DOI: 10.13009/EUCASS2023-305
Aerospace Europe Conference 2023 – 10TH EUCASS – 9TH CEAS

CALLISTO – on repurposing an expendable reaction control system (RCS) for a reusable demonstrator

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Abstract
Since 2008, Nammo Raufoss has heavily invested into the development of propulsion systems based on Hydrogen Peroxide (H_2O_2) as propellant for replacing more toxic solutions. Based on the promising development of these H_2O_2 systems, Nammo became part of another forward leaning project in 2017 through CNES and ESA for re-purposing the same RCS (Reaction Control System) technology for a reusable launcher named CALLISTO.

In this paper a general description of the RCS for the Callisto reusable launcher demonstrator, the FCS/R, is presented. An update on the system is given together with an overall update on its components heritage. While having a reaction control system using H_2O_2 is not something novel, its application on a reusable launcher amplifies other design choices and considerations that need to go into the planning, especially design and operative issues related to the maintainability, and what scrutiny are needed to ensure that the concerns regarding reusability are accurately addressed in terms of failure detection, fault isolation, corrective action and operational verification. . These issues and concerns will be further examined and detailed in this paper.

1. Introduction

CALLISTO (Cooperative Action Leading to Launcher Innovation in Stage Toss-back Operations) is a 13.5 meter high fully reusable launcher demonstrator scheduled to make its first flights from Guiana Space Centre in the near future. The demonstrator is a multi-national collaboration that builds on the concepts, studies and experience obtained through decades of research conducted in France (CNES), Germany (DLR) and Japan (JAXA) [1]. It aims at testing and maturing technology needed to advance in the field of reusable – earth to space – transportation. The overall work sharing and the general architecture of the launcher can be seen in Figure 1.

Nammo Raufoss, Norway, became part of the project in 2017 through its green monopropellant technology to be used for the Reaction Control System (RCS) of the Callisto demonstrator. The technology, primarily being co-developed for the green RACS of the VEGA launcher family, aims at replacing hydrazine based attitude control systems with a safer and environmental friendly substitution using High Concentration Hydrogen Peroxide as a monopropellant (H_2O_2 at 87.5%), which creates only oxygen and water as bi-products. Nammo has invested substantially in the last years to support the development of such propulsion systems from both a system integrator and a component manufacturer point of view. This includes notably process qualification and development of testing capabilities for the main components as well as the full propulsion system.

The key functions needed for the Callisto RCS or the FCS/R (Flight Control System - Reaction) are pitch and yaw control in all phases of the flight from launch to landing, in addition to tilt-over manoeuvers for returning to the launch site. The performance needed for these operations suits well to the aforementioned components developed for VEGA RACS. In addition, thanks to the safer nature of H_2O_2, the technology facilitates easier ground operations before, during and after flights. The system developed for VEGA RACS is an expendable system. The focus of this paper is therefore to address the key reusability needs and changes for adopting such a system into multiple repeating flights. Key subjects to be covered are applying aeronautics principles to the maintainability of the system; re-use implications to its components as well as the needs and complexity of the ground operations at CSG in Kourou.

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There will as well be a short update on the current development status, and how close Nammo is to demonstrate green RCS reusability on board Callisto.

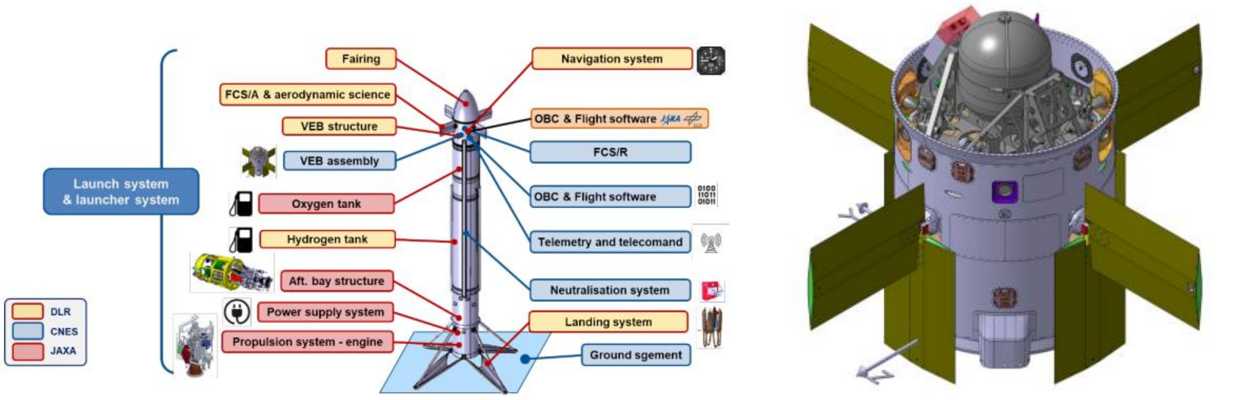

Figure 1 The overall work sharing of the project (left picture). A picture of the FCS/R structure and propulsion components can be seen in the right picture on top of the VEB (Vehicle Equipment Bay) [1]

1.1 The basics of the Nammo H_2O_2 RACS

The architecture of the Nammo RACS is shown in Figure 2, and is borrowed from Guerra et al. paper [3].

