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From the ground to DREAM ON: ground support equipment to new PERSEUS bi-liquid demonstrator

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Abstract

The CNES and the PERSEUS project are at the service of students in order to help them become game changers. The ambitious ground and flight segments implemented in the program both contribute to the development of innovative technologies, and are in line with the CNES strategy for space transportation systems. The long term objective of the PERSEUS project is to launch a bi-fluid rocket with an apogee of 5km and retrieve for reuse, a LOX/CH4 propelled rocket through DREAM-ON challenge.

Over the next 2 years the PERSEUS project will focus on the project's next generation of sounding rockets, called ASTREOS. This is a demonstrator of a recoverable first stage, including the associated ground segment. The ground segment, or "Stage 0", is a major part of the overall ASTREOS development and design. Due to the bi-liquid propulsion (ethanol and liquid oxygen in first version of ASTREOS) used for the first time in the framework of PERSEUS, fluid ground support equipment (FGSE) has been designed with the help of our partner Ariane Group and its expertise in Vernon site.

1. Introduction: ground segment in PERSEUS

The ground segment is at the heart of the launch autonomy objective, from ESRANGE or CSG, set by PERSEUS in order not to be depend on the equipment and limitations of the ground base in the future launch campaign.
In line with these PERSEUS objectives and roadmap, the round segment equipment is becoming increasingly important in the overall development of the PERSEUS project.
The ground segment developed under the PERSEUS program is fully modular and adaptable. The roadmap from ASTREOS-1 to DREAM-ON foresees the launch of at least one rocket per year, increasing in technology and complexity with each launch.
The main requirement of the ground segment definition within PERSEUS is the flexibility and the mobility of the equipment. The PERSEUS ground segment is fully mobile in contrast to standard launch company that are generally fix at one launch base with fix equipment. Moreover the ground segment has been designed to be as modular as possible: it must be able to adapt quickly to any new innovations of the ASTREOS versions, while maintaining the quality of service of all the necessary functions.
The solution to this problem has been to develop several products with a modular evolution planned in each technology choice. For each product, a major compromise has been made to anticipate future evolution and the possibility of upgrading the product after each launch campaign.
The ground segment has been split in 5 main products fully modular:

- A mobile launch rail
- A transport and connection vehicle
- A ground station and control bench of the ground equipment
- A fluid ground support equipment
- A flight safety support

All these products will interface with launch sites such as the Guyana Space Centre or Swedish Space Corporation, and allow the PERSEUS project to be autonomous on launch service. The article will summarise the results achieved by the students and project so far.

Distribution of ground segment systems of PERSEUS
The 2 main launch sites selected by the project are the ESRANGE Space Center site in Sweden and the CSG site in French Guiana, the ground segment is distributed over 3 to 4 distinct areas:

- Launch pad or launch area
- Fire Point area or a bunker that send the ignition signal near of the launch pad

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- Scientific room or payload room that manage and supervise all data from the demonstrator and the ground support equipment

The ground segment used a network base of connected objects that allows a complete monitoring of all equipment implemented around the launch base.

1.1. Example of distribution at the ESRANGE launch base

The ESRANGE site already have theses operation room or site available, and the distribution have been tested during the SERA 4 campaign explain further in this article.

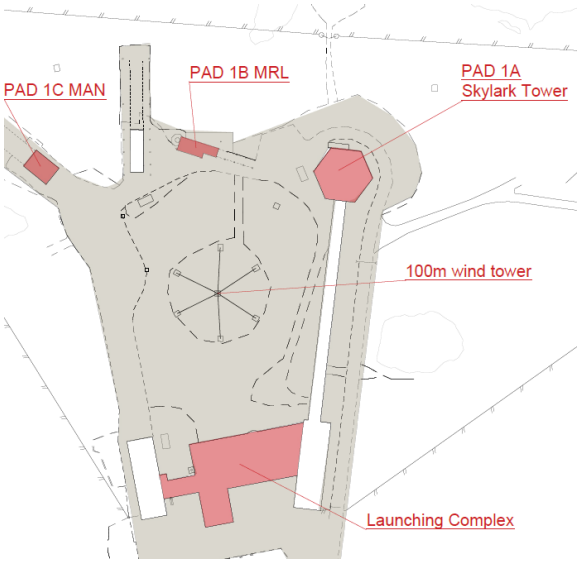

Figure 1 - Example of ground segment installation at SSC ESRANGE site

At the ESRANGE site, PERSEUS used either PAD 1B – MRL or PAD MAN2 noticed by the blank rectangle on the left of the MRL. The launching complex placed at 100m in the south of the launch area are already connected by a local network made with fiber optic.
The main building with the scientific room is placed at 1km west of this launching area, and the network connection are already made between this 2 sites.

