Development of a robotic Fluid Transfer interface based on RIDER connector

G. Guerra(1), J. Viñals(2), I. Soto(3), M. Díaz-Carrasco(4), J. Gala(5)

(1) *SENER Aeroespacial, Avda. Zugazarte, 56 - CP 48930 Las Arenas (Spain),* gonzalo.guerra@aeroespacial.sener
(2) *SENER Aeroespacial, Sp*ain, javier.vinals@aeroespacial.sener
(3) *SENER Aeroespacial, Sp*ain, isabel.soto@aeroespacial.sener
(4) *SENER Aeroespacial, Sp*ain, montserrat.diaz@aeroespacial.sener
(5) *SENER Aeroespacial, Sp*ain, jose.gala@aeroespacial.sener

ABSTRACT

Standard Interfaces (SI) are a central pillar for the On-Orbit Servicing, Assembly and Manufacturing (OSAM) applications. Inside the OSAM market it is expected that life extension and refuelling applications will represent a large share of the market demands, as shown by several studies [1]. Thus, SENER Aeroespacial is developing a SI product with fluid transfer capabilities based on the combination and leveraging of SIROM (Standard Interface for Robotic Manipulation) [2] and RIDER (Refuelling Interface Development for ESPRIT).

In this paper, SENER Aeroespacial will briefly present RIDER fluid transfer connector and how it has been implemented inside SIROM design, allowing to carry out refuelling activities as part of the SI performance. The modifications required for compatibility between RIDER connector and SIROM will be discussed, including the implementation of the axial movement to allow the connector mating/demating and dust/ESD cover mechanisms. Performances of SIROM with resupply capabilities will be shown, with special emphasis on the fluid transfer function. In addition, a development plan will be presented to increase current TRL3/4 of SIROM with RIDER up to TRL6/7. Finally, the SIROM family will be also presented in order to show the standardization of the SI for different applications based on modular configuration and common components, making SIROM as a very flexible SI platform.

1. INTRODUCTION

On the one hand, SIROM is a multi-functional interface developed in the frame of a European Union's Horizon 2020 project and used in several European projects (SIROM, EROSS, PERIOD, MIRROR). In short, SIROM allows mechanical, data, and electrical coupling, having reached TRL6 (Technology Readiness Level) in early 2021 [3].

On the other hand, RIDER Fluid Transfer Connector (FTC) has been developed for the IBDM HCS (International Berthing Docking System – Hard Capture system). This system provides active and passive elements for transferring, among others, Xenon (at 206 bar and 20-40ºC) or Hydrazine (at 24 bar and 20-40ºC) between a Servicer and a Client. Technological maturity of RIDER is also at TRL6.

Now, SENER Aeroespacial has developed a family product of SI with resupply capabilities leveraging on both projects.

2. STATE OF THE ART RESUPPLY INTERFACES

Several resupply interfaces with different degrees of maturity have been or are under current development. These interfaces are used in different missions with different applications that go from on-orbit satellite servicing to manipulation of payloads in planetary surface exploration. Here it will be presented some of the main resupply interfaces that have been identified: AFIS, ASSIST, RAFTI, Hotdock, Puck and the MAP.

2.1. AFIS

The AFIS is a rigid toroidal structure that is supported by four legs developed by Fairchild. It is an automated system that provides the capability for remote satellite refuelling. It is designed to be compatible mainly with the Orbital Spacecraft Consumables Resupply System (OSCRS), and the Orbital Maneuvering Vehicle (OMV).

AFIS was designed to be a flexible, completely redundant, reconfigurable system capable of resupplying either cryogens or bi-propellants and monopropellants. It can accommodate up to 8 fluid type couplers, 4 gas couplers and 8 C&DH electrical connectors on a single mission. The number and location of the coupler and connectors can be arranged as dictated by the mission requirements. The AFIS is 152,4 cm (5 feet) in diameter and 44,45 cm (17,5 inches) high without the legs.

