

OHB System's Propulsion Achievements - Heritage and Prospects

Markus Peukert

Head of Propulsion Systems Department

OHB System AG

Universitätsallee 27-29, 28359 Bremen, Germany

markus.peukert@ohb-system.de

Abstract

OHB-System has become a new actor in the field of propulsion systems. The development of its first Hydrazine propelled satellite bus SAR Lupe in 2001 marked the entry in the field of propulsion. This heritage design has been constantly improved and has set the basis for a new type of monopropellant standard system. In parallel to the Hydrazine system the Small GEO platform was developed. Since foreseen for geostationary applications its chemical propulsion system is based on helium pressurised bipropellant technology and equipped with electrical propulsion systems. Already the earliest OHB's propulsion systems do not follow the classical approach, special features and unusual design approaches have been followed with the goal to make it better.

This paper will give a brief overview of the heritage projects and discuss special achievements of those systems (e.g. SAR Lupe, SmallGEO), present the specifics of ongoing projects (e.g. Galileo, Exomars Trace Gas Orbiter, MTG, EDRS, Heinrich Hertz) and will derive hereof the demand for future systems. The achievements and improvements made in the mentioned systems will be described. On the technical side these are new design features on platform, subassembly or equipment level resulting in an improved performance, robustness or cost effectiveness of the platform.

To mention the most important, OHB's view of the needs for a passivation assembly, an electric helium regulator for a chemical propulsion system, an Orbit Control System versus a Reaction Control System for hydrazine platforms will be discussed. This simplification of mission requirements will enable the reduction of redundancies, resulting in increased costs efficiency.

An outlook for the needs of future propulsion systems based on the trends observed by OHB-System will be given.

Apart from the purely technical view also improvements in the management approach will be discussed. Here it is of importance how the interface between platform and the propulsion subsystem is defined, in particular the degree of platform level involvement for the subsystem tasks. A brief discussion of the known approaches and its implications to the management of the interface and associated documentation, i.e. URD/TRD vs. Procurement Specification will highlight potentials for cost savings, but also mention the risks.

1 Introduction

Last year OHB System has celebrated its 30th anniversary. The company has grown up from a small business with involvements in multiple projects of various fields, e.g. design of manned space experiments, service provider for space based services and contributor to a wide variety of well known space development and research projects.

Just in the recent years the focus was set to the development and manufacturing of satellites and its platforms. Starting with small satellites, as Bremsat and SAFIR, the satellite size as well as their attitude and orbit control needs have increased over the projects. So, today propulsion systems of all kinds are in use being individually optimised for the different project needs. Namely chemical propulsion systems for mono- and bipropellant, electric propulsion systems using xenon thrusters and finally cold gas propulsion using xenon are being employed in OHB satellites. For future applications more sophisticated propulsion concepts are under study and being prepared.

2 Recent and Actual Propulsion Systems

2.1 SAR Lupe

SAR Lupe marked OHB System's entry into the field of propulsion as it was the first OHB Satellite equipped with a propulsion system. The SAR Lupe satellites form a constellation of a few spacecrafts in Low Earth Orbit. To maintain the orbit and support AOCS needs, these satellites rely on hydrazine monopropellant propulsion, the subsystem is depicted in Figure 1.

