SCHUMANN - Fostering Satellite Modularity in the NewSpace Landscape

Pierre Letier [1], Maxence Debroise [1], Andres Martin Barrio [1], Jeremi Gancet [1], Daniel Silveira [2], Carolina Serra[2], Hugo Castaing [2], Giuseppe Mistritta [3] , Ignacio Chechile [4], Minka Suomela [4], Theodor Neacsu [4] , Carsten Plasberg [5], Martin Schulze [5]

[1] Space Applications Services NV/SA, Leuvensesteenweg 325, 1932 Sint-Stevens-Woluwe (Brussels Area), Belgium, firstname.lastname@spaceapplications.com
[2] GMV, 115 Alameda dos Oceanos, 1990-392 Lisbon, Portugal. daniel.silveira@gmv.com, cpserra@gmv.com, hcastaing@gmv.com
[3] ArianeGroup Bremen, Airbus-Allee 1, 28199 Bremen, Germany, Giuseppe.mistritta@ariane.group
[4] ReOrbit Oy, Itälahdenkatu 22a, 00210, Helsinki, Finland, firstname.lastname@reorbit.space
[5] FZI Forschungszentrum Informatik, Haid-und-Neu-Str. 10-14, 76131 Karlsruhe, Germany, lastname@fzi.de

ABSTRACT

The advent of NewSpace represents a significant shift in the space industry, with transformative applications on the horizon. Orbital Replacement Units (ORU), refueling, in-space assembly, reconfiguration, and recycling hold immense revenue potential, estimated at $6 billion by 2030. This paper introduces the SCHUMANN project, a Horizon Europe research initiative aimed at advancing the modular spacecraft ecosystem. SCHUMANN pursues two key objectives: maturing functional satellite modules (FSM) and developing the Satellite Construction Kit (SCK). These efforts align with European Space Robotics grants, fostering expertise and enabling European In-Orbit Demonstrations (IOD). The project's first goal is to develop a Refuelable Tank (RTa) FSM, demonstrating late-stage integration into IOD missions. The second objective focuses on establishing a reference SCK to enhance modularity in NewSpace spacecraft, offering guidelines and norms for FSM developers. This paper outlines SCHUMANN's goals, development drivers, and initial design activities.

Keywords: NewSpace, Modularity, In-Orbit Servicing, Standardization, Refueling, Life-time extension, Space robotics, ISAM, ESROCOS, HOTDOCK

1. INTRODUCTION

NewSpace, beyond its trendy tone, denotes a fundamental transformation of the space industry and applications landscape – a deep paradigm shift, which was initiated a few years ago and operates progressively. Applications such as life extension, by means of Orbital Replacement Units (ORU), refueling, in-space assembly and reconfiguration, in-space recycling are promising New Space applications that are poised to generate in the range 6 billion USD in revenue opportunity by 2030.

SCHUMANN is a Horizon Europe research activity aiming to strengthen the foundations of future space ecosystem for modular spacecraft and the perspective of their assembly, servicing and reconfiguration in space. This is accomplished by means of two complementary developments. First, there is the technical maturation of functional satellite modules (FSM) and their subsystems for flight qualification. Second, there is the development of the Satellite Construction Kit (SCK), a set of tools, which aims to streamline the design of the FSMs in the frame of a complete ecosystem. This project aligns with the framework of past and ongoing European Operational Grants (OG) that focus on fostering the advancement of European Space Robotics expertise and technologies. The main goals of these grants are to support the development of these capabilities and facilitate their short-term In-Orbit Demonstration (IOD).

The first objective of the project targets to develop and mature a FSM consisting of a Refuelable Tank (RTa), along with a Refueling Experiment setup to support the testing and the qualification of this module to TRL-6. This task will demonstrate that a “side”, standalone module development, by following appropriate design rules and leveraging previous building-blocks developments, can be integrated at a late stage into an in-Orbit Demonstration (IOD) mission.

