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Following a fast changing World of Space Operations: a Center ready to support the return to the Moon

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Abstract

A center devoted to provide specialized mission support services since the beginning of the millennium has developed and operated with various customers, for diverse purposes, integrated in different ground networks and with growing needs for optimization of resources.

In the years, ALTEC ground segment was grown from an initial setup with a single Mission Support Centre dedicated to the engineering support for the ASI NASA bartered ISS Elements, to the creation of a remote Support Center, integrated within the ESA ISS Ground Segment to provide various types of mission preparation and operations. From the design and operations of the Italian Data Processing Center of GAIA mission, to the setup of various complex and large scientific data processing and operations centers. From the adaptation of the first center to a multipurpose and customizable facility that was used as Flight Room of IXV, to the setup of the new Exo-Mars Rover Operations Control Center, including the necessary analogue simulators.

At each step of the growth, the experience gained was exploited and shared to design and operate the new facilities, and to maintain and upgrade the old ones, together with increasing synergies within the center, at both competences level and infrastructure level.

The result is a center that is capable to operate for a large span of scenarios, including human spaceflight, space vehicles and space exploration robotic missions, and to be flexible enough to allow rapidly adapt to provide operations services of new types of missions and integration in different ground network.

The latest need is to rapidly prepare for the upcoming return to the Moon.

Taking advantage of the competences and facilities grown, ALTEC is now preparing to be ready to support a variety of lunar mission operations activities, that could span for instance from Lunar Gateway related activities, to surface facilities and missions, initially with the development of the ERFNET Data Hub with the Lunar Gateway, and then with the setup of a Lunar Operations Center.

The primary objectives are to provide a pool of services for lunar missions for integrated logistics management, training, mission integration & crew support, operational management of missions (human, science, robotics), systems validation on lunar analogue, and eventually end-to-end missions implementations.

The Center is being conceived as a modular / incremental set of services, by integrating the use of concepts and elements available in ALTEC, such as the Exomars ROCC and Analogues, the European Logistics Center and the P/L management from Space Rider and ISS.

The purpose of this paper is to describe the evolution of the ALTEC Multi-Functional Space Center until the latest details of today's services and facilities, and to illustrate the concept of the Lunar Operations Center that is being conceived at ALTEC to be ready to support the return to the Moon.

Keywords: Moon, Lunar Operations, Operations Control Center, Exploration

Acronyms/Abbreviations

Aerospace Logistics Engineering Technology Company (ALTEC), Alpha Magnetic Spectrometer (AMS), Altec Space Data Processing (ASDP), Data Processing Centre – Turin (DPCT), Engineering Support Center (ESC), Gaia Data Processing and Analysis Consortium (DPAC), Hand Posture Analyzer (HPA), In Situ Resources Utilization (ISRU), Interconnection Ground Subnetwork (IGS), International Space Station (ISS), Intermediate eXperimental Vehicle (IXV), Mission Control Center (MCC), Mars Terrain Simulator (MTS), Multi Purpose Logistics Module (MPLM), Permanent Multipurpose Module (PMM), Rover Operations Control Centre (ROCC), Space Station Processing Facility (SSPF).

1. Introduction

ALTEC, originally named as Advanced Logistics Engineering Technology Center and now Aerospace Logistics Engineering Technology Company, was created in 2003 as a public-private partnership of Thales Alenia Space Italia, the Italian Space Agency (ASI) and Icarus ScpA (a , with the aim of for the provision of hi-tech engineering services relevant to operations and utilization of the International Space Station (ISS), other space infrastructure, and in support of future robotic and manned planetary exploration.

With that aim, ALTEC was assigned to organize and provide support services and related ground segment for various missions, from very specialized and diverse cases at the beginning, until a flexible and multipurpose center in preparation of future mission operations market.

The purpose of this work is to provide an overview of this evolution, and how it was possible to exploit the need to prepare for very different cases to obtain a center ready to provide mission support services for future space operations market and human exploration missions, and how this is now heading towards the readiness to support the return to the Moon.

2. Born of ALTEC Mission Support Center and ASINET - MPLM Missions to the ISS with the Space Shuttle

The definition and design of the ALTEC Mission Support Center, as well as of the ASI Network, started in mid-1998, in parallel with the delivery campaign of the MPLM Leonardo Module at KSC, and the definition and preparation of the Sustaining Engineering activities foreseen as part of the ASI-NASA MoU. Initial launch date of the first MPLM was set beginning of 2000, then shifted to March 2001. Considering the challenging date for operations start, a simplified documentation approach was agreed between ASI and NASA for the mission interfaces definition (data, voice and video) between the MSC and the MCC-H, including the installation of the communication gateway at MCC-H. An Interface Definition Protocol instead of an ICD was developed and agreed, allowing the implementation completion of both the ALTEC MSC and the first part of the ASINET by January 2001. It is worth to highlight that the ASINET design was based on the ASI requirement to build a “multi-mission” network, thus not only dedicated to ISS operations support. The ASI Gateway at MCC-H was since the beginning, considered as a gateway toward all NASA centers, in order to exploit at the maximum extent, the mission opportunities between the Agencies. The initial implementation of ASINET foresees the connection with MCC-H in Houston, and the connection with the SSPF at KSC for MPLM testing support. Subsequently the connection with MSFC was added for ISS P/L operations. The ASI Malindi Ground Station was then added as new node of ASINET, enabling its utilization by the SWIFT program, the first non-ISS project that used ASINET as network interconnection.

The first operational use of the ALTEC MSC (supporting both the mission operations of the MPLM and the ground testing) occurred in February 2001 with the support to the STS-102/5A.1 Pad IVT (this was done just for this first mission). The first mission support was performed from March.8 to March.21 2001 during the STS-102/5A.1 mission. NASA required for the first two MPLM missions a “double” support team, one at MCC-H MER and the other in ALTEC, in order to certify the entire system and associated personnel. The formal certification of ALTEC was obtained in August 2001 before the launch third launch of MPLM (STS-105/7A.1).

The ALTEC MSC was designed to concurrently support both mission operations and ground testing of MPLM. This was achieved during the second MPLM Mission, the STS-100/6A.1, when during mission operations, the ALTEC team supported the ground testing of the MPLM Leonardo at KSC in preparation of the STS-105/7A.1 mission in parallel.

3. Mission Support Center, today

After the initial setup and first MPLM missions, the ALTEC MSC has been used in an extended perimeter of ISS activities in which ALTEC (and also TAS-I) is involved, namely:

- for technical / operational support at all stages of check out and cargo integration of MPLM missions (from 2001 to 2011) and PMM, directly linked to KSC,
- for operational support to all MPLM missions from 2001 to 2011 and PMM,
- for operating support for Node 2, Node 3 and Cupola installation and configuration missions,
- for operational support to Esperia and DAMA missions, and for some HPA experiment sessions,
- to support the AMS 02 mission as regards the system installation and the first phase of data receiving and processing,
- to support the Cygnus cargo module during the Orbital resupply missions of ISS,
- for all stages of qualification and validation of the ground segment of the ESA IXV mission
- for Italian ISS utilization activities related to payloads developed with the contribution of ALTEC and for the activities under the umbrella of the UTISS (UTilization of ISS) service to ASI.

Figure 1 - ALTEC MSC

Currently the center is used continuously for supporting activities for the PMM module, and its general architecture is depicted in the following schematic.