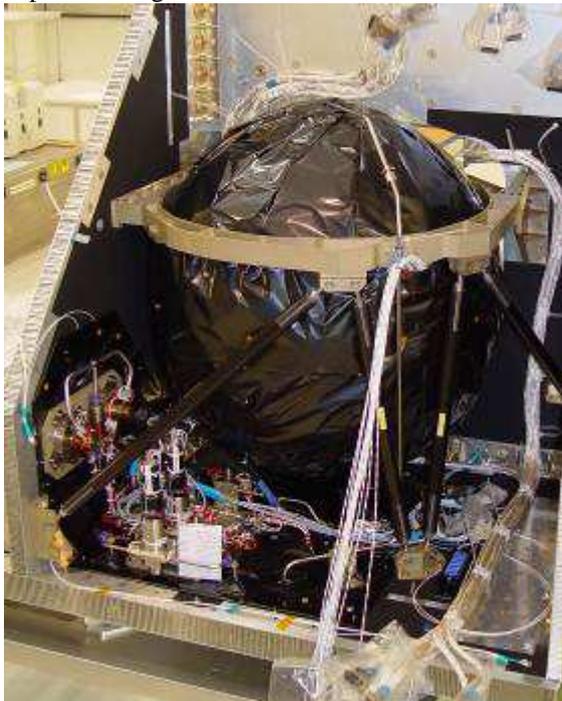


Figure 1 STM of SAR Lupe OCS

Due to the unusual functionality of the propulsion system the propellant demand was comparatively low. We call it an Orbit Control System (OCS) to distinguish from the commonly used Reaction Control Systems (RCS). Its purpose is solely to perform orbit manoeuvres. All other typical propulsion functions are taken over by other actuators as part of the AOCS. This limited functionality allows to simplify the system to the maximum extend. A small diaphragm tank and 1N thrusters were sufficient to support the nominal lifetime. Due to the requirement of supporting orbit manoeuvres only, the number of thrusters could be limited to two and still providing redundancy. This restriction also allows operating the thrusters predominantly in a long pulse mode. Herewith the total number of pulses could be reduced relaxing thruster lifetime requirements. Obviously the

thruster's total throughput becomes an issue in such a configuration. With the mentioned measures also this requirement could be satisfied.

Typically for hydrazine systems, the launch site safety requirement of three safety barriers against spillage of propellant results in having the problem of priming the system whilst avoiding the adiabatic decomposition regime of hydrazine. OHB System has solved it by using slow acting motor driven ball latch valves. Those were specifically developed and qualified for SAR Lupe. Since then the design of those valves was constantly improved to strengthen their advantages. Consequently, nowadays the ball latch valves are in use also in further European built propulsion systems of other satellite primes.

OHB System took the responsibility of the subsystem development, design and qualification. Manufacturing was subcontracted to a supplier. This work share strongly supported the employment of the above mentioned special design features.

2.2 Galileo FOC

In contrary to the SAR Lupe system, the propulsion system for the 22 Galileo Full Operation Capability satellites was subcontracted as subsystem to a supplier. Nevertheless also here OHB System consequently has evolved its design, based on the experience of previous systems. Here, due to the high number of spacecrafts and high manufacturing rate the concept of a mechanically separated propulsion module was established. The module includes also thermal hardware, brackets for e.g. tank and thrusters and related harness. This eases the integration of the propulsion module into the satellite tremendously - an important feature to comply with the tight satellite integration schedule. A more detailed description of the Galileo FOC propulsion system is given in a dedicated paper [1].

2.3 SGEO Platform

The SGEO platform in its initial intention was started as a full electric propulsion (EP) system platform. Due to shortage in availability of the direct GEO launchers at that time a chemical propulsion (CP) system was added to the platform leading to its actual configuration. Therefore the CP system is used for the GTO to GEO transfer only, the on-orbit control for the full station lifetime is taken over completely by the EP system.

On one hand this concept has relaxed several requirements for the CP system, but on the other hand a completely novel concept and design for the EP on-orbit propulsion has to be developed. It resulted into the following concept for CP:

- Bipropellant (MON and MMH) 400N Liquid Apogee Engine supported by two times four 10N Reaction Control Thrusters
- Propellant stored in 2 propellant tanks mounted atop of each other in a central tube
- Pressured regulated system using helium in two high pressure vessels
- For fulfilment of the debris mitigation requirements a passivation assembly is included. This is foreseen to vent the helium pressure after completion of the chemical mission.

The EP concept is as follows:

- 4 HEMPT thrusters of 44 mN thrust each
- 4 Hall Effect Thrusters (HET) of 75 mN thrust each, for redundancy reasons since the HEMPT is a new technology development
- For orbit control (de-tumbling) and wheel unloading reasons eight xenon cold gas thrusters with 50 mN thrust each are used.
- All thrusters are supplied with xenon stored in two newly developed xenon high pressure tanks.
- The pressure regulation is performed by a newly developed electric xenon pressure regulation assembly. This assembly is capable of controlling the low flow for the HEMPT and HET as well as the comparatively high flow for the xenon cold gas assembly via means of a bang-bang algorithm.