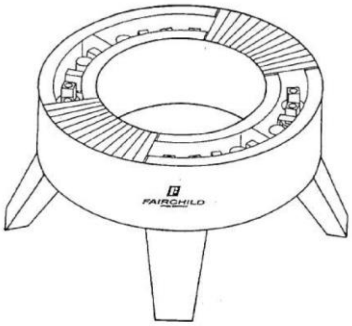

Figure 1. AFIS [4]

2.2. ASSIST

Harmonised System Study on Interfaces and Standardisation of fuel Transfer (ASSIST) developed by GMV is a capture system that allow for zero force capture to ensure that the target or client spacecraft are not pushed away from each other before a latching system can be deployed. ASSIST is composed as other refuelling systems by two parts, an active part (End effector) in the chaser satellite (servicing) and a passive part (berthing fixture) in the target one (serviced).

The end-effector includes the fluid and electrical connections and a grasping mechanism, which consists of an expanding pantograph located at the end of a probe, that attaches to the docking device on the serviced spacecraft.

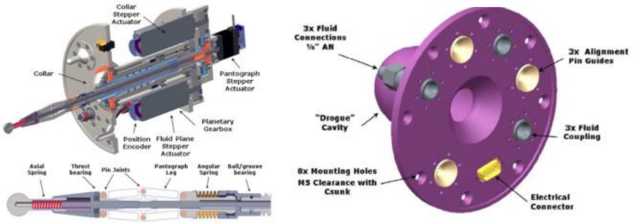

Figure 2. End Effector (left). Berthing Fixture (right) [5]

The berthing fixture is the passive half of the docking system found in the target vehicle. This part has a central cavity where the pantograph of the active part will be introduced as part of the docking process.

2.3. RAFTI

Rapidly Attachable Fluid Transfer Interface (RAFTI) service valve side is low profile, comparable to existing solutions. The rugged latching mechanism and triple seal design ensures a safe propellant transfer. RAFTI supports both primary docking or secondary attachment of two spacecraft. The double action latch mechanism accommodates significant misalignment on all axes during the docking process, allowing for self-aligning operations without the need for complex robotic arms. High clamping force accommodates high pressure fluid connections and satellite body movements. RAFTI allows for a flow rate of 4L/min @1,3 bar Δp (67 bar proof pressure) and 0,5L/min @1,3 bar Δp (310 bar proof pressure) [7].

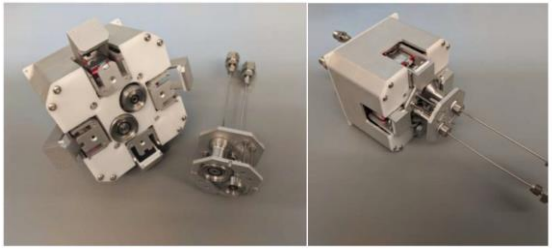

Figure 3. RAFTI coupled and uncoupled

2.4. HOTDOCK

Hotdock is a standard interface for on-orbit and planetary applications providing mechanical, power, data and thermal coupling capabilities. It features a compact and fully integrated androgynous and 90º symmetrical design. The locking mechanism consists of a locking ring featuring a set of balls that deploys into the passive Hotdock for hard docking. Both electrical power and data are transferred via spring-loaded POGO connectors. Some Hotdock versions can be equipped with a thermal interface consisting of 8 hydraulic Stäubli connectors (four male and four female) integrated in a 3D printed titanium structure.

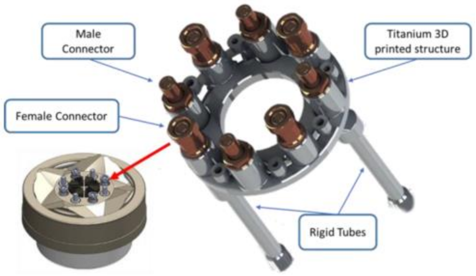

Figure 4. Hotdock thermal interface [7]

2.5. Puck

Obruta Space Solutions is developing an SI consisting of an active part (Active Puck) and a passive part (Puck). It is a lightweight 4-in-1 interface combining mechanical, fluid, power and data transfer. Puck is positioned as a low-cost interface. Additionally, to complement the product, the company is developing a RPO (Rendezvous and Proximity Operations) vision and docking system for both cooperative and uncooperative spacecraft docking and inspection.