The second objective aims at establishing a reference “Satellite Construction Kit” (SCK), primarily to the attention of FSM builders, to guide them in the selection of components and help create a unified ecosystem for space applications. SCK target users are the manufacturers of spacecraft modules. It aims to increase the modularity of NewSpace spacecraft by establishing a set of guidelines and norms supporting FSM developers. As part of this project, the SCK will be implemented as a software tool which will facilitate the process of selecting compatible components for FSM, and ensuring that resulting "SCHUMANN certified" modules can be conveniently and effectively integrated in spacecraft of the Future Space Ecosystem.

This paper is organized as follow. Section 2: Addresses the first objective of SCHUMANN, which is centered on the development and maturation of the Refuel Tank Functional Module (RTa). This section provides an overview of the main objectives, the target mission, and outlines the demonstration strategy aimed at achieving the qualification of the system at TRL-6.

Section focuses on the Satellite Construction Kit, detailing its objectives, describing various use cases and features, and presenting the development and testing strategy for this component.

Section concludes the paper by discussing the follow-up of the activity for each of the main project objectives.

2. REFUEL TANK MODULE MATURATION

2.1 Project Development Objectives

In SCHUMANN, the Refuel Tank (RTa) module aims to implement a refuelling experiment setup relying on an evolution of HOTDOCK as a refuelling interface. The RTa will undergo qualification tests to reach TRL-6 as a target. It should be self-contained, in the sense that it may be become a candidate for late integration to short-medium term IOD mission (e.g., EROSS-IOD[(1)]).

The key objectives related to this development are:

- Mature the design of FSM as a foundation of a future space ecosystem;
- As a practical use case and example of FSM, mature the relevant technologies to TRL-6 for a Refutable Tank module, and more particularly the HOTDOCK refuelling standard interconnect;
- Implement a software baseline on top of ESROCOS framework[(2)], EC software building block robotics framework;
- Developing the TRL-6 refuelling experiment demonstrator for the RTa.
- Demonstrate the feasibility of developing FSM on track dissociated from the other activities (mainly EROSS-IOD) and make them compatible with a mission integration at late stage;

The key performance indicators for the RTa development are:

- **KPI-1.1** – Successful qualification campaign at TRL-6
- **KPI-1.2** – Fuel transfer demo with pressure level of 200 bars
- **KPI-1.3** – Securing the possibility to include SCHUMANN Refuel Tank ORU in the IOD B2/C project's final demo

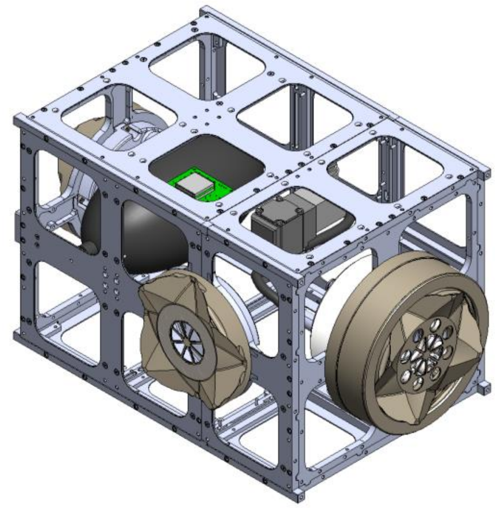

Figure 1. FSM Refuel Tank preliminary concept with HOTDOCK interface

2.2 Mission Scenario and CONOPS

Electrical propulsion systems are widely used in various space missions due to their high efficiency and relatively low fuel consumption. Such propulsion systems are employed in missions ranging from geostationary satellites to deep space missions, Earth observation, communications satellites, and science missions. Due to the large set of applications, The SCHUMANN RTa, it is targeting to be compatible for electrical propelled satellites. The nominal choice of propellant would be Xenon, as it is the standard today. However, as the price of xenon is drastically increasing, it is target for the system to be compatible for higher pressure (200-300 bars) for possible compatibility with krypton or other gaseous propellants.

As reference mission, a modular satellite is equipped with a fuel tank ORU, which is depleted – justifying a refuelling action to be carried out. As a starting point of our scenario, a refuelling servicer spacecraft is docked to the client satellite (which is required in most On-Orbit servicing scenarios). The servicer deploys a manipulator to mate with the depleted RTa ORU. The HOTDOCK refuel interface is disengaged, which free the RTa from the client S/C. The servicer S/C brings back the RTa with its robotic manipulator. Then 2 variations are possible.

