ALPHABUS
THE EUROPEAN HIGH CAPACITY PLATFORM FOR SATCOMS

S. Massier(1), G. Lubrano(1), P. Belliol(2), A. Obst(3), L. Petitjean(4)
(1) ThalesAlenia Space
100 Boulevard du Midi, BP 99, 06156 Cannes La Bocca Cedex, France
stephane.massier@thalesaleniaspace.com, gilles.lubrano@thalesaleniaspace.com
(2) EADS Astrium
31 rue des Cosmonautes, Z.I. du Palays, 31402 Toulouse Cedex 4, France
pierre.belliol@astrium.eads.net
(3) ESA/ESTEC
Mechanical Engineering Department, Postbus 299, 2200 AG Noordwijk, The Netherlands
andreas.obst@esa.int
(4) CNES
Centre Spatial de Toulouse, 18 avenue Edouard Belin, 31401 Toulouse Cedex 9, France
luc.petitjean@cnes.fr

OVERVIEW

A joint team of the two leading European satellite companies (EADS Astrium and ThalesAlenia Space) is working with the support of ESA (European Space Agency) and CNES (Centre National d'Etudes Spatiales of France) to define a product line able to efficiently address the upper segment of communications satellites. This product line will cover a payload power between 12 and 18 kW and a launch mass between 5.5 and 8.8 tons [R1]. The target is to increase the capacity of Satcom manufactured in Europe by 50%.

The design and manufacturing of the subsystems involve many European sub-contractors. In the year 2007 the functional chains and system Critical Design Reviews of the project are foreseen.

The mechanical validation of the Alphabus platform is challenging due to its size and complexity. At the same time it presents an excellent opportunity to improve the mechanical validation and qualification process, especially with respect to sine vibrations (i.e. the low frequency environment). Key points are :

- the platform will cover a large product line with various and complex mechanical configurations (e.g. for antennas)
- through the Joint Project Team and supported by CNES and ESA, both primes share their experiences to determine the "best" solutions
- the platform shall be competitive on the Satcom open market. Recurrent cost of manufacturing, integration, testing has to be minimized.
- Mechanical requirements on the subsystems shall be minimized or adjusted in order to comply as much as possible with current qualification for existing elements (re-use "off the shelf", avoid delta-qualification) or to limit technical difficulties/mass growth for new elements
- Mechanical acceptance testing at Satellite level shall be performed with empty tanks due to various constraints (force or mass limitation of existing vibration device, prohibition of some simulation fluids like Freon, test schedule reduction).

The objective of this paper is to present the general mechanical design of Alphabus Platform and the drivers of the mechanical validation plan. Concerning the mechanical validation plan, it will be recalled that the qualification robustness for the units is based on the margins between their qualification status and the levels seen from the Coupled Load Analysis, mainly when the satellite sine testing is not flight representative and especially when tests are performed with empty tanks.

Also this paper is divided in three parts :

- Project system requirements and organisation
- Architecture overview
- Mechanical validation

1. ALPHABUS PROJECT

1.1. Key figures

The following figures give an overview of Alphabus configurations :

- Payload Power : 12 to 18 kW
- Payload mass : 800 to 2000 kg
- Launch Mass : 5500 to 8800 kg
- Dry mass : 2700 Kg to 4900 kg
- Propellant mass (chemical propulsion) : up to 4200 kg
- Xenon (electric propulsion) : up to 350 kg
- Solar arrays : 4 to 6 panels wings
- Lifetime : 15 years
- Missions : mobile and broadband services, digital radio broadcasting and high-definition TV

The C/D phase of the program started in 2005. At the end of year 2007 the functional chains and system Critical Design Reviews of the project should have been held.