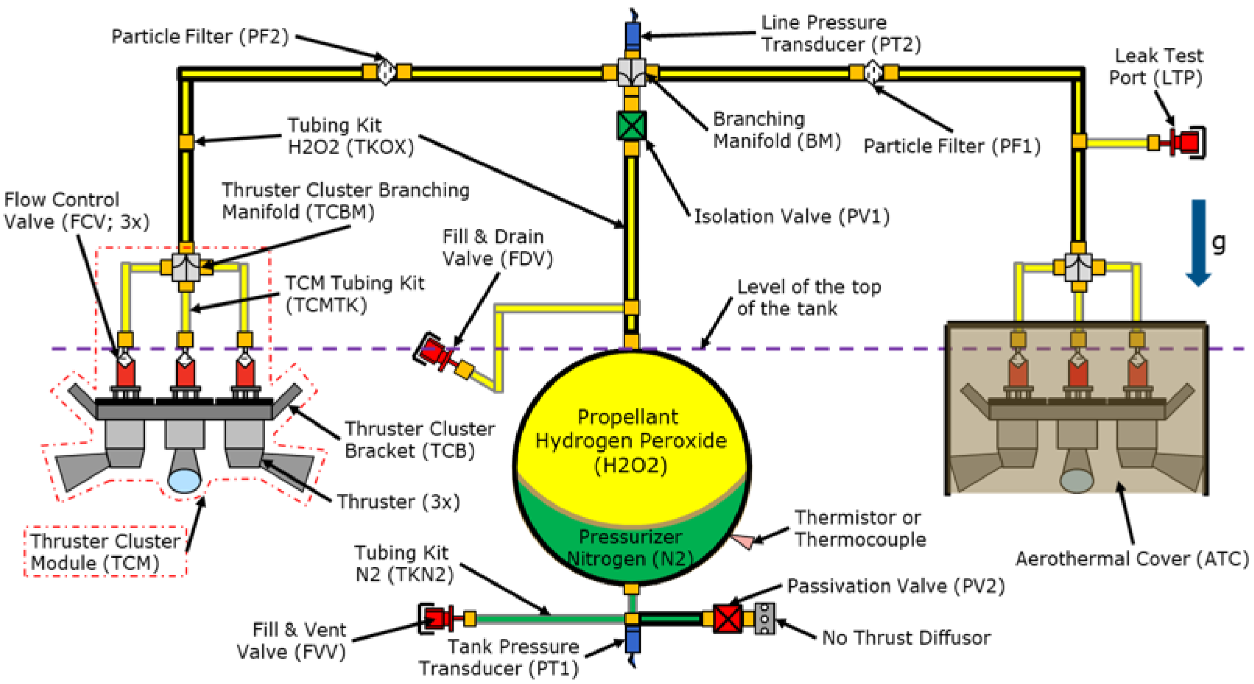

Figure 2 Schematic architecture of Nammo RACS [3]

Six monopropellant thrusters are divided in two Thruster Clusters Modules (TCM) located diametrically opposed on the outer surface . Four thrusters (two in each cluster) are needed for roll control, the remaining two are used for yaw and pitch control, as well as stage distancing during stage separation. Each thruster is fitted with a Flow Control Valve (FCV), regulating the mass flow according to the requested activation mode. An Aero-thermal Cover (ATC) envelops each TCM, protecting it from environmental agents and the aerothermal effects during the atmospheric phase of the launch.

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The thrusters are all fed from a common Aluminium Positive Expulsion Device (PED) tank, pressurized with nitrogen. The nitrogen is stored in the same tank as the propellant, leading to operation of the system in blow-down mode, with the pressure inside the tank decreasing while propellant is consumed. The tank diaphragm is used to separate the nitrogen (N_2) from the H_2O_2 and to ensure that the thrusters are fed with propellant at the correct pressure under any circumstances including high acceleration, launcher roll rate and zero-g conditions.

The thrusters are connected to the tank via a feeding system of tubing, valves and monitoring equipment. The RACS thruster is a H_2O_2 monopropellant thruster. Its design has roots back to the Nammo HGRS in the Ariane 5 ME project, and has been further developed through several maturation campaigns. Extensive test campaigns have been conducted in the past years and allowed Nammo to land on a thruster design sufficiently mature to be presented at PDR in January 2023. Since then, the thruster team effort is focused into consolidating the thruster performance and move the thruster closer to its qualification status.

Two filters (PF1 and PF2) are located on the H_2O_2 tubing, between the tank and the thrusters, to protect the downstream components from particles and other contaminants. To ensure safety on the ground, an isolation valve (a pyro-valve, PV1) completely separates the propellant from the thrusters until priming. Another pyro-valve (PV2) is used at the end of the mission to remove the pressurizing gas from the system and fully passivate the RACS at End-of-life (EOL). A set of three service valves (FVV, FDV, LTP) provides the on-ground fluidic connections required for filling, pressurizing and testing of the system.

The architecture is completed by two pressure probes (PT1, PT2) and thermistors and/or thermocouples, used to monitor the evolution of the system on-ground and during its use. The data obtained are used for monitoring purposes while on the ground, notably needed because of the propellant decomposition, as well as for post-flight analysis.

The propellant used is Hydrogen Peroxide (H_2O_2) at a nominal concentration of 87.5% per mass, the rest being water and stabilizer elements. At this concentration level, H_2O_2 is metastable and decomposes over time at a rate which depends on several factor, as temperature and material compatibility. With respect to the latter, it is paramount to select the material of the tank and of all the H_2O_2 wetted surfaces in accordance to their compatibility with the propellant to ensure the good operation of the system.

The RACS has passed its first programmatic milestone in September 2020 with the RACS subsystem PDR, following a contract signature in March 2019. In parallel, Nammo has worked on maturation work on all the different principal components. At todays' date the Tank and the Tubing and Equipment (T&E) have successfully passed PDR respectively in November 2021 and September 2022 whilst the TCM and the ATC PDRs are ongoing and their closure is expected within few weeks. An overview on the activities performed to-date and on the roadmap towards the fully qualified RACS specific system and its components are presented in [3] and [4].

