75^{th} International Astronautical Congress (IAC), Milano, Italy, 14-18 October 2024
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IAC–24–IAC-24-B4.IP.126.x91459

Derisking the AIV/AIT phase for constellation: the HERMES approach

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Abstract The HERMES mission consists of a constellation of six 3U CubeSats designed for the detection and triangulation of Gamma Ray Bursts (GRBs). The Istituto Nazionale di Astrofisica (INAF) developed the high-energy detector, while the Politecnico di Milano is responsible for the overall fleet design, assembling, integration and testing. Due to the complexity of the mission, several customizations were necessary. The platform, despite lacking propulsion, is equipped with three communication channels: S-band, UHF/VHF band, and an Iridium modem. Additionally, it features oversized reaction wheels, custom-designed winged solar panels, and a slightly modified structure. The onboard software has been entirely developed in-house. Given these unique requirements, the assembly and integration processes were specifically tailored to the mission. The small size of the spacecraft, coupled with the need to integrate numerous components in a limited internal volume, presented significant challenges. Adherence to European Cooperation for Space Standardization (ECSS) guidelines throughout the entire lifecycle added further complexity. To mitigate risks during the delicate Assembly, Integration, and Verification (AIV) and Assembly, Integration, and Testing (AIT) phases, two key solutions were implemented: a high-fidelity satellite mockup and a 3D virtual environment. The mockup played a crucial role in training personnel for assembly and identifying potential bottlenecks ahead of time, as it faithfully reproduced the entire satellite bus, including electronic boards and connectors. It was instrumental in finalizing the assembly procedures and harnessing, particularly given the small and crowded internal volume of the spacecraft. As a complementary solution, a virtual model of each assembly step, including routing, was developed. This model guides the operator through a 3D video, which replicates each action required for each step of the assembly sequence, while providing augmented details of the component being assembled. To validate the tool, personnel unfamiliar with the satellite assembly process were provided with the virtual augmented tool and the mockup. They successfully replicated the spacecraft assembly with minimal intervention. This approach significantly improved the assembly of the Proto-Flight Model (PFM) and allowed for efficient disassembly when non-conformances arose during the D phase, ultimately accelerating and de-risking the assembly of the remaining satellites in the fleet.
keywords: CubeSat, Harness, Cable Routing, Assembly, Verification and Testing, Virtual Environment.

1. Introduction

The HERMES mission (High Energy Rapid Modular Ensemble of Satellites) is conceived as a constellation of six 3U CubeSats in Low Earth Orbit, equipped with an advanced payload designed to detect the timing of bright high-energy transients, such as Gamma-Ray Bursts (GRBs). This mission is divided into two parallel projects, each consisting of three satellites: the HERMES Technological Pathfinder (HERMES-TP), funded by the Italian Space Agency (ASI), and the HERMES Scientific Pathfinder (HERMES-SP), supported by the European Commission's H2020 program.

HERMES seeks to prove that it is feasible to achieve precise and rapid localization of bright transients in the hard X-ray/soft gamma-ray spectrum, like GRBs [1–3]. Another key objective of the mission is to demonstrate that the use of nanosatellites, largely built with commercial off-the-shelf components, can significantly reduce both mission costs and time-to-orbit, cutting costs by one to two orders of magnitude compared to conventional space projects [1].

The mission involves the collaboration of various institutions, including the Istituto Nazionale di Astrofisica (INAF), which is responsible for the scientific payload, and Politecnico di Milano (Polimi), which is tasked with designing the service module. Polimi also handles the integration of the payload, the assembly, integration, and testing of the system, as well as the coordination of the mission's ground segment development [1–3].