Alphabus platform covers a large mass range to ensure compatibility with various launch vehicles performances :

- from Proton or H-2A at the beginning of the range (performance < 6 tons)
- to Atlas or Ariane 5 (single launch) on the top of the

range (performance < 9 tons)

By comparison the limit launch mass of generic Satcom platforms currently proposed by industry is around 6 tons. With the Alphabus platform, the European manufacturers will extend their own offers with high power and competitive solutions. Alphabus product line intends to contribute to the replacement of the major operators' satellites, by offering a lower cost per transponder and the capability to fly reconfigurable missions.
At the same time Alphabus re-uses and enhances existing technologies or products issues of European platforms :

- Eurostar E3000 for EADS-Astrium
- Spacebus 4000 for Thales Alenia Space

To re-use, adapt or enhanced existing products has many advantages :

- To limit cost and schedule
- To reduce technical risks during development and qualification, and then utilize flight-proven designs in orbit
- To convince the customers (for which insurance cost represents an important part of the budget)

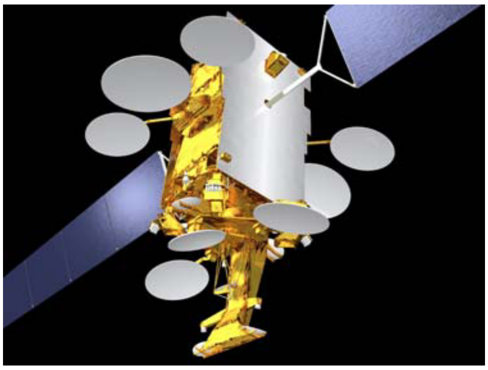

FIG. 1 : Alphabus on station

1.2. Project organisation

The project is initiated, co-funded and followed by CNES and ESA.

At industrial level, the 2 main Satellites manufacturers in Europe – EADS Astrium and Thales Alenia Space - are jointly prime contractors through the “Joint Project Team”. The design and manufacturing of the subsystems involve many European sub-contractors. Up to the end year 2007 the functional chains and system Critical Design Reviews of the project are foreseen. At the same time developments for the 1st application program – currently called Alphasat – will be started.

This organisation is fruitful because it involves people issued from different cultures or competence networks with complementary experiences :

- ESA and CNES teams which are involved in various projects (especially institutional or Science and Observation programs)
- Industrial teams from Telecom Directorates of EADS-Astrium or ThalesAlenia Space which have respectively specific habits and know-how.

This organisation allows concurrent engineering phases that lead to attractive solutions at design and validation levels.

2. ALPHABUS ARCHITECTURE

2.1. Design drivers

The Alphabus architecture objectives are :

- Modular to allow parallelisation of design, manufacturing and integration activities
- Generic to reduce non recurrent activities and to optimize cost and schedule for platform functional chains (avionics, propulsion, electrical power) and main structures
- Flexible to accommodate various payloads without jeopardizing the main structure qualification and reduce non recurrent engineering phase

The competition is widely open because the capacity of existing platforms is also increasing within a very competitive environment (even if the open market is up to now mainly shared between Europe and United States). In this frame, Alphabus project is very ambitious because it has to demonstrate its competitiveness in the upper part of the Satcoms market.

2.2. A modular design

The Alphabus architecture is based on a modular concept with three major modules:

- The Service Module (SM)
- The Repeater module (RM)
- The Antenna Module (AM)

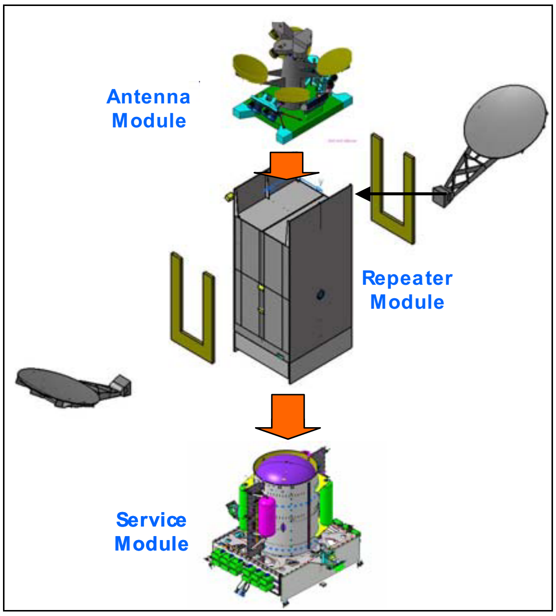

FIG. 2 : three modules design

The SM structure accommodates the main part of platform sub-systems (avionics, chemical and plasmic propulsion, electrical power). SM design is generic and includes the largest part of SL primary structure. The primary structure – that includes the central tube and the shear webs – is the backbone of the spacecraft and carries the global loads from the mechanical sub-assemblies to the interface frame.

