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ARCADE small-scale docking mechanism for micro-satellites

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ABSTRACT

The development of on-orbit autonomous rendezvous and docking (ARD) capabilities represents a key point for a number of appealing mission scenarios that include activities of on-orbit servicing, automated assembly of modular structures and active debris removal. As of today, especially in the field of micro-satellites ARD, many fundamental technologies are still missing or require further developments and micro-gravity testing.

In this framework, the University of Padova, *Centre of Studies and Activities for Space* (CISAS), developed the Autonomous Rendezvous Control and Docking Experiment (ARCADE), a technology demonstrator intended to fly aboard a BEXUS stratospheric balloon. The goal was to design, build and test, in critical environment conditions, a proximity relative navigation system, a custom-made reaction wheel and a small-size docking mechanism.

The ARCADE docking mechanism was designed against a comprehensive set of requirements and it can be classified as small-scale, central, gender mating and unpressurized. The large use of commercial components makes it low-cost and simple to be manufactured. Last, it features a good tolerance to off-nominal docking conditions and a by-design soft docking capability.

The final design was extensively verified to be compliant with its requirements by means of numerical simulations and physical testing. In detail, the dynamic behaviour of the mechanism in both nominal and off-nominal conditions was assessed with the multibody dynamics analysis software MD ADAMS 2010 and functional tests were carried out within the fully integrated ARCADE experiment to ensure the docking system efficacy and to highlight possible issues. The most relevant results of the study will be presented and discussed in conclusion to this paper.

1. Introduction

The development and constant improvement of orbital docking capabilities have been considered a highly important objective by all the space agencies around the world since the early phases of the space age, as it represents an enabling prerequisite for several different missions involving two or more spacecraft [1].

The first successful orbital rendezvous and docking in history took place on 16 March 1966 between the Gemini 8 capsule, under the command of Neil Armstrong, and an Agena target vehicle [1,2]. *Autonomous* rendezvous and docking was first realized less than two years later, on 30 October 1967, when the Soviet vehicles Cosmos 186 and 188 mated together after a first failed attempt [1,3]. Although the mission proved the feasibility of an automated rendezvous and docking process, it still lacked robustness and it was too much performance demanding for those times. The situation has remained mostly unchanged for a long time, with just a few concepts being considered between the late 80s and late 90s; a renewed, strong interest for complex space operations involving autonomous rendezvous and docking started to grow only after the turn of the millennium [4].

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Current appealing perspectives include:

(1) *On-orbit satellite automated servicing*. Recent studies have shown that on-orbit servicing has a good potential, due to the high number of serviceable satellites; it was indeed demonstrated that most of them could be refurbished even if they lack dedicated servicing ports [5]. Moreover, the costs will get lower and lower as standardization in repairing interfaces and processes is achieved [4], and the capability of performing inspection, repairing, upgrading, refuelling and re-boosting of existing spacecraft on a regular basis would increase mission flexibility [6] and provide several benefits, such as:
- extend their operational lifetime. This is particularly profitable for refuelling of geostationary satellites, which have the highest launch cost [5,7,8];
- improve or replace their payloads, allowing to repair non-functional assets and perform several missions with the same platform [7];
- modify their orbits, to solve insertion errors, to observe different areas or to increase–decrease the coverage [9].

2. *On-orbit assembly of modular spacecraft*. A significant reduction in costs would come from both the use of standard modules for typical satellite systems (power, telecom ...) and from the possibility of launching many self-assembling modules, possibly as piggybacks [10,11].
3. *Active debris removal*. Orbital debris, which mainly consist of obsolete spacecraft, rocket stages and fragments produced by explosions or collisions, poses a serious threat to working satellites. In addition, without a proper mitigation policy, the situation is predicted to dramatically worsen in a few decades due to the constantly increasing chances of random collisions, eventually preventing any further human activity in space. In this framework, especially for large debris, some of the proposed active debris removal solutions involve an automated capture. Cooperative targets would come with dedicated mating interfaces, while non-cooperative ones would be captured exploiting other common hardware features, such as nozzles [5,12,13].

Such promising applications require further developments and extensive orbital testing of a variety of enabling technologies [14], such as miniaturized docking mechanisms.

Most of the efforts devoted to the design and improvement of mating systems, in fact, have historically been directed towards complex systems for manned spaceflight, weighting in average hundreds of kilograms due to the need of establishing a large and pressurized tunnel between the coupled vehicles. The recent ATV docking mechanism, derived from the original Russian probe–drogue docking system [15] and the NASA ISS Common Berthing Mechanism provide two state-of-the-art examples [16].

A second category includes mid-sized docking and berthing systems for autonomous operations, such as the Orbital Express Capture System (OECS), successfully tested on orbit [17], and the Orbital Life Extension Vehicle (OLEV) docking mechanism [18], which has still not flown in space.

Last, only a few small-scale autonomous docking systems have been developed so far and they all lack orbital testing. Two representative examples are the Autonomous Micro-Satellite Docking System (AMDS) [19], a miniaturized and improved version of the Autonomous Satellite Docking System (ASDS) [20] and the Universal Docking Port (UDP) [10].

ASDS was originally a mid-sized docking mechanism, designed as a candidate for the DARPA's Orbital Express demonstrator. A prototype was built and successfully tested, but the system was eventually not selected for the mission and therefore it was not tested on orbit. Many of its technical solutions, however, were employed in its subsequent miniaturized version, called AMDS, which was optimized for on-orbit servicing of micro-satellites. This probe–drogue system has never flown in space as well, but it was tested in micro-gravity conditions during parabolic flights.

