Integrated Development of Space Systems - Design for AIT - Design for Assembly, Integration and Testing of Satellites - D4AIT

Adalberto Coelho Silva, Geilson Loureiro
Integration and Test Laboratory (LIT),National Institute for Space Research (INPE), São José dos Campos, SP, Brazil
adalberto@lit.inpe.br, geilson@lit.inpe.br

The Satellite Assembly, Integration and Testing (AIT) activities are a logical and interrelated sequence of events. The main objective in this phase of a space program development is to achieve a high degree of confidence that the satellite complies with its specified performance parameters. Traditional simultaneous engineering space systems (e.g. satellite) development can have a better approach for taking into consideration AIT requirements during the initial phases of satellite conception and project detailing. By combining model driven system design approach with simultaneous engineering concepts for process modeling, AIT requirements at system level can be dealt with during satellite conceptual and detailed design. AIT requirements comprise electrical, mechanical and environmental requirements. This paper aims to present a new process for the development of satellites, that includes - electrical, mechanical and environmental requirements of assembly, integration and testing (AIT) of satellites, at the system level, already at the design stage of the satellite project.

Keywords - **System, integration, space, AIT, process**

I. INTRODUCTION

The development of a satellite can be divided into several phases: feasibility, design, manufacturing and assembly, integration and testing phase (AIT).

This paper addresses the last phase (AIT), which includes assembling the various subsystems into an integrated satellite and performing functional and environmental tests on the satellite as a system.

The aim of this phase of a satellite program development is to achieve a high degree of confidence that the satellite: complies with its operational objectives, survives launching, and operates correctly during the designed satellite lifetime.

The development of complex space systems, using either a traditional approach or a concurrent engineering approach does not take into consideration AIT requirements in an appropriate way.

There is potential to improve the AIT process if actions are taken during the conceptual and detailed design phases of a satellite development.

This paper presents a new process of development of satellites, to include: electrical, mechanical and environmental requirements of assembly, integration and testing (AIT) of satellites, at the system level, already at the design stage of the satellite project.

The paper covers satellite AIT activities with Brazilian and International satellite programs, executed at the Brazilian Institute for Space Research (INPE), in its Integration and Testing Laboratory (LIT), the largest satellite testing lab in the South Hemisphere.

Section 2 presents the space system development & AIT concepts, definitions and interrelations.

Section 3 explains D4AIT concept/model.

Section 4 presents D4AIT framework, including matrices data flow definition, and implementation process flow.

Section 5 presents a brief summary of this research.

II. SPACE SYSTEM DEVELOPMENT & AIT

In the development of modern and highly complex systems, especially those related to aerospace, there is a gradual increase of the importance of AIT engineering as part of system engineering.

Eisenmann [1] emphasizes that the right time to carry out the analysis of compromise within the scope of AIT is at beginning of the process of developing the space system.

Thus, it is imperative that the development of requirements, specifications, procedures and test configurations are implemented in parallel with all other requirements and specifications of the system, or there may be no guarantee of quality in the final product, as pointed out by Mercer [2].

For all these reasons, the AIT Engineering must be fully integrated in the system design from the beginning, and especially in defining system requirements.

The space system has many interdependencies between its components (subsystems / modules) as explain by Bandecchi [3].

This implies that the definition and evolution of each component have an impact on other components and that any change will propagate through the system.

The initial assessment of the impact of changes is essential to ensure that the design process converges to an optimal solution.

The concurrent engineering approach is intended to provide the means to achieve this goal.

The D4AIT process reflects exactly this approach by establishing the need for interfaces between AIT and all satellite subsystems, bringing mechanical, electrical and environmental requirements from satellite assembly, integration and testing activities, as well as from ground test tools (EGSE/MGSE) and infrastructure testing for the achievement of system requirements, which flow into the preliminary and detailed design of the system.

III. D4AIT MODEL

Establishing a correlation with the literature and concepts relating to "Design for X", "Design for AIT," or D4AIT is defined.

The D4AIT seeks to advance the state of the art in the assembly, integration and testing of space systems in order to:

• Reduce the cost and schedule of the space program, particularly the Phase D (AIT);

• Manage more efficiently highly complex projects;

• Ensure high quality to the "product" (satellite).

The focus is on developing a process and methodology to improve the identification and allocation of requirements in a synergistic way related to the assembly, integration and testing of subsystems and systems (satellite), already at Phases A and B (conception and design) of system development.