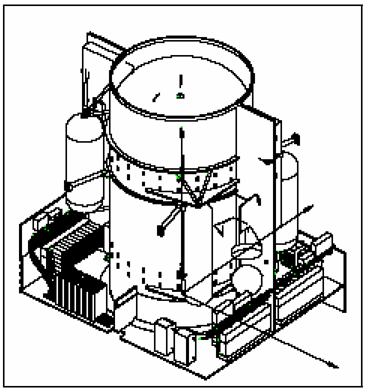

FIG. 3 : SM structure

The RM structure accommodates the payload units. Equipped surfaces are mainly the North and South walls and the 3 horizontal floors (a 4th floor is proposed in the extended range). It is designed to allow the maximum layout and dissipative surfaces for the payload.

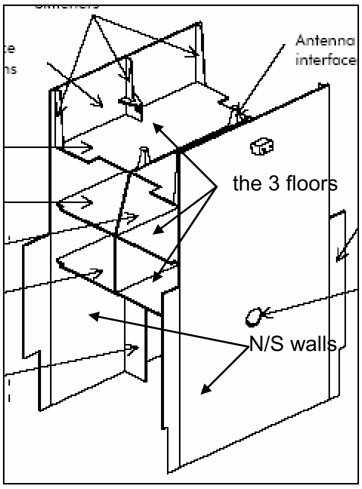

FIG. 4 : RM structure

The AM structure which is composed of a plateau (top floor) and lateral arms accommodates the fixed or deployable antennas. It is designed for in orbit stability and contributes to optimize the pointing performance.

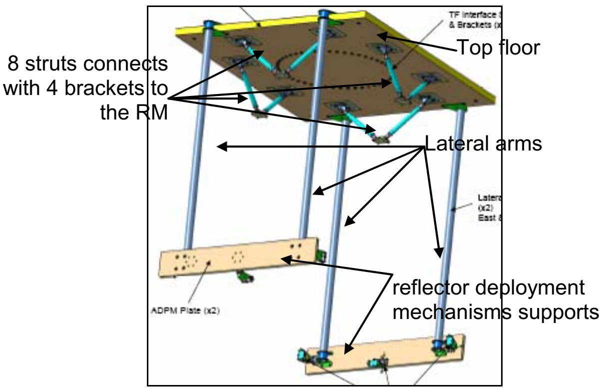

FIG. 5 : AM structure

2.3. Main Mechanical Appendages

The main mechanical appendages of the platform are the followings :

- Two propellant tanks with equatorial skirts connected directly to the central tube
- Two Xenon tanks connected by the poles to the central tube by means of "boomerang" shape panels and struts
- Two helium tanks connected to East and West shear webs by struts.
- Two solar arrays (with 4, 5 or 6 panels) stowed to hard points of North and South RM walls
- The apogee engine connected to SC central tube rear frame by means of a cross bracket
- Two Xenon propulsion modules connected by means of secondary structure to the SM horizontal deck and North/South webs.

The previous list of appendages impact the dynamic behaviour of the Spacecraft.

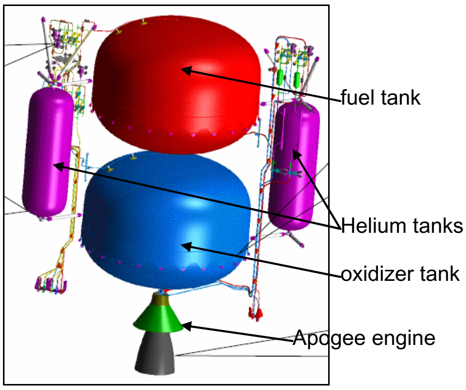

FIG. 6 : CPS (propellant and helium tanks, apogee engine)