UDP, instead, is an androgynous mating system developed by MIT in the framework of the SPHERES project. The goal is to validate, by means of spherical micro-satellites operated inside the ISS, several technologies for autonomous formation flight, autonomous docking, rendezvous and reconfiguration algorithms. On-orbit testing of UDP is expected in 2013–2014 [21].

This paper describes a small-scale docking mechanism developed by the University of Padova, "*Centre of Studies and Activities for Space*" (CISAS), for the *Autonomous Rendezvous Control And Docking Experiment* (ARCADE) and, more in general, for orbital docking of micro-satellites. A description of ARCADE is provided in Section 2, while the docking mechanism design, its concept of operation and the numerical simulations performed for verification purposes are presented in Section 3. Section 4 gives an overview on the manufacturing, assembly and testing phase and Section 5 provides the work conclusions.

2. Development framework: ARCADE

The combination of CISAS objectives in the context of Autonomous Rendezvous and Docking (ARD) with one of the most popular educational programmes of the European Space Agency (ESA), REXUS/BEXUS, set the base for a one-year project. Its primary objective was to test, aboard a stratospheric balloon and in extreme environment conditions, three custom systems designed to perform relative proximity navigation, relative attitude control and docking between two space or aerial vehicles. The chosen name was ARCADE: *Autonomous Rendezvous Control And Docking Experiment*.

The experiment reproduces a simplified autonomous docking scenario, where a small external vehicle, called *SMAV* (SMAll Vehicle), mates to its parent unit, named *PROXBOX* (PROXimity BOX). The PROXBOX is mounted on the *gondola*, the metal frame which hosts all the student experiments and which is lifted by the BEXUS balloon. The SMAV, on the other hand, is supported by an external rigid structure, called *STRUT* (STRUcTure), which connects the small vehicle to the gondola. A photo and a 3-D representation of ARCADE are presented in Figs. 1 and 2.

ARCADE houses three main systems specifically designed for the experiment: a navigation system, a motion control system and a docking subsystem.

The navigation system is employed to measure the SMAV instantaneous rotation and distance from the PROXBOX, by means of custom IR sensors, electromagnetic sensors and commercial MEMS gyroscopes. All the transmitters – two IR LEDs and EM antennas – are housed on the PROXBOX, while all the receivers – two IR photodiodes and two copper coils – are placed on the SMAV. One MEMS gyro is installed on each vehicle.

The motion control system includes a linear brushless motor, located on the STRUT, in addition to a custom reaction wheel (RW) and its backup rotational motor (BRM), which goal is to move and rotate the SMAV, to compensate the external disturbances and to maintain the correct alignment for the docking. The RW is installed inside the SMAV, while the BRM is located underneath the small vehicle.

Finally, the docking subsystem realizes a stiff and reliable connection between the PROXBOX and the SMAV, which can be finally released at a controlled velocity.

The design of the ARCADE docking mechanism was driven by a number of requirements and constraints that have been grouped according to four standard categories suggested by ESA [22]: *functional*, *performance*, *design* and *operational*.

In particular, the adopted technical solutions directly addressed the functional requirements that *define functionality that the experiment needs to have or the tasks it needs to fulfil in order to achieve the experiment objectives*. From this perspective the mechanism shall

(F.1) allow the capture of a chasing vehicle when its position and motion fall within the docking envelope;
(F.2) provide structural connection between the coupled vehicles after hard docking;
(F.3) provide repulsive force for undocking;
(F.4) provide signalling for hard docking.

Performance requirements *quantify to what level the functional requirements will be fulfilled* and many derived from the characteristics of the motion control system. From this perspective, the docking mechanism shall

(P.1) allow a combined pitch and yaw misalignment up to 5° (resp. to F.1);
(P.2) allow a combined pitch and yaw angular rate up to 0.5°/s (resp. to F.1);
(P.3) allow mating with a perpendicular approach velocity of the chaser from 0.01 m/s to 0.05 m/s (resp. to F.1);
(P.4) resist to axial loads of at least 100 N (resp. to F.2);
(P.5) provide a compression force between the mating interfaces of at least 2 N (resp. to F.2);
(P.6) provide a repulsion force for undocking of at least 2 N (resp. to F.3).

Due to the geometry of the mechanism, pitch and yaw misalignments and residual rates are equivalent and they have the same effects on the docking sequence. Concerning roll and lateral misalignments, no requirements were set, as in the experimental setup they are all locked DOF. They will be properly determined in case of further developments of the mechanism.

