# SEEDS – THE INTERNATIONAL MASTER PROGRAM FOR PREPARING THE YOUNG SYSTEMS ENGINEERS FOR SPACE EXPLORATION

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The SEEDS initiative originated by Politecnico di Torino and Thales Alenia Space Italy in 2005. It aimed at establishing a Post Graduate International Master Course in Space Exploration and Development Systems “SEEDS", to offer an opportunity to young engineers to get prepared for the future of Europe in space exploration. The SEEDS project has been shared with Supaero Toulouse in France and with University at Bremen (together with ZARM) in Germany, as the three European towns (Torino, Toulouse and Bremen) have a long common tradition of space activities at both the industrial and academic level and represent three poles of the European cooperation in space programs. The SEEDS course comprises two different steps in sequence: an initial Learning Phase and a Project Work Phase. Both the Learning and the Project Work Phase pursue a multidisciplinary approach, where all specialized disciplines are blended together and integrated to enable the students to acquire the system view and then to accomplish the conceptual design, through the Systems Engineering approach, of a selected case-study. The distinguishing feature of SEEDS is without any doubt the Project Work activity, performed by all students together under the supervision of academic and industrial Tutors, coordinated by the Education Project Manager. Main objective of the Project Work is to train the students on the basic principles of the System Engineering Design, through their application on a well defined project related to a specific space exploration mission. The Project Work includes the Preparatory Work, during which the students, starting from the definition of the mission statement, focus on the identification of the complete architecture of the space exploration mission, and the Conceptual Design activities, performed in the three European sites to develop a limited number of building blocks identified during the Preparatory Work. The first year of activity started in November 2005, with a Plenary Opening which took place at the ESA-ERASMUS Centre, Noordwijk, with the full support of the Human Space-Flight Microgravity and Exploration Directorate of ESA. Five years of activities have passed since then and five project works have been successfully completed, dealing with various space exploration themes. This paper focuses on the description of the SEEDS course and on the main results achieved in terms of project work activities and development of the future space workforce. The positive experience of five years of SEEDS is brought to evidence and the lessons learned are discussed in view of the SEEDS continuation.

## I. INTRODUCTION

The SEEDS initiative originated by Politecnico di Torino and Thales Alenia Space Italy in 2005. It aimed at establishing a Post Graduate International Master Course in Space Exploration and Development Systems “SEEDS", to offer an opportunity to young engineers to get prepared for the future of Europe in space. The SEEDS project has been shared with Supaero Toulouse in France and with University at Bremen (together with ZARM) in Germany, as the three European towns (Torino, Toulouse and Bremen) have a long common tradition of space activities at both the industrial and academic level and represent three poles of the European cooperation in space programs.

The Master course comprises two different steps in sequence: an initial Learning Phase and a Project Work Phase. Both the Learning and the Project Work Phase pursue a multidisciplinary approach, where all specialized disciplines are blended together and integrated to make the students able to acquire the system view and then to accomplish the conceptual design, through the Systems Engineering approach, of a selected case-study. The distinguishing feature of the SEEDS Master is without any doubt the Project Work activity, performed by all students together under the supervision of academic and industrial Tutors, coordinated by the Education Project Manager. Main objective of the Project Work is to train the students on the basic principles of the System Engineering Design, through their application on a well defined project related to a specific space exploration mission. The Project Work includes the Preparatory Work, during which the students, starting from the definition of the mission statement, focus on the identification of the complete architecture of the space exploration mission, and the Conceptual Design activities, performed in the three European sites to develop a limited number of building blocks identified during the Preparatory Work.

The SEEDS Master program comprises two different steps in sequence:

1) an initial "Learning Phase", lasting about six months, during which the students attend courses and perform exercises with the aim of understanding space basic concepts and learning the fundamentals of Space Systems Engineering Design;
2) a "Project Work Phase", lasting about nine months, during which the students carry out the conceptual design of an Exploration Mission and of a Space Architecture matching the mission objectives.