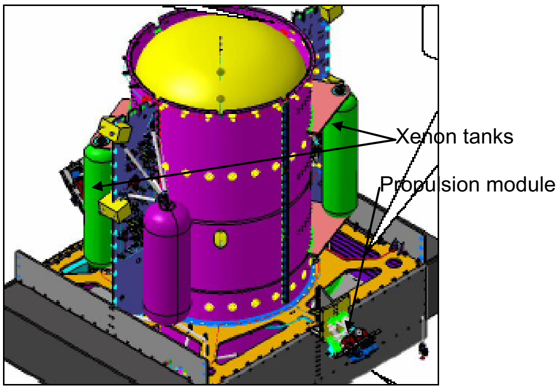

FIG. 7 : CPS & XPS (Xenon tanks, propulsion modules) assembled on SM

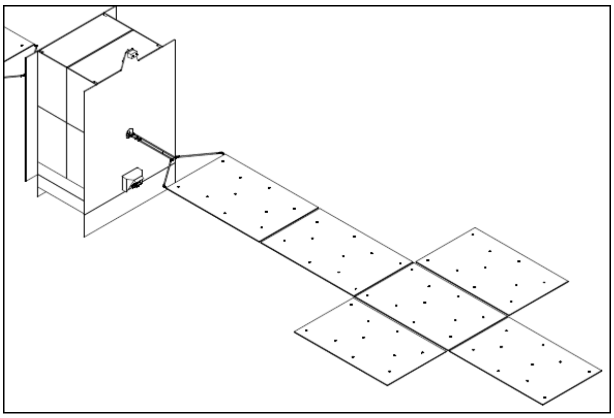

FIG. 8 : Deployed Solar Array (6 panels version)

3. DEVELOPMENT AND VALIDATION PLAN

3.1. General

Alphabus is a product line instead of a single point with a frozen platform and payload. The platform (including its generic elements) has to be qualified without structural model (STM) that could definitively not cover all the range.

The objective of the validation is to demonstrate that each item (unit, sub-assembly, appendage, etc…) of the platform is qualified with appropriate levels to cover the need over the range.

The condition of the success is the ability to demonstrate clean and robust qualifications of the subsystems within a fully clear and coherent validation logic.

In practice the mechanical analyses team has to work in parallel with several Finite Element Models to cover typical configurations of the product line from light to heavy. Due to the empty testing approach, dynamic analyses have to be done in empty and filled configurations.

3.2. Empty tank testing need

Intuitively one could think that the main purpose of empty testing would be to suppress filling before system mechanical testing and that a “normal” sequence as if the tanks were filled could be performed.

However at development and validation levels it brings several constraints :

- For the tanks which have to deal with a dual qualification (empty + filled)
- For the Spacecraft structure which have to avoid as much as possible dynamic coupling with appendages in both configurations.
- For the sub-systems flight models at acceptance tests level in order to proof the load paths from tanks to SL interface.

These constraints have an important impact on the validation rationale from subsystem to system.

But Empty testing at SL level is a requirement for Alphabus project :

- Existing test facilities (shakers for sine vibrations) in Europe are not compatible with Alphabus maximum launch mass (8.8 tons) or I/F loads. SLs of Alphabus product line will be integrated in EADS-Astrium premises in Toulouse. Therefore SL mechanical testing shall be performed with neighbouring facilities at Intespace.
- Some usual substitution fluids are now prohibited by legislation (e.g. Freon as MON substitute) or generate safety constraints on test campaign. Backup substitutes are not easy to find (equivalent densities, no contamination, draining and drying, chemical or fire risk)

In addition it is relevant for System AIT. The advantages are :

- 1st of all, without filling and draining, to reduce AIT activities by several days at the end of the project (critical wrt late delivery penalties), often a few weeks before the launch campaign.
- To limit “hazardous” operations (hoisting at full mass with more and less dangerous fluids inside pressurized tanks)

Empty testing impacts significantly the validation plan of the platform. It must be considered since the early phase of the project in order to address the associated constraints to the concerned items (tanks and their supporting structures).

