breakdown structure. For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on [1].

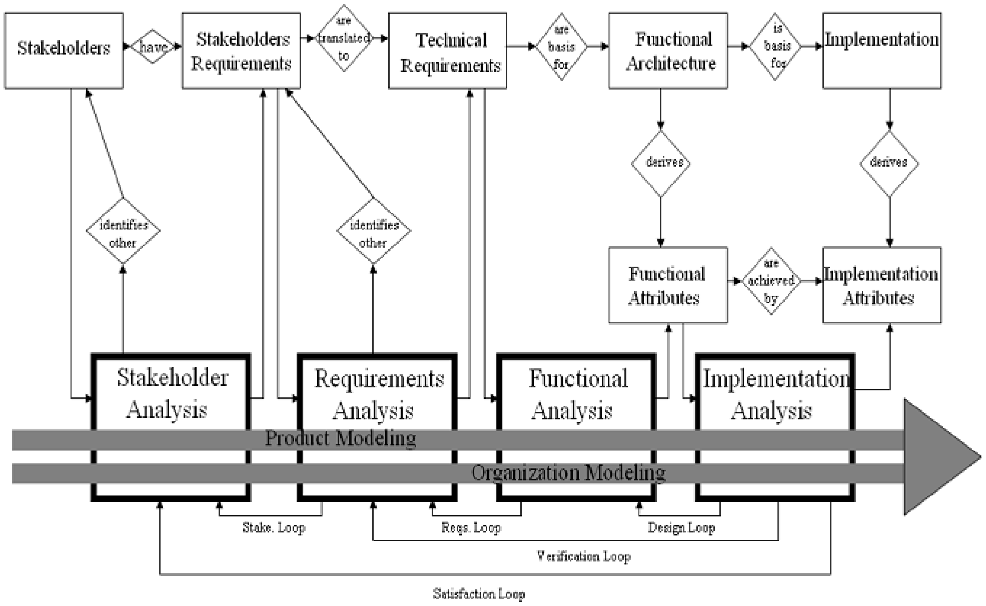

Figure 3. A method within the total view framework – the concurrent structured analysis Method (Source:[1])

4 The Hypersonic Accelerator Vehicle system concurrent engineering

This section illustrates the steps showed in Section 3 highlighting where the proposed approach is different from traditional approaches. First, the proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analyses are performed for each life cycle process scenario, for product and organization simultaneously. Traditional approaches focus on product operation and development organization [1]

The mission statement is a document established by the customer, which reflects the users needs, and is used as input to Phase 0 of a space system project [4].The mission established for the VAH is: *“To provide flight conditions within* *the speed, flight altitude, flight attitude and dynamic pressure specified in 14-X project and to return valid flight test data".*

Successfully understanding and defining the mission objectives and operational concepts are keys to capturing the stakeholder expectations, which will translate into quality requirements over the life cycle of the project [5].

The life cycles processes and scenarios for the VAH are shown in Table 1.

Table 1. VAH life cycle processes and scenarios

Processes	**Development**	**Manufacturing and Assembly**	**Operation**
Scenarios	Conception	Components Manufacturing	Launching
	Detail Project	Assembly	Flight test
	Components Project	Integration	Data recording and telemetry
		Qualification test	
	Simulation	Acceptation tests	recovery

The highlighted cells 'conception', 'Detail Project', 'Assembly', 'Integration', 'Qualification test' and 'Acceptation tests' are considered the scope of the development effort. Stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis will be exemplified for the processes of the life cycle. In practice the methodology explained in Section 3 must be run for all life cycle process scenarios. Figures 4 to 7 just exemplify some steps for selected processes.

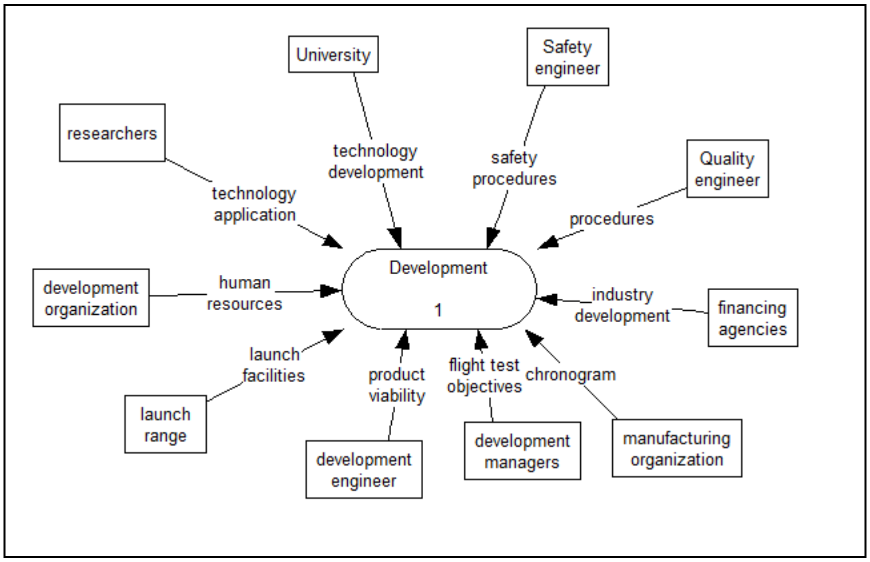

Figure 4. Stakeholder analysis - 'Development' life cycle process.