This means a process to integrate the requirements for AIT (electrical, mechanical and environmental) in the set of satellites requirements.

This framework also includes effective planning of testing capabilities, including the use of test equipment (GSE) and special test facilities.

Figure 1 shows the generic model (D4AIT model) of this new process that adds AIT synergistically in the development of integrated space systems.

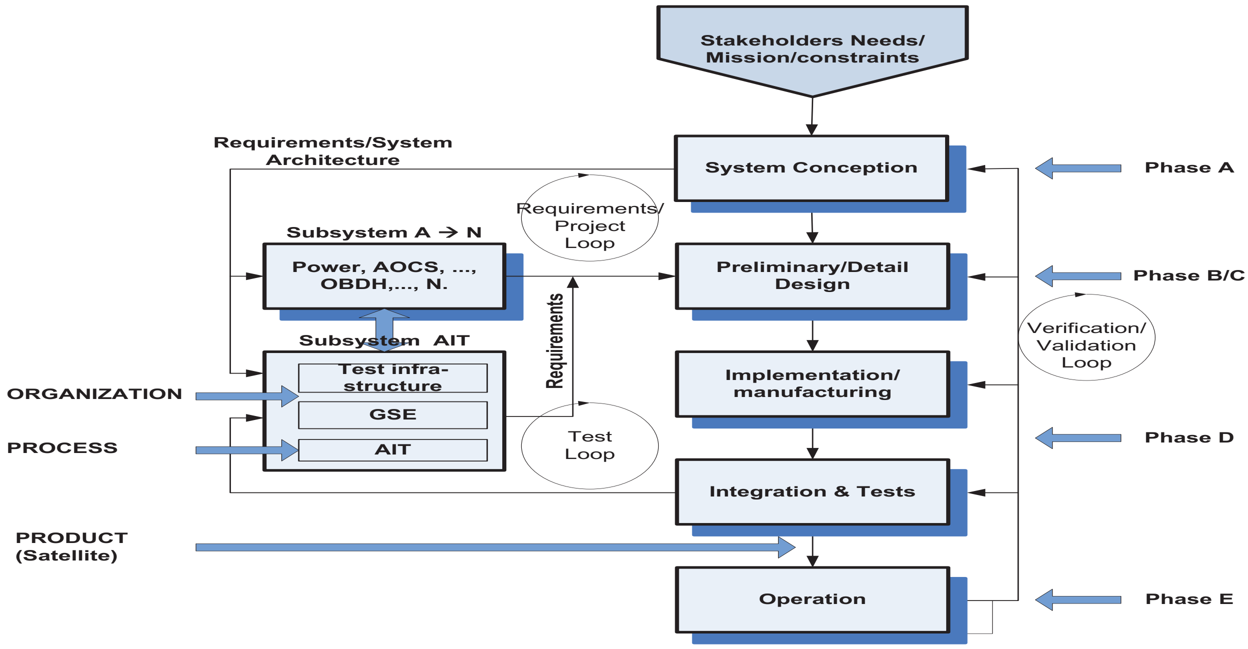


Fig. 1 D4AIT model.

Loureiro [4] explains that the modern development of complex space products requires to be taken into consideration the aspects of product, process and organization.

The model proposed by D4AIT highlights these dimensions when explicitly considers the infrastructure tests (Test Labs) and Ground test tools (GSE) as organizational elements.

Efficient and high quality AIT is the result of the D4AIT process.

The model also features a special feedback loop coming from the activities of system integration and testing (Phase D) that enables a continuous process improvement.

IV. D4AIT FRAMEWORK

The D4AIT symbolic representation is divided into three levels of general decomposition:

• Subsystem: based on the product tree (system / satellite WBS).

• Project Functions: are subsystems development functions - translating needs into requirements which in turn give the specifications of subsystem / system. They reflect the project teams related to each subsystem.

• Disciplines of Engineering: are the specialties of . They support the "project functions" (project teams) in order to achieve the desired attributes of the subsystem. They perform analysis, simulations.