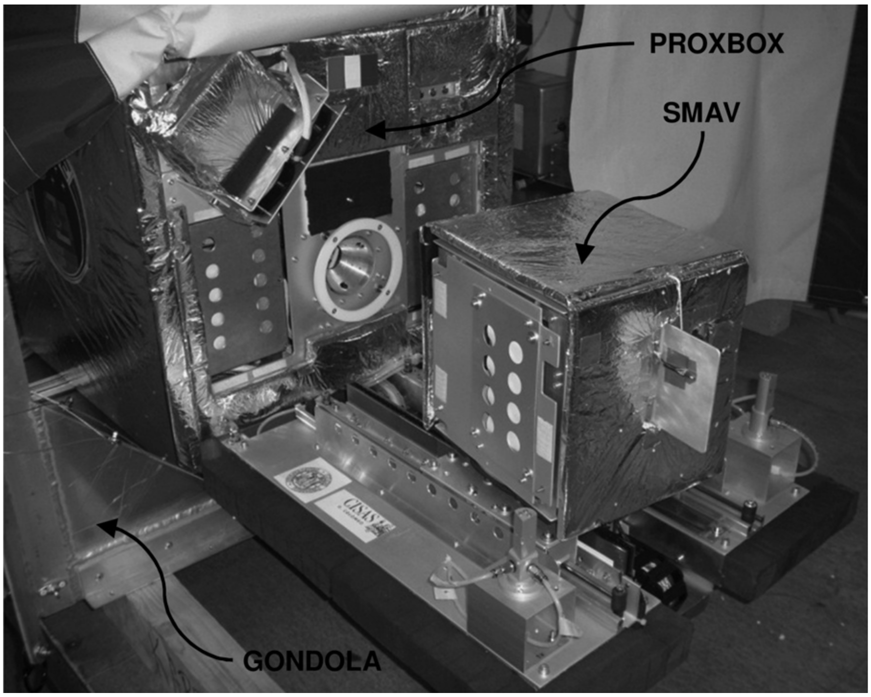

Fig. 1. Fully integrated ARCADE experiment on-board the BEXUS 13 gondola.

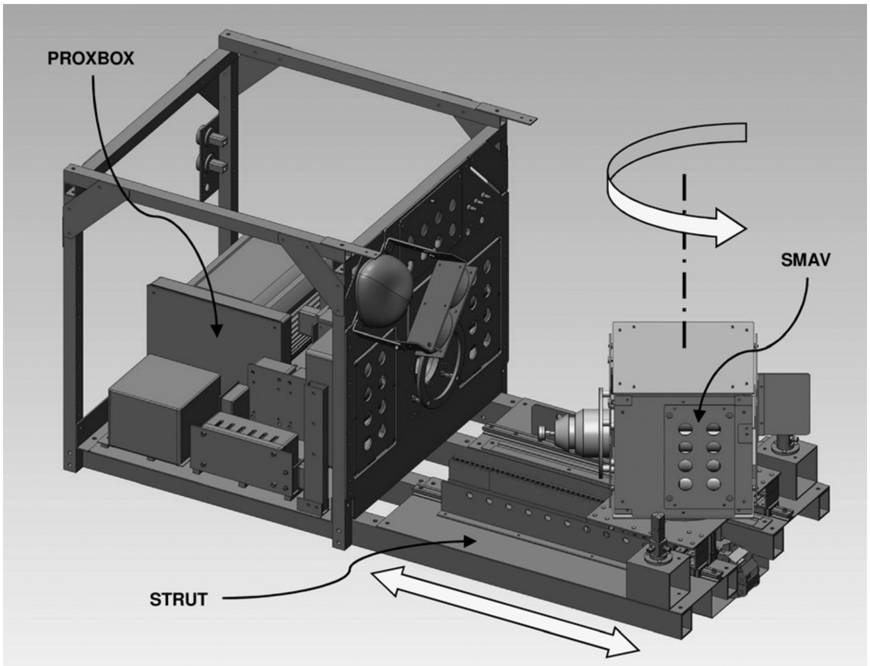

Fig. 2. ARCADE experiment main units and SMAV degrees of freedom.

Design requirements, which *define all the design aspects that the experiment needs to fulfil in order to achieve the experiment objectives*, mostly depended on the ARCADE flight environment, as they included acceleration, temperature and mass constraints.

Operational requirements, which are *conditions that the experiment has to fulfil to be handled and operated safely and reliably*, finally stated that the docking sequence could be performed both automatically, by the on-board computer, and step-by-step, by an operator.

3. ARCADE docking mechanism

3.1. Mechanism design

The ARCADE docking mechanism (Fig. 3), comprises two mating parts.

The first interface is mounted on the front face of the SMAV (chaser vehicle) and it is purely passive. It consists in a spring-damper, equipped with a soft iron round tip, mounted on an Al-2011 cone (Fig. 4).

The second interface is attached to the PROXBOX external wall (target vehicle), it is more complex and it includes many active devices (Fig. 5). Its characterizing part, however, is represented by the central Al-2011 drogue, which matches the SMAV docking cone.

Due to the mechanism design and the fact that it does not allow to establish a gas-tight connection, the ARCADE mechanism can be classified as small-scale, central, gender mating and unpressurized. Contrarily to the AMDS, which falls within the same category of mating systems and is effectively the only comparable one, the ARCADE docking mechanism features an active target interface and a passive chaser interface. This could be a big advantage in scenarios where several cheap servicing vehicles shall visit much more expensive and complex satellites at different times.

Having this mission concept in mind, materials and components were selected so that the docking mechanism – and the target interface in particular – could be reused many times. Further benefits in terms of costs come from the use of only COTS active devices, which have been used for the demonstration of the mechanism concept; in case of an orbital mission these components should undergo further testing at space-qualification level. The total mass of the mechanism is 1.25 kg. The requirement was to keep it under 1.3 kg, equivalent to about 4% of the total mass allocated for ARCADE on-board the BEXUS balloon, which was 32 kg.

The capture of the chaser (Req. F.1) is performed by means of a round electromagnet, which features small dimensions (external diameter = 17 mm), low power consumption (1.6 W), high attraction force (35 N at contact) and that provides *soft capture* capability (Req. F.1). In particular, it catches the soft iron tip of the chaser spring-damper, after it has been aligned with the centre of the target interface by the conic drogue. This aligning effect is one of the characterizing advantages of the cone-drogue concept and it is determined by the long torque arm that spans from the tip of the spring-damper to the centre of mass of the SMAV. In this case, due to the inertia ratio, the SMAV is the rotating vehicle.