3.3. Mechanical validation logic

According to FIG. 9, the general logic consists of several steps :

1) the environments knowledge (ground, launch, on orbit/station)
2) the definition of system specifications
3) the flow-down of requirements to subsystems (specifications)
4) the subsystems tests
5) the system tests

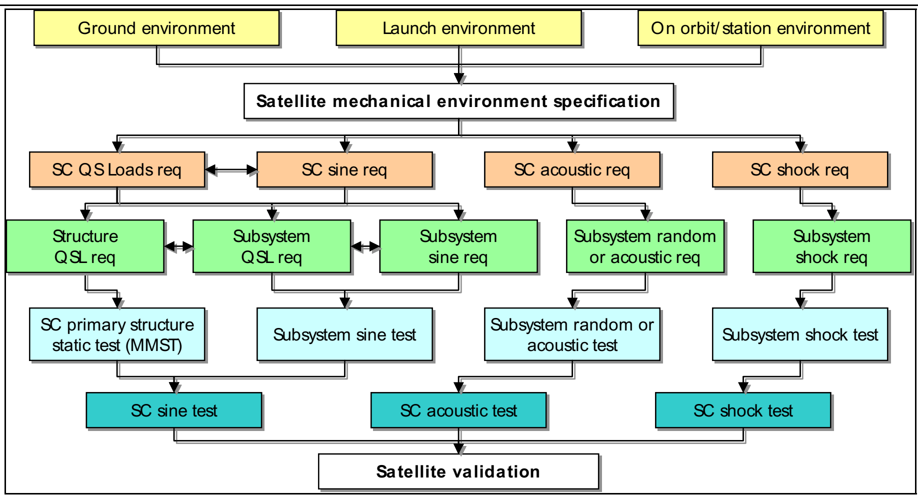

FIG. 9 : Mechanical validation logic

Remark 1 : the figure does not take into account other mechanical environments (thermo-elastic strength or distortion, moisture desorption, micro-vibrations, …).

Remark 2 : for the subsystems, launch QS loads (including especially the axial thrust) are covered by sine vibration tests (at low frequency). But for the SL primary structure, the QS loads are covered by the static test performed on the primary structure qualification model (which is called MMST on Alphabus). The interaction between primary structure static qualification (generic envelope for the product line) and the System sine vibrations (specific for each SL) is a key point.

3.4. SL Sine validation

3.4.1. Foreword

The usual argument against SL Sine Empty testing is that it is not representative of the launch configuration. That is obvious in term of SL configuration because fluids represent about the half of the launch mass (for Satcom with 15 years lifetime).

The correct but provocative answer to this assessment is that Filled testing is also not launch representative from the point of view of the dynamic environment even if the mass is representative. Indeed empty or filled, the 3 separate axes sine sweeping vibrations on the shaker rigid base are not representative of the envelope flight events (transient events mainly) when the SL is mounted to LV flexible interface (with a 6 degrees of freedom motion). It can be illustrated by comparison of the relevant frequencies between flight and test.

In fact it is important to remind that the objective of mechanical environment tests (at subsystem or system level) is not to simulate/reproduce but to cover the launch environment. That is the main difference with respect to functional or performance tests.

Differences of nature between launch and test are illustrated when following figures 10a, 10b and 11 are compared :

- Alphabus/Ariane 5 I/F base acceleration and force for axial direction issued from CLA (time history and shock spectrum) [R2]
- Sine Axial force at SL I/F for E & F configurations (force (kN) vs 1m/s² base input) [R3].

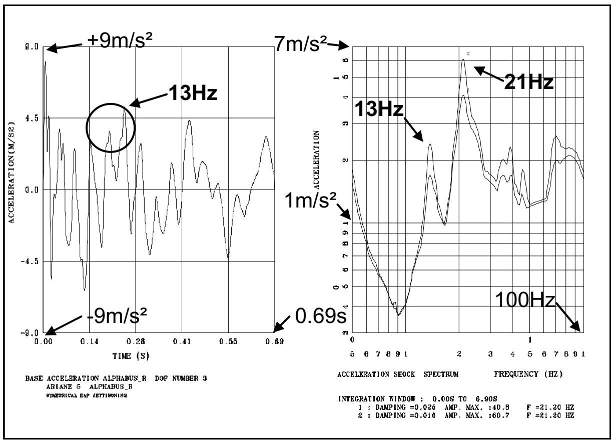

FIG. 10a : SL/AR5 interface acceleration (m/s²)
(Left : time history, Right : SRS) (event : EAP jettisoning)