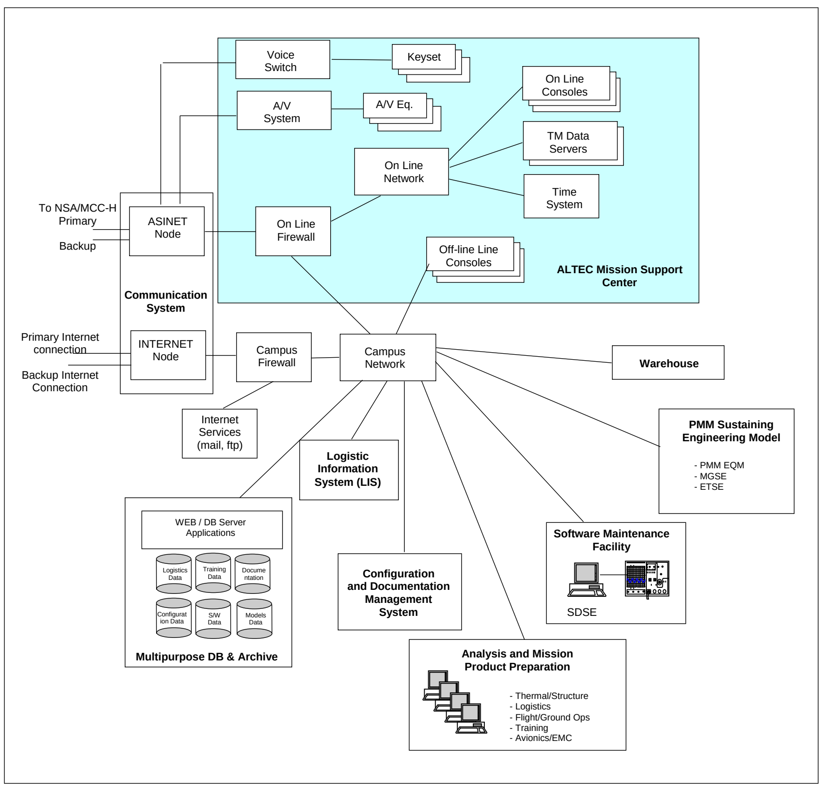

Figure 2 - MSC and Engineering Support System

The architecture above provides everything needed to perform the activities for support for PMM, both real-time and off-line. Alongside the real-time operating part, a similar development environment is provided to carry out development and testing activities. The latter is connected to the NASA development environment, called HITE.

This architecture is integrated within the physical infrastructure of ALTEC, which uses facilities and services, as well as the IT support infrastructure provided by the company (campus network, domain controllers, account management, storage, backup, etc.), keeping logical and / or physical separation and appropriate access controls (depending on security requirements).

For the purposes of supporting the PMM activities, the following main functional elements are provided by the center:

Communication Systems:
- External communications (ASINET, Internet)
- The local internal network (separate from the operational and development network)

The Mission Support Center, which includes:
- Systems for receiving, archiving and processing telemetry data
- Voice loops (voice loops)
- Video reception and management systems
- Time management and synchronization systems

Systems dedicated to development and testing activities
- Operational support and engineering support activities:
- Databases, archives, and documentation / configuration management systems / applications, mission logs, logistic aspects, etc.

Systems for engineering analysis
- PMM Software Maintenance Facility
- The Sustaining Engineering Model

As previously explained, the ALTEC Center is currently part of the ASINET network that the Italian Space Agency has implemented to support national activities related to the Space Station program and other programs in which ASI is involved.

The ASINET network, through its gateway to Houston's MCC-H, is currently integrated with both the ISS ground segment (providing connections with NASA JSC, MSFC), and other NASA non-ISS operational networks.

Figure 3 - Current ASINET configuration

The connection node at KSC was dismissed with the end of the Space Shuttle missions, but such configuration or other connections can be established if needed.

The above features allow to perform the following functions by means of the MSC:

- Support the "real time" operations of PMM.
- Participate in the simulations of the ISS.
- Process telemetry data, both real-time and periodically archived data.
- Access both PMM and ISS archive data for all the necessary analyses.
- Access the MPLM mission archive data from both the Shuttle phase and the ISS phase.
- Receive, record (when required) and view the video signal from the MCC-H.
- Access NASA operating voice loops for mission support.
- Receive real-time data from the Northrop Grumman Cygnus module during cargo missions to ISS.

The above is just the current list of functions performed, but, as anticipated, it was already possible to easily perform important reconfigurations to allow the support to very different type of missions (see also the IXV chapter below). The choices made in the course of the design and upgrades of the MSC and its interfaces, have allowed indeed to obtain a flexible/reconfigurable facility.

4. Columbus Engineering Support Center

Columbus is the European laboratory permanently attached to the ISS. It has been launched on December 2007 aboard Shuttle Atlantis during mission STS-122 and became operational in February 2008.

ALTEC ESC is one of the two Engineering Support Center of ESA Columbus mission. The ALTEC ESC design and implementation followed the development plan of Columbus Ground Segment and supported the qualification phases of the system. ALTEC ESC has been in operation since beginning of the Columbus Operations. ALTEC ESC is part, along with the USOC and Col-CC, of the ESA Columbus ground segment network devoted to the operations and support of ESA ISS Columbus module and its payload/experiments. The ALTEC ESC has a dedicated connection to Col-CC via the Interconnection Ground Subnetwork (IGS). The IGS comprises also “ESA Relay” located at MCC-H, HOSC and MCC-M, and IGS Nodes located at the European sites. The overall management of the network is performed centrally at COL-CC.

Through this link it is possible to receive Columbus and P/L data, voice and video services. As an Engineering Support Center ALTEC is entitled to receive Columbus telemetry parameters, with no telecommanding capability though. ALTEC ESC is also entitled as payload ESC, as such EDR and EDR2, FSL and Solar (until it was returned) Telemetry parameters are/were received at ALTEC. During the ATV era also some engineering parameters were received to provide support to ATV-CC. Voice connectivity allows ALTEC ESC operators to communicate with their counterpart at Col-CC through a dedicated voice loop system (VoCS). Through this system it is also possible to listen to selected voice loops from MCC in Houston and in Moscow and Space-to-Ground loops, that are the loops where astronauts speak with ground. Video system allows ALTEC ESC to receive a video stream sent from Col-CC. Col-CC has six video links with MCC Houston and has the capability to select them and to route them to ALEC ESC. These video are mainly providing real-time coverage of activities occurring on-board the ISS.

ALTEC ESC provides 8 full consoles for real-time operations support. Nowadays ALTEC ESC is mainly used by COSMO (Columbus On orbit Stowage and Maintenance Officer) operators, by PASO (Product Assurance and Safety Officer) and, when required, by Columbus Engineering Support Team for what concerns Columbus module activities and also P/L support.

Figure 4 - ALTEC ESC during operations

The following Figure shows the Columbus Ground Segment network and centers, with connection toward external sites (NASA MCC-H, NASA HOSC, RKA MCC-M and Canadian CSA)

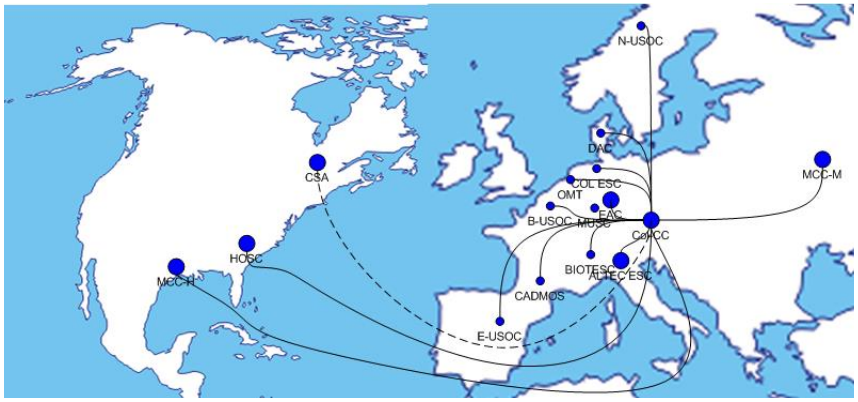

Figure 5 - Columbus Ground Segment

In particular, links toward NASA and Russian centers are redundant, while connections toward internal node of the IGS network are not redundant. Connectivity toward CSA occurs through VPN over internet.

5. From a Mission Specific to a Multi-Mission Environment: the Virtual ALTEC Mission Operations System (VAMOS) and the IXV Mission

The end of the Shuttle Era and consequently the end of the MPLM logistic flights, drastically changed the operations and utilization needs of the ALTEC MSC described above. On the other hand, the assets available in the MSC and its connection to ASINET provided a unique infrastructure that could satisfy new mission requirements, such as those of the IXV Mission.

The ESA mission Intermediate eXperimental Vehicle (IXV) is a re-entry demonstrator vehicle that performed a successful atmospheric re entry mission on the 11th of February of 2015. ALTEC designed, developed and implemented, along with other Italian partners, the mission Ground Segment. In particular, mission operations were performed from IXV Mission Control Center, hosted at ALTEC premises.