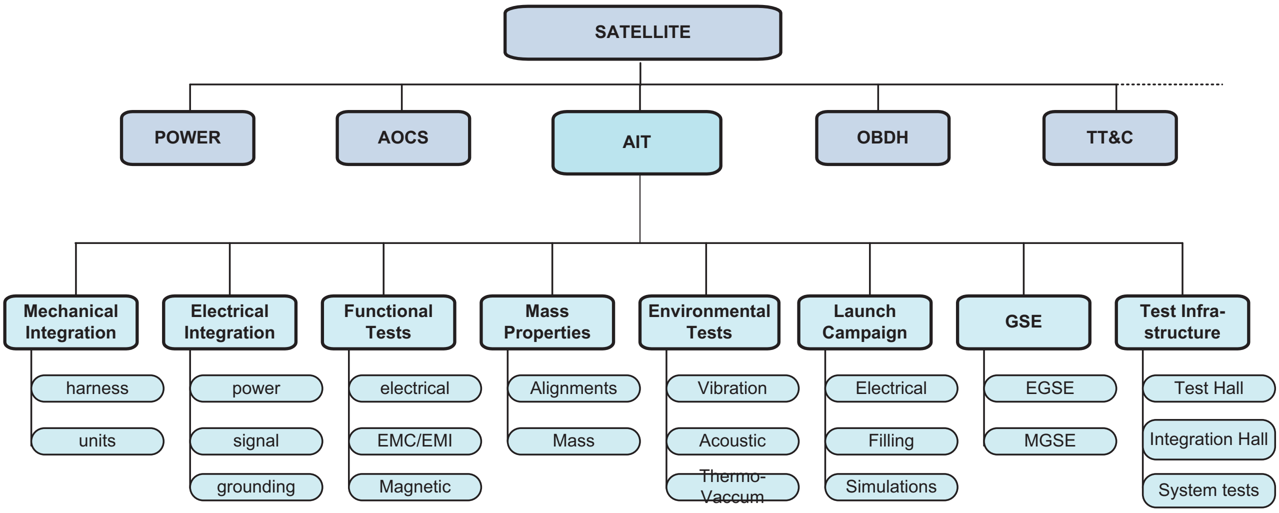
In the specific case of D4AIT process, we have:

• Subsystem: AIT. Figure 2 shows the WBS for a generic satellite, giving emphasis to AIT.

It is defined the following AIT sub-subsystems: mechanical integration, electrical integration, functional testing, physical measurements, environmental testing, launch campaign, GSE and Infrastructure, with their lower order sub-subsystems.

• Project Functions: would be, for example for AIT: system (integration), thermal, vibration, acoustics, EMC / EMI, contamination, mechanics test, antennas / RF project developers.

•Disciplines of Engineering: mechanical, computing, electrical, electronics, chemical engineering.



The activities of project functions and disciplines must be integrated into the satellite technical design process (Phases A / B).

This is achieved using two matrices, called SxS and AxA.

The SxS matrix is associated with all interfaces (physical/functional interfaces, and data) of hardware / software between satellite subsystems.

Usually this information is in the IDS ("interface data sheets).

The matrix AxA, similarly, is associated with the data flow between the sub-subsystems related to AIT, supported by the project functions (teams) and disciplines.