In Figures 4 is exemplified the organization stakeholders concerns for life cycle process of 'Development'. The stakeholder concerns are represented by the connection labels between the stakeholders and the center bubble, indicating the process of the life cycle. This cycle process is a scenario of the 'scope of development effort'.

This pictorial view allows the systems engineering team to identify and rank stakeholders and their needs over that particular process. This done, in a concurrent manner, to all life cycles process and scenarios, allows the accurate capture of the needs as part of the product and organization requirements specification.

Figure 5 presents the product stakeholders identified and their needs for the 'Operation' life cycle process.

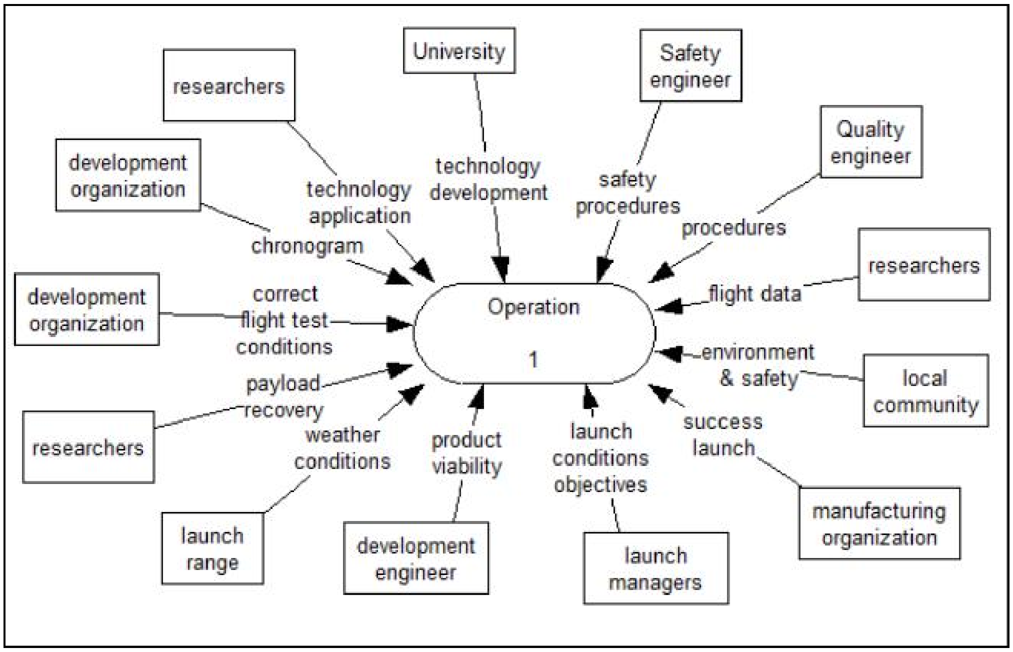

Figure 5. Stakeholder analysis - 'Operation' life cycle process.

From stakeholder concerns, requirements are identified and measures of effectiveness (MoEs) are derived. Examples of 'development organization' MoEs, in 'Operation' life cycle process, about the flight conditions during the flight test, can be stated as:

1) The maximum variation for the VAH angle of attack during the flight test was below 3°?
2) The maximum rate of variation for the VAH angle of attack during the flight test was below 6°/s?

Based on identified MOEs the stakeholder requirements will be stated. This is of fundamental importance because it is necessary to understand what the stakeholders want, or believe they want, and translate it in clear and irrefutable characteristics that will compose the final product.

From stakeholder requirements, functions, performance and conditions are identified. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements, changing the traditional focus on systems engineering the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements [1]. Another important point of analysis and source of requirements is the environment where the system life cycle occurs. Each environment element interacts with the system in three ways: exchanging energy, information or material. The clear observation of these factors may lead to relevant requirements. Figures 6 represent an example of context analyze for product in operation.

The context diagrams give a pictorial view of this relationship between environment and system in its life cycle processes. The links between the center and the elements of the context diagram show the kind of information, material or energy exchanged between the environment and the system.