Figure 3 showcase some key components and later developments of the tank build, testing, CAD model of the thruster presented at PDR and two examples of thruster PoC installed on test benches at Nammo Raufoss in addition to the DM build at the test site.

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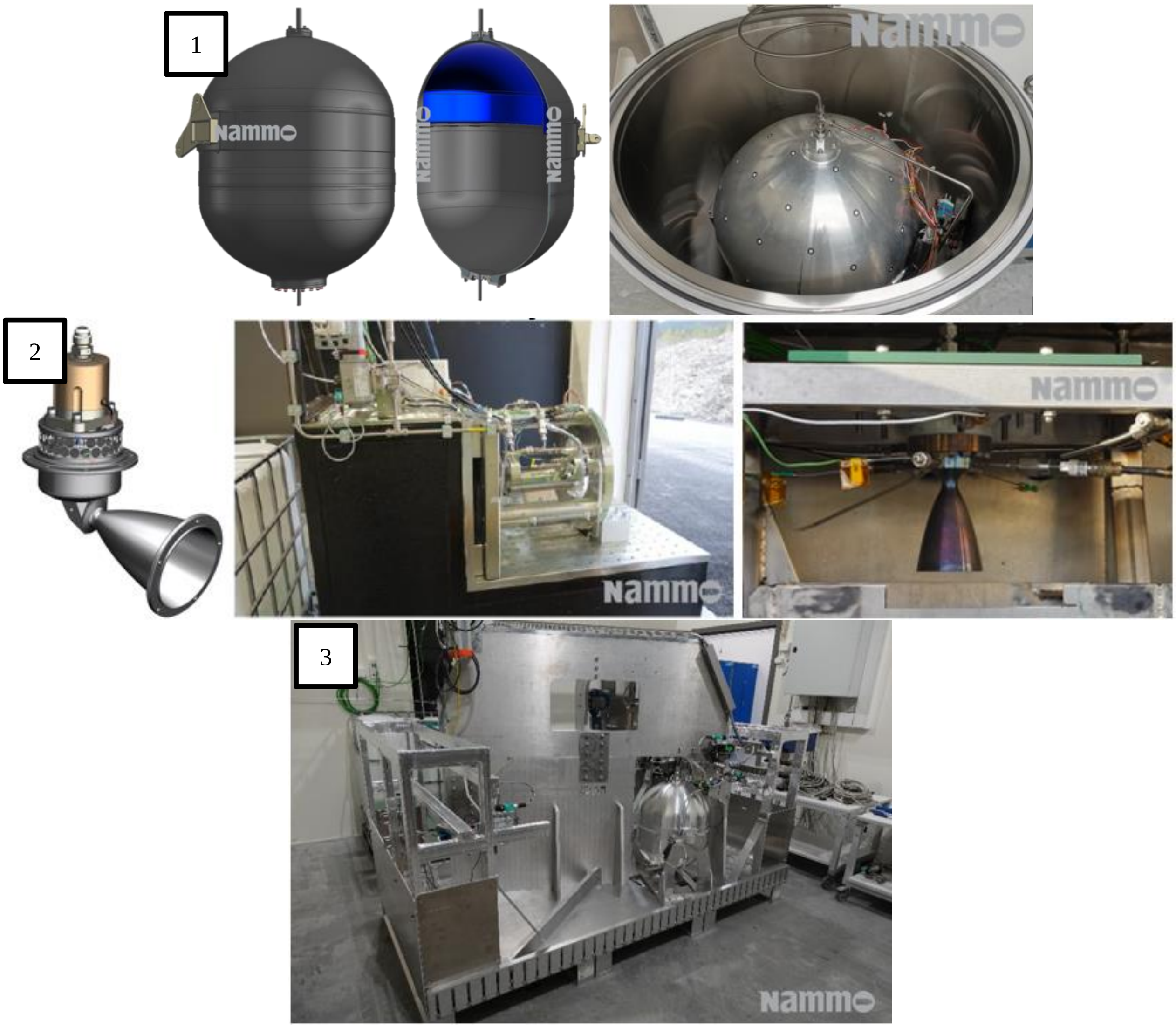

Figure 3 (1) Tank PDR CAD model (left), Tank PoC 2.1 in preparation for the external leakage test [2] (2) Thruster PDR CAD model (left), thruster PoC3 (centre) and PoC4 (right) installed on the test bench (3) RACS DM system test setup inside the test cell

1.2 General architecture of the Callisto RCS

The FCS/R system contracted for the Callisto launcher reusability demonstrator (is, as of the publication of this paper, approaching its CDR (Critical Design Review) phase, and is rapidly transforming into the manufacture phase. Only the propulsive elements are handled by Nammo, while CNES is responsible for the mechanical structures, interfaces to the VEB and the controller with the harness. CNES developed and manufactured also with Mecano ID a dummy of the full FCS/R as designed at PDR level. This dummy will be used by CNES and DLR at VEB and vehicle level to verify experimentally mechanical models.

While the project is relying on the development of the H_2O_2 system at a whole, the prompt development attitude of the Callisto project allows Nammo to transform hardware into demo flight hardware on a more rapidly scale. Using the experience from Nammo Proof of Concept (PoC) testing, Development Model (DM) testing, in addition to the experience from setting up production and testing facilities for such work [2],[3],[3],[4],[6],[7] and [8]. Enough confidence has therefore been implemented at component level that ensure their effective implementation on a system such as the Callisto FCS/R.

DOI: 10.13009/EUCASS2023-305

The current layout of the project can be seen in Figure 4. To reach the needed performance a PED-tank has been paired with 8 thrusters where three of them are mounted in 2 pairs. These thrusters are allowing for full vehicle control in terms of roll and transient compensation of the main engine and pitch and yaw control in all phases of the flight, from launch to landing. Key technical details of the FCS/R are as well seen in Table 1 and in Figure 4.