Both the "Learning Phase" and the "Project Work" phase pursue a multidisciplinary approach: at the beginning the basic design techniques and criteria pertaining to various engineering disciplines are introduced, later on the acquired knowledge is focused on the development of an integrated system level design concept, where the attention is mainly oriented to ensure the adequacy and coherence of the proposed solutions. Students are therefore supported along a technical education path where individual capabilities are progressively incremented through the acquisition of new information and methods and then enhanced and tested through intensive team working sessions. The system level sensitivity towards the design objectives is developed and the engineering best practices applied to a selected case-study.

As a matter of facts the distinguishing feature of SEEDS Master is without any doubt the Project Work activity, performed by all students together under the supervision of academic and industrial Tutors, coordinated by the Education Project Manager. Every year the project work is oriented towards a different case-study related to a specific space exploration mission.

Generally speaking, the Project Work of the SEEDS Master always includes:

1) a Preparatory Work, during which the students focus on the investigations of whys and wheres of space exploration, on the definition of the mission statement, mission objectives and top level system requirements and then on the accomplishment of the top level functional analysis. The major system level functions are thus allocated onto various categories of composing building blocks and the final result of this work is the identification of the complete architecture of the system of systems.
2) Conceptual Design activities, carried out in the three European sites (Toulouse, Bremen and Torino), to further develop the design of a selected subset of the aforementioned building blocks. Selection criterions are usually the following:
    - the building blocks represent innovative concepts, both in terms of functions performed and technical challenges;
    - the building blocks are highly characterizing elements, which constitute an added value for the whole system of systems.

The paper focuses first on the results obtained by the SEEDS Master in terms of Project Work activities and then on achievements in terms of development of a future space workforce. Eventually the lessons learned are discussed and main conclusions are drawn.

## II. PROJECT WORKS ACTIVITIES

In the first edition the Project Work has focused on the design of human initial settlement of the Moon surface, which has been named ULISSE, hUman Lunar Initial Settlement for Space Exploration. ULISSE mission statement is reported hereafter: "*To land on the lunar surface an initial outpost for sustaining human presence at a site with a pre-existing robotic capability as a first test-bed to conduct scientific experiments and demonstrate innovative technologies and ISRU (In Situ Resources Utilization) processes*".

In order to achieve the goals, identified in the Mission Statement, eleven building blocks and three Mission Phases (the robotic phase, the human tended phase and the human phase), have been established. Six out of eleven building blocks have been chosen for a phase A design, as shown in Table 1.

<table>
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**SUM, Service Utility Modules**
**(designed in Toulouse)**

SUM provides the lunar initial settlement with power and communications between rovers, habitation modules and Earth ground segment. Moreover it strongly supports the Guidance Navigation and Positioning system. SUM distributed architecture is shown in the figure beside [1].

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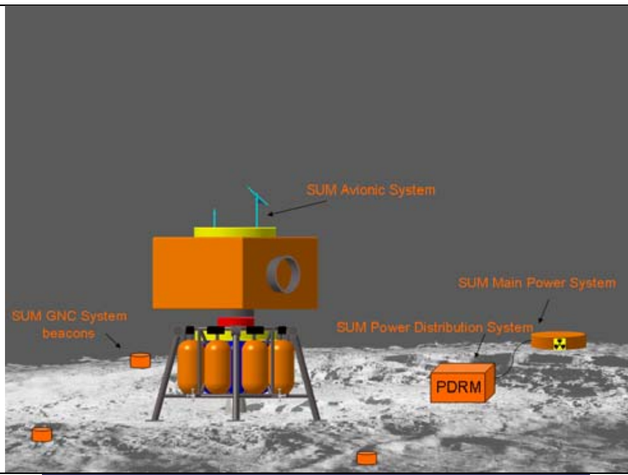


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**HOW, Heavy Operation Worker**
**(designed in Toulouse)**

HOW provides the initial lunar settlement with the capability of preparing the landing pad and excavating the hole where the Permanent Habitable Module (PHM) will be accommodate. HOW is also in charge of unloading, transporting and covering PHM with regolith [1].