Each CubeSat has a high number of cabled connections resulting in a 20 m of wire in a XXXX volume

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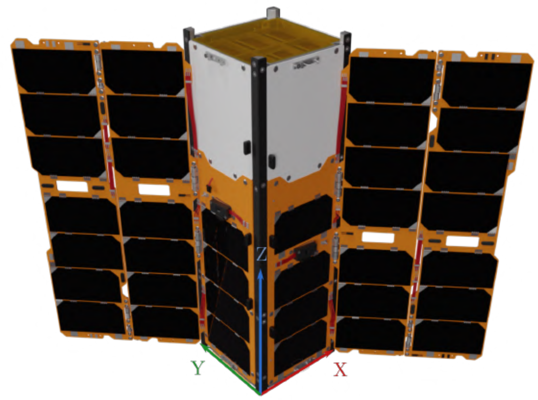
stacked together with all the other electronic components and panels that leave very small spaces for the routing of the cables. Upon that, the scientific payload needs to be managed carefully as the optical filters and the electrical connections can be damaged by small object impacts. For the reason above, the necessity to find the proper routing of each cable and the assembly sequence of all the hardware in order to forsee possible interferences. To fulfil such objective the Polimi team, in charge of the design, assembling and testing of the platform decided to find the proper routing of the cables first by using SolidWorks Routing, which enabled measuring the lengths of all the cables and finding the harness routing without mechanical intersections. Being Polimi in charge for the in house manufacturing of all the cabled connections the harness routing has been validated using a mockup of the HERMES CubeSat composed of the Structural Qualification Model, 3D printed versions of all the electronic boards as well as replicas of all the cables with the lengths computed in SolidWorks routing. The verification led to many changes in the cable lengths, especially the RF cables that have bigger diameters and are more rigid, such changes avoided mistakes in the manufacturing that would have been discovered only during the first flight model assembly.

Once the cables routing is validated, the team moved to design the assembly sequence. The study of the sequence is first performed on the mockup and then is finalized using a virtual environment producing as output the complete assembling sequence, comprehensive of every single cable positioning. Any team member can use the 3D virtual sequence for training or checking the time sequence for test scheduling. The final sequence allowed the team to prepare all the tools as well as design and manufacture all the Mechanical Ground Support Equipments (MGSE) needed for the assembly of the first flight model.

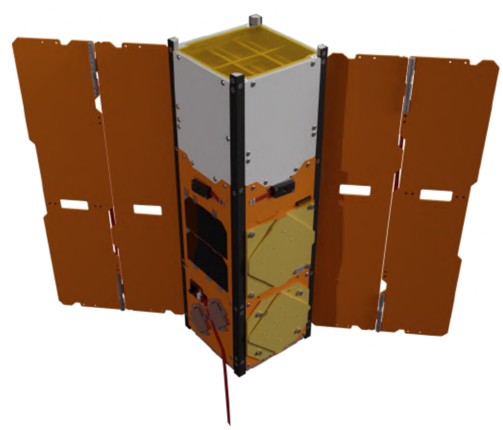
The present work reports the methodology followed for the harness routing and for the design of the assembly sequence thus exposing all the lesson learnt in this process that can be a valuable asset for future CubeSat missions. The article is divided in the following sections: Sec.2 reports the Harness routing design and validation, in Sec.2 the Assembly sequence design and validation using the virtual environment, in Sec.4 the lessons learnt and the conclusions.

2. Harness Routing Design and Validation

Each CubeSat contains a complex network of cables, amounting to approximately 20 meters of wiring



(a) Front



(b) Back

Fig. 1: HERMES CubeSat.

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in a compact 30cmx10cmx10cm volume, where space for cable routing is minimal due to the presence of other electronic components and panels. Additionally, the scientific payload, particularly optical filters and electrical connections, must be carefully managed to prevent damage from small object impacts. Therefore, determining the optimal cable routing and assembly sequence is essential to avoid potential interferences.

To address this challenge, the Polimi team, responsible for the design, assembly, and testing of the platform, utilized SolidWorks Routing to first determine the optimal cable routing. This approach allowed for precise measurement of cable lengths and ensured that the harness layout avoided any mechanical intersections.

The scheme followed for this process is reported in Fig. 2

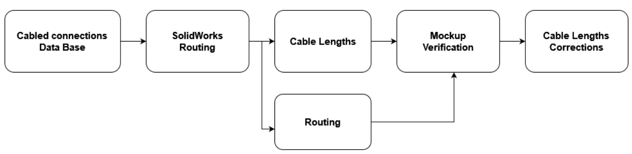

Fig. 2: Scheme used for harness routing design.