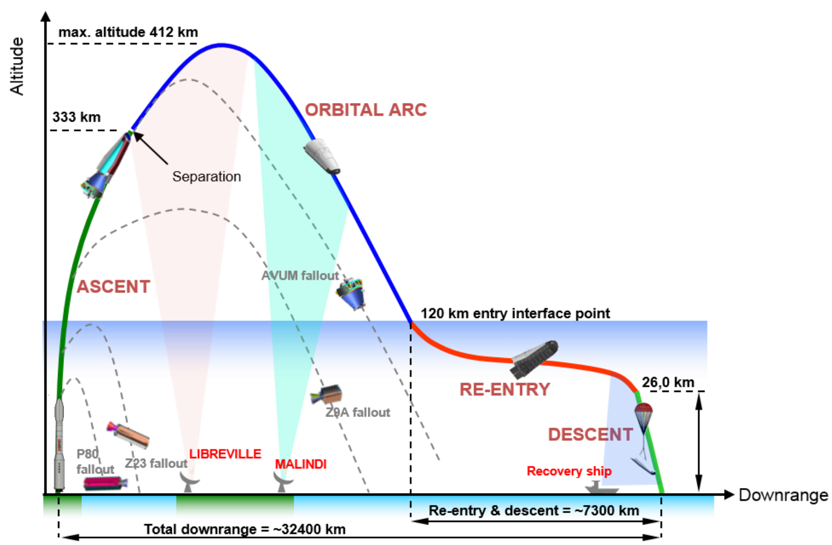

Figure 6 - IXV Main Flight Phases

The Mission Control Center (MCC) was developed re-using at maximum extent the ALTEC MSC infrastructure, making use of virtualization techniques (VmWare based) in order to host different space mission data system, associated to a reconfigurable mission operations room. This approach allowed to host the IXV MCC upon the existing ALTEC Mission Support Center infrastructure, operative since 2001 for ISS support, and to run in parallel the two virtualized environments.

Thanks to this mission, ALTEC has been able to upgrade its ALTEC Mission Support Center toward a virtualized infrastructure, being thus able to implement the concept of a Multi-Purpose Mission Control Center. Virtualization allows for high and easy re-configurability of the operative assets, as multiple environments can run in parallel. Also, the supporting elements already available at ALTEC MSC (i.e. voiceloop, recently refurnished) provide high versatility and configuration options, permitting thus to support and cope mission requirements and operations needs.

The path that led to a virtualized Mission Control Center was carefully considered and planned. In particular specific test campaigns, aimed at verifying the possibility of using virtual machines for real-time ops environment, have been conducted. This allowed for a full ISS ops environment virtualization and also provided the go-ahead for installation, integration and testing on virtual environment of the ESA MICONYS suite, adopted to implement IXV Mission Control System (MCS).

Virtualization feasibility tests have been conducted at several stages. First tests focused on verifying the performances of a virtual MCS system (ISS one was used as test bed) with no impacts for the end user. Then the tests focused on verifying the IXV MICONYS functionalities over a virtual environment; finally the formal qualification review processes were conducted by validating the whole MCC with its virtual MCS.

Tests were conducted on the original ISS development environment that used to be hosted on physical machines. The aim of these tests was to demonstrate that no impacts were introduced on an OPS environment by virtualizing it. Tests were conducted based on the application of benchmarking concepts, that is a set of typical activities performed by an operative system, measured and compared with reference values (i.e. the physical original deployment versus the virtual deployment of the same environment). These tests were successful in demonstrating that no impacts are introduced by virtualization, moreover they showed that for some specific task the virtual system outperformed the physical installation. These tests showed that no noticeable impacts were to be expected with the introduction of virtualization layer on ALTEC OPS system.

To further support this an “end-user perceptive test”, at qualitative level, has been conducted. This test was conducted involving the ALTEC support team that usually uses the ISS MCS system. The test involved the execution of a procedure covering normal work activities with such system (e.g. TM retrieval etc.). The test had to be repeated three times against three different deployment environments: physical, virtual, virtual under stress. The order of the platform was randomly chosen. The test user were provided with a qualitative test report form to be used for evaluating the system responsiveness.

The MCC provided infrastructure, tools and applications that have been used during the IXV mission for TM monitoring, storage, processing, displaying and detailed trajectory prediction. The MCC was the central node of IXV Ground Segment and it was interconnected with all Ground Segment elements, providing thus the required infrastructure for coordination and support, during IXV operative mission phase.

IXV Mission Control System (MCS) configuration was based on ESA EGOS-MICONYS framework, with SCOS-2000 for TM monitoring and processing and NIS for Ground Stations’ SLE provider interfacing system by means of ESA SLE API. The peculiarity of the IXV MCS was that all servers run on virtual machines. This setup was chosen to re-use available equipment and to support multiple ops environments, increasing implicitly reliability of the whole infrastructure.

The IXV MCC had the responsibility to conduct and coordinate operations up to the complete recovery of the spacecraft on board the recovery ship and completion of the post recovery activities. The Flight Control Team was sitting in IXV MCC and monitored the mission evolution through the S2K consoles and displays prepared by ALTEC team.

Figure 7 - IXV Flight Control Team

ALTEC team operated the Ground Controller (GC) console, to provide, in particular, access to Mission Control System control services, and to monitor overall MCC systems (workstations availability, CPU/Memory load, time synchronization with NTP server). This was achieved through SCOS2000 console and through a monitoring and management console where all these info were gathered altogether and displayed in a single synoptic. GC console also controlled and coordinated video reception from Recovery Ship and video re-distribution toward CSG and through the broadcast service that aired the IXV mission over DVB-S Satellite TV service. Last but not least from the GC console the Network and Data Interface Unit (NDIU) control GUI was operated.

Figure 8 - IXV after splashdown

6. The heritage of the ESA GAIA DPCT: Big Data and ALTEC Space Data Processing System

In parallel to the ISS Operations (starting around 2008), under ASI contract, ALTEC in collaborations with the INAF Observatory of Turing, started the design and implementation of the GAIA Data Processing Center Turin (DPCT), the Italian center of the scientific mission ground segment constituted by the six DPC (under the coordination of the Gaia Data Processing and Analysis Consortium (DPAC)), connected using a hub and spoke topology where the DPCE has the role of the hub at DPAC.

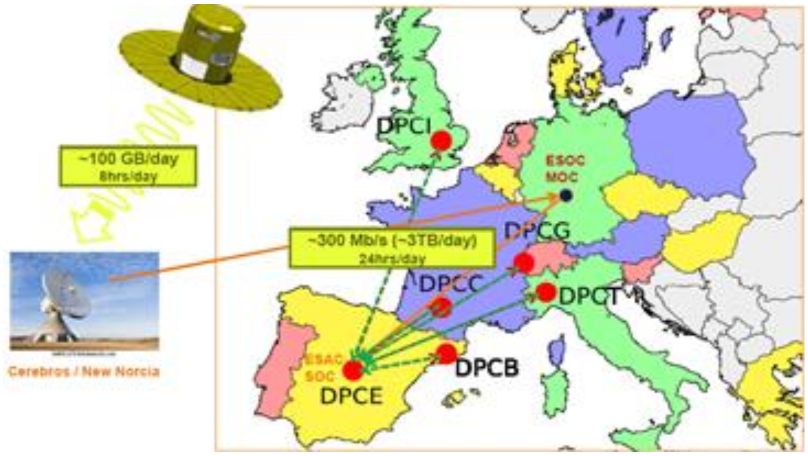

Figura 1 - Gaia DPAC

DPCT operations started about one month after the Gaia satellite launch (Dec 2013) and since then data have been received and processed without interruption with a huge numbers of executed workflows and jobs and databases size of tens of terabytes.

The DPCT system has been designed as an integrated system with the capability to manage, in a full unattended way, all the phases of the data processing pipeline: data receiving, data processing, data extraction, data archiving and data sending. In addition, the DPCT system includes also data access and analysis tools allowing Italian scientists to be active users during operations. The overall architecture has been designed to reach the following goals: scalability, performance, high-availability, reliability, modularity and security.

Among the different component of the DPCT SW architecture, it is worth to highlight the workflow manager, which provides the control logic to coordinate and manage the processing execution on the processing subsystem, which runs and controls the execution of all defined jobs based on the input provided by the workflow manager. The processing system is a distributed software which manages hardware resource provided by the processing cluster. The data storage subsystem is a heterogeneous subsystem including databases, cluster file system, data access layer software and application dedicated software to perform data ingestion and data extraction in the Gaia mission file format. Persistent data management is the main critical point of the overall DPCT.

The most important elements of the data storage subsystem are the databases built with the Oracle RAC technology, which actual size is beyond the 400 TB. The data transfer subsystem manages the regular data transfer with the ESAC DPC (DPCE- ESAC) and other external computing center like CINECA that will provide support to run complex scientific algorithms that cannot run on the local hardware resource.