Table 1: Main characteristics of the H_2O_2 FSC/R items and system

Item:	**Tank**
Tank type	Positive expulsion tank device (PED)
Mass (incl. adapter brackets)	16.05 kg
Propellant compartment	27.5 kg nominal
Tank Expulsion Efficiency	99 %
Item:	**Thrusters**
Mass	1.45 kg
Nominal Total Impulse Delivered	>45’000 Ns
BOL Thrust - Vacuum	>200 N
BOL Thrust - Sea Level	>140 N
Minimum Isp (PMF/SSF) (Vacuum)	120/150 s
Item:	**Latch Valve (Isolation Valve)**
Actuation	Magnetic latching actuator
Mass	1.5 kg
Maximum flow rate	640 g/s
Redundancy	On/off sensor
Item:	**FCS/R system characteristics**
Minimum total impulse (vacuum) per flight	35000 Ns
Propellant	H_2O_2
H_2O_2 Concentration	85.0 – 88.0 %, nominally 87.5 %
Pressurizer	N_2 grade B
Maximum number of thruster firings simultaneously	4
Operational temperature	15 to 40 ˚C
Propellant Compatibility	< Class 1
MEOP	32barA
Acceptance Proof factor	1.5
Burst factor	>2.0
Size of the FSC/R (Diameter x height)	1080 x 810 mm
Leak tightness (Helium)	>8.33 x 10^-3 scc/s
Operational time	> 6 months
Wait time – filled and pressurized	> 30 days
Operation time per flight	> 300 sec

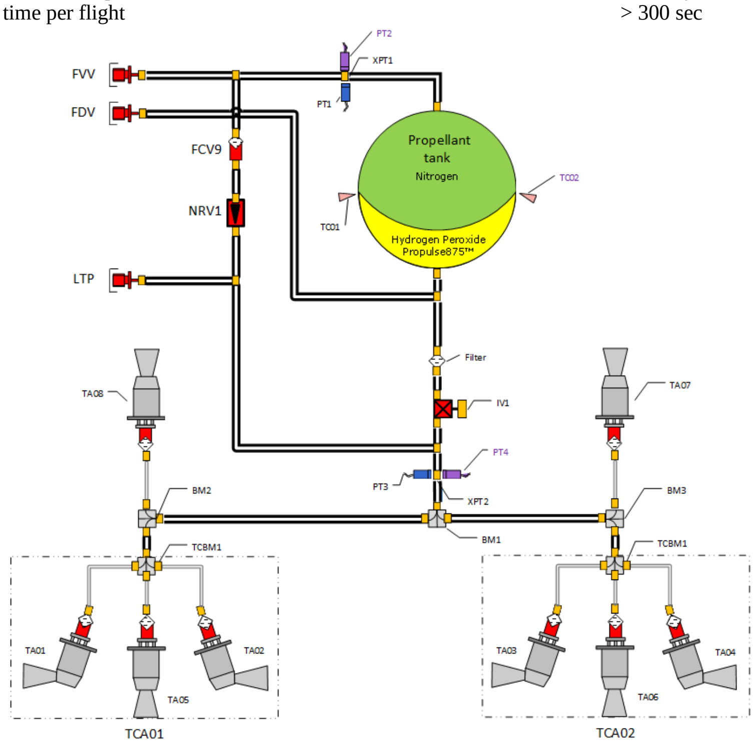

Figure 4 General schematic of the FSC/R with naming of some key components. Note: BM – Branching Manifold, TCBM – Thruster Cluster Branching Manifold and TCA – Thruster Cluster Assembly

DOI: 10.13009/EUCASS2023-305

Comparing Figure 2 to Figure 4 clear synergies can be seen between the projects as both project require many of the same base components to be operable such as the thrusters assembly (TA), PED-tank, tubing and in-line filters together with temperature probes (TC) and pressure transducers (PT). Moreover are the same architect for service valves adopted with a Fill and Drain Valve (FDV), Leak Test Port (LTP) and the Fill and Vent Valve (FVV).

In difference to RACS, there are some significant differences implemented to allow for system reusability:
- A FCV (Flow control valve) and a NRV (Non-return valve) mounted in a bypass function to allow venting and purging of the system downstream of the IV (isolation valve) instead of having a passivation valve and diffusor.
- An electrically controlled IV, that will only be opened and closed by the flight avionics when it’s active
- Filter moved upstream of the IV to avoid contamination of this valve
- Increased redundancy of PTs and temperature probes to allow a secondary system to monitor the system status when the avionic is off. (purple PTs and TCs in Figure 4)
- Tank rotated 180 degrees compared to the RACS application to allow for a lower centre of mass (COM) and more convenient emptying of the tank in between flights.
- Avoiding welding of propulsive tubing parts by the using of Permaswage® fittings in conjunction with AN-connections (AS4395 fitting ends, flared) to ensure a leak tight system that are replaceable at key locations.

The a more detailed general architecture of the FCS/R can be viewed in Figure 5.