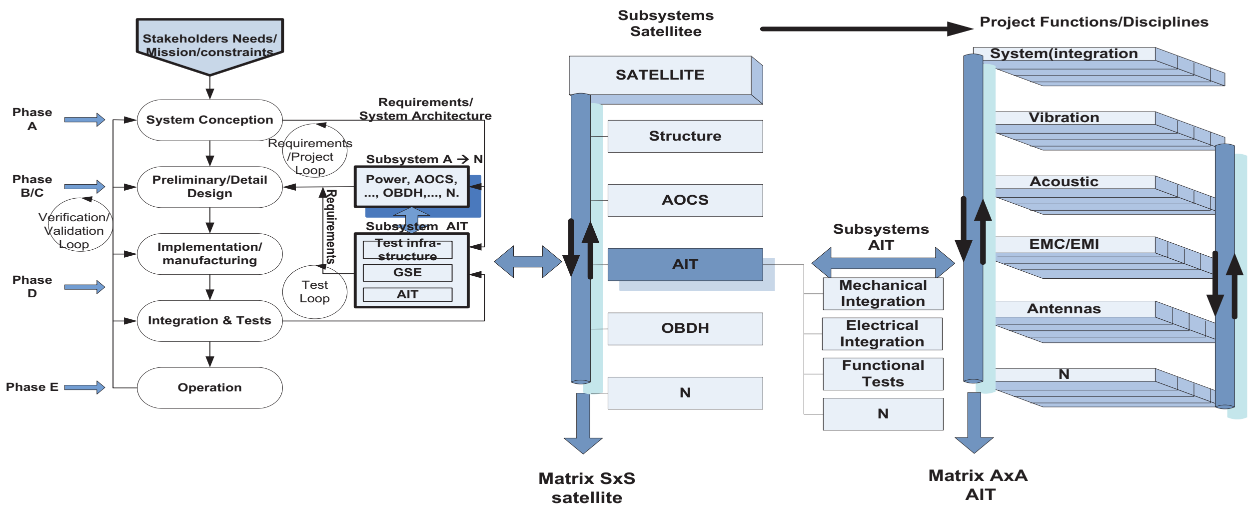


Fig. 3 D4AIT design flow.

Necessarily for all satellite subsystems, including AIT, there is always a project function called "system" (in the case of AIT - integration) that "integrates" all data from all other project functions.

There is a flow of information between the project function “system” and other project functions.

Flowing from the project function “system” to the other project functions, there is information primarily from high-level system requirements, the architecture, philosophies, and criteria.

Flowing from project functions (vibration, acoustic, EMC/EMI, antennas, etc.) to project function “system” (integration) is basically information on attributes of the AIT sub-subsystem (mechanical integration, electrical integration, functional testing, mass measurement, environmental testing, launch campaign, Ground support equipment, test infrastructure).

There is also information flowing between the project functions.

This kind of information results from the interactive nature of the design process and the fact that the project functions are coupled, ie, attributes of a project function, can affect attributes, requirements or restrictions of other project functions.

Exchange of information also occurs within each project function, resulting from the activities of multiple disciplines related to this project function.

All that information is managed by the use of matrices SxS (satellite) and AxA (AIT).

	#	1	2	3	4	5	6	7	8	9	10	11	
#	INPUTS	SATELLITE	Interface Requirements: Satellite → Subsystems										← OUTPUTS
1	⇩	[2.0]	Satellite → Structure	Satellite → Power	Satellite → AOCS	Satellite → Thermal	Satellite → AIT	Satellite → OBDH	Satellite → Payloads	Satellite → DTs	Satellite → Harness	Satellite → TT&Cs	
2		Structure → Satellite	Structure [2.1]	Structure → Power	Structure → AOCS	Structure → Thermal	Structure → AIT	Structure → OBDH	Structure → Payloads	Structure → DTs	Structure → Harness	Structure → TT&C	
3		Power → Satellite	Power → Structure	Power [2.2]	Power → AOCS	Power → Thermal	Power → AIT	Power → OBDH	Power → Payloads	Power → DTs	Power → Harness	Power → TT&C	
4		AOCS → Satellite	AOCS → Structure	AOCS → Power	AOCS [2.3]	AOCS → Thermal	AOCS → AIT	AOCS → OBDH	AOCS → Payloads	AOCS → DTs	AOCS → Harness	AOCS → TT&C	
5		Thermal → Satellite	Thermal → Structure	Thermal → Power	Thermal → AOCS	Thermal [2.4]	Thermal → AIT	Thermal → OBDH	Thermal → Payloads	Thermal → DTs	Thermal → Harness	Thermal → TT&C	
6	Interfaces Descriptions Subsystem → Satellite	AIT → Satellite	AIT → Structure	AIT → Power	AIT → AOCS	AIT→ Thermal	AIT [2.5]	AIT → OBDH	AIT → Payloads	AIT → DTs	AIT→ Harness	AIT → TT&C	Requirements/ Interface Descriptions Subsystem → Subsystem
7		OBDH → Satellite	OBDH → Structure	OBDH → Power	OBDH → AOCS	OBDH → Thermal	OBDH → AIT	OBDH [2.6]	OBDH → Payloads	OBDH → DTs	OBDH → Harness	OBDH → TT&C	
8		Payloads → Satellite	Payloads → Structure	Payloads → Power	Payloads → AOCS	Payloads → Thermal	Payloads → AIT	Payloads → OBDH	Payloads [2.7]	Payloads → DTs	Payloads → Harness	Payloads → TT&C	
9		DTs → Satellite	DTs→ Structure	DTs → Power	DTs→ AOCS	DTs → Thermal	DTs→ AIT	DTs → OBDH	DTs→ Payloads	DTs [2.8]	DTs→ Harness	DTs → TT&C	
10		Harness → Satellite	Harness→ Structure	Harness → Power	Harness→ AOCS	Harness → Thermal	Harness→ AIT	Harness → OBDH	Harness→ Payloads	Harness→ DTs	Harness [2.9]	Harness → TT&C	
11		TT&C → Satellite	TT&C→ Structure	TT&C → Power	TT&C→ AOCS	TT&C → Thermal	TT&C→ AIT	TT&C → OBDH	TT&C→ Payloads	TT&C→ DTs	TT&C→ Harness	TT&C [2.10]	

Fig. 4 D4AIT – matrix SxS.