Figure 9 - DPCT Operational Platform

The design, development and operation of the DPCT, that is considered the first big data project, allowed ALTEC to acquire new technological skills in the area of so called "big data", applied then in developing new big data products and systems to continue the extension of Big Data approach on the space and other domains.

ALTEC big data systems manage, process, analyze, visualize and preserve space data characterized by huge volume, variety and veracity. One of the most relevant ALTEC tool is ASDP (ALTEC SPACE DATA PROCESSING). It is a distributed data processing framework dedicated to the on-ground handling and transformation of any aircraft and spacecraft data. Its modular architecture gives it the flexibility to be easily adapted to several other domains where commonalities with ground centers could be found, even outside of aerospace domains. ASDP enables both automatic and batch processing of large dataset and the automatization of complex pipelines. It is implemented using several state-of-art IT technologies allowing the system to be maintainable, robust, scalable and easily extendible.

In addition, ALTEC is interested in the definition of data exploitation platforms for users' communities using space data in their business. To complement platforms, ALTEC has several data analytics systems dedicated to extract new values from space data and be able to design best systems on the basis a complete understanding of events in past applicable missions.

The core capabilities of ASDP allows ALTEC to applied it to different project:

- in the ISS domain, with the continuous collection, processing and automated analysis of the PMM telemetry data,
- in the ExoMars mission, as the core element for the implementation of the automated pipeline management of all downlinked platform and scientific data in order to quickly generate the required mission products
- in all other ALTEC ground segment project where automation, distributed processing, automated data analysis is a key component (Space Rider PGCC, ERFNet-DH, Solar Orbiter METIS Operations Facility, HERMES Pathfinder MCC).

ASDP has been properly integrated with the ESA SCOS-2000 and is planned to be integrated with the new EGOS-CC infrastructure.

7. The VAMOS and the ALTEC Multi-Purpose Control Center today

The successfully results of the IXV Mission convinced ALTEC to progressively expand and use the VAMOS infrastructure for its space mission operations activities, in particular (in coincidence with the dismission of the legacy and obsolete HW of the Columbus ESC) hosting all the needed ESC data systems in the VAMOS specific virtualized environment, while maintaining a dedicated setup for the operations room.

The VAMOS infrastructure, in these days under full HW refurbishment and upgrade, is planned to be used to host the mission control center of new missions in which ALTEC is involved:

- *Solar Orbiter METIS Operations Facility (MOF).* The METIS Operations Facility (under ASI contract and already operational) is the specific center dedicated to the management of all data of the METIS Instruments, embarked on ESA Solar Orbiter. It consists of several systems allowing the Metis Instrument Science Team to prepare and execute the Metis operations in the Nominal Mission, Extended Mission and Post Mission Phases. In addition, the Metis Operation Facility has been used also in the LEOP and NECP operations phase to support the Metis instrument commissioning as secondary data processing system, due to the fact that the Metis Science Team participated to the commissioning activities at MOC.

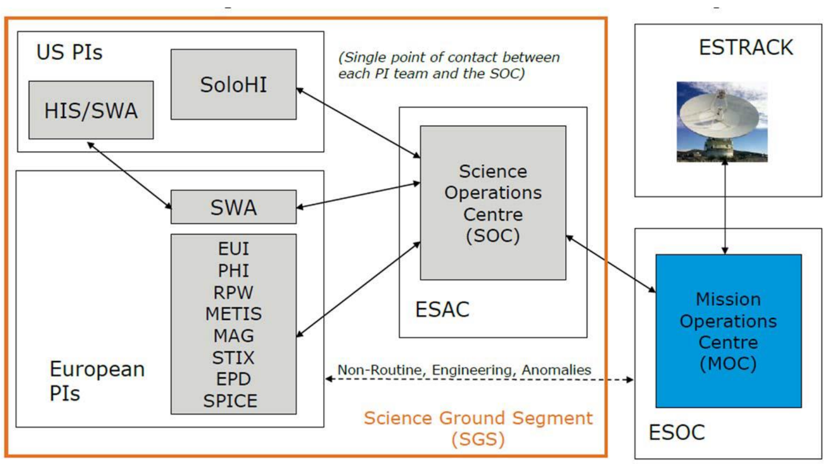

Figure 10 - Solar Orbiter Ground Segment

The MOF provides the following capabilities:

- Retrieval of input file for planning activities from SOC interface;
- Supporting instrument observational plan generation at long, medium and short level;
- Metis command request file delivery to SOC;
- Low Latency output data retrieval from SOC;
- TM/TC data retrieval from MOC interface;
- L0 data product generation (uncalibrated data);
- L1 data product generation (uncalibrated data);
- L2 data product generation (calibrated data);
- L3 data product generation (calibrated data);
- L2 and L3 data delivery to SOC;
- Data Access to the mission database maintained to support operations;
- Metis TC sequences validation using the Metis Reference Model (MRM);
- Metis planning execution monitoring.

The following figure shows the logical blocks composing the Metis Operation Facility (MOF):

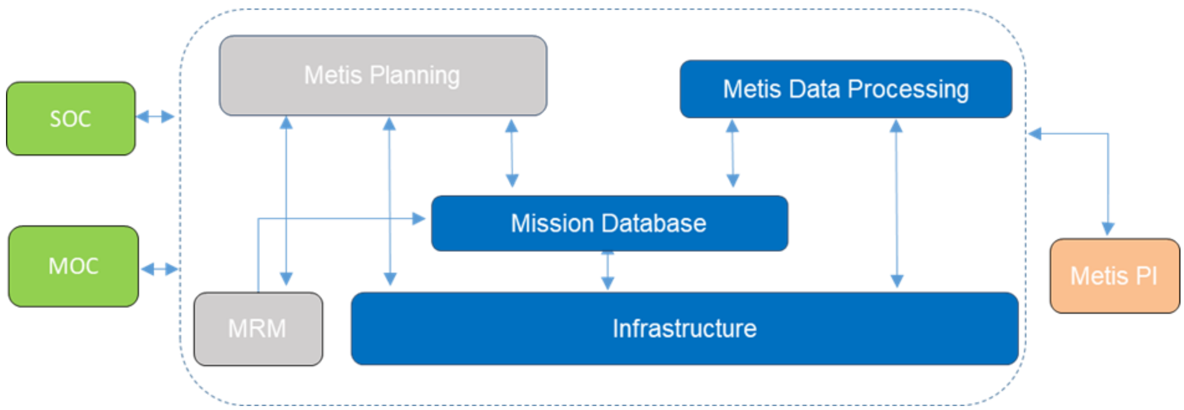

Figure 11 - Metis Operation Facility Architecture

- *ASI HERMES Pathfinder Mission Operations Center (MOC)*, responsible for the mission operations of a constellation of six 3U cubesats, deployed on an equatorial orbit at around 500 km. All cubesats host the same type of P/L, constituted by simple but innovative X-ray detectors to probe the X-ray emission of bright high-energy transients. The objectives of the mission are the accurate and prompt localization of bright hard X-ray/soft gamma-ray transients such as Gamma---Ray Bursts (GRBs), the investigation of the temporal structure of GRBs down to fractions of micro-seconds and test quantum space-time scenarios by measuring the delay time between GRB photons of different energy.

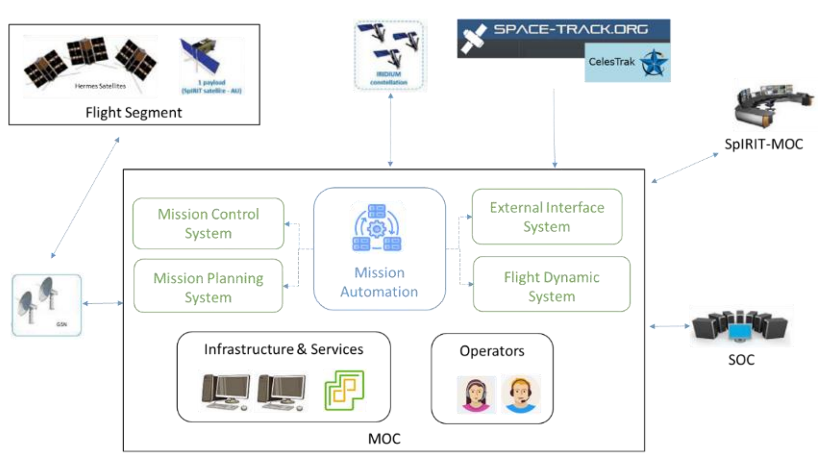

Figure 12 - HERMES Mission Operations Center

- *ESA Space Rider Mission Ground Segment*, (in collaboration with Telespazio), the implementation of the Landing Control functions of the Vehicle Control Center (VCC-LC) and the P/L Ground Control Center (PGCC) of the mission, which will exploit all the services and characteristics of the VAMOS infrastructure, including its interface with ASINET for the connection to the Landing Site Ground Stations.