2. SERA IV, a demonstrator of the new PERSEUS ground segment

On June 3 the SERA IV demonstrator was launched from the ESRANGE spaceport from the 1B MRL launch pad, the entire launch campaign having taken place from 22 May to June 3.
This campaign allows the PERSEUS project to test in an operational context the new ground station and the electrical support equipment developed for the next demonstrator ASTREOS and compatible with SERA IV. This ground station is a part of the future ground segment of ASTREOS, it was the first use of a modular ground segment for PERSEUS.

The objectives of this ground station are:

- Data reception and decoding of the rocket
- Supervise all ground products and interface box (connection to the network and behavior)
- Remote control of all power supply

The same base of network of ASTREOS has been set up at the ESRANGE space centre, a local network with a MQTT protocol available inside with 3 separate networks:

- Generic network : local network with UDP/TCP frames / IP camera
- Ground MQTT network : all data from the ground (rocket and ground equipment detailed below)
- Radio MQTT network : only data received from the rocket by radio emission and using the ESRANGE antenna

Different areas of the launch base are connected to each other:

- The scientific room which is the PERSEUS operational centre of the rocket
- The bunker : the area closest to the launch site with operator, pyrotechnical and electrical command of the rocket

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- The launch site : at ESRANGE, SERA IV was launched from the MRL area
- The TM and radio reception centre from ESRANGE

These networks allow the operational centre to have completely separate network and redundancy of data processing computers or storage. Two MQTT brokers have been plugged inside the SERA IV operation centre, called the Scientific Room, and all the equipment has been used to connect automatically to these networks.

Figure 2 - Scienfic room at ESRANGE for the SERA IV launch

3. PERSEUS SCADA GROUND SEGMENT: Supervisory Control and Data Acquisition

The purpose of the control-measure network is to facilitate the communication between each system of the ground segment. It is responsible for recording and distributing measurement and control data. The data will flow between the different areas of the ground segment.
The ground station systems are used to perform the following general functions:

- Ensure the communication between the different systems of the ground segment
- Manage the vehicle command and surveillance through the ground/vehicle interface
- Manage ground control and process monitoring for vehicle operations
- Ground safety check
- Acquisition of vehicle telemetry (TM), delivery in real time (until landing)
- Operational real time video images
- Synchronize operations
- Real-time visualization of on-board TM and ground information

A «Machine to Machine» (M2M) messaging protocol must be chosen to implement the control-measure network. It is a technology widely used in the Internet of Things (IoT) framework to make several machines communicate with each other on a network. Several protocols exist, and for each protocol, several open-source implementations exist.
One protocol have been identified, it works with systems for sharing data by subscribing to some specific types of data. In its use we find the same concept of «subscriber» and «publisher». The big difference here is that the system is centralized. All data goes to a "Broker" which redistributes it to interested users. Like some other protocols, it can also be associated with an archiving service that records data as it goes along. A dozen open-source dashboards solutions exist and support MQTT (Message Queue Telemetry Transport [1] as a real-time data source.

The network is designed in a hub-and-spoke format, with a MQTT server, called a “broker” because it is in charge of receiving, recording, and distributing messages that circulate on the network.
The operating principle of MQTT is as follows: data exchanged on the MQTT network are called "message", a message can have a size ranging from 1 o to 260 Mo, the data transits in the form of string format. Each machine connected to this network is called "customer", it is connected to the network by connecting to the broker. A machine that creates/publishes messages is called "publisher", a "publisher" generates messages that are sent to the broker to which the machine is connected.