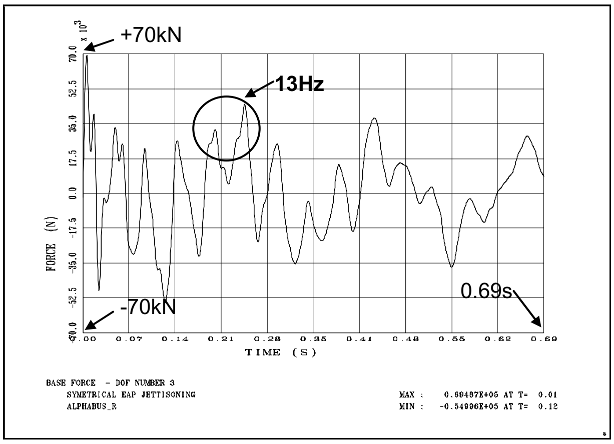

FIG. 10b : SL/AR5 interface force (kN)
(time history) (event : EAP jettisoning)

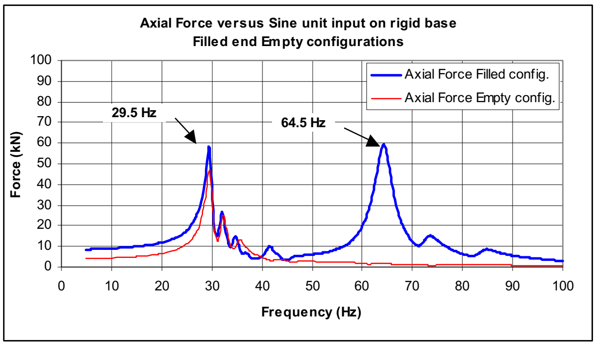

FIG. 11 : Alphabus interface force (kN) vs 1m/s² (8.8 tons model with E+F configurations)

During launch, SL dynamic environment is mainly driven by modes that are issued from LV flexibility (on the example, the critical frequency is 21Hz).

The sine test on shaker sweeps the SL normal modes on rigid base. The 1st critical frequency is around 30 Hz on the 1st axial mode (the SL meets the stiffness requirement : axial frequency >27 Hz). Empty and Filled 1st frequencies on rigid base are very similar. From 40Hz, there is no more similarity between the dynamic behaviours.

In most of the case, the CLA shows that the launch environment from SL point of view is mainly Quasi-static. The dynamic acceleration when filtered around SL normal modes are often negligible. On a certain way, only these components should be covered by the test on rigid base.

3.4.2. Building QS and Sine specifications

There is several ways to build or update a Quasi-static and Sine specification for a Subsystem (QS and Sine are related) :

1) To take the heritage (if any, and if it is relevant wrt Alphabus architecture)
2) To perform a sine analysis and build the S/S specification to "avoid" notching at SL level on the response of this S/S
3) To consider the results of SC/LV CLA (with a "sufficient" uncertainty factor)

Method 1) presents the advantage to limit the risk at S/S level for recurrent products or technologies (not to change something that already works)

Method 2) increases System robustness and simplifies System test strategy (even if it is too conservative with regard to the actual need). But on the other hand, in case of over-specification at S/S level, it increases the programmatic risks (design iterations, mass growth, test failures).

Method 3) is the optimized one to design and test at the right need. But it requests the availability of the CLA and a sufficient level of confidence in the models. Nevertheless CLA results database of existing Satcoms platforms allow to estimate typical accelerations on various appendages which are also valid by design similarity.

On Alphabus, method 1) (heritage) has been selected for a large part of appendages.

Tentative to select method 2) (avoid notching) leads rapidly to unsolvable equations between strength and mass saving. Considering the mission range covered by Alphabus platform, it is quite impossible to avoid notching on each S/S. Due the size of Alphabus structures and appendages, the frequency content between 20 and 50Hz is typically significantly more important that for smaller platforms.

Notched Sine analysis and CLA results are jointly used to justify S/S and System notchings.

At last, solution 3) (CLA results) is used for design optimization (mass saving typically) and/or to relax specifications.