The damping function is delegated to a spring-damper, which has been chosen in place of a more effective hydraulic damper due to the very low kinetic energy of the chaser that could be easily dissipated by solid friction and a small rubber damping element. The selected model is capable to store, along its full stroke, the kinetic energy of a 8.5 kg chasing vehicle traveling at ~ 0.10 m/s (Req. P.3).

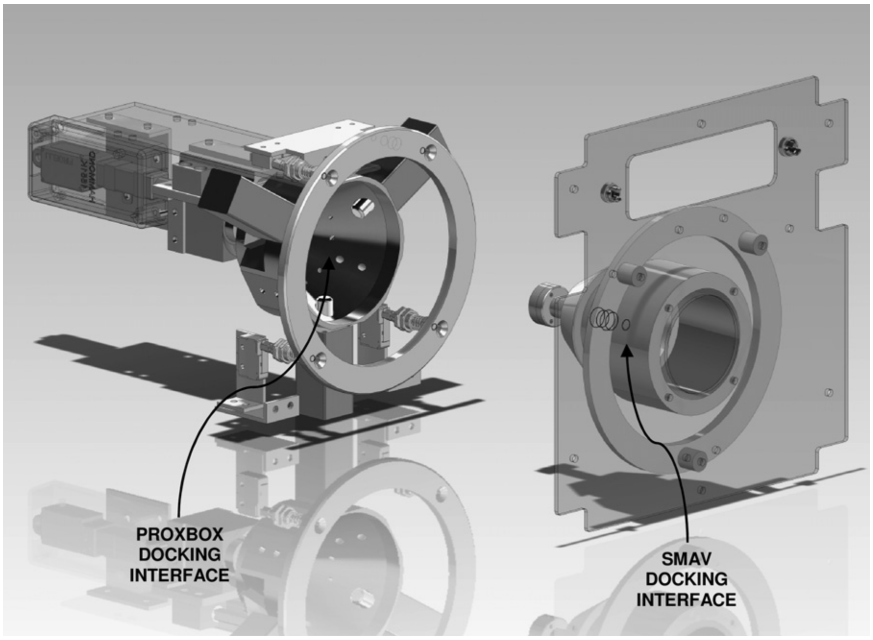

Fig. 3. Overview of the ARCADE docking mechanism.

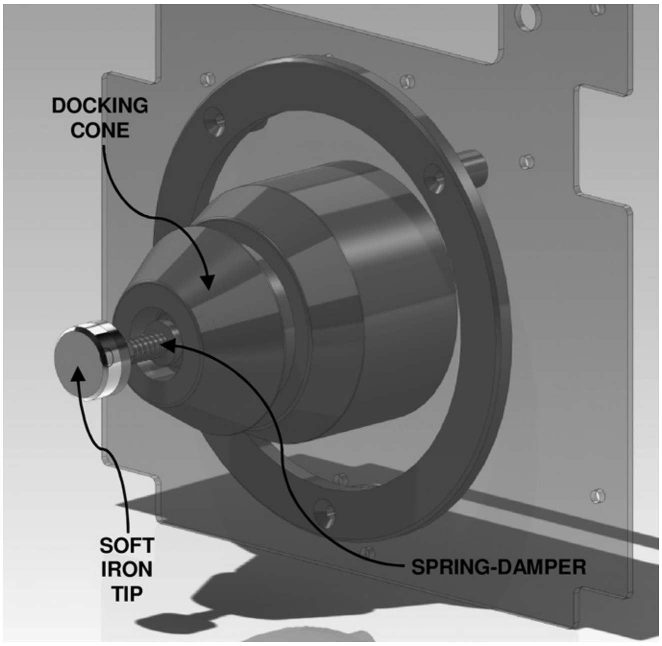

Fig. 4. SMAV (chaser vehicle) docking interface.

Once capture has been achieved, the chaser is pulled towards the target vehicle by a miniature linear actuator, which has a stroke of 30 mm and provides a position feedback. This movement couples the drogue with the cone, setting the relative position of the docking interfaces in such a way that the structural latches can be engaged.

The structural connection (Req. F.2) is achieved by means of three locking solenoids that extend their cores inside a groove carved in the chaser docking interface. As they are the only holding elements of the coupling, the selected actuators provide high radial strength (100 N each), long stroke length (10 mm) and feature a moderate power consumption (4.6 W each). Thanks to this choice and the arrangement of the solenoids within the mechanism, the connection can withstand axial loads up to 300 N.

The employed solenoids are normally retracted, i.e. they need to be powered during the docking phase. This means that the failure of one of the solenoids would not