2.2.1 Scenario Variation 1

The servicer S/C mates the depleted RTa on its structure (in a purposely defined location), using either the HOTDOCK Refuel interface or one of the other SI. Then a different pre-filled RTa is deployed with the help of the robotic manipulator and mated to the client S/C on its HOTDOCK refuel interface. This new tank is in place and ready to provide fuel. The refuelling operation is completed.

Variation 1 reduces servicing time, which may be important in the case of costly infrastructure (e.g., Telecom), while minimizing operational risks induced by the refuelling operation itself (actual refuelling would take place at an orbital "gas station", similar to OrbitFab model[3]).

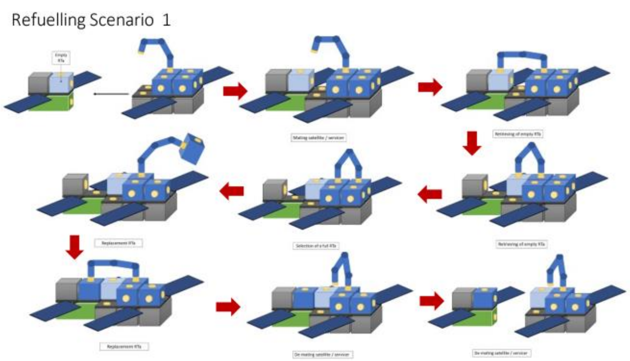

Figure 2. SCHUMANN refueling scenario 1

2.2.2 Scenario Variation 2

The servicer S/C mates the depleted RTa on its structure (in a purposely defined location), on a dedicated refuelling site (i.e., featuring a HOTDOCK refuel interfaced to a servicer supply tank). The servicer S/C triggers the refuelling of the depleted RTa. After a while, the RTa is full and ready to be brought back in position, on the client S/C. The servicer S/C brings the refilled RTa back to the client S/C, and mate it at its original location. The refuelling operation is completed.

Variation 2 doesn't require the servicer to be featured with a replacement RTa. The original RTa is reused, which some customers may find preferable.

2.3 Demonstrator

The RTa demonstrator will be derived from the flight mission architecture (see Figure 4).

As the baseline of a generic FSM module, the hardware of the RTa will be mainly based on available COTS flight components for the mechanical structure, the avionics and internal power distribution units. This will allow to perform qualification of the full RTa with vibration and TVAC testing. The interface between the module and the MGSE

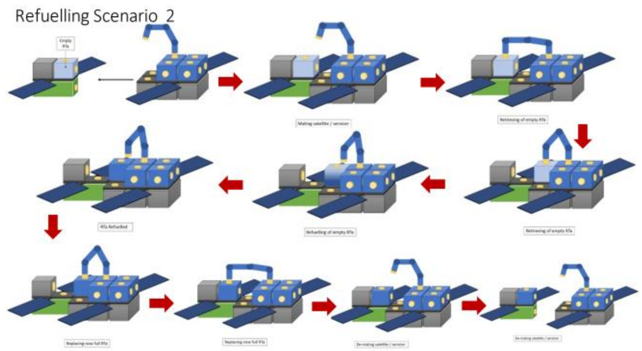

Figure 3. SCHUMANN refueling scenario 2

(representation of the servicer) will be an Engineering Model of the qualified HOTDOCK interface, in its fluidic configuration. Figure 5 illustrates the TRL-4 model, previously developed.

The fluidic subsystem will be specifically developed for the project, as a first iteration of the future flight model. It will also be based on available COTS components (for valves, sensors) compatible with the temperature and vibration testing constraints. The critical parameters such as the pressure of operation will be identical to the flight mission requirements. However, due to the costs for Xenon, it is considered to use another gaseous medium with similar properties as Xenon and representative of the application. The considered gases are Argon and Nitrogen.