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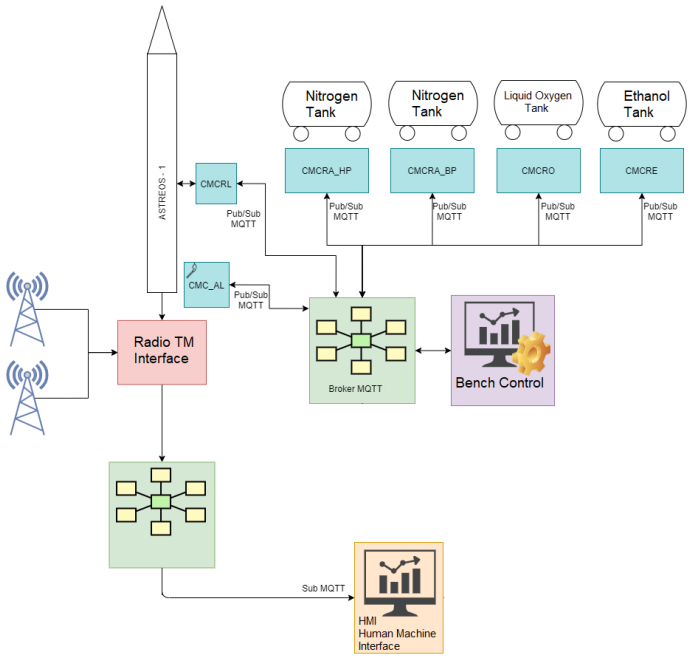

Figure 3 - Example of an ASTREOS-1 ground segment with MQTT protocol

A machine that consumes or reads messages is called "subscriber", it is subscribed to receive data from the broker. A machine publishes or subscribes to “topics”. Each topic corresponds to a data whose value may change. The topics are organized in a tree structure, it is possible to subscribe to all the changes belonging to the same tree structure (For example, the pressure measurements of the LOx tank on the ground will be published and accessible via the path "Ground/tanks/LOx/pressure").
A machine subscribed to a topic will receive all messages sent on that topic as soon as they have been received by the broker.
A machine can be both publisher and subscriber.
A machine can connect to several topics, as will be the case of the monitoring HMI stations.

The ground segment measurement-control cards communicate exclusively with the broker. The machines used for the control bench or the monitoring of the data collected through HMI (Human-Machine Interface) will connect to the broker as well. The broker’s job is to quickly transfer the data to the machines that request it, and to save it on disk in a database at the same time. The broker is also in charge of guaranteeing the origin of control bench orders via secure authentication. Thus a message publication - that can be orders such as the opening of valves and cylinders - can only be done by a machine that has received a certificate of connection recognized by the network, for which the project will be responsible.

3.1. Remote power supply of SERA IV

The ground MQTT network was used to manage the electrical connection of the rocket, it’s one of the new products of PERSEUS. SERA IV had to be power by two separate ground power supply until the switch to the rocket’s internal batteries 3 minutes before launch. The new ground station allows the operations center to monitor the rocket’s consumption in real time and the switch of the power supply from OFF to ON or from external to internal power can now be made remotely from the bunker. Thanks to the MQTT network, the operational centre can monitor all these operations via intercom from the scientific room.
This implementation of the power supply allows the project to be modular at the launch site, so that no matter where the project is launched, it will be possible to reproduce the same rocket power control operation independently of the existing infrastructure.

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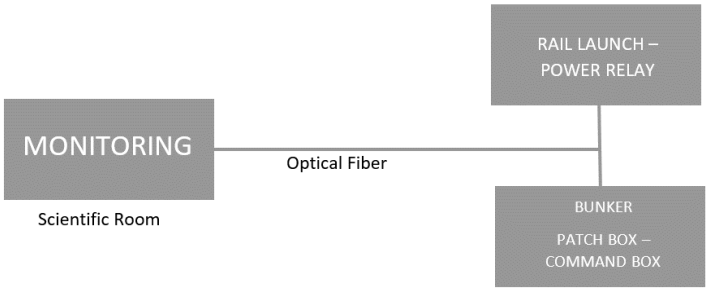

Figure 4 - Network installation at ESRANGE for the remote power supply of SERA IV

The power electrical support equipment has been placed inside a mobile rack completely waterproof and heated / ventilated, the MQTT box that remotely controls this supply is placed directly on the rail launch on the interface of the umbilical to the rocket.
This electrical rack is fully compatible with our launch site for ASTREOS: ESRANGE in Sweden or CSG in French Guiana. The power supply placed inside the rack can be controlled by an Ethernet connection with a secure connection, so that the scientific room has real time information on the electrical consumption of the rocket.