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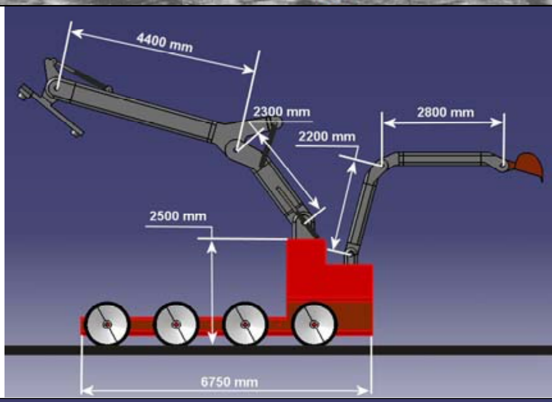


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**TSM, Transport Service Module**
**(designed in Bremen)**

TSM provides the injection of the payload into lunar transfer orbit and low lunar orbit. Moreover TSM performs trajectory control [2].

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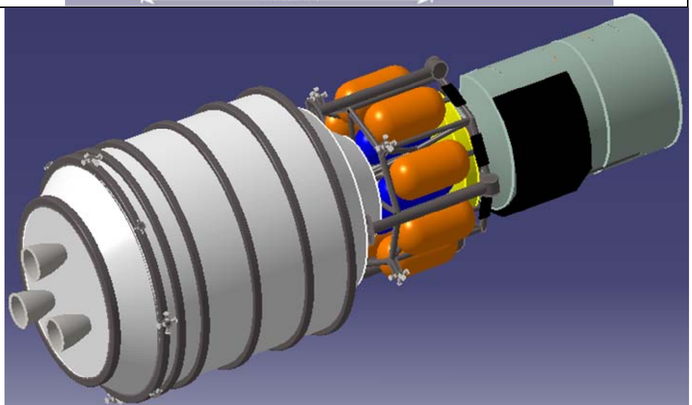

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**CDM, Cargo Descent Module**
**(designed in Bremen)**

CDM performs lunar cargo landing [2].

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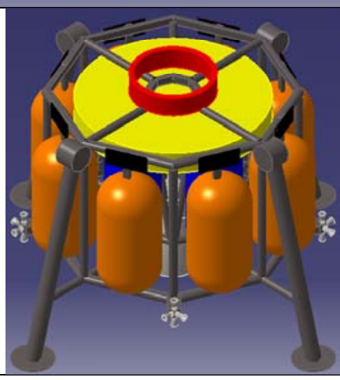