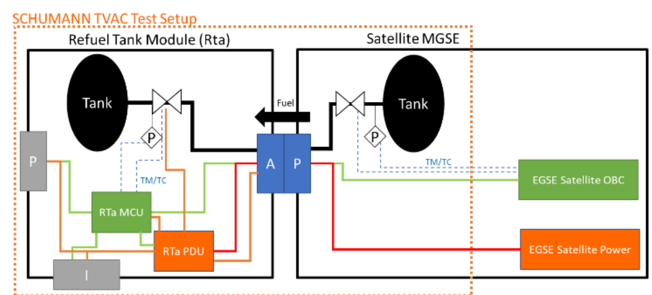

Figure 4. SCHUMANN demonstrator architecture

The RTa's software compatibility with the IOD mission relies on the use of the European Space RObotics Control and Operating System (ESROCOS), an open-source framework designed to streamline space robotics software development. ESROCOS offers a suite of tools and promotes component reusability. We'll leverage ESROCOS for the OBC software to ensure RTa's compatibility with other ESROCOS-based activities. It will also benefit from tools like TASTE, an ESA-developed modeling toolchain for heterogeneous embedded systems. TASTE enables system creation using formal models and automatic code generation. To optimize costs and efficiency, we'll capitalize on heritage from past and current projects wherever possible.

Figure 5. HOTDOCK Standard Interconnect with fluid transfer

2.4 Model and Testing Philosophy

Following the model philosophy selected for the SCHUMANN RTa, we anticipate three main phases of testing:

- The EM functional testing by PDR, with the main purpose to de-risk and update the EQM design and testing/validation activities.
- The EQM functional testing by TRR, with the purpose to validate the readiness of the demonstrator for the TRL 6 validation phase
- The EQM validation at TRL 6 including verification of functional performance of flow and leakage in TVAC environment, and vibration tests of the integrated module.

3. Satellite Construction Kit

3.1 Project Development Objectives

The main objective of the "Design and Development Specification for the Satellite Construction Kit" (DSSCK) is to create a design and development specification primarily aimed for FSM developers. By applying this specification to their work, the FSM developers can make their products compatible with the Future Space Ecosystem, i.e. ensuring that FSM can be effectively adopted and integrated by satellites developers, for a faster and more affordable access to space in the context of Newspace economy.

The goal of the project is not only to name and classify norms and standards of components with their respective interaction, but to also deliver a simple yet effective tool to oversee and understand the processes needed to be able to have components integrated into the greater European satellite construction kit.

The main objective can be divided into multiple sub-objectives:

- Using notional or real OSAM use cases, define the boundaries of the DSSCK and create a comprehensive ontology for it.
- Set the baseline requirements.
- Create a design, verification, and validation plan (DVVP) including the methodology for the FSM developers to apply and the verification and validation plan to follow to make their FSM fulfill the DSSCK specification.
- Test the DVVP by having third-party satellite component manufacturers use it at a conceptual level on their pre-existing or new module.

The key performance indicators (KPI) for the DSSCK objective are:

- **KPI-2.1** – Baseline of 3-5 representative OSAM use cases reviewed in the elaboration of ontology.
- **KPI-2.2** – Successful validation of DVVP with third-party users. Target is to include 3 to 5 third-party users, covering 5 to 10 FSMs.

3.2 Tiers and Use Cases Description

DSSCK and by extension SCK target the space market place. At this development stage, the software targets specific users, identified based on the needs of the supply chain. The users are classified in 3 Tiers. The tiers are classified descending, based on how far each type place from the finished spacecraft. These are defined below:

- Tier 0 represents users which integrate all components (and FSMs) into the finalized spacecraft. The users in this Tier represent, in most cases, the prime contractors of the space segment. They handle the spacecraft development stages and manage the engineering process.
- Tier 1 consists of users which integrate products and realize the subsystem level functionality. They provide products which fulfill one or several functions of the space segment.
- Tier 2 consists of users which provide components, or a set of materials which cannot be disassembled without destroying it's capabilities. The components, in the context of this statement provide a simple functionality and are the building blocks of Tier 1 (or subsystem).