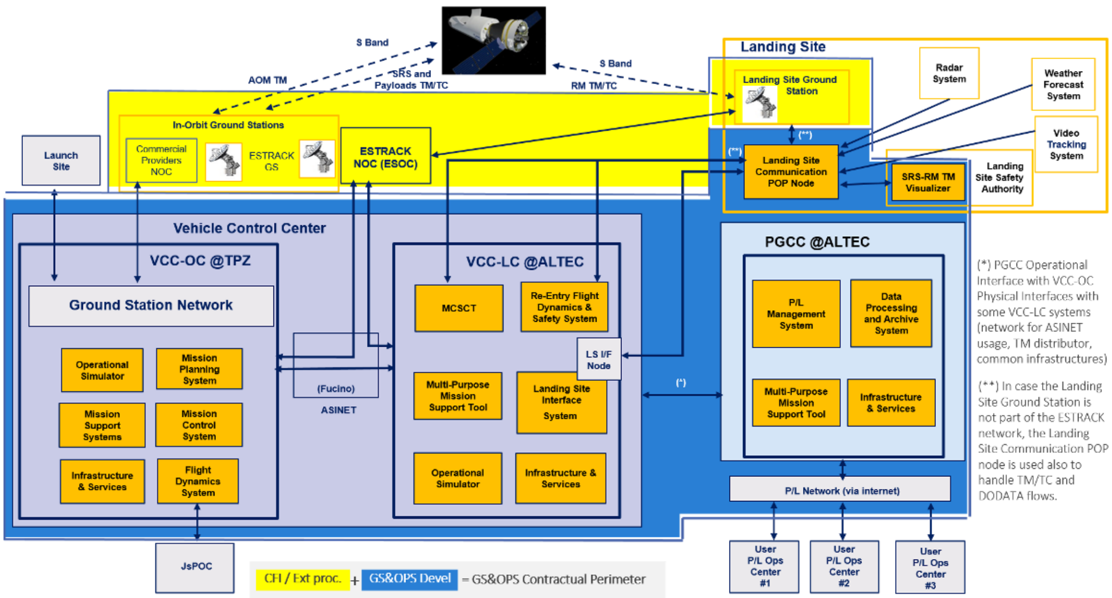

Figure 13 - Space Rider Ground Segment

- *ESA European Radiation Facility Network Data Hub (ERFNet-DH)* functions dedicated to the operations and data processing of the ERSA and IDA P/Ls that are the ESA contribution to the Gateway mission. These capabilities are still under definition.

It is worth to highlight that, based on the experience in ISS ground segment, the VAMOS infrastructure has been designed taking into consideration specific security requirements of the mission control center, in particular hosting them on separated physical clusters (each of them hosting MCCs with similar security requirements), but also design them is such a way to distribute functions to guarantee always the respect of the security policies.

8. ExoMars Rover Operations Control Center

In the frame of ExoMars Project ALTEC has been assigned with the responsibility to design, build and operate the control centre for the ExoMars Rover (Rover Operations Control Centre – ROCC) located at ALTEC.

During the ExoMars Rover Mission, the ROCC will host the team of engineers and scientists and will be the Centre which will manage all the activities of monitoring & control, engineering support and preliminary scientific analysis, relevant to the operations of the Rover on the Martian surface. It will be connected to other elements of the ground segment including:

- European Relay Coordination Office (ERCO) / MOC, located at ESOC, during cruise and surface operations, to receive and transmit Rover data through the ESA TGO relay satellite
- ESAC, to archive the Scientific data for long-term archiving
- Scientific Community remote sites to dispatch scientific data during the mission

The ROCC is equipped with several operations rooms, devoted to perform operations and support scientific and engineering team in contributing to the mission, as well as with an area devoted to the physical simulation with the Ground Testing Model (GTM) of the Rover, called Mars Terrain Simulator (MTS), where the Rover model will be operated to verify some performance aspects, to evaluate possible command options and to support the analysis of anomaly situation potentially occurring on Martian surface.

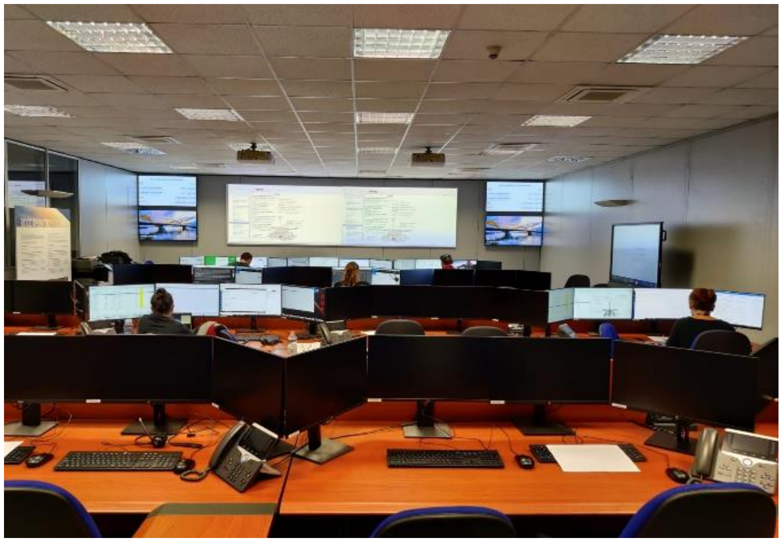

Figure 14 – The Rover Operations Control Centre (ROCC)

8.1 Mars Terrain Simulator

The Mars Terrain Simulator (MTS) is an indoor analogue facility located inside the Rover Operations Control Centre (ROCC), designed to represent, from a morphological and mineralogical point of view, some possible terrain on Mars at the landing site and to support the daily ground operations through rehearsal and troubleshooting on representative hardware and instrumentation [6].

The MTS facility is specially tailored to perform ExoMars Rover GTM functional testing and to give the adequate support to the Rover surface mission in case of contingency.

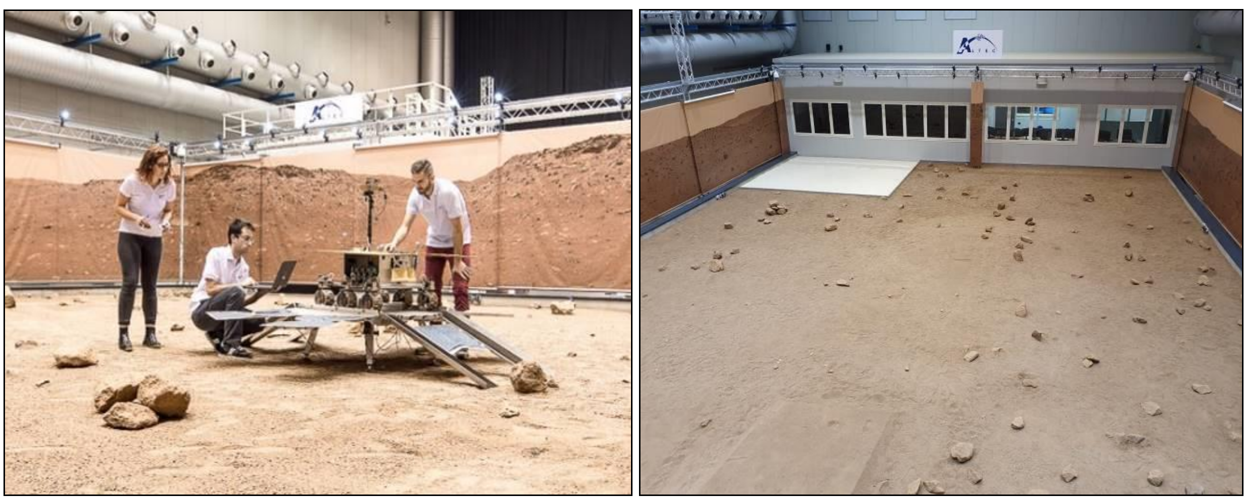

Figure 15 – The Mars Terrain Simulator (MTS); ExoTeR Rover – ESA property

The MTS is composed of three areas, marked out in Figure 16:

- Arena: is the zone where the GTM functional tests are performed
- Equipment Area: is the zone dedicated to the support equipment disposition, to the storage of sands and rocks, to host the GTM, the Tilting Platform, the Lander mock-up and the Dust Aspiration System when not involved inside the Arena
- MTS Electrical Ground Support Equipment (EGSE) Area and Control Room

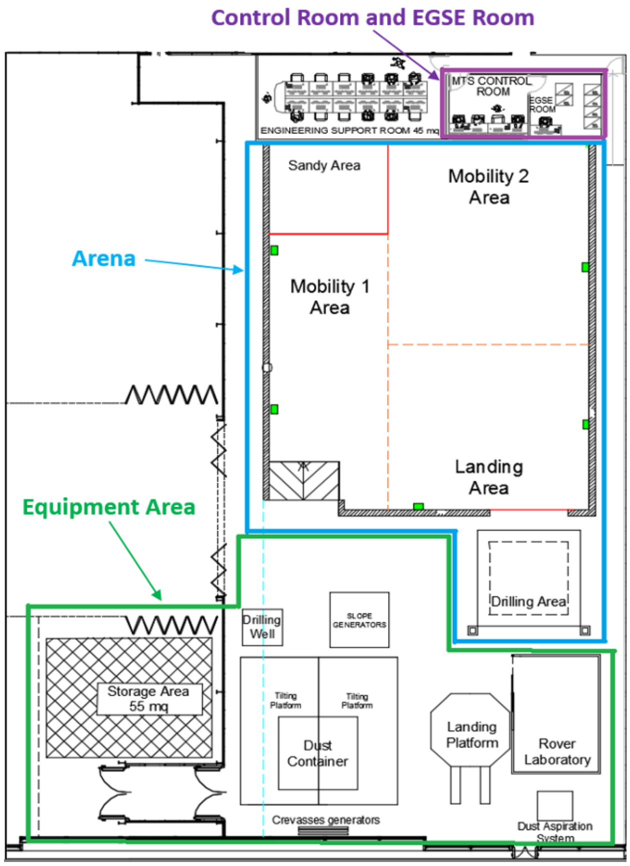

Figure 16 - MTS layout

The MTS Arena is covered with two soils: the Rheinquartz Phyllosilicates (a very fine sand) in the Sandy Area and the Pozzolana Volcanic Tuff (a cloddy silty sand with gravel and rocks with size up to 0.5 meters) in the Landing and Mobility Areas. The terrain can be physically adapted as necessary, in terms of crevasses, sand, rock distribution, dunes, hills and ramps, in order to replicate the scenario that the Rover will face on Mars.

The Rover GTM drilling operations are simulated on a defined zone, the Drilling Facility (see Figure 17), consisting of a sandbox and a Drilling Well, a cylinder 2.1 meters long with a diameter of 30 cm, filled with different types of materials (e.g. Geyserite, Claystone, Sandstone, Gypsum, etc.) disposed in layers in order to simulate experiment cycles and vertical surveys foreseen for the nominal ExoMars mission. In this area it is located also the Illumination Facility, where the Rover cameras optical tests are executed with varying illumination intensity and direction.


Figure 17 - Drilling Facility

The MTS provides a large set of tools and devices with different purposes:

- Dust Aspiration System, to maintain on safety conditions the environment and to protect the instruments from the particulate contamination
- Tilting Platform (see Figure 18), a 8x8 meters platform tiltable up to an inclination of 30 deg, to perform the GTM climbing test and egress operations from a Lander mock-up
- Gravity Compensator Device, to simulate the Mars gravity (equal to 0.38 g) in the Earth's environment
- hand tools
- terrain reconfiguration devices, e.g. crevasses and slope generators
- MTS Arena Systems (see Figure 19), composed by:
    - Measurement Cameras System, to track the motion of 3D objects inside the Arena
    - Modelling Cameras System, to generate the Digital Elevation Map (DEM) of the Arena
    - Ambient Cameras System, to record and monitor the tests and the GTM operations

Figure 18 – Tilting Platform

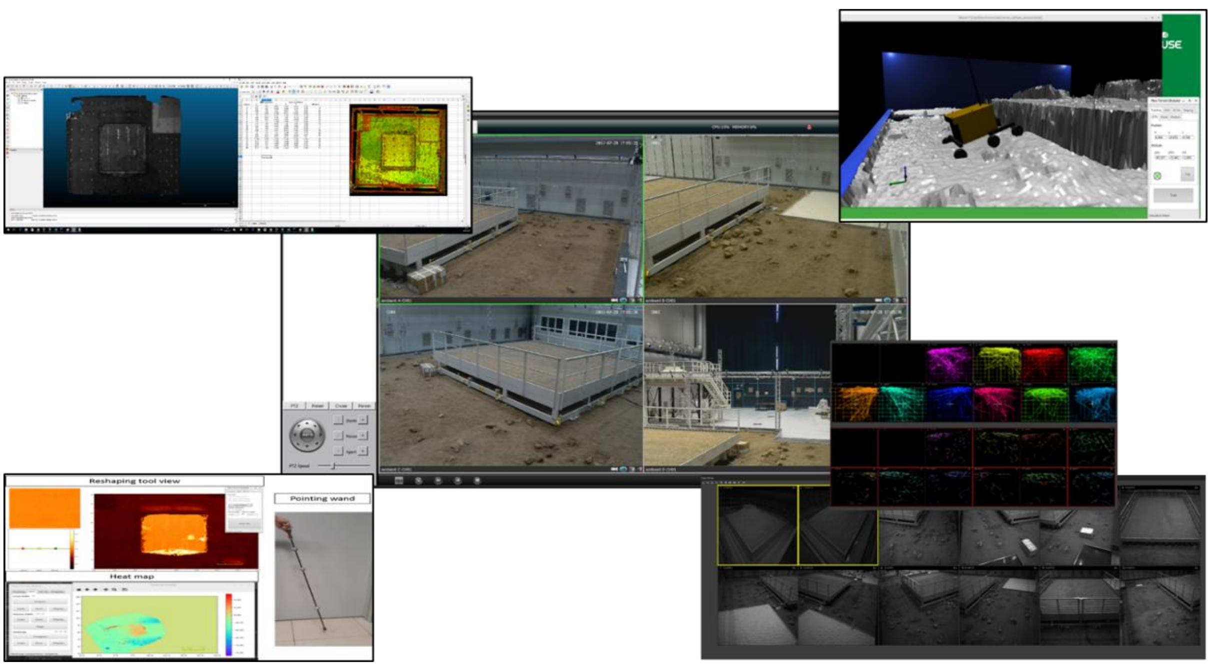

Figure 19 – MTS Arena Systems

8.2 ROCC Operational Tools

The ROCC Operations Control System (ROCS) provides the core capabilities in direct support of Rover mission operations, for telemetry receiving and analysis, science and vehicle planning, activity plan simulation and command sequence generation and validation, on-board software management, command sequence uplink.

The ROCS is thought with strict relationships with the operations concept for the Rover and supports all the requested ground processing. The major key drivers for the concept design of this system are the following:

- Provides the Rover Operations Team and the Science Team with a “complete set of downlinked products. The term “product” refers to the fact that ground processing is expected on downlinked data before they can be used by the operations team. In addition, in support of the planning activities, this set could be completed by other ground products generated directly by the operations teams.
- Provides the Rover Operations Team and the Science Team with proper tools for the assessment of the Rover vehicle, the payloads status and their performances (with particular care to the navigation aspects), as well as for the assessment of the executed on-board plan.
- Provides the Science Team with tools capable to support distributed operations, supporting the science objectives identification and a collaborative science activity plan building, that already takes into account as much as possible constraints, flight rules, Rover status and resources. The tools shall be as much as possible “integrated” (in terms of an effective collaboration) with the tools provided for the Rover Operations Team, in order to allow fast and reliable Rover surface operations planning.
- Provides the Rover Operations Team with proper tools for the preparation of the required Rover Activity Plan (including Rover navigation and mechanism movement) based on the science requirements and engineering needs and constraints, its simulation, verification, and final uplink to the Rover. This is considered a critical activity because the Rover will interact with an unknown environment. Thus, it is necessary to react in due time within the next uplink opportunity and adapt plan and activities to the actual encountered conditions, always assuring the vehicle safety at the maximum level in order to not risk a mission loss.
- Therefore, advanced capabilities need to be provided to the operator in terms of planning development that take in consideration mission, environment, and resource constraints, generating constraints and error free plan to be uplinked to the Rover. Particular care shall be given to the robotic elements (navigation and locomotion system, drill system) that strongly interact with the Martian surface. Also for the Rover Operations Team, the tool shall support collaborative activities performed by the different engineers.