3.4.3. Sine validation logic

The Sine validation logic is based on :

- The primary structure qualification (completed by the static test of the MMST)
- "Subsystems" - including units, secondary structures, interfaces - qualifications (completed by sine and/or static, elementary tests)
- Sine vibrations on the 1st PFM (Alphasat) of the product line that will be treated differently from the following ones. Indeed for validation/correlation purpose, a "mixed" empty + filled sine sequence on Alphasat is mandatory.
- Sine vibrations on the 2nd or next PFM (Alphacom) will be performed in empty configuration only.

Alphasat and Alphacom qualification logics are presented on the next figures.

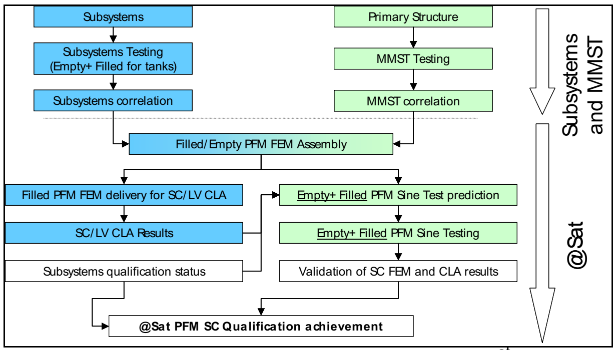

FIG. 12 : Alphasat sine validation logic (1st SL)

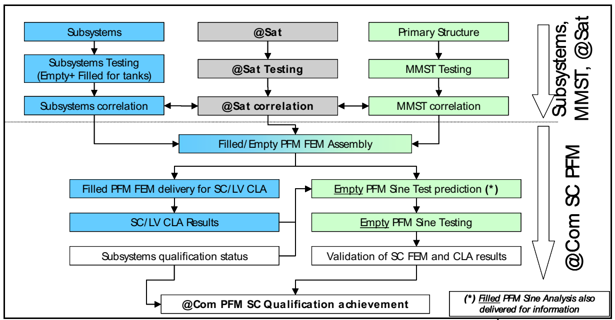

FIG. 13 : Alphacom sine validation logic (2nd SL and following)

Remark : Static Qualification test on the MMST is performed once. It is a key element of the Alphabus platform justification and qualification status.

The specific "mixed" test sequence for Alphasat is the following (baseline scenario) :

Test	@sat in EMPTY configuration	@sat in FILLED configuration
Sine vibrations	3 axes PFM Qualification sequence. Each axis with : • 1 Low Level, • 1 Intermediate Level, • 1 Qualification Level, • 1 Control Low Level (+ extra runs if needed) Sweep rate 4 oct/min	1 Low Level for each axis Sweep rate 4 oct/min
Acoustic vibrations	PFM Qual sequence : • 1 Low Level, • 1 Intermediate Level, • 1 Qualification Level, • 1 Control Low Level Each run duration : < or = 60" (= 60" for QL)	1 Low level (= QL-8dB) Each run duration < or = 60"
Shocks (NO fatigue impact)	1 clamp band release for the selected LV + solar arrays and antennae releases	

FIG. 14 : Alphasat mixed test sequence

The mixed test sequence avoids a Empty and Filled qualification at "high" level (cycling constraint to respect units qualification status).

Alphasat SL finalizes Alphabus platform validation by a correlation in Empty and Filled configurations. By this demonstration :

- CLA results are validated
- Test feasibility in empty configuration is demonstrated (with its own objectives)

Since the 2nd SL of the product line “Alphacom” only System Empty testing will be performed.

In the frame of empty testing, the load path between tanks and SL I/F is not validated by the system test sequence. But what is not done at System level must have been done at S/S level. Also the mechanical chain between tanks and SL I/F has to be tested and validated at elementary level. That implies for sub-assemblies flight models constraints on acceptance tests :

- At tank level, sine vibrations in filled configuration
- At central tube level, a static proof test including tanks interface
- At tanks I/F bolts level, acceptance tests on the bolts batches and well mastered procedures at integration level

3.4.4. Analysis, Test and Correlation

A well achieved Alphabus mechanical validation is pending on Analysis, Test and Correlation both at subsystem and system levels. It is over more important on Alphabus because at System level the tested empty configuration is not the launch one. During System test the main objective is not to achieve more or less envelope accelerations. The goal is to demonstrate that achieved levels are close to predicted ones. Indeed if the CLA is valid, flight responses are already covered by qualifications at S/S level.