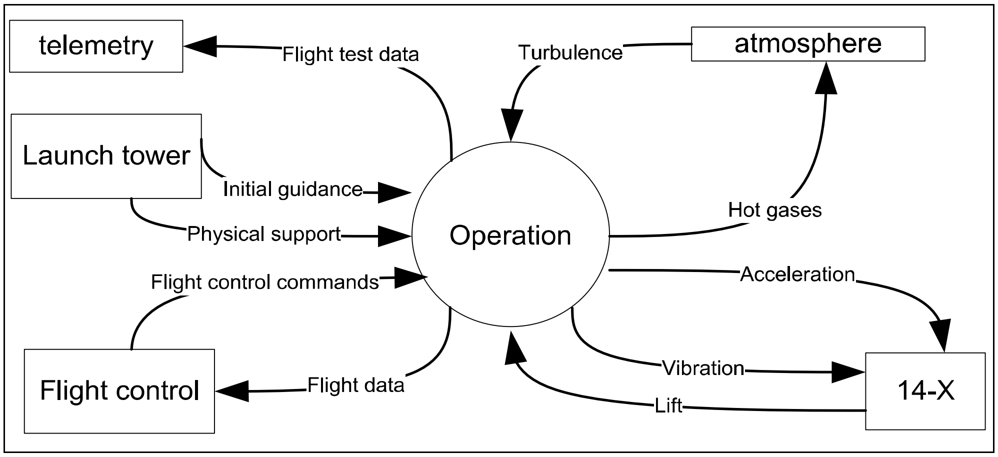

Figure 6. Context analysis – product in 'Operation' life cycle process.

Figure 7 presents VAH physical architecture and describes the structural elements and the physical connections, where information, material or energy flows between them.

Concurrent engineering presented here was restricted to dealing with stakeholders, measures of effectiveness, context analysis and physical architecture. But the comprehensive approach covers the analysis of circumstances from which states the system allows the identification and analysis of hazards and risks from the circumstances, thru a FMEA (Failure Mode and Effect Analysis) observing failures and non functions in flows between the elements: product, process and organization with environment, in addition to presenting the behavior of the system and allocation matrix that allows better visualization of the relationship function versus element / subsystem.

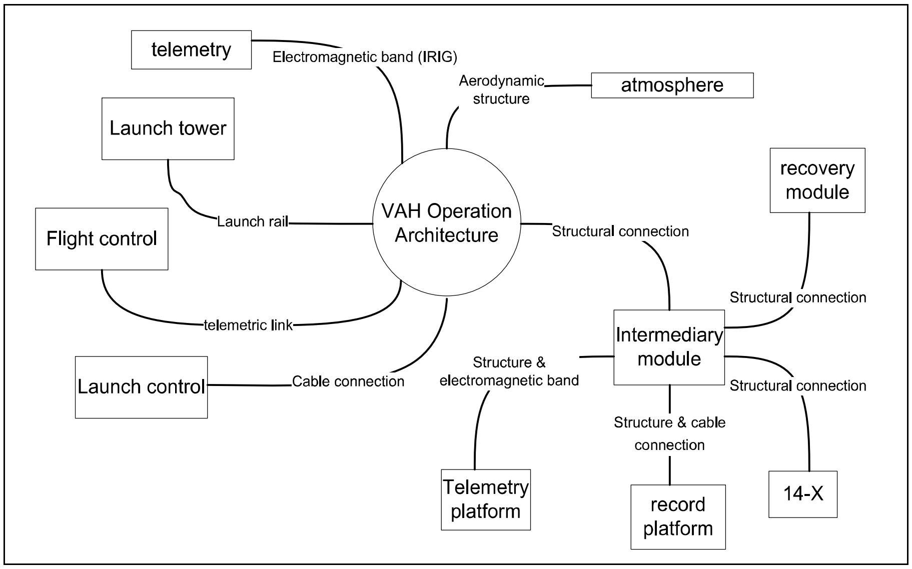

Figure 7. VAH Operation architecture: structural elements and physical connections

5 Discussion

Concurrent Engineering applied in this work has the advantage of generating broad understanding by looking in parallel at each stage of system development, focusing not only in the product but also in the processes and organizations. The method enables the interaction between multidisciplinary teams reducing failures of non-conformity between one and another stage of product development. Another advantage is the methodological approach and the ease of recognition and consideration among others, the stakeholders involved, as well as their needs, increasing the chances of developing the system required in a efficient and effective way.

Although the method is extremely laborious in the beginning of a project, it shows that, as the study progressed and some new relevant items appeared, most of the time is spent before the actual development of the system, providing a confident progress through the subsequent process, where changes must be avoided and safety must be increased, providing a concurrent safety to the system. It is extremely important to apply this method since the cost advantages are considerable. Since a product developed, without proper planning of its development stages, is likely to present failures not envisaged at some stage, among other situations liable to happen any time during product development may cause rework, schedule delays, generating unnecessary costs, and may even derail completion of the development.

6 Conclusions

This study aimed to apply systems engineering to concurrent system design of the VAH, observing the life cycle from the point of view of product, process and organization, the stakeholders that influence this development and the context where the process take place. Concurrent engineering was able to detail the system's development from conception until the operation. Through a vision of parallel processes, the methodology allowed to plan all stages of the life cycle of the system in an integrated and thorough manner.

The paper also described the approach as a way to provide a additional maturity on safety, once the complex product in case has hazardous potential, not allowing failures at any process of its life cycles. This concurrent safety point of view provides a robustness that may guarantee the final objective of a flight test system: to provide the valid flight test data and the information necessary to the continuous development process of a future product.

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