2.1 *Design*

The routing design starts by creating the database (DB) that contains all the cabled connections indicating the pin-to-pin layout, the cable diameter as well as the geometry file of each end of the cable. Once the DB is complete, all the different connectors geometries must be imported in SolidWorks Routing where they can be set as cable item and be prepared for the pin-to-pin layout. Within the complete CAD of the satellite every cable, one by one, is created with the given pinout and routed to avoid intersections. The finale result is reported in Fig. 3

2.2 *Verification*

As Polimi handled the in-house manufacturing of the cable connections, the harness routing was further validated using a mockup of the HERMES CubeSat. This mockup comprised the Structural Qualification Model, 3D-printed versions of the electronic boards, and replicas of the cables based on the lengths computed in SolidWorks Routing. The verification process resulted in multiple adjustments, particularly to the RF cables, which have larger diameters and greater rigidity. These modifications prevented errors that would otherwise have been detected only during the assembly of the first flight model. Pictures of the mockup are reported in Fig. 4 to give a better idea of the tool.

3. Assembly sequence design and validation

Once the cable routing was validated, the team moved to design the assembly sequence. The study of the sequence is first performed on the mockup and then is finalized using a virtual environment in Blender producing as output the complete assembling sequence, comprehensive of every single cable positioning. Any team member can use the 3D virtual sequence for training or checking the time sequence for test scheduling. Furthermore, the 3D virtual environment was fundamental in writing the actual assembly procedure and necessary to check the proper routing of each cable at every step of the integration. This last point is very important to avoid interferences when closing the panels and without the 3D virtual environment it would have been very difficult to perform such checks. Pictures reporting the different frames of the assembly sequence in the virtual environment are reported in Fig. 5

The final sequence allowed the team to prepare all the tools as well as design and manufacture all the Mechanical Ground Support Equipments (MGSE) needed for the assembly of the first flight model.

The sequence is tested in the clean room using the mockup of the satellite and using the virtual environment, pictures of such operations are reported in Fig. 6. Pictures of the virtual environment used during the actual assembly phase of the first flight model are shown in Fig. 7 compared with the same step performed and tested using the mockup.