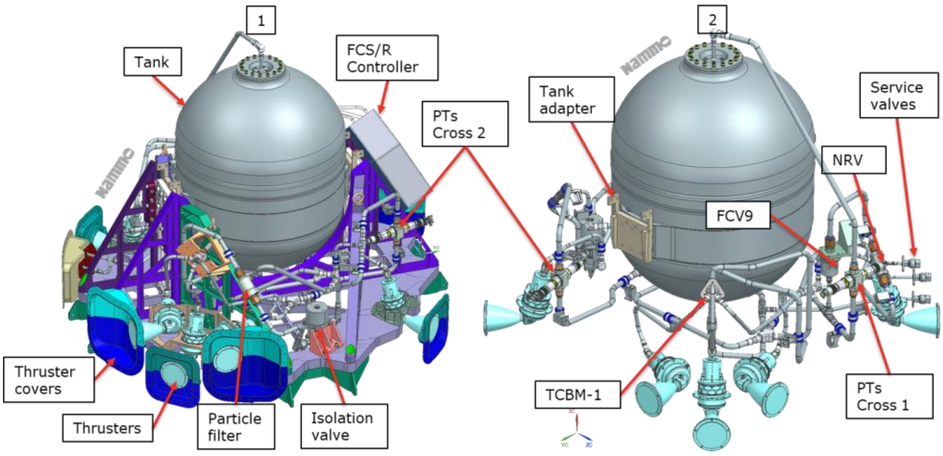

Figure 5 (1) Overall CAD of the FCS/R placed within the structural support and (2) The propulsive elements of the FSC/R – which is the Nammo scope. Some key elements of the systems is marked in the figure

1.3 Callisto RCS status

As of the date of this paper, the design has more or less been frozen towards the CDR, with components reporting to move toward production. The isolation valve, developed simultaneously on a separate ESA contract for a first application on Callisto, completed PDR march 2020, and are on schedule to complete testing and hardware delivery soon.

The FCS/R structure, while originally a Nammo scope, was contracted by CNES to a company named Mecano ID, and accomplished PDR in March 2022. The overall propulsive system of the FCS/R conducted its PDR in November 2020, and has been later supported by a wide array of test data as described in section 1.1. The FCS/R controller has been developed by KN system under CNES responsibility with a flight model near completion.

The layout of the ground support equipment (GSE) is as well moving forward, being a significant scope of the development of the FCS/R and could in fact be assigned to a paper by itself. While Nammo has not only undertaken the task of developing and delivering a RCS system, the GSE is also part of that scope. As one of few in Europe, Nammo is conducting its own GSE work for a H_2O_2-based system which in return widen the scope significantly. Nevertheless, based on experience from the Nucleus sounding rocket, FLLP4 Large hybrid engine development and RACS [2],[3],[3],[4],[6], [7] and [8] a lot of ground operation and testing experience is available leading to an efficient development process of this equipment.

DOI: 10.13009/EUCASS2023-305

1.4 Callisto RCS boundary and operation

The Callisto launcher will operate out from Centre Spatial Guyanais (CSG) in Kourou. Here a dedicated site has been developed by CNES [9], as seen in the leftmost illustration in Figure 6. While launching out of CSG poses few new developments in terms of operation limitations, the repetitive flights, quick turnaround and environment in CSG impose demanding limitations.

While the flights of Callisto poses few extremes in the world of rocket engineering in terms of height, speed and power, the FCS/R will more or less operate constantly under what we can term an high energy environment in terms of constant vibration, shock and temperature shifts.

In addition, the nature of the FCS/R component must be completely understood. While a flight scrub is certainly less demanding than a full flight, it will itself encompass temperature shifts, cycling of valves and pressure cycles that need to be considered for the operation of the system.

These situations are not new to the industry, but what makes the FCS/R different in this instance is that it mostly encompass heritage components developed for the purpose of system seeing a high energy environment (one flight) and a limited amount of cycling both mechanically and environmentally. These limitations need to be carefully assessed when implemented in a reusable system, and have a significant impact on operations.

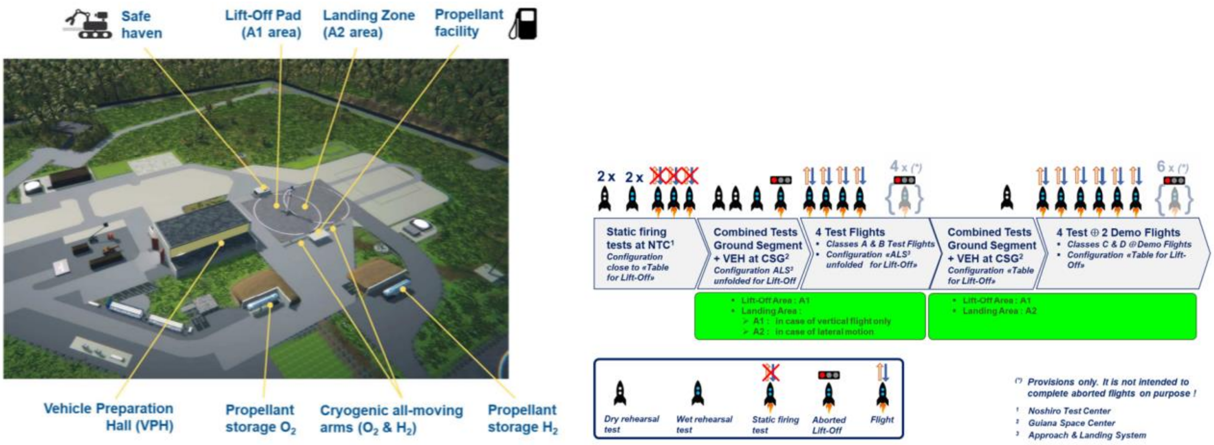

Figure 6 The overall launch site (left) and the Callisto life cycle (right) [9]

2. Philosophy of reusability

The main principals of the FCS/R design are constrained both of it encompass of non-reusable components and the limited space inside the VEB of the launcher demonstrator. Other constrains worth mentioning are the need for a rapid turnaround time, ability to change certain components conveniently (corrective operations) and easy inspections of equipment status.

Given the aforementioned constraint the four main task of maintenance must take place, namely (1) Failure detection, (2) Fault Isolation, (3) Corrective action and (4) Operational verification.