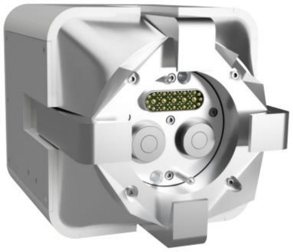

Figure 5. Active Puck [8]

2.6. MAP

In February 2022, Lockheed Martin published an open-source, non-proprietary interface standard to support on-orbit docking. The MAP (Mission Augmentation Port) consists of an active side, the Host Docking Port, and a passive side, the SAV port (Satellite Augmentation Vehicle). Currently, the published standard only covers the physical geometry of the mating interfaces but does not include other design features such as motors or internal mechanisms. Fluid transfer connectors and mechanisms may be specified in future versions.

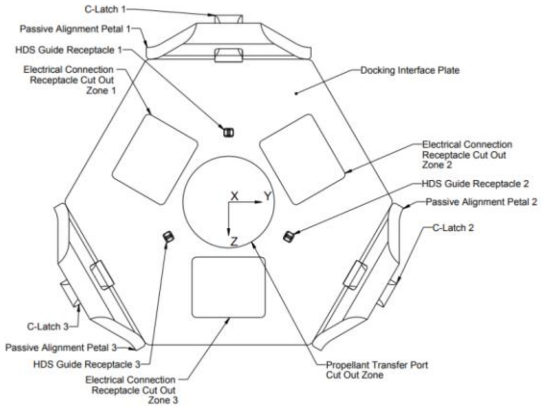

Figure 6. Host Docking Port [9]

3. SIROM APPLICATIONS

SIROM is a SI with a number of applications that include:

- On-orbit servicing
- Refuelling, resupply
- In-orbit assembly
- Assembly of large structures or antennas in space
- Payload upgrade or replacement for satellites
- Robot tool exchange
- Active debris removal

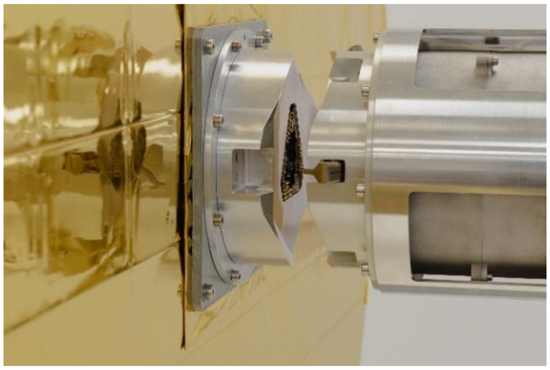

Figure 7. Two SIROMs during docking

4. SIROM GENERAL DESIGN

SIROM is designed as an androgynous interface allowing easy mating/demating with other SIROMs. Its high capture-range latches are based on the docking system for ISS. This, combined with its guiding petals, provide SIROM a self-aligning capability tolerant to very large misalignment conditions. The docking system keeps the locked position without the need of friction brakes or power consumption. Also, SIROM features a capture switch independent of illumination conditions, that gives information once two SIROMs are within the latching capture range. Once mechanically latched, SIROM deploys its connectors board to establish a physical plug for data, electrical power transmission and fluid transmission (optionally). One of the data lines is for CAN (Controller Area Network) protocol and is managed by SIROM electronics. The other data lines are fully customizable and typical uses are high-speed data transmission such as SpaceWire or Gigabit Ethernet. These lines directly bypass SIROM electronics and thus, signal attenuation is minimal. In terms of electrical power each SIROM is provided with at least two lines:

- Regulated/switchable, bi-directional, power transfer at 28V used for SIROM power supply.
- Unregulated power transfer bypassing SIROM electronics allowing high power transfer

The resupply interface is based on RIDER connector, currently at TRL6, allowing the transfer of propellant (Xenon, Hydrazine, etc.) or coolant, among others, without the need of flexible hoses.