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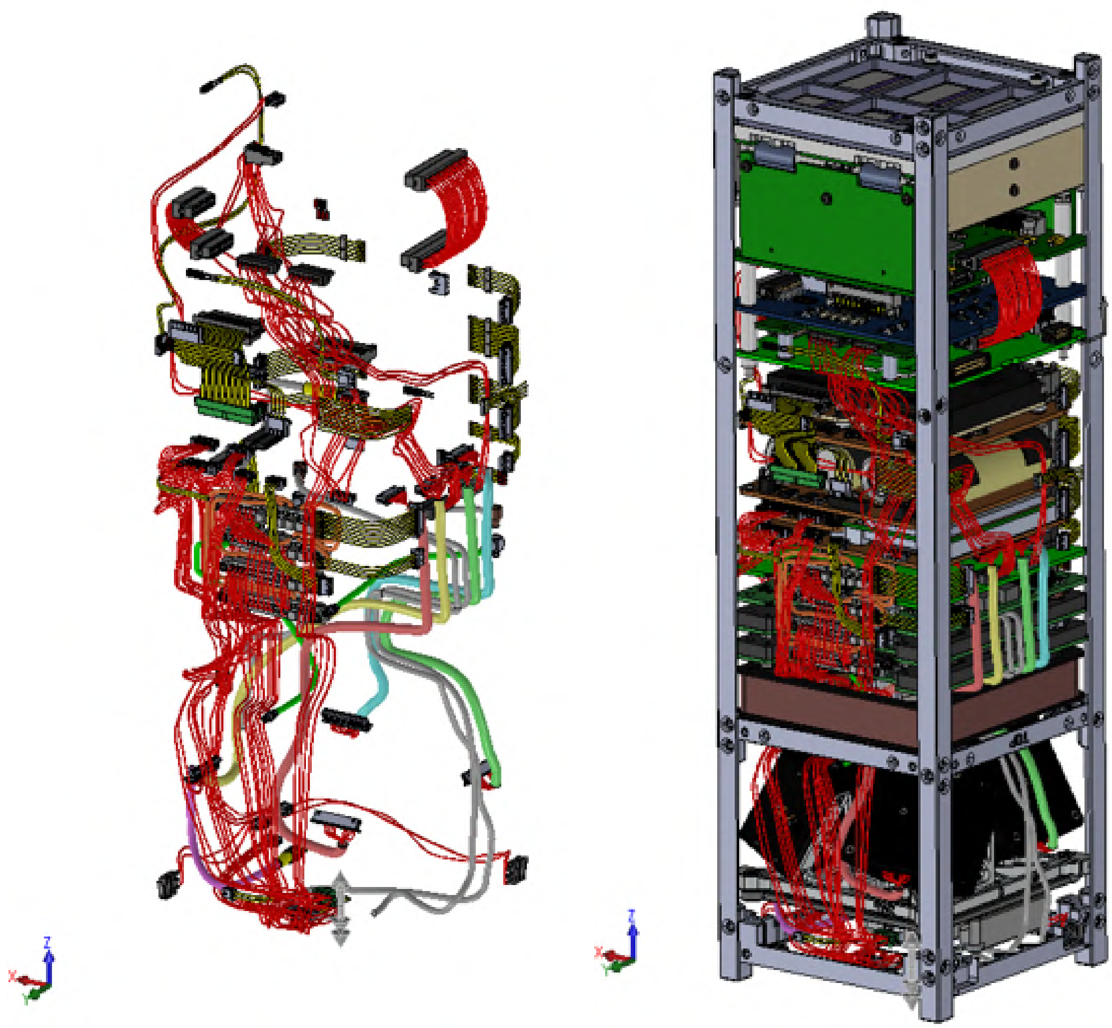

(a) Harness routing (b) Harness integrated in HERMES CubeSat

Fig. 3: HERMES Harness Routing.

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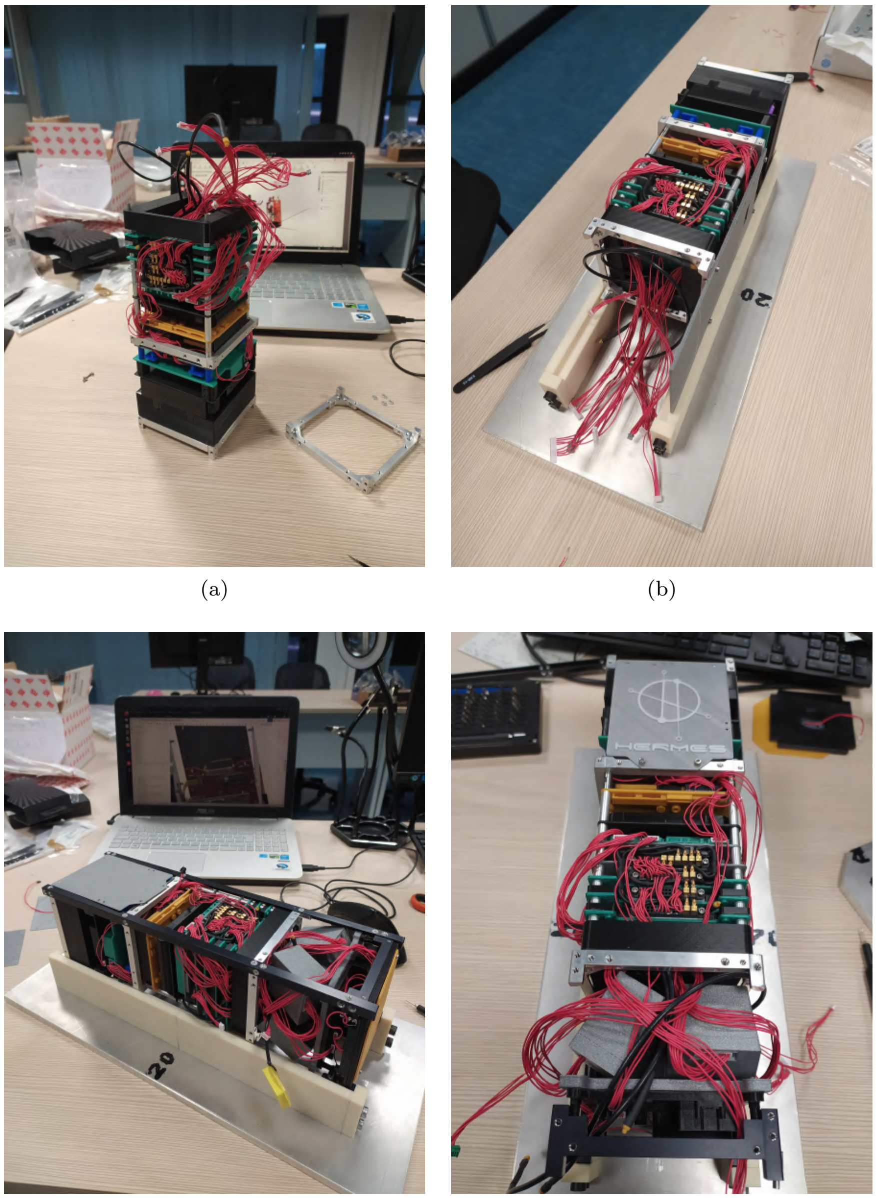