These matrices have different dimensions depending on each system / satellite in development.

In summary, the project functions (teams) can be represented by planes that produce the design specifications.

Each plane (project function) has a set of interrelated disciplines that support the activities of each function (plane).

There are a set of planes (functions / teams associated with each subsystem of the satellite), with a special project function (system) that "systematizes / includes" all other project functions results.

The flat top of the stack - the system, is responsible for integrating the functions of the other planes of the stack.

Figure 3 shows the overview of this process.

Most of the requirements and restrictions are derived from high-level mission objectives (e.g. performance, cost, schedule, reliability, operability), while others are determined by experience.

Figure 4 presents the matrix SxS - satellite, based on the satellite/AIT WBS typical (Figure 2).

	#	1	2	3	4	5	6	7	8	9	
#	ENTRADAS	AIT	Interface Requirements: AIT → Subsystems AIT								← SAÍDAS
1	⇩	[2.10]	AIT → Mech. Int.	AIT → Elec. Int.	AIT → Func. Tst.	AIT → Mass Prop.	AIT → Envir. Tst.	AIT → Launch Camp..	AIT → GSE	AIT → Infra	
2		Mech. Int.→ AIT	Int. Mec [2.10.1]	Mech. Int. → Elec. Int.	Mech. Int. → Func. Tst.	Mech. Int. → Mass Prop.	Mech. Int. → Envir. Tst.	Mech. Int. → Launch Camp..	Mech. Int. → Carga GSE	Mech. Int. → Infra	
3		Elec. Int.→ AIT	Elec. Int. → Mech. Int.	Elec. Int. [2.10.2]	Elec. Int. → Func. Tst.	Elec. Int. → Mass Prop.	Elec. Int. → Envir. Tst.	Elec. Int. → Launch Camp..	Elec. Int. → GSE	Elec. Int. → Infra	
4		Func. Tst. → AIT	Func. Tst. → Mech. Int.	Func. Tst. → Elec. Int.	Func. Tst. [2.10.3]	Func. Tst. → Mass Prop.	Func. Tst. → Envir. Tst.	Func. Tst. → Launch Camp..	Func. Tst. → GSE	Func. Tst. → Infra	
5	Interfaces Descriptions Subsystem → AIT	Mass Prop. → AIT	Mass Prop.. → Mech. Int.	Mass Prop. → Elec. Int.	Mass Prop. → Func. Tst.	Mass Prop. [2.10.4]	Mass Prop. → Envir. Tst.	Mass Prop. → Launch Camp..	Mass Prop. → GSE	Mass Prop. → Infra	Requirements/ Interface Descriptions Subsystem → Subsystem
6		Envir. Tst. → AIT	Envir. Tst. → Mech. Int.	Envir. Tst. → Elec. Int.	Envir. Tst. → Func. Tst.	Envir. Tst. → Mass Prop.	Envir. Tst. [2.10.5]	Envir. Tst. → Launch Camp..	Envir. Tst. → GSE	Envir. Tst. → Infra	
7		Launch Camp.. → AIT	Launch Camp.. → Mech. Int.	Launch Camp.. → Elec. Int.	Launch Camp.. → Func. Tst.	Launch Camp.. → Mass Prop.	Launch Camp.. → Envir. Tst.	Launch Camp.. [210.6]	Launch Camp.. → GSE	Launch Camp.. → Infra	
8		GSE → AIT	GSE → Mech. Int.	GSE → Elec. Int.	GSE → Func. Tst.	GSE → Mass Prop.	GSE → Envir. Tst.	GSE → Launch Camp..	GSE [2.10.7]	GSE → Infra	
9		Infras → AIT	Infra → Mech. Int.	Infra c. → Elec. Int.	Infra → Func. Tst.	Infra → Mass Prop.	Infra → Envir. Tst.	Infra → Launch Camp..	Infra → GSE	Infra [2.10.8]	

Fig. 5 D4AIT – matrix AxAm

This matrix has an overall typical size of 11x11.