Figure 5 – Electrical support rack of SERA IV placed near of the launch rail inside an electrical container

The implementation tests of the SERA IV ground station have been a complete success and allow the project to follow the ASTREOS road map to adapt the station to ASTREOS performance.

4. ROADMAP of PERSEUS Ground Segment Equipment

The ground segment developed under the PERSEUS program is fully modular and adaptable; from the ASTREOS-1 demonstrator to DREAM-ON the plan is to launch at least one launcher per year / every two years with the possibility of launching from different locations. PERSEUS has to be modular, versatile and mobile so that it can be launched from any location with a minimum of modifications and constraints. The objectives for the ground segment are to have the minimum requirements for the launch base, such as a concrete slab that can accomodate the mass and size of our mobile launch rail, sufficient electrical power and buildings to comply with ATEX environmental regulations and to carry out the assembly of the ASTREOS rocket.

Mission Requirements and Life Cycle Phases

The minimum mission profile required for the PERSEUS ground segment includes the following 8 phases:

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- Transport: Due to the number of vehicles to be launched and the variety of launch sites used, the first step is a transport phase. There are several sites in France for all the equipment, the 3P office in the centre of Paris and a test and storage area in Normandy within the Ariane Group site.

- Storage: storage must be anticipated as it is the longest life phase for all ground segment equipment and there are different types of storage (waiting for the launch campaign, waiting in the launch area, waiting to return to France). For the PERSEUS ground segment, the most important is to anticipate the MOC (Maintenance in Operational Condition).

- Distribution: distribution is the first mission of the entire ground segment, with electrical and fluid support (ethanol, nitrogen and liquid oxygen for ASTREOS-1).

- Integration and testing of the launcher in the launch preparation building: once the ground segment is assembled and ready for the launch sequence, all integration and testing of the launcher can be carried out in an assembly building. The ground segment supports the avionics and propulsion/launcher teams in the final checks and procedures before the rocket is closed. In the future, the rocket will be assembled directly on the launch vehicle.

- Pre-launch preparation: During this step, the launcher is transported to the launch area and connected to the launch pad rail. All connections (mechanical, electrical and fluid) are made. At the end of this phase, the entire launch area is evacuated before the launcher is erected on the ramp. This phase ends with the filling of the ASTREOS tanks. Safety monitoring: When the launcher is up-right on the launch rail and during flight, the ground segment is responsible for the safety of the entire launcher and the installation. It requires a real time surveillance of the launcher, the ground segment and all the interfaces.

- Launch sequence: The launcher must be guided during the launch sequence to maintain the right flight angle until it leaves the rail.

- Mission support: Surveillance, flight analysis after the launch.

5. Main products of ASTREOS ground segment

In order to ensure a quality of service for the launcher with a minimum adaptation time and launch autonomy for the PERSEUS project, the ground segment has been developed with a committed modularity. The ground segment has been divided into 5 main products to meet the minimum requirements of the mission profile:

- A mobile launch rail
- A transport and transfer vehicle
- A ground station:
    - Ground station and control bench of the ground equipment
    - A monitoring ground station with TM/TC (telemetry/tele-command) with the vehicle
    - Electrical support equipment
- A fluid ground support equipment :
    - Ethanol support for filling, flushing the on-board ethanol tank
    - Liquid oxygen for cooling the line and filling, flushing the on-board tank
    - A nitrogen support to sanitise all the ground segment fluid lines and fill the 240 bar high pressure tank on board
- A flight safety support (software and data analysis)

6. TRANSPORTABLE launch rail

The launch rail pad developed in the PERSEUS project is a mobile/transportable rail. It must be compatible with SSC or Guyana space facilities. It is mobile because it can be installed and uninstalled in 2 days where the future demonstrator will be launched. This launch rail product has be installed and tested at the Ariane group site within a PERSEUS test area.
With a ground footprint of 15m in horizontal position, the vertical arm of the launch ramp is 14m to allow 12m guidance of the demonstrator, visible in figure 4.