(a) (b) (c) (d)

Fig. 4: HERMES mockup

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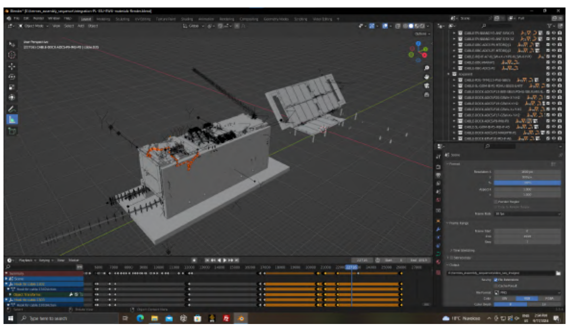
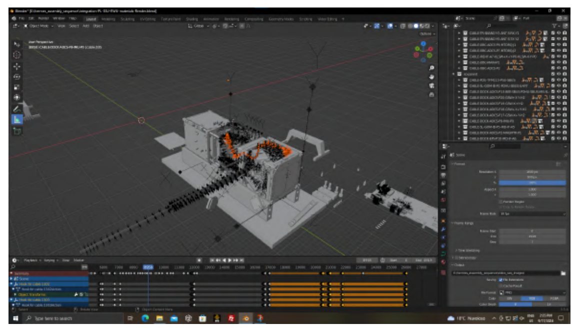


(a)



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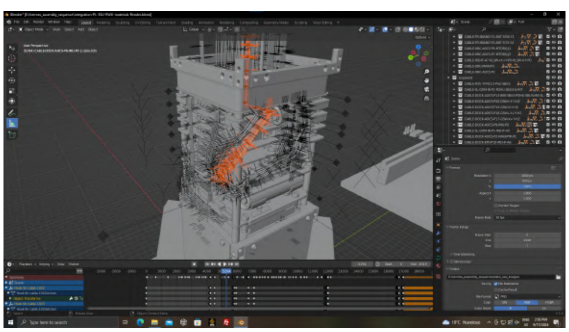

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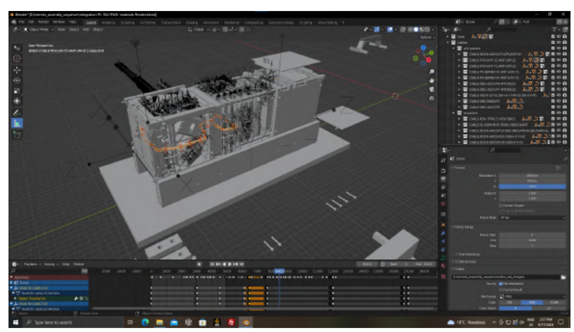