Especially the EP propulsion system of SGEO has enabled OHB System to acquire unique experience and push forward this concept with the goal of developing a full EP geostationary satellite bus for the near future.

For more advanced description of especially the EP system of SGEO it is referred to [2].

Actually derivatives of the initial design are under development considering a wider integration of the chemical system into the on-station mission. Therefore different variations of the SGEO bus are actually being developed (at different development stages) and underlines its high versatility, e.g. for:

- SGEO/Hispasat as described is equipped with CP for transfer, EP and Xenon CG for on-station
- EDRS is equipped with CP for transfer and on-station
- MTG is equipped with CP for transfer and on-station, but employs modifications on platform level wrt the SGEO bus to satisfy specific MTG mission requirements.

- Heinrich Hertz to be equipped with CP for transfer and on-station. The high delta-v manoeuvres on-station are performed by EP.

2.4 Exomars Trace Gas Orbiter

In contrary to the chemical propulsion systems for the SGEO platform the Exomars orbiter reaction control system (RCS) is of very complex nature due to its demanding mission. So, main engine boosts are required throughout all phases of the transfer flight to planet Mars, early after separation from the launcher until the Mars Orbit Insertion burn (MOI). In consequence the chemical propulsion system including the pressurisation assembly and the main engine supply are active throughout the complete transfer time of roughly 7 months. Hereof several requirements in comparison to a standard GEO satellite application have been adapted. Such are:

- The pressurisation assembly including a mechanical helium pressure regulator and check valves are in use for 9 months instead of 2 weeks as for a GEO satellite
- The main engine valves are in contact with propellant for the complete transfer time.
- The long telemetry signal delay has increased the need for a higher degree of autonomy, resulting in increased FDIR and redundancy requirements
- An initially foreseen launch from the US has resulted in a different interpretation of the 3 barriers against propellant spillage for ground safety rule.

To satisfy all those needs the propulsion system is equipped with:

- Bipropellant (MON and MMH) 400N Main Engine supported by 20 10N Reaction Control Engines
- Propellant stored in 2 propellant tanks mounted atop of each other in a central tube
- Pressured regulated system with redundant pressurant control assembly, using helium in two high pressure vessels
- A pyrotechnically valve ladder to subsequently open and close the high pressure helium supply
- Helium latch valves upstream of the propellant tank for improved isolation against propellant vapours migration
- Propellant latch valves upstream of main engine for improved leakage protection

As for some of the monopropellant systems, OHB System continues its way of taking over the subsystem responsibility for the propulsion system.

For the Exomars Orbiter a work share with the supplier was negotiated to strengthen assets of both parties. OHB System takes over the responsibility for development, design and verification of the subsystem and was supported by its supplier in all MAIT activities, the manufacturing design and the equipment procurement. Especially the supplier's established procurement chain for those propulsion equipment has secured the very tight project schedule and ensures a launch in 2016.

Simulation and Analysis Capability

Since OHB System is responsible for the subsystem engineering this project has boosted the build-up of our analysis and simulation capability and tools. Standard propulsion analysis tools as ECOSIM Pro were in use already before this project, but all the specific tools for detailed propulsion system performance simulation and prediction were improved, some even specifically developed for this project. This includes tools for determination of interactions with space environment, including plume effects analysis.

EVM Test Campaign

A special feature for the development work is the performance of a quite comprehensive test campaign. This so-called Engineering Verification Model (EVM) test is necessary to verify the compliance with the Exomars mission requirements. The test campaign will include tests for validation of the Pressurant Control Assembly and the Propellant Isolation Assembly. As such cross coupling tests for interaction of pressure regulator and check valves are foreseen as well as pressure loss tests with real propellant to ensure a precise determination of the main engine trimming to ensure a high accurate Mars Orbit Insertion manoeuvre. Unlike a standard GTO to GEO transfer as being split into several burns, here on Mars one manoeuvre only with considerable long burn duration is performed. This manoeuvre needs to be precisely pre-determined. The paper [4] gives more insight into the general Exomars Orbiter propulsion system. Also a flow schematic can be found there.

3 Trend - Future expectations

3.1 Overview

It is obvious, the cost pressure for new projects will persist. Consequently the space industry has to adapt and employ measures for cost reductions.