These again would lead to planned, preventative and corrective actions for each given components of the FCS/R, which need to be assessed correctly for a system which originated from a non-reusable background and therefore has its inherit aged limitations and usage based on this design philosophy. However, what is often beneficial for system being planned for one time usage without any means of post inspection or part replacement (European heritage launchers) is that it requires high attention to the production processes, post production inspections and significant margins on issues impacting the component lifetime.

Space qualified components under the governing rules of the ECSS (European Cooperation for Space Standardization) ensure a level of quality from parts production in terms of facility cleanliness, material traceability, tools and inspection calibration, environmental conditions, packing and inspection processes that ensure subs-system components are on a pristine level before installation. The installation itself also entails a significant number of

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control mechanism that steer the direction of the quality. Some examples worth mentioning are requirements on hydrogen embrittlement issues in manufacture (ECSS-E-ST-32-08C), damage tolerance (ECSS-E-ST-32C) and stress corrosion cracking (ECSS-Q-ST-70-36).

This is highly beneficial for components and technologies planned to be used in a reusable application while originating from a system such as VEGA RACS. Two direct examples were this applies to: (1) the identification of fracture critical flaws and (2) material treatment to ensure best long time exposure to the propellant.

For the establishment of fracture sensitivity and in the establishment of fracture critical items list (PFCIL) significant testing and analysis work is needed to establish the correct stress states due to the foreseeable thermal and mechanical loads that a given component are expected to see. To foresee these mechanical loads which can be in the form of vibrations, shocks, reaction forces or kinematic accelerations, a long pre-study has to be conducted. As a development program, such as for instance Callisto, a lot of design changes and re-fits occur during the development process, which means a significant portion of margin has to be given to its sub-systems so it ensures that the components used will survive its operational lifetime.

While the load levels are not directly linked between a vehicles to another, such as from Callisto to VEGA, which is another launcher which Nammo is synergizing from, a down flow of the mechanical and thermal requirements on a component levels often make them comparable, or possible to linearize to an applicable level. This in return, creates an easy assessed start point for what kind of damage control which have to implement into the failure detection operations, and take corrective actions before any flaws might impose a problem when the system is inspected between flights.

Nevertheless, the opportunity of reusability imposes some new issues that are usually not considered for a one-launch item, and that seldom goes into the significant part of that system design. Namely; the cyclic swap of parts, opening and closing of connections and repetitive installation, removal of threaded connections as well as more proof tests in case of re-assuring the health of the system after opening of any pressurization components. These additional operational cycles has to be taken into account when assessing the real life potential of the system.

In retrospect, the aforementioned issues are nevertheless of a less concern when working on a reusable system as the failure modes of these components can be investigated and mitigated between flights. However, this puts a lot of pressure on the both the design and the operators as the design need to encompass the idea of inspectability, maintainability (easy replace) and tooling to perform such task. Later in the project, sufficient resources has to be allocated to ensure that maintenance operation procedures (MOP), load-cycle tracking and know how is planned to ensure that any issues are foreseen and prevented accordingly with corrective actions.

With these two considerations in mind and with a correct approach to handle maintenance related topics such as fracture sensitivity, correct establishment of load cases, accounting for cycles and critical failure assessment allow for lowering the safety factors in regards to the life cycle of the system. In accordance to ECSS this safety factor is in many circumstances set to 4, i.e. a system has to survive 4 times is nominal operational mechanical and thermal load cycles. However, by the principals of establishing when hardware is approaching its lifetime usage and by implementing efficient inspection approached, this margin can be put on scrutiny leaving components originated from a non-reusable design philosophy be more efficiently employed on a reusable system without major safety or reliability impacts.

The next sections will discuss more in details the approaches applied to the Callisto FCS/R for achieving such a maintenance philosophy.

2.1 Assessing planned maintenance

A significant part of the of the planning for a complicated system such as the FCS/R propulsive elements are to define and establish a robust input to the maintenance planning based on the life cycle assessment of each component. As earlier mentioned, this could be subtracted from COTS earlier test history, and superimposed onto the planned flights of the new system in terms of dynamic, functional or thermal loads.

While this logic is not unfamiliar from most hardware planned for a space mission, and it’s a good engineering approach overall to assess the life cycle of the components in a system, this becomes especially important for a reusable system due to two main factors. 1) There are more high energy load situations (ascend and descend). 2) Part

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replacement is often necessary as designing something for safe-life would be not cost-effective, or impossible in some instances.

As seen in Figure 7 the overall life cycle of the FSC/R are shown and it encompass the main phases of the propulsive elements. Each phase has its own load cycling, and counting these are a cumbersome but necessary task for establishing the maintenance plan. However, some limitations apply that frame this work.

For instance, up until flight, most of the cycles are solely depending on fixed amounts of specific testing and inspections that can be established with a fair degree of certainty. Like seen in Figure 8, as an example for the tank element. Moreover, since components such as the tank, are having relatively high stiffness (in terms of eigenfrequencies), and since the flight campaign loads are tenfold more demanding, the transportation loads can usually be overlooked. They will have non-detrimental effects on the components in terms of crack growth or functional cycling. Especially since such components will be protected by some types of transport container alleviating high temperature fluxation, sudden shocks or other bad handling situations. Normally this is monitored by shock recorders, and parts and assemblies are post-inspected after transport to further ensure no issues exist.

While this paper so far has mostly been concerned with planned maintenance in terms of establishing the correct life cycles, those are not the only data necessary to be established to plan the required preventive maintenance. Other examples worth mentioning are the establishment of filter dirt accumulation, leakage rate budgeting, corrosive calculations and decomposition rating of fuel that are all not directly classic NDT (non-destructive testing) parameters from an aviation point of view.