(d)

Fig. 5: Virtual environment in Blender

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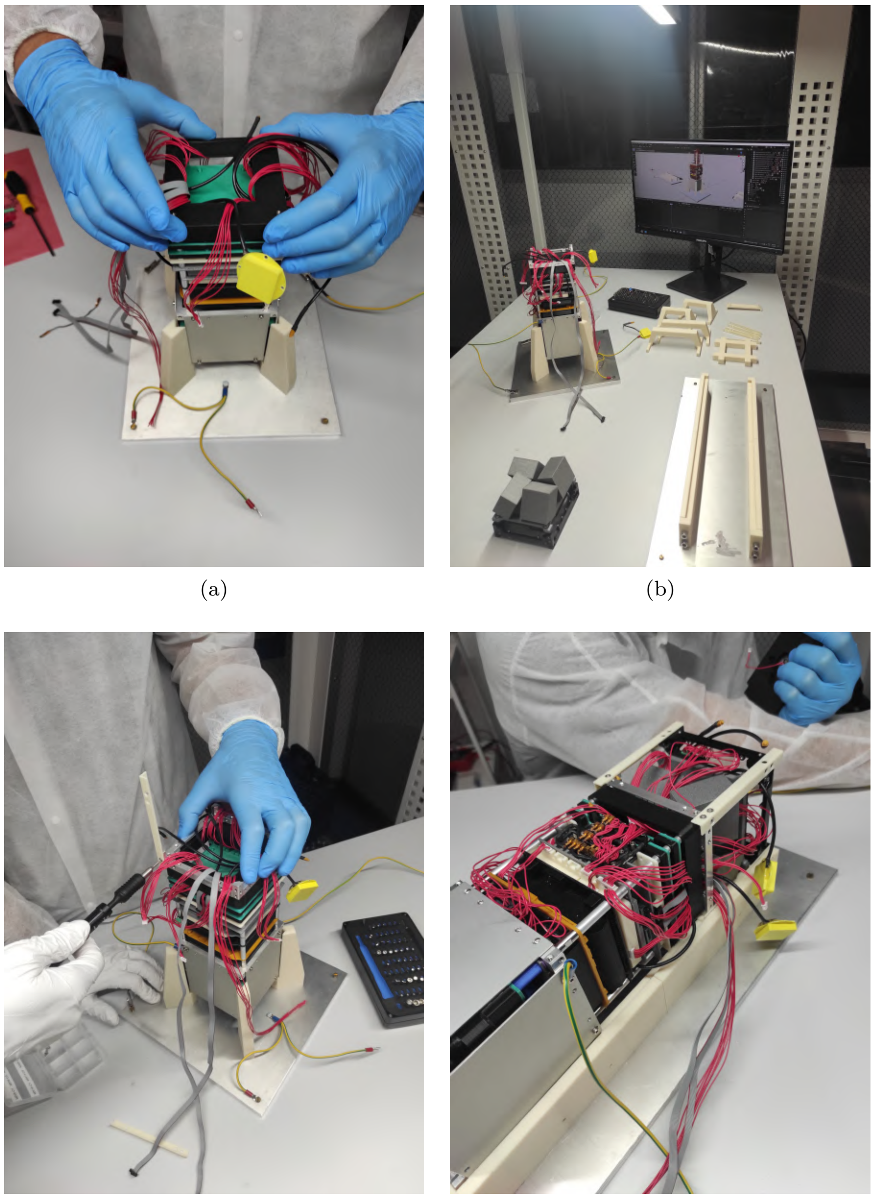

(a) (b) (c) (d)