On one hand future developed technologies offer this potential. Applying new technologies generally will increase the costs in the first instance, but if successful in the long run cost cuts become possible. Electric propulsion bears the potential for such a technology. Also on lower level, i.e. at equipment level developments are under way targeting in this direction. Some of them will be discussed below.

But also the work organisation offers potentials for cost cuts. It is the authors belief that here the significant steps forward can be made. It will be discussed in paragraph 3.3.

3.2 Technical Needs

3.2.1 Gauging Needs

The combination of chemical with electrical propulsion technologies has resulted in the need for high precision gauging techniques for the chemical section of the propulsion system. This is a direct consequence of the reduced on-orbit chemical propellant demand for those systems since the goal to determine the instance to de-orbit within a certain duration accuracy, typically a few months, remains unchanged. Due to the reduced propellant consumption within the specified remaining duration significantly less propellant is consumed, thus the gauging methods have to improve their accuracy accordingly to ensure the reliable determination of that same duration. To satisfy the above mentioned requirement an achievable gauging accuracy of 1 to 2 kg per propellant tank are beneficial. Of course the introduction of a high precision gauging technique shall avoid or at least minimise adverse effects on mass and reliability.

Employing those high accuracy gauging techniques to systems being equipped with chemical and electric propulsion will simply preserve the status of today in terms of accuracy of remaining lifetime. Only when employed to full chemical systems an advantage in increased useful lifetime due to a reduced propellant inaccuracy will be obtained. Thus, only for full chemical systems a cost benefit may be achieved.

3.2.2 Passivation for Debris Mitigation

Mitigation of space debris is a hot topic today. Triggered by some incidents in the past, this topic has been arrived in the community. ESA has reacted by issuing a recommendation and nowadays even places specific passivation requirements in its specifications. It is common sense that the helium high pressure supply of pressurised bipropellant

systems shall be passivated by releasing the pressure. Nevertheless, the details for passivation the propellant section are still under discussion. Here actual OHB System projects as SGE0 or MTG are at the forefront of setting these details.

To simplify the helium passivation process as well as having additional options for performing the propellant passivation OHB System together with its supplier Bradford-Moog has initiated the development of a dedicated passivation valve. This valve shall specifically be developed to perform the venting process in an easy, reliable and cost efficient way.

3.2.3 Simplification of Systems

When evaluating historical failures of space missions it becomes evident that the propulsion system is a significant contributor. When comparing insurer data [5] as in Figure 2 and taking into account that the high failure rate of solar arrays is linked to a specific and untypical effect in the years 1998 to 2001 the propulsion system is the major contributor to failures originated by the platform.

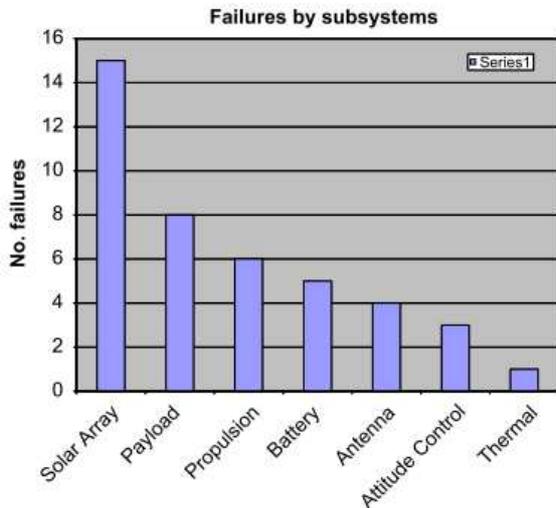


Figure 2 Insurer data of failures of GEO platforms from a total of 219 spacecrafts. The reference points out that the high failure rate of solar arrays is attributed to unique effects linked with specific problems of the BSS702 platform - 9 -[5].

Typically the consequence is drawn to increase redundancies for better protection against possible failures. As result propulsion systems for equal applications have become more complex over the last decade, e.g. by applying redundant pyrotechnical valves for the normally close path, redundant branches to thrusters isolated by latch

valves or even adding the latch valve to the thruster on equipment level. Also monitoring equipment, e.g. pressure transducers or thermistors have been applied in redundant configuration. As a result first of all the complexity, testing effort and the price have increased. But did those efforts really result in lower failure rates of satellites?