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Figure 6 - View of the mobile launch rail in VERNON at the horizontal

The objectives of the launch pad are to:

- Connect ASTREOS to the guide rail
- Support the rocket during the raising of the rail
- Raise the rail to the desired angle
- Guide the launcher to the desire flight angle during launch
- Isolate the cryogenic tank from the launcher
- Host ground electrical equipment
- Host fluid support equipment and interface with automatic disconnection at the lift-off.

During installation, the mobile launch rail is aligned to the correct ground azimuth targeted for the flight. This angle can handly be adjusted prior to launch with wheels on the ramp without dismounting the ramp.
At the current state of development, the launcher requires a minimum guidance of 12m to leave the ramp with sufficient aerodynamic stability. The launcher will be connected to the rail by the kart (a specific transport vehicle for PERSEUS demonstrator) and custom guide pieces. It is also at this step that the launcher will be connected to its electric and fluid umbilical.

All subsequent steps are then be fully automated by the control bench, without the presence of any operators near the launch pad. The first step is to bring the launcher into a vertical position in order to bring the ASTREOS demonstrator into its firing angle. To do this, the pad uses industrial electric type cylinders, the set providing a thrust of up to 2 tonnes. As we bring the launcher into a vertical position, another by-product will be used to help the launcher to support the mechanical loads during this dynamic phase. This product is currently under development and will be placed directly on the launch rail. Once vertical, the tank filling steps will follow.

7. VADOR: Vehicle of assembly, transport and connection to the rail

Named as the kart, this vehicle has different functions:

- Transport the rocket (whether in parts or full integrated)
- Support the assembly of the rocket
- Connect to the rail

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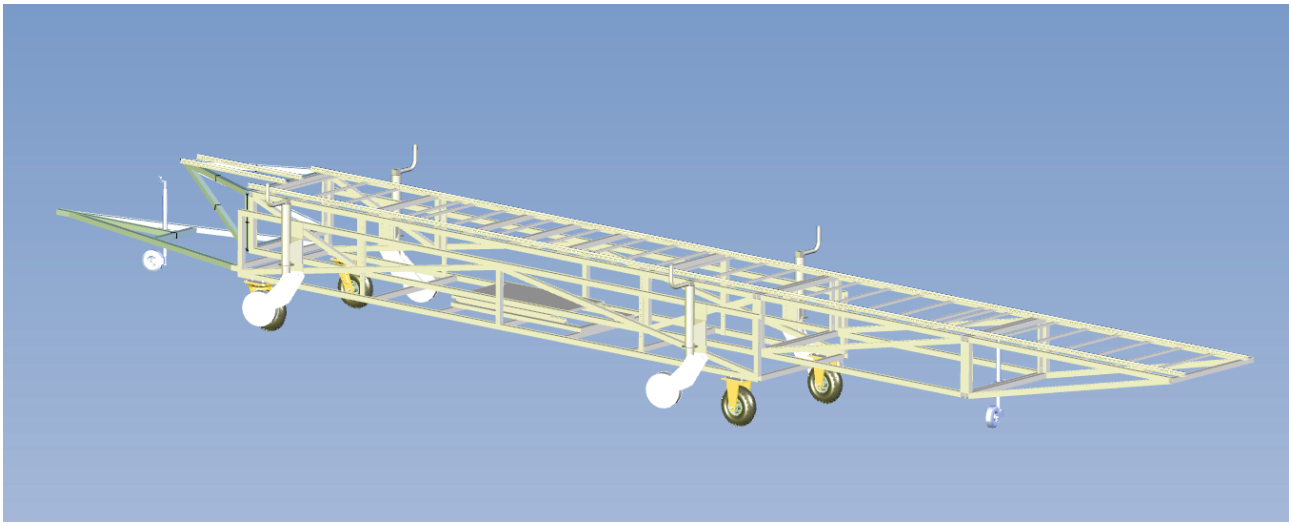

Figure 7 - View of kart system for ASTREOS

The layout of the chassis for the kart system is visible on figure 5: for the launcher assembly, cradles are present on the straight guide rail serving as an assembly rail. This is the added value of this system, which consists in attaching the starter's assembly bench directly to the kart, which makes it possible to have a versatile system that will be used for both transport and assembly. The transition between the rocket closing and moving sequences will take place directly on the kart. We thus find the same behaviour of assembly bench as for SERA 4.