For example filter limitation not a new function to an aerospace system. However the significant longer propellant flow through, its non-reusability heritage and the sensitivity of space rated propulsive elements to cleanliness makes this though a significant aspect of the maintenance planning.

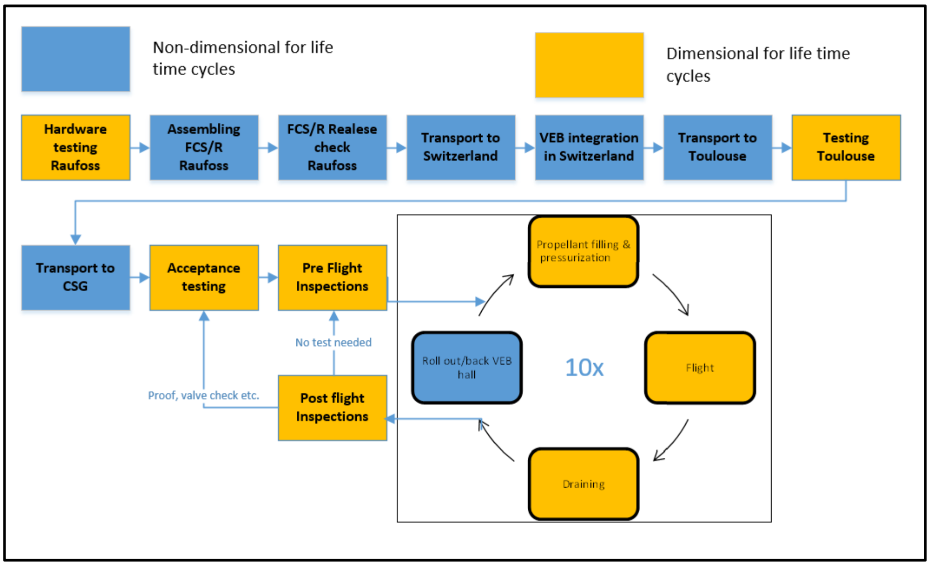

Figure 7 Overall life cycle for the FSC/R propulsive elements for the Callisto launcher

DOI: 10.13009/EUCASS2023-305

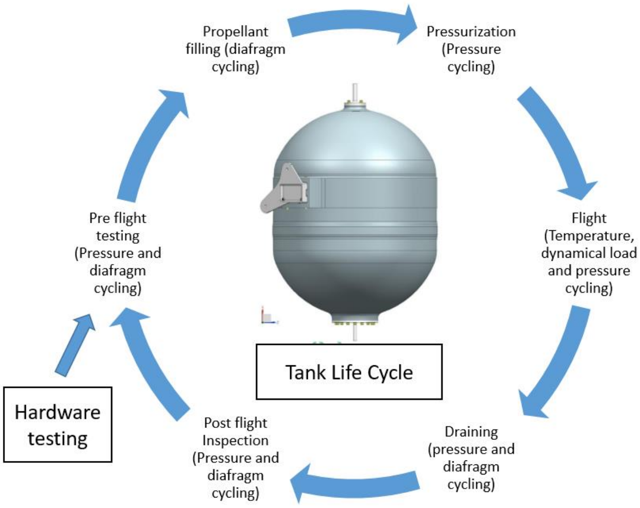

Figure 8 Illustrative assessment of the total Life Cycle for a FCS/R component: Tank

2.2 Preventive maintenance of the FCS/R

Establishing the parameters for the planned maintenance is necessary, but not useful without the preventative maintenance planned. Procedures for inspection and testing have to be established to ensure that the FSC/R components are performing in accordance with the plan. We need to start by defining the characteristics deemed necessary for replacement before a performance drop or functional loss is established. Examples are such as a failed valve seats or a leaking tube section. Significant work is therefore being done to correctly assess the status and effective procedures to maintain that status on the critical components.

The precarious components deemed for higher inspections could be established from several approaches such as the total exposure rate to the propellant, crack growth propagation based on the local stress levels or potential critical leakage points.

For mechanical inspections, and especially in terms of crack growth, it is important to establish robust models that give valuable input to the operators of the system. While ideally, mechanical components should not incorporate cracks, this is in reality not possible due to the nature of most materials and their processes. Therefore, realistic maximum crack sizes have to be established that can be easily surveyed by NDT in places that are identified as critical.

The aforementioned paragraphs describe typical predictive maintenance that must go into the determination of the condition of the system. However, it is not only limited to crack growth. Effective procedures, checks and inspections needs to address other operative issues. For instance, leakage tests need to be performed to test if the system is still sealing correctly, something that would be especially important when components are changed, and would even require a proof cycling. Critical places need to be inspected for damage effects, corrosive effects and leakages. Plans must ensure that contamination levels of the system are within the limits, and functional checks performed to check that valves are acting as to their minimum specified performances.

Other foretelling methods that could be incorporated are indirectly indication readings obtained through flights. While Nammo does not control the flight acquisition system, data should be available to indicate dynamic pressure differences in the system as shown in figure 2 between the up and downstream pressure transducers (PT). This can as an example indicate that the filter is contaminated more than expected, and therefore needs replacement. Another indication that could be read is the response of the thrusters, again indicating that performance is less than specified, and therefore a more thoroughly inspection or replacement is necessary.

In difference to most launch and satellite systems that the Nammo RCS are intended for, the reusable demonstrator of Callisto set some extra constraints on the system design with the needs of such preventative and predictive maintenance actions. Critical components needs to be easily inspected while tools and methods must be defined. This

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often sets some conditions for the design, as lines of inspection with or without aid must be established and checked if they are operable in an environment such as where the launcher will operate in CSG.