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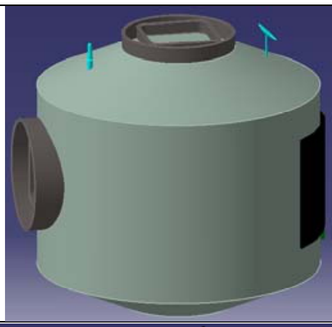
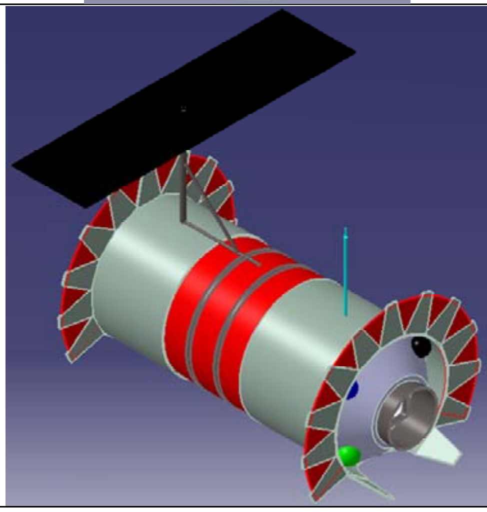
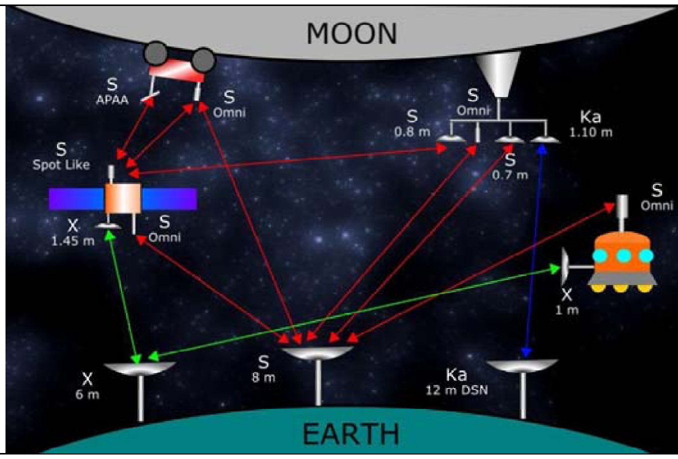
| **THC, Temporary Habitable Cabin (designed in Turin)**<br><br>THC is a pressurized module/cabin used to support temporary habitation in space and on the lunar surface. Moreover THC may be used as escape vehicle in emergency conditions [3]. |  |
| **PHM, Permanent Habitable Module (designed in Turin)**<br><br>PHM is the first permanent module of the initial human settlement on the Moon surface. PHM provides the initial lunar settlement with an operations centre and a safe haven [3]. |  |

Table 1. ULISSE building blocks selected for a phase A design

In the second edition the Project Work has focused on a permanent human Moon base, which has been named PHOEBE, Permanent Human mOon Exploration BasE. PHOEBE Mission Statement is reported hereafter: "*To establish a permanent lunar base for a nominal crew of 18 astronauts (maximum 24 during crew exchange) with a turnover time of 6 months, to support scientific research, In-Situ Resources Utilization (ISRU) development, surface exploration and commercial exploitation; its evolution will provide an outpost for further space exploration*".

Table 2 describes the building blocks that have been selected for a phase A design.