In any way it is important to examine the failure probability of an equipment by a thorough assessment of its design. Here very carefully it has to be distinguished between the designs of different suppliers as those will result in different reliability estimates. Well-designed equipment may even allow reducing redundancies on unit level.

Another approach to reduce the likelihood of propulsion system failures do exist. It is the simplification of the propulsion system by simplifying its operational requirements. This approach OHB System has chosen for its OCS (Orbit Control Systems). The limitation of the propulsion system to orbit manoeuvres, excluding most of the attitude manoeuvres have resulted into a very simple propulsion system for the LEO application, as used for SAR Lupe and follow on systems. This idea will be followed and consequently further developed.

Hereof resulting as an immediate need is a monopropellant thruster in the 1N range (or higher), qualified for high throughputs when applying long pulses and designed for high reliability.

3.2.4 Electronic Pressure Regulator for Pressurised Chemical Propulsion Systems

Electronic pressure regulators have become standard equipment for pressurising xenon electric propulsion systems. Nevertheless, its use for helium pressurised bipropellant systems until today is very seldom which might be linked to the higher flow demand and the effort of sealing helium at the high operational pressure of typically 310 bar.

However, such a regulator will add some benefits to a propulsion system as:

- Modifying the system mixture ratio by adjusting the tank pressure. Herewith the dynamic part of the residuals could be minimised
- Offering robustness for failure cases having resulted into a massive de-trimming of the system or the thrusters.
- Enabling high accuracy gauging techniques based on the foreign gas injection technique

Unfortunately also drawbacks are linked with this equipment:

- The system reliability is affected since the helium supply is sealed by latch valves for the entire lifetime only and not by pyrotechnical valves, resulting in a much lower leakage rate as traditionally concepts foresee.
- Depending on the size of the cavity volume pressure oscillations are introduced in the feed system with potentially detrimental effects to the thrusters pulse accuracy (depending of their operation mode).
- An active control has to be ensured throughout the lifetime, also in failure cases. In contrary to a mechanical regulator additional resources in the avionics section of the satellite are required.

OHB System will monitor the ongoing developments closely to adapt this technology once readily available.

3.2.5 Full EP

In the beginning of the SGEO project OHB System has already performed extensive trade-off studies to demonstrate the advantages of an all-electric propulsion system [6].

The following recommendations were formulated:

- Technically and under the assumption of increasing launch opportunities, the direct-to-GEO scenario offers the most effective and flexible solution and allows the most competitive satellite product.
- The major benefit is seen in the simplicity and flexibility of the S/C. The compromise of launching S/C designs, optimised for GTO injection, without making use of the design advantages offered for direct GEO injection designs is commercially not promising.
- The use of an external tank module or additional separate transfer module, as well as pure EP transfer may be promising concepts to achieve a GTO capability for SGEO in a modular way.
- The development and availability of launchers has to be carefully evaluated on a risk management basis for a final decision.

The above-cited findings from the OHB study, performed 5 years ago, are still valid today. With this in mind recently the Full EP configuration based on the SGEO platform was investigated in more detail. The purpose is the development of a highly

competitive product for space propulsion applications.

Several thruster concepts and configurations with the resulting implications for mission, AOCS strategy and affected other subsystems are investigated and updated, now with the experience gained during the development of the SGEO platform. The variant shown in Figure 3 foresees four electrostatic thrusters mounted on two gimbals, placed on the north and south panels of the spacecraft. These thrusters provide station keeping operations. The orbit transfer is performed using two thrusters (two additional for redundancy). The trades are still on going, so the final configuration is not yet found.