Moreover, spare parts and maintenance items need to be scoped and sourced, and having an effective strategy on inspection and verifying its lifetime accurately would be important. Many components for such a project are expensive, and changing them prematurely would bear noteworthy costs.

2.3 Corrective approach of the FCS/R

While the requirements for easy inspections control the design, and even more important aspect is the need for part replacement when they are not performing to their minimum performance, or are failing prematurely. Here an approach of easy corrective part replacement and heavy corrective part replacement will be detailed, where the easy maintenance are components substitutions that can be performed while the FCS/R are placed in the VEB.

In the easy group, most minor components and components that have been established for relative rapid replacement will be detailed. Parts such as the filter, pressure transducers, and sensor electronics are for instance components that fall into this category. These parts are placed on locations that are easily available while the FCS/R is placed in the VEB, and could be swapped as part of the normal work in between flights. As seen in Figure 9, some of these locations are visible, such as the location for the filter element. While the part is easily available, a lot of care has to be taken for such maintenance as both the changed part and the rest of the system has to be effectively protected for contamination, and avoid leakage to the surrounding FCS/R parts.

For the heavy corrective part replacement this definition is used for operations that requires that the FCS/R is taken out of the VEB and made available for more access points. Parts in this group can be the tank, thrusters, tubing sections or valves that requires both stricter contamination control as well as good access to be removed and installed correctly, especially taking into consideration the strict tolerance control some of these components are requiring.

Significant emphasis is put on these part replacements for the design to allow such operations to occur as effectively as possible .Tooling needs to be revised for each setup and that there is enough elbowroom for such tooling to operate. Every component is verified for inspection access if and how they can be mounted and dismantled efficiently and without the risk of introducing any damage to the parts, and any special tools are brought forward to aid in such part installation and swapping. One example here is the need for the tank to be able to be unrestricted, and hoisted out of the structure if such a replacement is deemed necessary.

While many of the defined corrective maintenance plans are strictly following one single part, or part configuration in the system, the treatment of leakage might be slightly different. By designing for a very low gaseous leakage, the system can be said to be liquid leak tight. Measuring this in between flights are part of the mandatory pre-flights checks, however identifying where it occurs if there is a leak is not a trivial task. Using typical methods such as a pressure decay test would at best identify which sublevels the leak occurs at. However, using a helium leak detector gives the possibly to locate the leakage specifically at which connection it is occurring, which is another maintenance tool that needs to be planned accordingly.

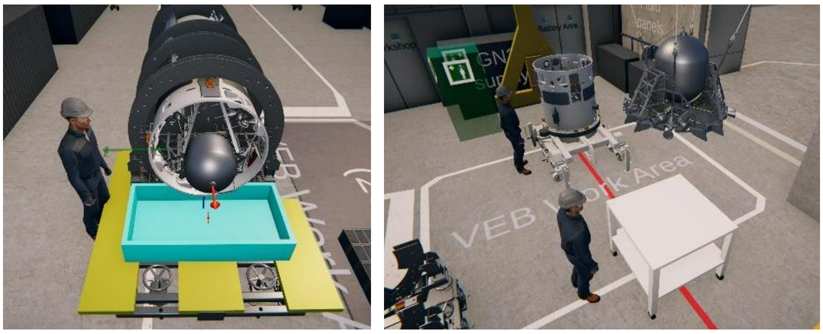

Figure 9 The FCS/R placed horizontally in the VEB (left) (for easy maintenance tasks) and while its freestanding (for heavy maintenance tasks) (right) Credit: CNES

DOI: 10.13009/EUCASS2023-305

3. Conclusion

In this paper, a general description of the reaction control system for the Callisto launcher demonstrator, the FCS/R has been presented. An update on the system was given together with information on its components heritage. While having a RCS using H_2O_2 is not novel, its application on a reusable launcher amplify other design choices and considerations that need to go into the planning for such a system, especially in regard to designing and planning for maintainability as the life cycle is different to a classical European heritage launcher

Using typical models and methods already established for the aircraft industry together with carefully assessing the lifetime limits and inspection approach of each sub-system component, a robust maintenance plan can be put forward. Such planning has a significant design impact on what components the system should use, their placing, easiness of access and changeability that needs to go into the design principles of such a system.

While components intended used for non-reusable applications are not always created with this philosophy in mind, the design of the propulsive FCS/R show that with the correct assessments, planning and verification methods, these components are well suitable for reusable applications even though they have a significant more operational time under the high energy load situations. This is in contrast to non-reusable launchers and satellite technology that often entail a “fire and forget” design philosophy that often don’t lead engineers to think for easy components inspection and replacements.

For a reusable launcher such as Callisto this is in general not acceptable as the whole launch campaign cannot be stopped for a component that cannot be replaced. Therefore a significant effort has been put forward to frame these components maintainability, finding parameters to plan their maintenance by and ensure that they are replaceable when changes are needed. This entails as well a significant focus on the spare parts, as these need to be available when maintenance actions are necessary.

By using space-rated components developed through other Nammo project, as such as planned for the FCS/R of Callisto, the aforementioned effort is easier. Through Nammo heritage and other current parallel development there exist a lot of technical and operative experience that the project can benefit in the development going forward. However care has to be taken, especially in terms of planning maintenance tasks, correctly detect failures before they occur and consider this in the design effort.

Taken all this into consideration, using a non-reusable system for reusable system is suitable when the correct approach is taken. As a bonus, since the quality and known detail level of space rated components is high, they are usually even more suitable for a long life operation in a challenging environment such as this.

Acknowledgments

Nammo would like to acknowledge CNES, ESA and NOSA for their support to this development and to Mecano ID, DLR and JAXA for their continuous collaboration and technical guidance.

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