SIROM is available in three basic configurations:

- Active-Passive (X), which can mate with any other configuration
- Active (A), which can only mate towards a P or X configuration
- Passive (P), which can be mated by an A or X configuration.

Each configuration presents different characteristics in terms of internal mechanisms and electronics and thus results in a different mass, volume, and cost. This allows to optimize your system design.

Figure 8. Active SIROM (left), Passive SIROM (right). Version not for resupply

5. SIROM WITH RESUPPLY

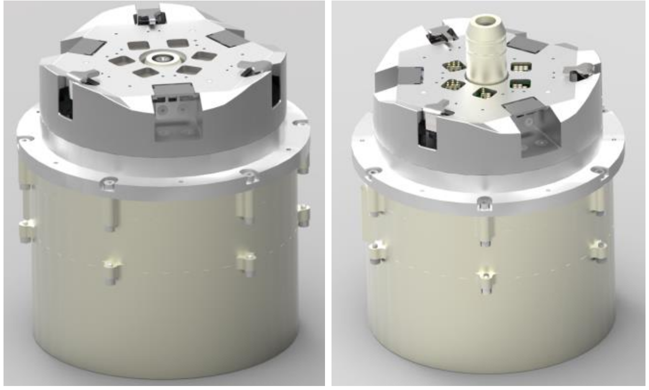

Figure 9. SIROM-A for refuelling: latched position (left), connected position (right)

SIROM with resupply consists of an active interface (SIROM-A) mating towards a passive interface (SIROM-P). Initially, SIROM-A and SIROM-P have the data and electrical POGO connectors placed inside the housing, being protected to dust and ESD (electrostatic discharge). As a result, the connectors being hidden under the cover during the latching maneuver offers protection in case of docking collisions and misalignment correction between SIROMs.

The mating procedure starts with SIROM-A mechanically capturing, correcting misalignments and hard-docking with its passive counterpart. Refuelling procedure stars after positive latching.

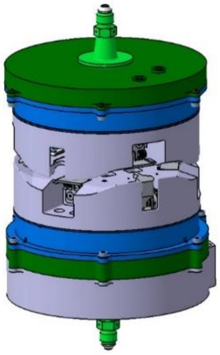

Figure 10. SIROM interface close to latch

Once the latch is completed, SIROM-A deploys the external sleeve of its FTC (fluid transfer connector) via a set of three leadscrew-nuts, while the central needle tubing remains static. This way, it is avoided the need of using flexible hoses inside SIROM. The central needle features four radial drills at its tip allowing exit of the fluid and an output fluid fitting placed at the bottom of SIROM.

In the first phase of its axial stroke (0-20mm), the external sleeve of SIROM-A enters SIROM-P, displacing its FTC external sleeve and making it slide inwards. Then, in the last phases of its axial stroke (20-30mm), the external sleeve of SIROM-A pushes the connectors plate (containing the data and electrical POGO connectors) which is mounted on a series of springs that allow to return back to the undeployed position in the demating procedure. Simultaneously while deploying, the connectors plate releases the end-stop of three spring-loaded mechanisms that open the three dust/ESD covers.

On its side, during the second phase (20-30mm stroke) the external sleeve of SIROM-P drives a passive linkage that pushes SIROM-P connectors plate (that in its turn opens the three dust covers).

At the end of the full stroke, data, electrical and FTC mating is completely achieved.

During pressurization and fluid transfer, mechanical forces are transmitted directly via the fixed needles (green parts) and supported by SIROM latches. FTC position is maintained via non-backdriveable leadscrews allowing to maintain the insertion force in the event of loss of power or pressure.

After fluid interchange is finished, the active sleeve performs the reverse movement, returning both SIROMs to their initial position.