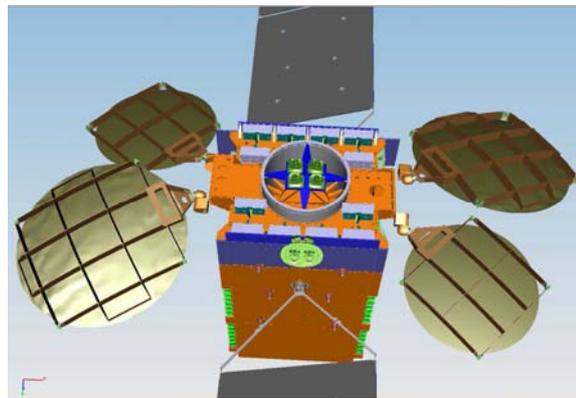


Figure 3 Conceptual view of SGEO with Full EP

3.3 Improved Work Organisation

Since a propulsion system is typically spread over most of the structure in a satellite platform it necessarily interacts with and has many interfaces to other subsystems. Its functionality, performance and other limitations have a severe influence on the platform and satellite design. For a typical GEO bipropellant system interactions are given with:

- Mission design, AOCS concept
- Structural concept and accommodation
- Mechanical loads
- Thermal design
- Power, data handling and commanding strategy
- Software design
- FDIR, Safety and Reliability
- Plume and lifetime issues
- Verification and validation at different levels

OHB System conducts projects with different degrees of involvement in propulsion subsystem

level, see paragraph 2. The lessons learnt are summarised below. A crucial point for an effective and thus financially successful project is the organisation of the interface between propulsion supplier and platform level as presented in Figure 4. The important task is the management of the interface between platform and subsystem level. Consequently it has to be ensured that requirements, interfaces and limitations placed by both parties to the other are handled, well complied and correctly and unambiguously understood. Especially the latter is difficult since both parties will talk a different language caused by their different views on apparently equal topics.

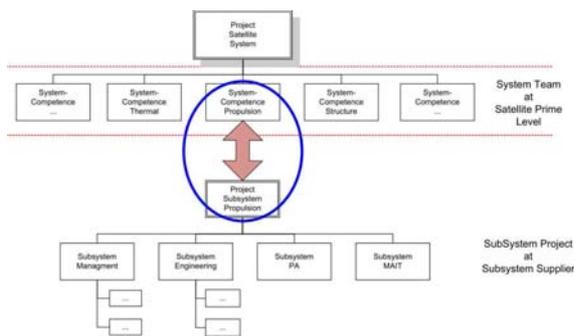


Figure 4 Interface Platform – Subsystem level.

How to organise the interface depends on constraints such as:

1. Degree of subsystem competence at platform level
2. Degree of system competence at subsystem level
3. Degree of formalism required to manage the interface between both levels
4. Available time and money to be spend for interface management

Figure 5 orders typical propulsion subsystem tasks according to its affinity to platform tasks. The number in front indicates the degree of platform level involvement (DoPI), e.g. with a degree of 10 the subsystem task is reduced to a pure MAIT work excluding any subsystem engineering. Nevertheless production engineering is still to be deemed necessary in this example. A degree of 10 shows that all subsystem engineering tasks are conducted by the platform level.

In contrary, a degree of involvement of 0 indicates the full subsystem responsibility and even the architectural definition of the subsystem are performed at subsystem level.

DoPI	Subsystem Task
0 Platform	Architecture
1 Level	Subsystem Sizing
2	Development Logic
3	Equipment Selection
4	Equipment Procurement
5	Accommodation
6	Subsystem Functional Analyses
7	Manufacturing Design
8	Detailed Analyses
9	Testing (Equipment and Subsystem)
10 Subsystem	Assembly / Integration
11 Level	Manufacturing of piece parts
12	Manufacturing of Jigs

Figure 5 Example of extreme Work Share between Platform and Subsystem Level. The numbers in front indicate the Degree of Platform Involvement (DoPI) in Subsystem tasks.

Taking these extreme examples, it is obvious that the interface between platform and subsystem level has to respect completely different information and thus has to be managed and controlled in a different way. To the first case with a degree of 10 it is often referred as build to print, a short specification and design drawings may be sufficient. Whereas to the latter with a degree of 0 a comprehensive functional specification, often referred to as User Requirements Document (URD) is requested. This case implies that the platform level has little experience and knowledge about the subsystem work. Consequently the URD cannot contain design requirements, as the architecture and the design will be established on subsystem level, described by the subsystem level in a Technical Requirements Document (TRD). To bring those two views, the platform URD view, and the subsystem TRD view together and ensure completeness of all requirements an additional iteration loop is necessary, as depicted in Figure 6 by the loops between URD and TRD.