The top line (1), called the satellite line - corresponding to high-level requirements / mission coming from the system / satellite - are the inputs to the process.

In the first column (1), there are the requirements / description of the interfaces of the subsystems to the system / satellite.

Column 6 (AIT) depicts the development of synergistic requirements of AIT.

Column (6), called AIT, presents the requirements coming from satellite subsystems to AIT – AIT inputs.

Row (6), called AIT, depicts the requirements to the subsystems - AIT outputs.

In particular the cell (1.6) on the first column is the focal point of the whole process, i.e. the AIT requirements to the satellite.

The main diagonal elements are the subsystems (or sub-subsystems) of the satellite.

The other lines show the requirements flow between the subsystems.

Each project / system / satellite will have a specific SxS matrix, basically depending on the corresponding system architecture.

The matrix AxA - AIT, as shown in Figure 5, based on the Satellite / AIT WBS - (figure 2), has an overall typical size of 9x9.

Similar to matrix SxS - satellite, this matrix provides on the first row (1), the AIT row, the high level requirements of AIT to its subsystems. These requirements come from the matrix SxS - column (6) / AIT.

On the first column (1), also known as AIT column, there are also requirements / description of the interfaces from the AIT subsystems to AIT system, which in turn is the reference input to matrix SxS - row (6) / AIT.

The main diagonal elements are in turn AIT sub-subsystems.

The remaining rows / columns present the requirements flow between of the subsystems, which may present a strong or weak coupling depending on each project.

The generic implementation of the D4AIT model is structured in the following steps / stages:

- Identify the high level requirements of the satellite / mission;
- Design (size / subsystems) Matrices SxS and AxA;
- Identify & allocate the satellite / subsystem requirements to AIT;
- Allocate the requirements to AIT subsystems;
- Identify & allocate requirements between AIT subsystems;
- Synthesize & evaluate the AIT sub-subsystem requirements to AIT;
- Allocate AIT requirements to satellite subsystems;
- Summarize the AIT requirements to Satellite.

The executors of these steps are the design functions for the subsystem AIT, namely: project function AIT - system (integration), project functions relating to sub-subsystem AIT (teams of vibration, thermal, acoustics, EMC / EMI, antennas, and others.) and "engineering disciplines," i.e. specialist engineers (software, data acquisition, and others).

V. CONCLUSIONS

D4AIT is the process that correlates the requirements from the assembly, integration and testing of satellites (AIT), considered itself satellite subsystem, as well as the requirements coming from the test tools (GSE), and testing infrastructure, already in design phase and detailed design of the satellite.

This means a process to integrate the requirements of AIT in its dimensions: electrical, mechanical and environmental requirements in the satellite requirements.

The proposed model includes all subsystems / areas of AIT, namely: mechanical integration, electrical integration, functional testing, measures of mass / alignment, environmental testing, launch campaign, systems testing (EGSE / MGSE) and also required test infra-structure.

It is applicable to any type of space system - satellite, using matrixes as means of transfer of data / information between systems / subsystems / AIT, in a process that connects the systems engineering and concurrent engineering concepts.

The D4AIT model can be applied to any type of mission (Earth observation, telecommunications, scientific.) as well as for any class of satellite (small, medium and large), also including the activities of the launch campaign.

In summary, the D4AIT model allows AIT requirements (electrical, mechanical and environmental) to be incorporated into phase A / B of a space system development in an integrated, synergistic way.

REFERENCES

[1] H. Eisenmann, “ESA Virtual Spacecraft Design”. ESA / ESTEC. SECESA 2010. Noordwijk, 2010.

[2] R.D. Mercer, K.A. Horst, “Increasing Importance of Testing within systems Engineering”. *In:* Proceedings of EuSEC 2000 ISBN 3-89675-935-3. 2000

[3] M. Bandecchi, B. Melton, F. Ongaro, “Concurrent Engineering Applied to Space Mission Assessment and Design”. ESA Bulletin 99 - september 1999. Netherlands, 1999.

[4] G. Loureiro, P. G. Leaney, “A systems and concurrent engineering framework for the integrated development of space products”. In: Acta Astronautica, 53 (12), p.945, Dec 2003.