6. FLUID TRANSFER

SIROM FTC is based on RIDER connector. RIDER is composed of the three following main subassemblies:

- Fluid Coupling, with only one movable part, Pin Sleeve
- Alignment System, for mating & docking miss-alignment compensation
- Traveling Mechanism, for mating / demating the fluid coupling active sleeve

Within SIROM, only the fluid coupling is maintained, while alignment correction is provided by the SIROM mechanical interface (latches and guiding petals) and the traveling mechanism is provided by a leadscrew system inside SIROM, as in RIDER solution.

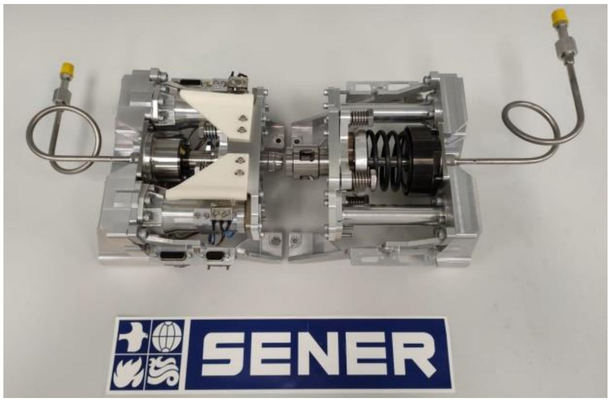

Figure 11. RIDER

The probe tip is designed to minimize wear of the seals during the stroke of the external sleeves of the FTC. In addition, both active and passive tips feature a conical design to improve centering and alignment between the sleeves.

Table 1. SIROM FTC performances

Fluid compatibility	Xenon, Hydrazine, MON-3, MMH, gaseous He, gaseous Ni, alcohol, water, coolants, etc.
Flow rate	Gas (He): 0,8 g/s @ 1 bar Δp Liquid (water): 35 g/s @ 1 bar Δp
MEOP	150 bar (gas), 30 bar (liquid)
Burst pressure	375 bar (gas), 75 bar (liquid)
Pressure cycles	>260 cycles (tested)
Operational life	15 years GEO (with 5mm satellite shielding)
Leakage	$<10^{-4}$ scc/s Helium

7. MECHANICAL INTERFACE

The mechanical interface is responsible for providing SIROM capturing capability against another SIROM and also compliance to loads arising during operation, once the attachment is done. The mechanical interface presents an external housing with three guiding petals and three capture hooks (or latches) evenly distributed with 120º apart. Each latch consists of a titanium four-bar-linkage moved by its own pinion and synchronized by an internal gear. The mechanical interface is complemented with a capture switch based on hall sensors and magnets that automatically triggers a telemetry to the controller once two SIROMs are within the latches range of capture. This switch is not affected by illumination conditions in the surroundings.

Table 2. Mechanical performances

Mass resupply SIROM-A	1,5 kg
Capture range	Axial: + 15mm Radial: +/- 5mm
Docking time	7 seconds
Traction load	2,4 kN
Compression load	5 kN
Radial load	5 kN
Torque	770 Nm
Bending moment	270 Nm

8. ELECTRICAL, HIGH-SPEED AND LOW-SPEED DATA TRANSFER

As previous SIROM versions, the resupply family features a connectors plate consisting of spring-loaded POGO pins/pads to establish a physical plug for electrical, high-speed and low-speed data transmission. In this version, the plate implements a total of 24 pins and 24 pads distributed as per Figure 12.

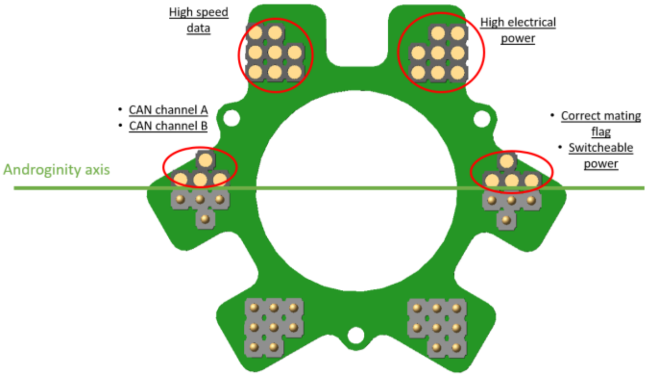

Figure 12. Connectors plate distribution

Figure 13 diagram represents the routing and internal connections between the connectors plate (POGO lines), SIROM electronics, and SIROM lateral connectors.