Analysis shows the theoretical design behaviour and capability (from subsystem level to SL/LV CLA).

Test validates Analysis.

Correlation between analysis and test improves the models. Correlation is first of all a requirement at S/S level in order to build a 1st platform model (for Alphasat) enough accurate. After system testing, correlation activities allow to improve the maturity of the model for the following programs.

Correlation is also a need when the specifications have to be relaxed and/or the design to be optimized.

About correlation implementation, the main difficulty is often to convince equipment suppliers in the interest of accurate models because it is a key node of the system approach.

At system level, and especially for Satcoms product lines as Alphabus, it is important to dispose of standard methods and tools [R5] and at the end to define standard validation criteria.

3.5. SL Acoustic validation

For acoustics, Alphabus validation plan is not different from other SC programs (such as Spacebus or Eurostar ones) considering that empty tank testing will not modify significantly the SC behaviour.

Nevertheless this assessment of minor modification between “empty/filled” testing for acoustics will be demonstrated by Alphasat test.

3.6. SL Shocks validation

Alphabus units shocks specification are based on heritage.

This status leads to get comfortable margins or specification relaxation at unit level because shocks specifications at SL I/F have been relaxed in reason of recent developments at LV level :

- Generalization of “low shock” clamp bands for SL/LV separation
- Reduction of shocks generated by fairing jettison

On shock topic, the effort done by the LV authorities (Arianespace especially [R4]) has to be acknowledged. It solves many problems at SL units level.

4. CONCLUSION

Alphabus program is ambitious :

- The size and range to be covered induced a complex dynamic behaviour that must be studied in empty and filled configurations. Also the design has to be optimized with project decisions well balanced between mass saving, manufacturing cost and system robustness.
- The Alphabus platform has to be attractive and competitive on the Satcom open market in term of proposed solutions, cost and schedule. It is the condition of the existence of Alphabus product line.

To succeed on the mechanical point of view, the condition is mainly to build a fully consistent validation plan which include the empty tank testing justification.

As the system sine test covers only partially the launch environment in term of accelerations or loadings, especially in empty configuration, it is necessary to place at the foreground the qualifications at subsystems levels. That is the basement of the platform qualification. And it is even more important for the elements on the load path from tanks to SL I/F (tanks, junctions, central tube).

At the end, to demonstrate that the platform is validated and qualified, it is necessary to get a good confidence level in the models from subsystem to system (by Analysis, Test AND Correlation).

5. GLOSSARY AND ABBREVIATIONS

AIT/AIV	Assembly, Integration and Test/Validation
Alphasat, Alphacom	Alphasat is the “beta” name of the 1st SL of Alphabus product line Alphacom is the “beta” name of any SL of Alphabus product line after Alphasat
CLA	SL/LV Coupled Load Analysis
E+F	Empty and Filled
I/F	Interface

LV	Launch Vehicle
MMST	Mechanical Model for Static Test (Alphabus primary structure model for the Static qualification test)
Notching	For Sine analysis or test, the notching consists in limiting a system response to a design or qualification value. It has for effect to reduce the drive level at System I/F.
QS, QSL	Quasi-static, QS Loads
Satcom	Telecommunication Satellite
SL, SC	Satellite or Spacecraft
SM, RM, AM	Service, Repeater, Antenna Module
S/S	Subsystem (any element, unit, appendage of the Satellite, …)
System	Satellite
SRS	Shock Response Spectrum

6. REFERENCES

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[R2]	ARIANE 5 ECA/ ALPHABUS SINGLE LAUNCH COUPLED LOADS ANALYSIS REPORT N° 2307/04 - AE/DP/SY/ES
[R3]	Alphabus CDR dynamic analysis – July 2007
[R4]	Arianespace customer seminar – April 2006 HSS-3 Improved fairing, Horizontal Separation Subsystem Improved Payload Adapters Systems
[R5]	Local damping identification from spacecraft sine test. G. LADUREE, R. REDONDO 10th European Conference on Spacecraft Structures, Materials and Mechanical Testing Berlin, Germany, September 2007