All these tools are implemented in such a way to support both the Tactical Planning (short-term) as well as the Strategic Planning (long-term) activities. In addition, they are also able to be used for managing end-to-end simulation activities with the Rover HW in the loop (i.e. the Rover GTM, Ground Test Model, in the Mars Terrain Simulator).

From a functional point of view, the classification and breakdown of the ROCS system capabilities is the following:

- ROCC-ERCO Data Interface
- Rover TM Data Acquisition and Processing
- Rover HK Data Assessment and Planning, including tools for:
    - Data Assessment and Analysis
    - 3D Graphical Visualization
    - Rover Navigation and Localization function
    - Rover Status Estimation
    - Orbital Computation
    - Rover Engineering Activity Planning
- Science Data Assessment and Planning, including:
    - Data Display and Analysis Capabilities
    - Science Activity Planning Capabilities
- Rover Planning Capabilities
    - Activity Planning and Scheduling
    - Visualization and Planning

    - Rover Plan Validation and Command Generation
    - Activity Preparation and Validation
- TC Processing
- Rover Simulation and models
- Rover OBSW Management
- Data Archive and Retrieval
- Science Post Mission Data Product Generation
- ROCS System Control and Administration
- ROCS Mission Configuration Control

The specific ROCC operations capabilities listed above are complemented by selected Operations Support Systems made available and accessible from the operations consoles, namely:

- Voice Conferencing System
- Time Management Systems
- Multimedia System
- ROCC Operations Portal, managing the following specific tools:
    - Anomaly Reporting and Tracking System (both for Flight and Ground issues)
    - Console Log
    - Documentation Archive (User Manuals, Reports, Drawings, CD phase documentation)

All the ROCC capabilities are hosted in a project dedicated IT platform in a full virtualized environment based on VMWare, following concept and solution derived from the design and development of the VAMOS and DPCT IT infrastructures.

As far as the ground communication, the main interface is with ERCO at ESOC. This connection has been implemented both through a dedicated point to point connection between ALTEC and ESOC and also using the existing connection with ESOC already available via ASINET. Science team members working outside the ROCC can access the science team services via individual assigned VPN over Internet.

9. The new Lunar Operations Center

The initiative in the field of space exploration has seen a new and strong impulse in recent years, mainly dictated by the race to return to the Moon which, under the guidance of NASA, sees Italy, with ASI and via ESA, position itself as a strategic partner. Recently, in fact, many initiatives are being recorded in the lunar sphere, with NASA's ARTEMIS program being the most shining example.

In the ARTEMIS context, Italy is among the main contributors to the *accords*, with the commitment to provide Lunar Multi-Purpose Habitats and related services. Also on the European front there is a strong participation by ESA for what concerns issues related to lunar exploration. In addition to the important contributions to NASA activities with the Service Module of the ORION capsule and with participation in the Lunar Gateway, where Europe provides the iHab and ESPRIT modules, ESA has recently launched a series of studies and activities aimed at affirming the role of the Agency and European companies as key partners in this area. For example, the activities related to the Lunar Communication and Navigation Systems, the initiative called EL3, European Large Logistic Lander, and linked to this a number of further initiatives such as the European Moon Rover System – EMRS, as well as the identification and launch of a number of specific missions within the Polar Explorer initiative. Of particular importance, always in the ESA panorama, are the initiatives related to ISRU, In Situ Resource Utilization, which provide for a series of studies addressed, for example, to the development of systems for the extraction of oxygen from lunar regolith. For all ESA initiatives, however, the strong Italian contribution is noted.

In this frame it therefore evident that there is a need in Italy to develop infrastructures and services that aim at creating and implementing the necessary conditions to support national technological developments, scientific experimentation, and operational activities to make the most of the opportunities offered by international collaborations in upcoming lunar exploration programs.

In consideration of the stage of development of technologies, the opportunities given by the international collaborations, where the presence of an Italian ground center is expected to be required, and by virtue of the availability in the short / medium term of flight opportunities for P / L, it is clear the need to implement and have the availability in the shortest possible time of a test, validation and command & control environment.

In this context, ALTEC intends to capitalize the experience and heritage of all activities and infrastructures that were developed since its birth. ALTEC, in fact, now hosts the most advanced control and simulation center for surface robotic operations at TRL in Europe, albeit with a strong oriented towards Mars, the ExoMars Rover Operations Control Center mission (the ROCC). This capacity, together with the experience and infrastructure developed to perform LEO Human and Payload Operations, as well as advanced data handling and extreme environment testing, can be exploited to quickly evolve in an advanced center to support lunar mission preparation, simulations and operations.

9.1 The Control Center for Lunar Missions

ALTEC, under the coordination of Thales Alenia Space Italia, contributed to the "Pre-feasibility Study for Lunar Modules and Systems", in particular with regard to Study 3 for the control center and Study 10 specifically for the ground control component for the robotic part.

This study highlighted how the construction of a single reference center for all lunar operations, carried out with an "incremental" and "scalable" approach and that reuses to the maximum the infrastructures built in the ISS and capitalizing on the experience of robotic missions such as that of the ExoMars Rover, and open to interconnection by "users" for the exploitation of the opportunities offered by lunar missions in terms of scientific research and technological, represents a strategic asset for the achievement of the objectives of the Agency.

This center, as well as in ExoMars, must be strongly integrated with a series of facilities that can allow the testing and validation of technologies and experiments, supporting an operation that is the closest to the next mission implementation, both in the prototype or development phase, and subsequently in the preparation and execution activities of the mission.

The diagram below provides a possible scenario related to the ground segment of the Italian control center and its interconnections with external partners, depending on the potential collaborations developed.

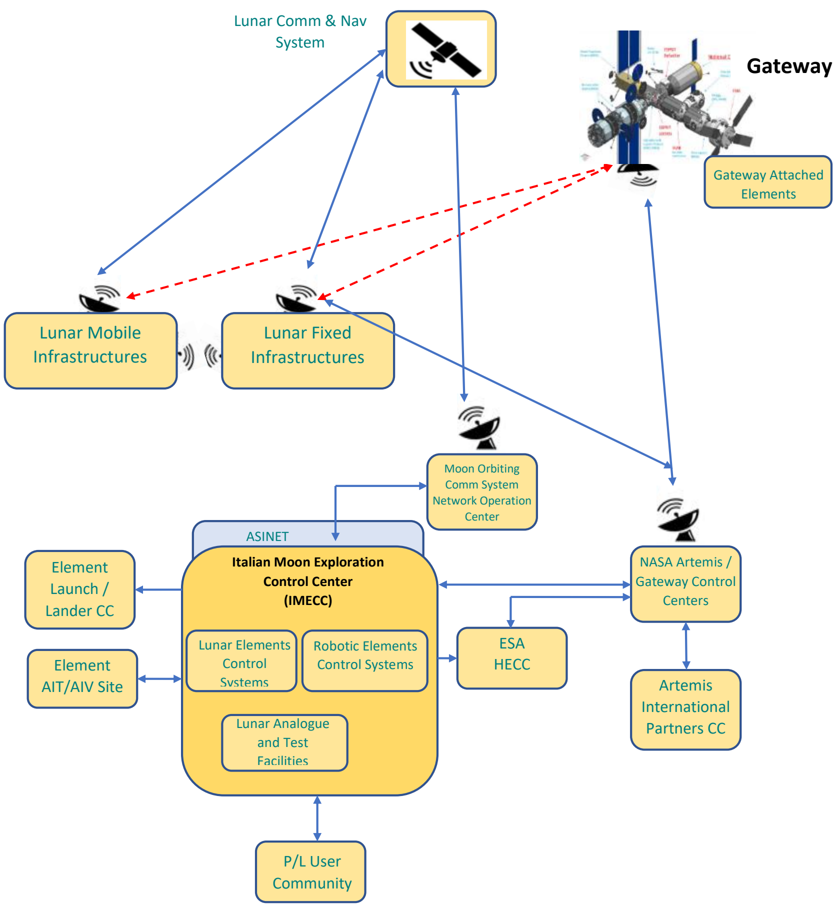

Figure 20 – Lunar Control Center Ground Segment

The next diagram identifies the functional blocks that constitute, in the broadest possible view of the functionalities, the composition of the control center.