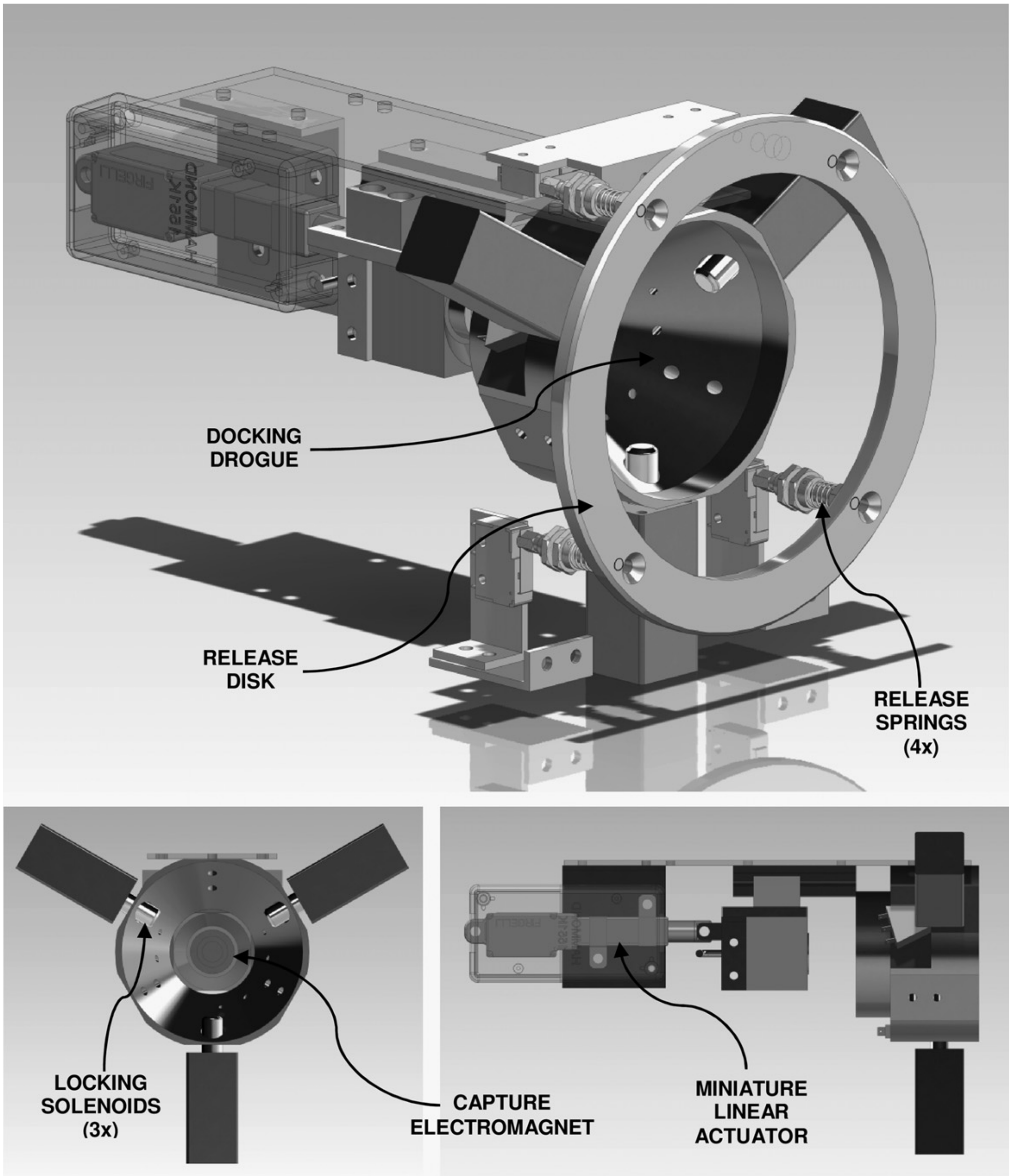

Fig. 5. PROXBOX (target vehicle) docking interface.

compromise the overall functionality of the mechanism, which is a relevant safety feature in a technology demonstrator such as ARCADE. On the other hand, this solution produces a considerable impact on the power budget when the two vehicles are in hard docking, which may not be acceptable in actual missions that are longer than a BEXUS flight. In this case normally-extended solenoids should be used, as they do not consume power during the joint phase.

The connection is finally secured applying a compressive force between the docking interfaces; a 6.5 mm compression of the spring-damper pushes the chaser vehicle docking interface against the locking solenoid cores and therefore applies an axial force of 2.1 N.

The gondola docking interface is equipped with a spring-mounted release disk, which is able to push away the SMAV once the locking solenoids are opened (Req. F.3). The selected release springs are about half the size of the one used as damper and they are compressed by 2 mm thanks to the pulling force of the miniature linear actuator. Their compression produce on the target vehicle an opposite force of 4.7 N, which adds up with the one provided by the spring-damper and rises the total compression between the docking interfaces to 6.8 N. Despite the overall stiffness of the connection is only due to these five unidirectional springs, it was judged to be high enough for an unpressurized connection.

Finally, the target vehicle docking interface includes a signalling system to confirm the correct achievement of the hard docking configuration (Req. F.4). In detail, four microswitches are used to assess the compression of the four springs of the release disk, while three optocouplers allow to confirm the proper extension of the locking solenoids (Fig. 6).

3.2. Concept of operation

Hereafter it is provided the description of nominal docking and release sequences within the ARCADE framework, where the SMAV mates with the PROXBOX.

Operations start when the SMAV interface is aligned – within the specified tolerances – with its counterpart on the PROXBOX. The *docking sequence* consists of 6 steps (Fig. 7):

(1) The SMAV moves towards the gondola and the spring-damper enters the drogue on the PROXBOX wall.
(2) The internal capture electromagnet catches the round disk mounted at the end of the spring-damper. The two vehicles are now connected, but the joint is not rigid. This configuration is called *soft docking*.
(3) The capture electromagnet and the SMAV are pulled backwards by the miniature linear actuator, until the release disk comes in contact with its counterpart on the small vehicle.
(4) The miniature linear actuator further retracts the SMAV by 2 mm, compressing the release springs. At this point the docking cone is inserted into the PROXBOX drogue and its groove is aligned with the locking solenoids cores.
(5) The structural solenoids are activated and the holding electromagnet is shut off.
(6) The spring-damper is compressed 6.5 mm by the linear actuator, significantly increasing the applied load. During this operation the external vehicle translates outwards by 0.25 mm, until the wall of the SMAV docking interface groove is pushed against the solenoid cores. The SMAV is now rigidly connected to the PROXBOX, in a so-called *hard docking* configuration. As a secondary result, a very small gap between the docking interfaces is produced.