The kart is an assembly bench mounted on wheels, with a couple of support cradles on each part. This support allows to move and connect the different stages of the ASTREOS demonstrator during the preparation. On this step the vehicle is used to support the launcher assembly, it allows to have the launcher directly ready to be transported on the kart and with the right configuration (horizontal position and the rail interface connector on the top of the launcher). The second way of using of the kart is the transport to the launch pad, only the 4 pneumatic wheels are used. It is based on a trailer design, the 4 industrial jockey wheels are not used during this phase. The jockey wheels are placed on the high position before rolling out the launcher by using the crank casement of each wheels.

When the vehicle arrives, the four jockey wheels are deployed and lift the vehicle up, the 4 conventional wheels in the centre then no longer touch the ground. The position of ASTREOS on the launch rail is achieved by means of the jockey wheels, which are free to move in all directions. The launcher is guided with an X and Y direction to be aligned and linked. The modularity of this vehicle lies in the possibility to have different rocket diameter of the ASTREOS family, only the customized support on the cradle will have to be changed; from now on 3D printing or in foam are used to manufacture the support at the correct diameter with specific geometric.
This version of the kart design is a second version improved by our agile method and prototyping, a first version have been imagined and prototyping with wood and a FabLab (fabrication laboratory) – ElectroLab at Nanterre near Paris. An analysis and feedback on the prototype allowed us to arrive at this third version.

The vehicle can be towed by a vehicle or can be manipulated by using an electrical pusher tractor placed at the extremity with the trailer tongue.

8. Transportable Fluid Ground Support Equipment

The fluid system is an essential component of the ground systems, since it allows the storage of propellants and their delivery to the launcher (these new functions lead to the need for a new specific PERSEUS ground segment). It must allow the ground station control bench to manage and control fluid operations. The fluid system must be compatible with the launcher interface, which is derived from the design of the tanks and the power supply inside the rocket. It is therefore designed in close collaboration with the launcher and propulsion system teams as well as with the Ariane Group Vernon team.
The fluid ground support equipment is based on the use of 3 different propellants and can be broken down into 3 filling subsystems and 1 ignition subsystem:

- Nitrogen Tank System (pressurization fluid)
- Ethanol Tank System
- LOx Tank System

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- Ignition system (Propane must be confirmed)

The ground fluid system is currently designed taking as a constraint the need to fill to its full capacity the ASTREOS-1 rocket. The system is intentionally modular to be compatible with future designs.
The ASTREOS tanks have a storage capacity of 47L.

The ground fluid system has been developed to allow the fluid supply of the ASTREOS-1 launcher. Design margins were taken to easily evolve from ASTREOS-1 to ASTREOS-X and DREAM ON without a complete redesign of the ground fluid system.

Each tank system includes a set of lines, valves and sensors that will be specific to the fluid being piped.

Details of the fluid subsystems and their functions are detailed below:

- Nitrogen System
    - Filling: High Pressure Nitrogen will be delivered directly to its edge tank, without interaction with other fluids. It must arrive in the embedded tank at a pressure of 240 bar.
    - Sanitation: the sanitation part will be carried out at low pressure, to allow a sweep of all the lines of the system. The purpose of this sweep is to flush out all impurities in the lines to avoid unnecessary interactions while filling with other fluids. This will be the first step in the filling sequence. It will be pressurized at a value slightly higher than the respective load loss of each line (Nitrogen, LOx and Ethanol)
- Ethanol system: this fluid is one of the 2 propellants of the MINERVA bi-liquid engine. It will therefore be piped to its tank after cleaning. It will be at room temperature, in liquid state and will not require any specific equipment
- LOx system: this fluid is the second propellant of MINERVA, and will also be sent to the embedded tanks after sanitation. Since it will be in a liquid state, some specific equipment will have to be defined anticipating the extremely low temperatures required to keep oxygen in this state.