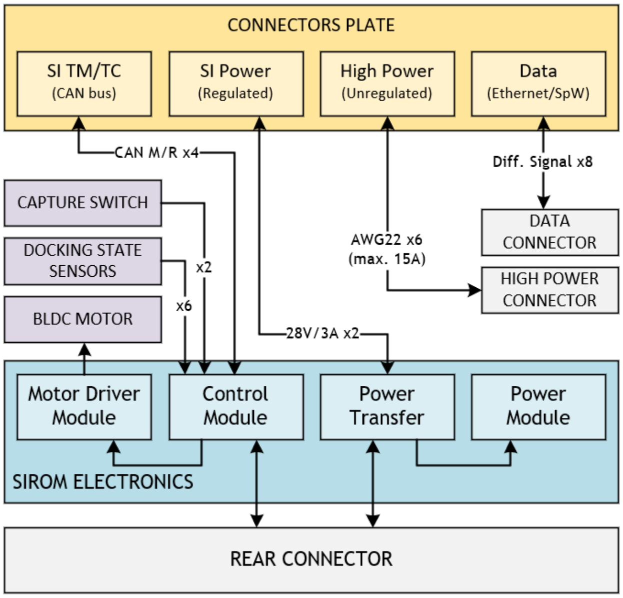

Figure 13. SIROM electrical and data diagram

Table 3 summarizes SIROM for resupply electrical, high-speed and low-speed data transfer.

Table 3. Electrical, high-speed and low-speed data performances

Electrical	SIROM power input	20-34V
	Regulated/ switchable	3,5A @28V (98W)
	Unregulated	16A @150V (2,4kW)
High-speed data	Data transfer	Gigabit Ethernet. Other protocols also valid
	Data rate	1 Gbit/s
Low-speed data	SIROM Control	CAN bus

8.1. Electrical

8.1.1. Regulated/switchable power transfer

SIROM implements lines for regulated/switchable power transfer failure tolerant (with reduced performances) thanks to the POGO connectors symmetric design. These lines are connected to the power module of SIROM electronics, which manages the power transfer between the connectors plate and SIROM lateral connectors. The transference is handled by two MOSFET that allow bi-directional power transfer or disabling power transfer.

8.1.2. Unregulated power transfer

In addition, SIROM includes a set of lines that by-pass SIROM electronics, and that are routed directly to a lateral connector. These lines represent a medium for unregulated power transfer with capabilities to transfer bidirectionally 16A at 150V. They are also failure tolerant (with reduced performances) thanks to the POGO connectors symmetric design

8.2. High-speed data

Regarding the high-speed data transfer, SIROM includes four differential pairs for Gigabit Ethernet (1 Gbit/s data rate), failure tolerant (with reduced performances) thanks to the POGO connectors symmetric design. The impedance of the lines is adapted to minimize signal distortion.

8.3. Low-speed data

The main and redundant low-speed data lines consist of two separate CAN channels (channel A & B). The signals from the connectors plate are routed to SIROM electronics control module and they are used to command and control SIROM states, although it can be used to transmit other data via SIROM pairs.