When, on the contrary, the SMAV needs to be separated from the PROXBOX, the 4-steps release sequence is performed:

(1) The capture electromagnet is turned ON and the spring-damper is decompressed by pulling back the miniature linear actuator.
(2) The locking solenoids are shut off and, as soon as the compression force on their cores goes to zero, they retract.
(3) The release disk, thanks to its compressed springs, pushes away the SMAV that separates from the PROXBOX.
(4) The capture electromagnet is turned OFF and the miniature linear actuator is extended back to its initial position. The mechanism is ready for the next docking attempt.

It is important to point out that the presence of a small gap between the docking interfaces while in hard docking

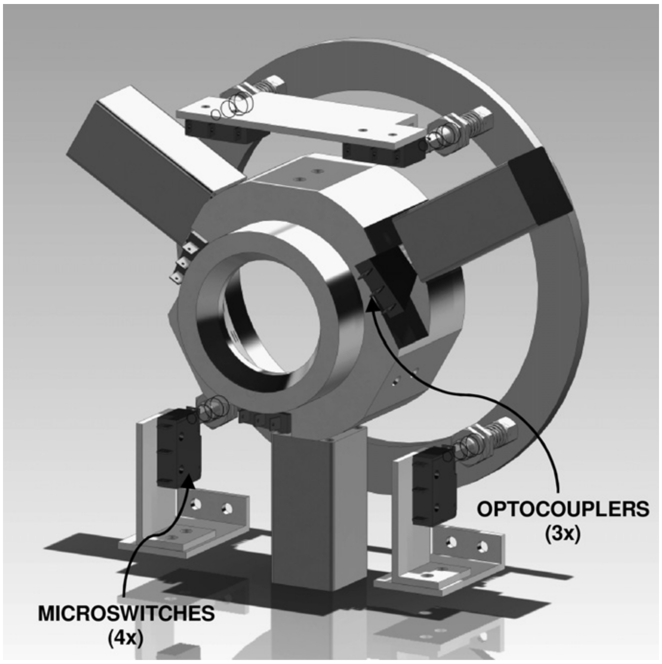

Fig. 6. Hard docking signalling system.

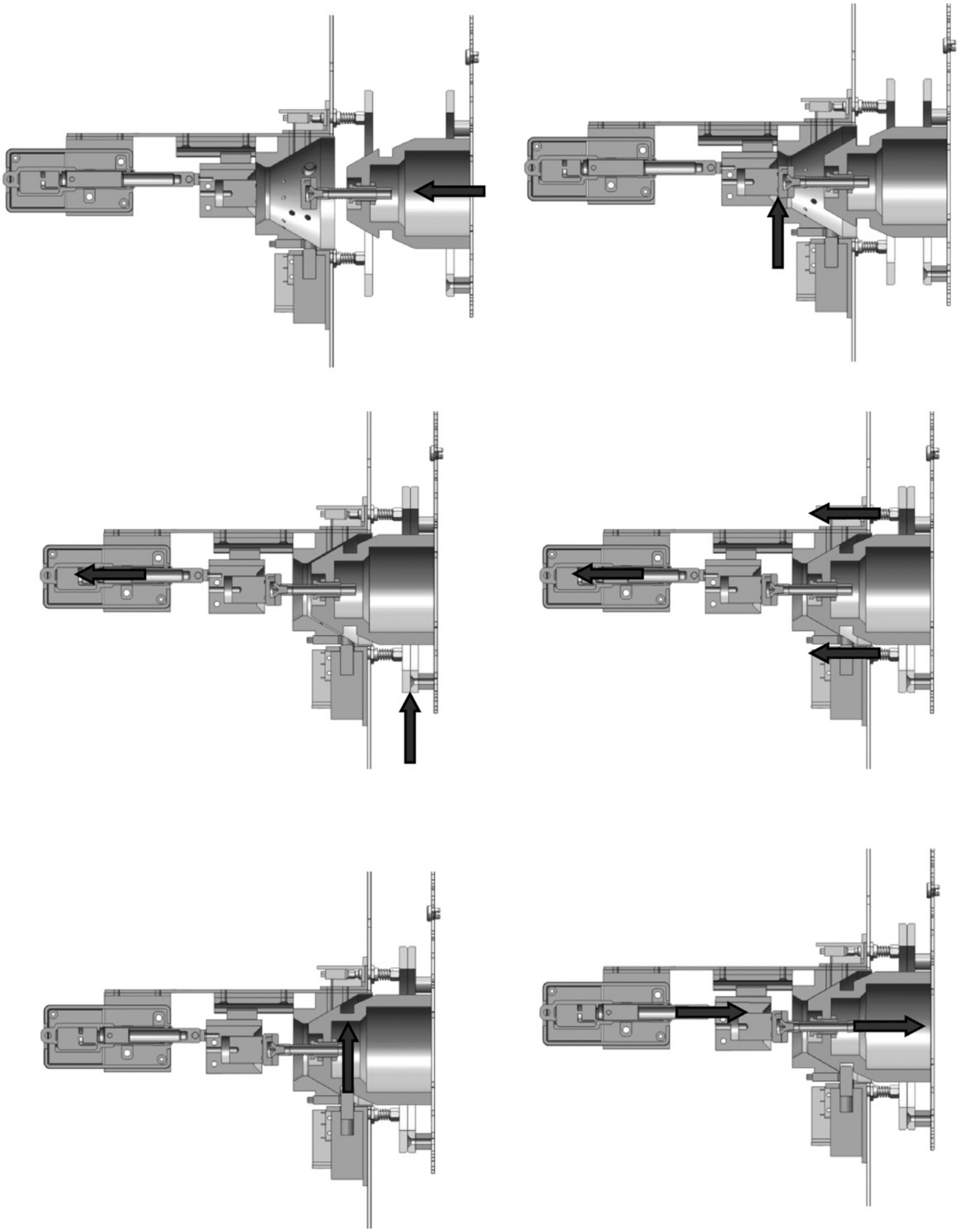

Fig. 7. ARCADE docking mechanism concept of operation.