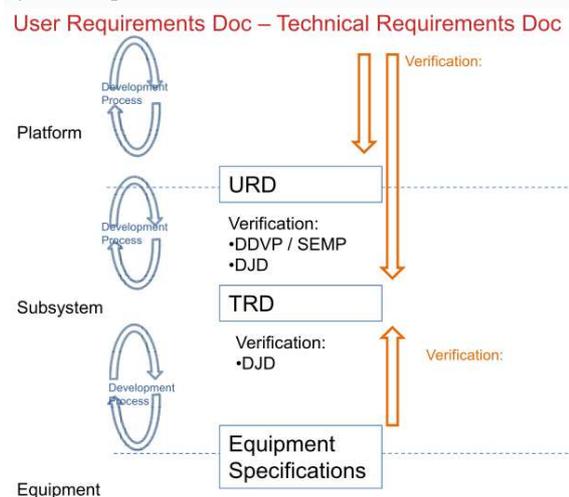


Figure 6 Complex Interface handled via URD and TRD as necessary for DoPI of 0.

Additional loops are necessary for the platform level to establish the URD, whereas the subsystem level has to iterate and develop to issue the TRD. The result is quite significant effort to be spent by both sides to manage this interface.

The Figure 7 presents the management of a simpler interface being typically applicable for higher DoPIs, e.g. 2 or onwards. The subsystem development process ranges from the subsystem level up to the platform. An interaction between both levels is essential to design the subsystem appropriately. The significant advantage is the reduced effort and associated costs to manage and control this interface. On the other hand the essential cooperation has to be performed well organised to ensure completeness of the requirements.

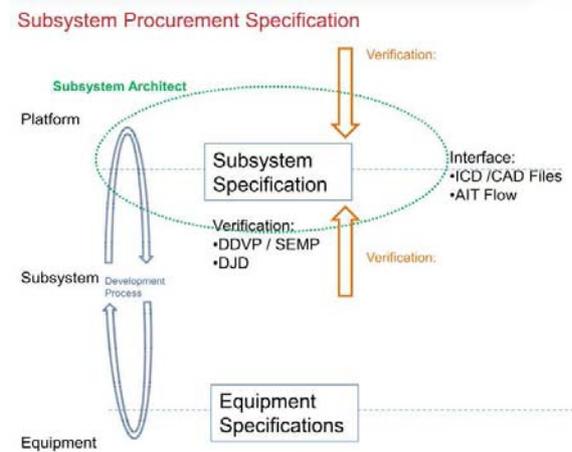


Figure 7 Efficient interface between platform and subsystem, but requires subsystem knowledge at platform level

OHB System has made experiences with both above presented extreme work shares, thus with DoPI 0 or 10. In the retrospective those projects with low DoPI were extremely extensive, in short they were a pain. Highly effective projects were run with a work share of DoPIs around 7 to 10.

At begin of this paragraph already four general constraints were named driving the selection of the DoPI. Based on OHB System's experience of projects with high involvement in subsystem design (e.g. SAR Lupe, Exomars TGO) vs. highly subdivided projects (e.g. SGEO) some lessons learnt can be formulated supporting an effective interface between both levels and thus allowing cost effective supplier management. Essential points are:

- On technical level the understanding for the needs of the other party is of utmost importance

- Openness of communication with the willingness to share knowledge
- Similar working philosophy, the same understanding how technical points need to be solved
- Similar management, risk and cost assessment philosophy
- Flexibility and responsiveness

In purely commercial projects it is easier to achieve the above outlined ideal situation - associated to institutional projects are quite often political constraints, which of course have to be satisfied in addition.

A high DoPI bears a major drawback. Aside of taking over subsystem level tasks it also takes over the responsibility for the proper design. So the platform level needs significant subsystem level knowledge and experience to handle this risk in an adequate manner. The verification and validation of these tasks can only be performed correctly if all the subsystem interactions are well understood.

4 Summary and Conclusion

In a world of shrinking space budgets the pressure to remain competitive increases. Improvements with respect to the organisation of the work share between platform and subsystem level were outlined. In addition technical needs for further improvement were discussed being relevant to the space projects OHB System is involved.

Together with its suppliers OHB System will continue the described way to strengthen its capability of offering competitive products to its customers.

5 References

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