9. TRL6/7 DEVELOPMENT PLAN

In short, the TRL6/7 development plan for SIROM with resupply will include the following phases and main tasks:

1) **Mechanism validation with dummy FTC**
   a) Mechanism assembly and calibration with COTS electronics
   b) Single SIROM-A functional test
      i) Mechanical docking
      ii) Dust cover opening/closing
      iii) POGO connectors (electrical, data) stroke
      iv) Dummy FTC stroke
   c) Single SIROM-P functional test
      i) Passive mechanisms test
   d) Paired SIROM functional test
      i) Mechanical mating
      ii) POGO lines continuity test
2) **Lessons learnt applied to SIROM with resupply version**
3) **SIROM with resupply**
   a) Physical measurements test
   b) Functional tests (before/after vibration, shock, TVAC, thermal life, load test)
      i) Motorization margin
      ii) Electrical/data transmission
      iii) Fluid transfer
      iv) Leakage test
   c) Vibration
   d) Shock

e) TVAC
f) Thermal life
g) Load test
h) Disassembly
    i) Seals wear evaluation
    ii) Internal mechanisms inspection

10. SIROM FAMILY PRODUCT

SIROM is to be understood as a product family where each SI inside family shall be compatible (at least in a mechanical point of view). Most of the parts are common for all the interface selections with all the standardization and industrialization advantages.

Within each family line, SIROM allows customization of:

- Resupply option
- Data protocols and number of data lines
- Electrical power transfer (number of lines, electrical performances)
- Active-Passive (X), only Active (A) or Passive (P) versions
- Integrated electronics or distributed electronics to allow the control of several SIROMs with a single and modular electronics module
- Visual-servoing system (under development)

Table 4. SIROM family line

Family version	*A-P-X*	*Functionality*
OG5-H2020 (SIROM) [10]	X	- Mechanical capture - Switchable electrical power - High-speed data (SpaceWire) - Low-speed data (CAN) - Thermal fluid
OG7-H2020 (EROSS) [11]	X	- Mechanical - Switchable electrical power - High-speed data (Ethernet) - Low-speed data (CAN)
	P	
MIRROR [12]	X	- Mechanical - Switchable electrical power - High electrical power by-pass - High-speed data (Ethernet) - Low-speed data (CAN)
	P	
Resupply	A	- Mechanical - Switchable electrical power - High electrical power by-pass - High-speed data (Ethernet) - Low-speed data (CAN) - Resupply (optionally)
	P	
	X	- Mechanical - Switchable electrical power - High electrical power by-pass - High-speed data (Ethernet) - Low-speed data (CAN)

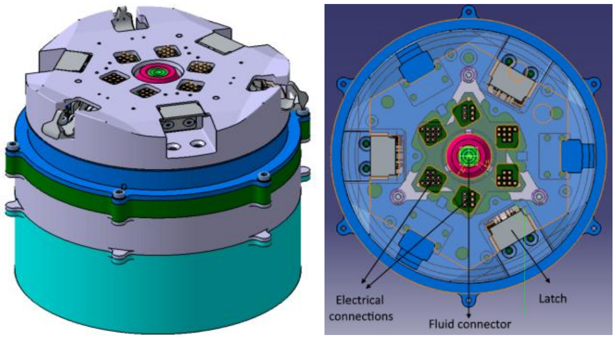

Figure 14. Resupply SIROM-A

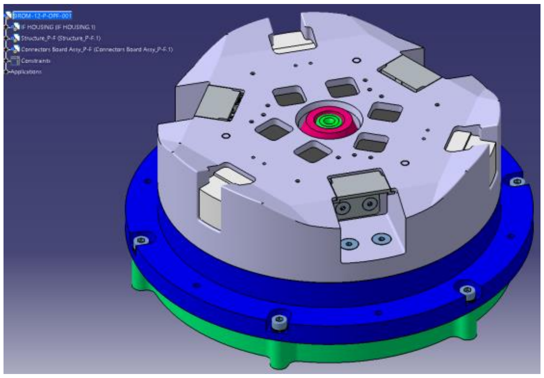

Figure 15. Resupply SIROM-P

11. CONCLUSIONS

SIROM versions for OG7-EROSS and MIRROR reached TRL6 in early 2021. Now, a roadmap to reach TRL6/7 for the resupply version has been drafted and the testing activities are starting. Currently, SENER is in the first phase of the development plan, manufacturing two EM (Engineering Model) of SIROM for resupply using a dummy FTC. In the next months, assembly and first tests of the mechanisms will start which will result in a series of lessons that will be implemented

ACKNOWLEDGEMENTS

The SIROM project is part of the PERASPERA project on Space Robotics Technologies and has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement number 730035.