is essential to perform the second step of the release sequence. In this state, in fact, the SMAV can be slightly translated towards the PROXBOX by means of the miniature linear actuator, if the electromagnet is ON. This small SMAV movement causes the contact between the SMAV docking interface and the solenoid cores to briefly cease, allowing them to freely retract.

3.3. Design verification by numerical simulations

The dynamic behaviour of the mechanism was verified by means of *numerical simulations*, carried out with the multibody dynamics analysis software MD ADAMS 2010. Four of them simulated capture and structural attachment attempts in different approach conditions, both within and outside the acceptable docking envelope defined by requirements, while the fifth verified the effectiveness of the release sequence. As the main goal was to verify the capability of capturing and latching the chaser vehicle within the proposed docking envelop, no in-depth assessment of the mechanism performances was performed. A more refined sensitivity analysis will be carried out in case of further development of the mechanism.

The ADAMS model, however, featured an exact reproduction of the ARCADE mechanism geometry. In fact, all the parts were imported as 3-D Parasolids, which were natively created by the Solidworks 2011 CAD software. The same setup (Fig. 8) was used for all the five simulations.

The SMAV was considered as an unconstrained free-floating vehicle, with 6 DOF. The miniature linear actuator, the locking solenoids and the electromagnet force were modelled as described below.

Miniature linear actuator

ADAMS action: constant velocity translational motion; Direction: actuator main axis; Magnitude: $+/-3$ mm/s, depending on the docking/release sequence step

Locking solenoids

ADAMS action: constant force applied to the solenoid core; Direction: solenoid core main axis; Magnitude: 0.5 N pushing force (after activation)

Holding electromagnet

ADAMS action: two-body force between the tip of the spring-damper and the electromagnet itself; Direction: electromagnet central axis; Magnitude: $F_{em} = 35 \cdot (0.5 - \Delta x_{mm}/\ 0.5)^2$ N if $\Delta x_{mm} \leq 0.5$ mm, otherwise $F_{em} = 0$ N.

Thanks to a virtual impact sensor, the electromagnet force is applied at the first contact between the electromagnet and the tip of the spring-damper. The miniature linear actuator is activated 3 s later and, last, the locking solenoids are extended after a 12.5 mm retraction of the SMAV. All the contacts were modelled with the standard ADAMS IMPACT formulation and accounted for dynamic friction. Stiffness, damping coefficients and friction coefficients were chosen coherently with the impacting materials and, for all the metal–metal collisions, the full damping effect was applied at zero penetration.

Simulations results indicated that both capture and structural connection correctly take place at a velocity of 50 mm/s, even with a yaw misalignment of 5° and with a residual rotation rate of 0.5°/s. In this case, however, the SMAV showed an oscillating behaviour prior to the structural locking, suggesting that these values, located at the boundary of the desired docking envelope, truly represent its limits. It was also verified that docking sequences featuring a higher approach velocity, 100 mm/s, or a greater misalignment, 10°, did not succeed. As already mentioned, a more refined sensitivity analyses would help to better identify the mechanism operational limits.

The structural compression load and the repulsion force for undocking were also verified to be compliant with the requirements, as they respectively reached 6.8 N and 4.8 N in hard docking configuration. Last, also the

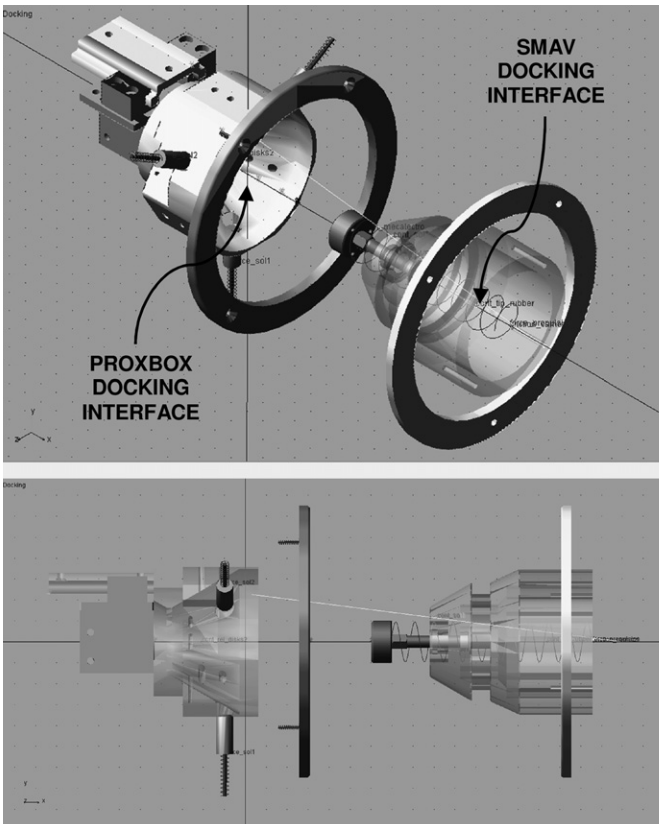

Fig. 8. MD ADAMS 2010 model of the ARCADE docking mechanism.

release sequence took place successfully, with the SMAV departing at about 33 mm/s.