<table>
<tr><td>MONACO, Moon Navigation and Communication (designed in Toulouse)<br><br>MONACO provides PHOEBE with a continuous and reliable communication system between PHOEBE and the Earth and between the modules of PHOEBE, guaranteeing high rate channels with variable rates according to weather conditions. MONACO provides also PHOEBE with a navigation system for the mobile elements [4].</td><td>
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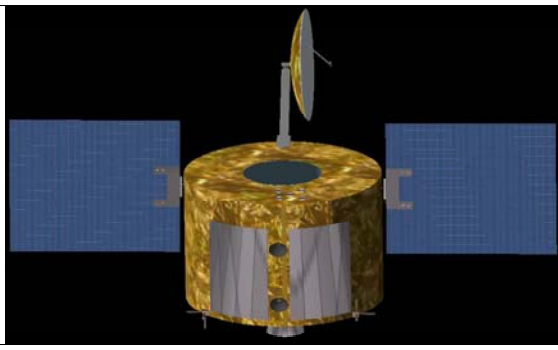
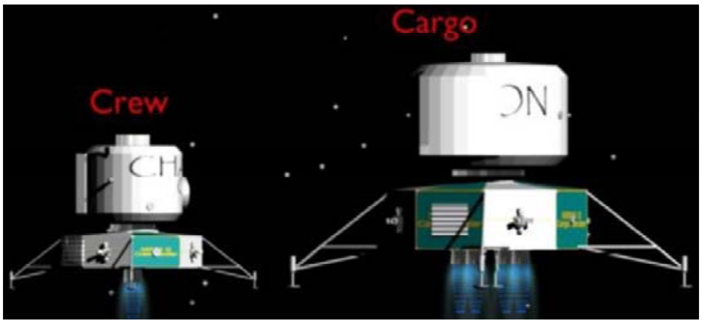
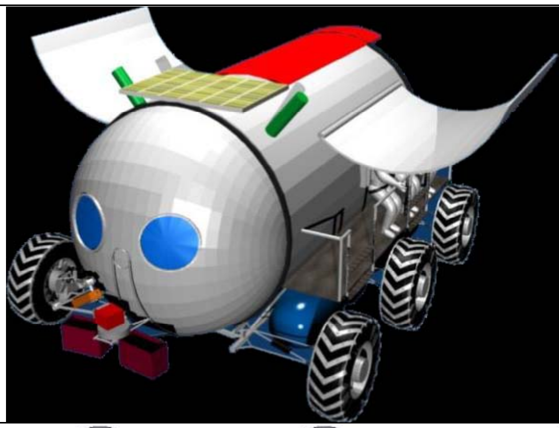
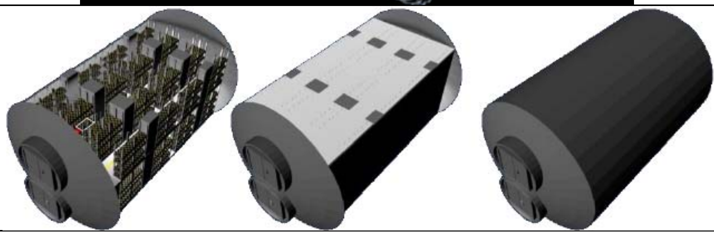
| **POLO, Polar Observation Lunar Orbiter (designed in Toulouse)**<br><br>The next Moon exploration activities need a better knowledge of Moon orography. The observation mission POLO provides high resolution topography of Lunar South Pole, ensuring safer landing, navigation support and easier development for Moon settlements [4]. |  |
| **CHARON, Cargo and Human AscendeR and lander for the moON (designed in Bremen)**<br><br>CHARON allows transferring cargo and crew from SLM (Space Lagrangian Module) to the Moon surface and vice-versa by means of reusable vehicles. Two different types of Reusable Lander and Ascent Vehicles have been envisaged to transfer separately crew and cargo: the Crew RLAV and the Cargo RLAV [4]. |  |
| **CAMPER, Crew Autonomous Moon Pressurised Exploration Rover (designed in Turin)**<br><br>CAMPER allows transporting a crew of three astronauts in a pressurized environment, in order to perform Moon exploration [4]. |  |
| **FARM, Food And Revitalization Module (designed in Turin)**<br><br>FARM provides PHOEBE with a biological controlled environment, allowing for the regeneration of resources and the production of food to support the astronauts life [4]. |  |

Table 2. PHOEBE building blocks selected for a phase A design

In the third edition the Project Work has focused on a Lunar Orbiting–Space Operation Centre, which has been named ECLIPSE, European Cis-Lunar Interplanetary Port for the Space Exploration. ECLIPSE Mission Statement is reported hereafter: "*To establish a permanent habitable orbiting station located in Earth-Moon Lagrangian Point 1 (EML1) to support space exploration, acting as the central hub for the future interplanetary transportation system between Earth, Moon, Mars and beyond, and to foster the commercial development of space*".

Table 3 briefly describes the building blocks that have been selected for a phase A design. Other ECLIPSE building blocks, that have not been considered for a phase A design, are: Habitat Modules, Orbital Tugs, AOCS (Attitude and Orbit Control

System) Module, Nodes, Truss, Power Module, Arrival/Departure Pad and TCS (Thermal Control System) Module.