The positioning of the ground tanks on the launch zone will vary according to the launch site. Thus it was chosen to work only with flexible lines connecting mobile filling trays (see 2 examples on figure 6) that will be positioned on the launch area. Some trays such as the ground/launcher connection trays and ASTREOS rocket filling valves will be placed directly on the sides of the launch ramp.

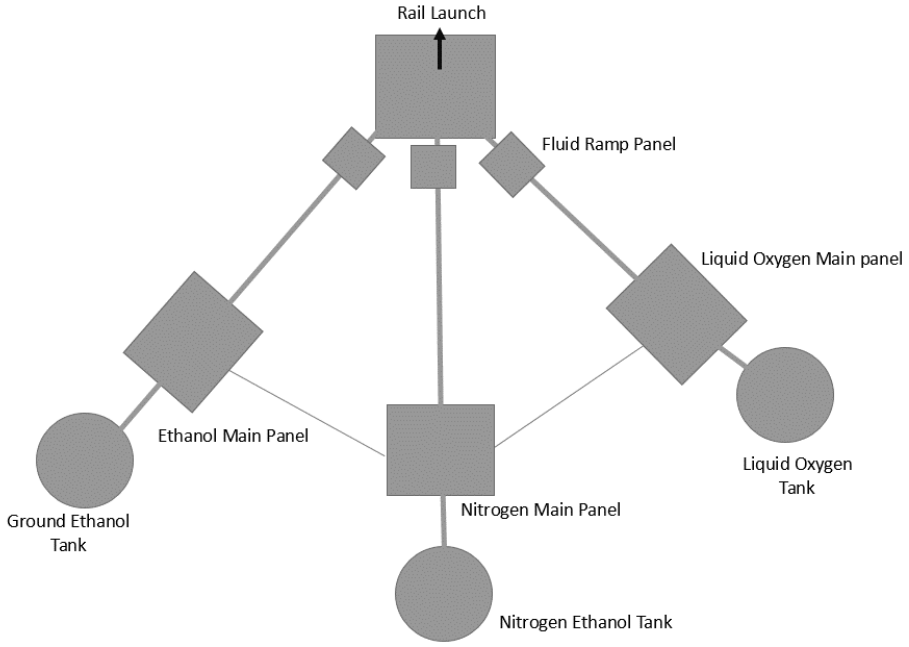

Figure 8 - Fluid panel installation on the ASTREOS launch area

All fluid panel will be placed on trolley in order to be easily move during campaign and qualification campaign in France, all these installations are fully mobile. All the permanent storage between using of these equipment will be the PERSEUS container placed near of the rail launch during campaign. The trolley will be placed only when it's required in order to avoid the time when they are placed outside, the fluid connexion between all the panels and flexible will be made by using quick connector that ensure a complete seal.

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The fluid ground segment is designed taking into account a filling by Ethanol, which has a voluntarily simplified line: the ground segment has for future objective to switch to Methane, to follow the various evolutions of the ASTREOS range.

9. Synthesis and perspectives of the PERSEUS ground segment

Many other features have already been identified for the recovery of the post-ASTREOS launcher family, called DREAM ON. The ground segment to be used for this demonstrator will depend on the type of recovery (VTVL-Vertical Take-off Vertical Landing or Smartcatcher) and the objective will be to return the demonstrator to a safe mode.
The PERSEUS project is already working on a recovery robot that will allow the demonstrator to be flushed out in the event of a vertical landing recovery. The future of the PERSEUS ground segment will also include the incorporation of Industry 4.0 technologies and equipment, such as an operational tactics tablet. This tablet will help the operator during the pre-campaign installation and during all the qualification phases, it will contain all the procedures and QRCode recognition in order to easily find the documentation and specifications on a line, interface, connector...

In line with the transformation of new demonstrators and launchers, the ground segment must adapt to modularity and continuous support.

The PERSEUS project represents this evolution of the new launcher market, with the possibility of developing the ground segment within the launcher development department. The future of the ground segment seems to be moving towards modularity and rapid adaptation from one launch to another with different requirements in the shortest possible time.

Acknowledgments

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