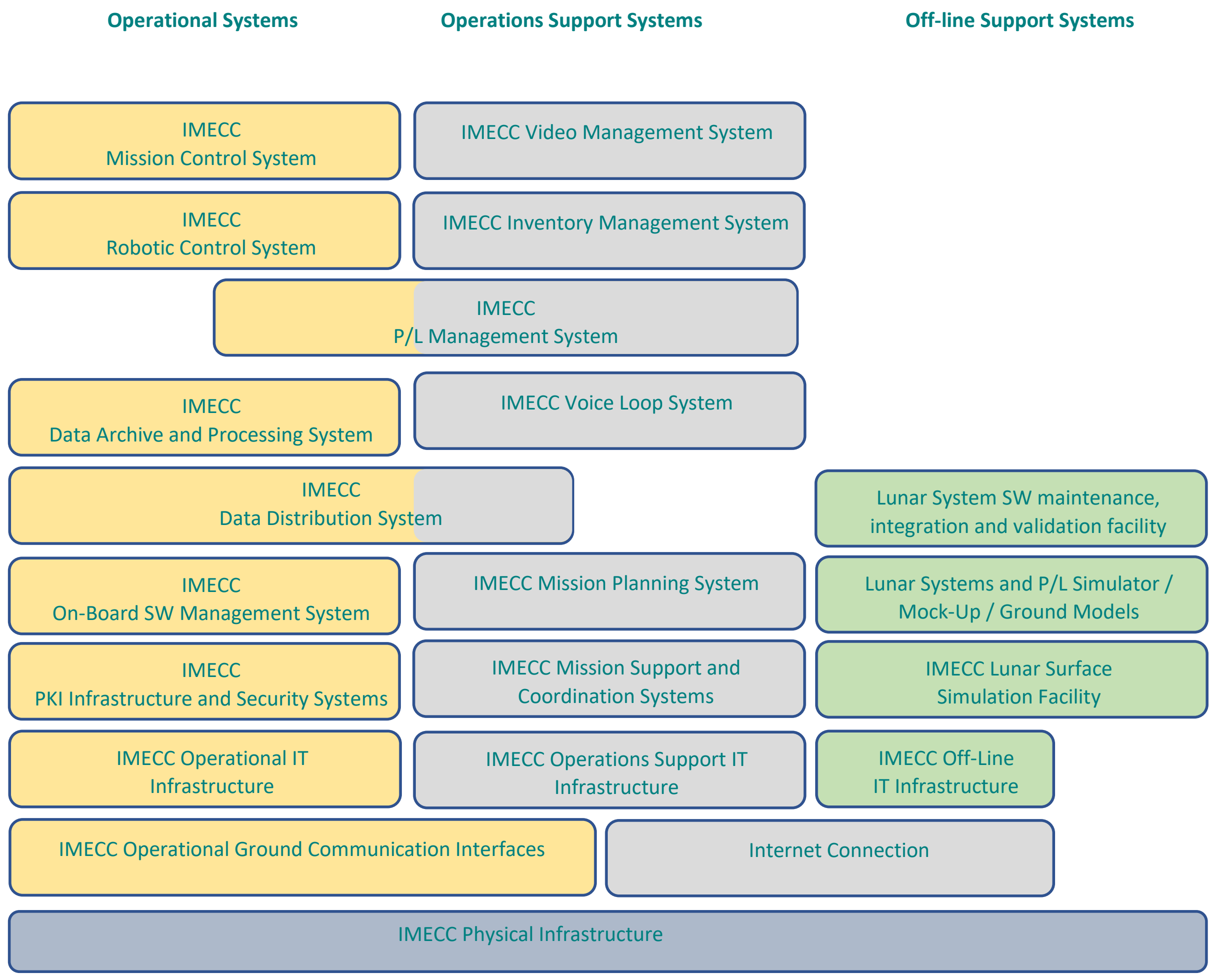

Figure 21 - Lunar Control Center Functional Block Diagram

The above architecture is designed to maximize the developments and investments made or in progress, on various programs in which ASI is directly or indirectly (via ESA) involved: ISS (PMM, Columbus), ExoMars ROCC, Space Rider.

9.2 *The facility*

Three main area are therefore envisioned, to support the above mentioned functions:

- The Lunar Terrain Simulator
- A Environmental Chamber to test the IRSU technologies
- A multipurpose control center to support the tests, the simulations and the operations

The follwing picture shows a first cut of the center layout being designed.

Figure 22 - Lunar Control Center Preliminary Layout

As for the Lunar Terrain Simulator, ALTEC has launched an internal study for the progressive adaptation of the current Mars Moon Terrain Demonstrator (MMTD), carried out during the STEPS program of the Piedmont Region and which constituted the breadboard for the subsequent realization of the ExoMars MTS, in a new facility dedicated to specific activities on the Moon.

The scheme is to reuse much of the design of the Mars Terrain Simulator, especially with regard to mobility issues (terrain, inclination, reconfiguration, external tracking, rapid digital terrain model, drilling, soil material management, etc.) and at the same time evaluate the adjustments necessary to cover the need for testing and validation of particular operations (eg gravity reduction systems, systems for ISRU tests, systems for test support in particular environments such as temperature and / or vacuum, excavation, etc.). Dust prevention systems are also of particular importance, in order to create a safe environment for use by personnel.

Here are some technical features currently selected for thepart of Lunar mobility:

- Useful area dimensions: 19 x 17 meters
- Minimum soil depth 20 cm (for a total of about 75 m3)
- Lunar region to be simulated selected, based on major experimental interests: South Pole region
- Progressive implementation of features to support test cases. Possible initial test scenarios achievable with only the reconfiguration of the terrain:
    - Lunar surface mobility
    - Surface features (i.e. grades and rocks)
    - Regolith handling and excavation
- However, there are many simulation types of lunar regolith, so an evaluation of the most suitable type to support the start of the first implementation activities is underway.

One of the concepts that we want to implement for the Lunar Terrain Simulator is to provide an IT infrastructure that allows the execution of field tests by scientific / industrial teams with the on-site involvement of the least number of people, and therefore allowing to perform the planned activities remotely. This can scale towards simulating mission operating conditions.

This infrastructure could in turn evolve towards a platform that can also support the execution of tests and simulations on analogues of the lunar territory in outdoor mode, obviously thanks to the availability of a telecommunication kit with the selected operating area.

The Moon Environmental ISRU Testing Chamber will be a vacuum testing chamber aimed at test the technologies and the equipment requiring dedicated environmental testing, in particular in presence of regolith, such as IRSU Oxygen extraction systems, or flight elements to be tested against the moon environment. The chamber will therefore be:

- Sized to accommodate the expected equipment
- Able to simulate the extreme moon environment expected (vacuum, temperature, potentially illumination, etc.)
- Able to accommodate regolith
- Able to allow control of the tested equipment and potentially handle the regolith.

10. Conclusions

The choices made throughout the years, the possibility to share the knowledge and the assets, to create synergies, have led to develop a set of facilities, capabilities and skills that are readily available and span from configurable control rooms, to the connection to several ground networks and control centers, from consolidated approaches for engineering and operations integration to big data management and advanced analysis systems, from organizations able to support real-time data and operations, to setup advanced facilities and skills to test and operate complex robotic exploration missions.

The result is a center that offers a variety of possible and reconfigurable services, from human spaceflight mission support to space vehicle missions, from low earth orbit operations to robotic missions, from ISS payload operations support to astrophysics data analysis, from realtime mission operations to deep space operational setup.

This is the key element that allows to prepare for the next step: the possibility to easily conceive and setup a Lunar Operations Control Center that, making advantage of the experience gained in these years, and the synergic (re)use and integration of the infrastructures and the tools developed for these broad types of space missions, will be quickly available to support the rapidly approaching new lunar exploration era. In this frame ALTEC is preparing to host a Lunar Operations Center devoted to both provide services to support the development and testing of the new technologies (e.g. ISRU systems) and lunar robotic exploration vehicles, and also to perform mission preparation and operations activities.

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