4. Prototype functional testing

A *functional test* of the complete docking mechanism was performed at ambient conditions within the fully integrated ARCADE experiment, with the SMAV interface, the PROXBOX interface, the release disk, the micro-switches and the optocouplers all properly installed in their flight locations

The goal of the test was to verify the docking mechanism correct integration and functionality, to identify criticalities in its geometry, in the docking sequence logic and in the docking signalling system. Due to project constraints, it was not possible to conduct a complete *performance* (e.g., impact forces, actual docking envelope, etc.) characterization of the mechanism, which will be carried out in case of an ARCADE re-flight.

The control logic was necessarily different from the one employed for the dynamic simulations, because the prototype did not include an impact sensor, on which most of the simulation timings relied on. Moreover, the SMAV was no longer a free-floating vehicle, having only one free translational DOF (along the docking axis) and one free rotational DOF (yaw rotation). For these reasons, actuation timing was based on predefined delays and translations were commanded as absolute displacement from the HOME position of the linear motor that moves the SMAV, which is the farthest from the PROXBOX allowed by the ARCADE design.

Each performed test consisted in a "Docking sequence," in which the SMAV is brought from PROXIMITY – a condition where the distance between the tip of the docking spring-damper and the external wall of the PROXBOX is equal to 20 mm – to hard docking, followed by a "Release sequence," in which the opposite operation is performed. The SMAV approach velocity was varied from test to test up to 50 mm/s, with a maximum yaw misalignment at first contact of 5°. Systematic tests, however, were conducted only for the docking conditions expected during the BEXUS flight, thus with a SMAV velocity of 25 mm/s and a misalignment between the docking interfaces of about 2°. Docking attempts and following releases in such conditions were repeated manually five times, executing all the steps one by one, and other five times automatically.

All the attempted sequences were correctly executed. On the other hand, the signalling system used to assess the extension status of the locking solenoids resulted to be highly unreliable and two out of four release spring assemblies required custom modifications to work properly.

The docking mechanism had to be tested eventually during the ARCADE flight on-board BEXUS 13, where extreme environmental conditions were expected. Prior to launch the SMAV was hard docked to the PROXBOX, in order to secure the external vehicle during the initial and most turbulent phase of the ascent. A manual release sequence was commanded from ground and correctly executed at about T+12 min from lift-off, but a communication dropout was experienced shortly after, preventing any further attempt to control the experiment.

5. Conclusions

The development of micro-satellites orbital autonomous rendezvous and docking capabilities is expected to pave the road to a number of interesting mission scenarios, including on-orbit servicing, automated assembly of modular structures and active debris removal. Many technologies required to reach this objective, however, still require further developments and orbital testing.

In this context, the University of Padova, *Centre of Studies and Activities for Space* (CISAS), developed the Autonomous Rendezvous Control and Docking Experiment (ARCADE), with the scope of testing a proximity relative navigation system, a custom-made reaction wheel and a small-size docking device.

This paper focused on one of these innovative systems, the ARCADE docking mechanism. In particular, the objective of this work was to provide an overview on the most relevant features of the mechanism, on the technical solutions adopted to fulfil the requirements, on the design numerical validation, on the functional testing and, finally, to highlight the overall outcome of the requirements verification process.

The ARCADE mating system can be classified as small-scale, central, gender mating and unpressurized. In addition to the classic capture and structural connection functions, it provides repulsion for undocking by means of a spring-loaded release disk and soft docking capabilities, thanks to a capture flat electromagnet. The need for a low-cost and easy-to-manufacture device, in addition, led to a large use of commercial components.

The tolerance to misalignments and residual velocities of the final version of mechanism was assessed with dynamic simulations, carried out with MD ADAMS 2010 and employing 3-D Parasolid parts. Results showed that all the testable performance requirements were satisfied and that they truly represented the physical operational limits of the device. In detail, the system was able to capture and latch the chaser traveling at a velocity of 50 mm/s, with a yaw misalignment of 5° and with a residual rotation rate of 0.5°/s, establishing a structural compression of 6.8 N when in hard docking and providing a repulsion force for undocking of 4.8 N.

Functional testing was performed at laboratory conditions, on-board the fully assembled ARCADE experiment, to verify the effectiveness of the manufactured docking system during the capture, latching and release phases. In this framework, the actual docking and release procedures developed for the BEXUS flight were executed, both step-by-step and as automatic sequences, at different SMAV misalignments, approach velocities and residual yaw rotation rates. All the attempts within the docking envelope resulted in a success. The signalling system for the hard docking attainment, however, did not produced reliable readings.

Future developments of the ARCADE mechanism should start with the rethinking of the hard docking signalling logic and the substitution of the optocouplers with, for example, inductive sensors. Notably, however, the device successfully captured, latched and eventually released the chasing vehicle. In addition, with the sole exception of the signalling system, the fulfilment of all the requirements was verified.

These encouraging results qualify the ARCADE docking mechanism as a good starting point for the development of a docking system for micro-satellites that, in the future, could be better characterized in more advanced facilities, during another BEXUS flight, and, ultimately, in micro-gravity conditions.

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