Use cases are the main input of the SCK development process. Since the target application has a niche and limited scope, it is important to identify how the actual users will interact with the software. The Consortium identified several System Level Use Cases. Figure 6 illustrates a typical use case, where a FSM builder retakes the task of developing an on-going FSM design or bases their design in “reference design” of sorts, that is, existing FSM examples which may accelerate the process compared to starting from a clean sheet. To achieve this, the system must ensure correct serialization/deserialization of the data structures, as well as keeping a repository of exemplary designs users can leverage.

Figure 6. HOTDOCK Standard Interconnect with fluid transfer

SCK provides the following features which enable a unified space industry supply chain:

- Covers all required elements needed to build an FSM, by category and enables to create a new category.
- Provides guidance and information to users, aiding in the verification and validation process with the SCHUMANN compliance standards.
- Manages NDAs and creates a trust baseline between buyers and suppliers, allowing for dynamic management of public data.
- Provides power and mass budget analysis capabilities.
- Provides Graphical User Interface Wizards, which allow Users to access and customize SCK functionality (Figure 7)
- Provides error management system to avoid corrupting User data with errors data.
- Provides access to open-source code which allows users to customize the functionality of the tool.

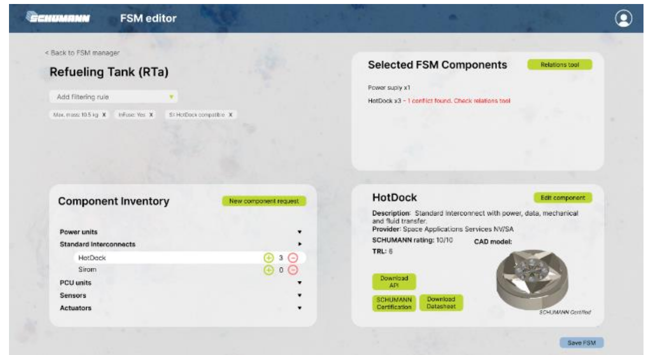

Figure 7. SCK FSM Editor screen (preliminary concept)

3.3 Development and Testing Strategy

Given the SCK scope and purpose, together with the uncertainties and risks associated with the project, the Consortium approaches development and testing strategies using a lightweight Agile methodology.

The validation strategy will be twofold – internal testing of the DSSCK will be worked out by the consortium over the whole development effort, and as a major validation steps, we will invite external third parties to do the exercise of applying the DVVP to a selection of satellite components of theirs.

Third party actors, which will be selected based on approved EC rules (best value for money). We intend to involve 3 to 5 such third party organization, and intend to obtain a total of 5 to 10 “conceptual FSM”. In addition to validating the DSSCK / DVVP, this approach will allow populating the FSM catalogue with a selection of valuable modules.

4. CONCLUSION

The paper introduces the NewSpace paradigm shift and SCHUMANN project, aligning with European Space Robotics grants. It outlines two key objectives: maturing the RTa to TRL-6 and developing the SCK for FSM builders. The RTa focuses on refueling and compatibility with IOD missions, while the SCK aims to unify space industry supply chains. The development and testing strategies are agile and involve external validation. This paper provides valuable insights into advancing modular spacecraft and enhancing the NewSpace ecosystem.

In the follow-up phase of the SCHUMANN project, we will proceed with the Manufacturing, Assembly, Integration, and Testing (MAIT) phase for the RTa, preparing for subsequent Engineering Model (EM) and Engineering Qualification Model (EQM) testing and validation. During each testing phase, we will assess the system's compliance with project requirements. Simultaneously, for the SCK, based on the preliminary concepts, we will initiate the software implementation of the SCK's back-end and front-end, along with the Design and Specification description. This phase aims to convert the design and development specifications into a fully functional toolset for FSM developers, streamlining the integration process and ensuring compatibility with the broader Future Space Ecosystem. External actors, including FSM developers and component suppliers, will be invited to participate in the Agile process, with a select group actively involved in evaluating and validating the initial version of the DSSCK tool.

5. ACKNOLEDGEMENTS

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Project Website: https://www.horizon-schumann.eu/

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