Fig. 6: Testing assembly sequence using mockup and virtual environment

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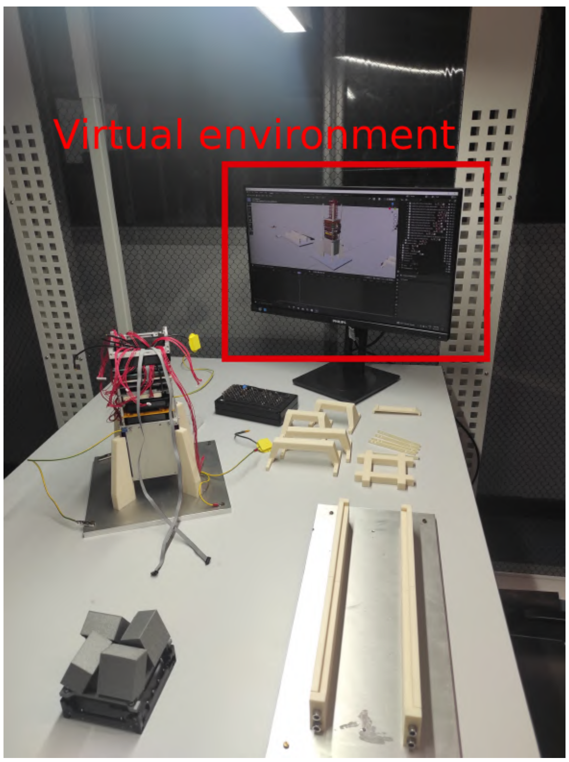
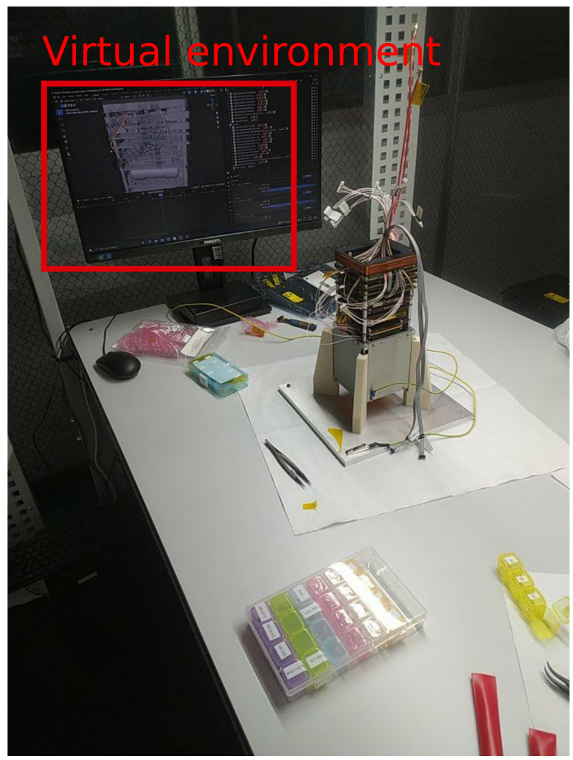


(a) Assembling using the mockup and virtual environment



(b) Assembling first flight model using virtual environment

Fig. 7: Assembling of HERMES CubeSat. Sequence tested using mockup (left) and first flight model with the help of the virtual environment (right)

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4. Conclusions and lessons learnt

The paper presented the method used by the Polimi team to design the harness routing, validate it and create the complete assembly sequence of the CubeSat. The full assembly procedure is finalized in a 3D virtual environment in Blender, such environment proved to be a valuable instrument in checking the routing of each cable during the integration and fundamental to train the other team members that need to operate during the assembling. In conclusion, the following lessons learnt are listed as useful guidelines for future CubeSat missions:

1. **Cable lengths must be checked with mockup:** despite the useful design computed in SolidWorks Routing the lengths of the cables had to be modified after the check with the mockup. Among such modifications the ones on the RF saved the team from interferences with the panels as such cables have a larger diameter and are quite rigid thus no errors are admitted in their lengths.

2. **Virtual Environment is fundamental to check routing and team personnel:** without a 3D virtual environment is almost impossible to explain to the operators how to layout the cables and coordinate with the operators. Furthermore, checking the proper routing at each step is indispensable and saves the team from non-conformities later on in the assembling.

3. **Virutal environment is very helpful for the assembly sequence:** the virtual environment allows the operators to move forward in time in the assembling procedure thus allowing them to prepare themselves and all the necessary tools in time, thus speeding up the assembling.

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