SIROM is also part of EROSS [9] under grant agreement number 821904, and PERIOD [10] under grant agreement number 101004151.

REFERENCES

[1] S. H. H. Bokhari, "Northern Sky Research," 17th February 2021. [Online]. Available: https://www.nsr.com/in-orbit-servicing-stepping-up-to-the-challenge/. [Accessed 4th April 2022].

[2] "Standard Interface for RObotic Manipulation," SENER Aeroespacial, [Online]. Available: https://www.aeroespacial.sener/en/products/standard-interface-for-robotic-manipulation-sirom. [Accessed 4th April 2022].

[3] M. Díaz-Carrasco, G. Guerra, G. Gala and J. Viñals, "Standard Interface for Robotic Manipulation (SIROM): Current state and future development for one of the main building blocks for space robotics advancement," in *IAC-21-D1.6.5, 72nd International Astronautical Congress*, Dubai, 2021.

[4] Fairchild Space, "Automated Fluid Interface System (AFIS) Final Report Document," April 1990. [Online]. Available: https://ntrs.nasa.gov/api/citations/19910001718/downloads/19910001718.pdf. [Accessed 20th April 2022].

[5] A. Medina, A. Tomassini, M. Suatoni, M. Avilés, Solway, Nick, I. Coxhill, I. S. Paraskevas, G. Rekleitis, E. Papadopoulos, R. Krenn, A. Brito, B. Sabbatinelli, B. Wollenhaupt, C. Vidal, S. Aziz and G. Visentin, "Towards a standardized grasping and refuelling on-orbit servicing for geo spacecraft," *Acta Astronautica,* vol. 134, pp. 1-10, 2017.

[6] Orbitfab, "Rapidly Attachable Fluid Transfer Interface," [Online]. Available: https://catalog.orbitaltransports.com/content/brands/orbitfab/RAFTIBrochure.pdf. [Accessed 20th April 2022].

[7] P. Letier, T. Siedel, M. Deremetz, E. Pavlovskis, B. Lietaer, K. Nottensteiner, M. A. Roa, J. Sánchez García-Cassarrubios, J. L. Corella Romero and J. Gancet, "HOTDOCK: Design and validation of a new generation of standard robotic interface for on-orbit servicing," in *International Astronautical Congress*, CyberSpace Edition, 2020.

[8] Obruta Space Solutions, "Satellite Confers," [Online]. Available: https://www.satelliteconfers.org/wp-content/uploads/2021/02/Obruta_One_Page_Company_Info.pdf. [Accessed 20th April 2022].

[9] Lockheed Marin Space, Advanced Program Development, "Lockheed Martin Mission Augmentation Port (MAP) Standard," 2022.

[10] SIROM consortium, "Standard Interface for Robotic Manipulation of payloads in future space missions (SIROM)," [Online]. Available: http://www.h2020-sirom.eu/. [Accessed 27th April 2022].

[11] EROSS Partners, "EROSS (European Robotic Orbital Support Services)," 2022. [Online]. Available: https://eross-h2020.eu/eross/. [Accessed April 2022].

[12] J. Estremera, J. García, A. Rodríguez, I. Colmenarejo, M. Lucia, A. Rusconi, G. Sangiovanni, M. Tsagarakis, J. Viñals and G. Guerra, "Re-locatable manipulator for on-orbit assembly and servicing," in *16th Symposium on advanced space technologies in robotics and automation (ASTRA)*, Noordwijk, 2022.

[13] PERIOD partners, "PERIOD (PERASPERA In-Orbit Demonstration)," [Online]. Available: https://period-h2020.eu/. [Accessed April 2022].