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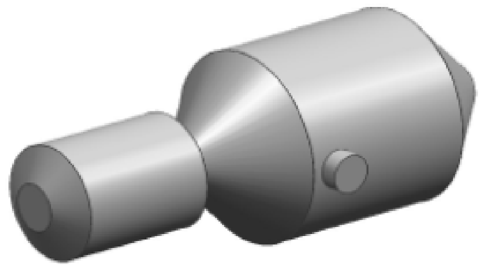
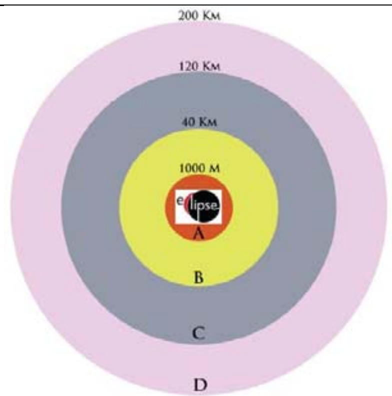
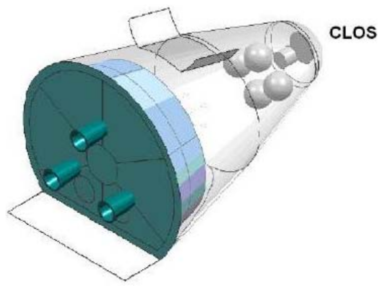
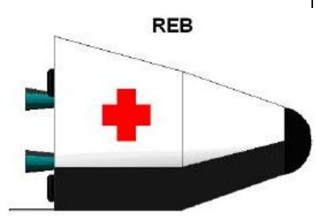
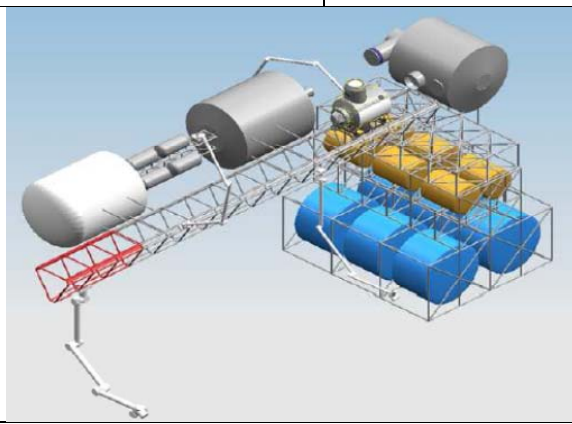
| **Medical Centre and Quarantine Facility (designed in Toulouse)**<br><br>ECLIPSE provides on-board crew, the Moon Base and any manned vehicle in the cis-lunar space (i.e. free-flyers, other exploration vehicles) with advanced medical support for. Biomedical research and quarantine capabilities for the Mars mission crew are additional functions provided by this system [5]. |  |
| **Telecommunication System (designed in Toulouse)**<br><br>ECLIPSE exchanges data (i.e. audio, video, housekeeping data) with the following subjects: Ground Segment, Moon Base, Crew Transportation System and all vehicles in cis-lunar space. The telecommunication system provides both short range and long range reliable data links [5]. | <br> |
| **Crew Transportation System (designed in Bremen)**<br><br>The orbital shuttle for the nominal crew rotation and the rescue boat to evacuate the station, either in case of overall station evacuation or medical problems, are the two elements of the Crew Transportation System. The first performs a monthly round trip from Earth to ECLIPSE, while the latter is constantly docked to the station, ready to fly on short notice [5]. | <br><br><br> |
| **Orbital Hangar (designed in Turin)**<br><br>The core of the envisaged architecture is the hangar that provides revolutionary on-orbit capabilities. Thanks to the hangar, exploration vehicles can be assembled, maintained and refuelled directly in EML1 (Earth Moon Lagrangian), allowing a whole new class of missions [5]. |  |

Table 3. ECLIPSE building blocks selected for a phase A design

In the fourth edition the Project Work has focused on an itinerant exploration mission of the lunar surface, which has been named ALICE, Advanced Lunar Itinerant Caravan for Exploration. ALICE Mission Statement is reported hereafter: "*To explore wide areas of the Moon surface by means of a human itinerant caravan able to accomplish long-duration multi-purpose missions, in order to perform scientific experiments, technological demonstrations and resources mapping in several locations*".

Table 4 briefly describes the building blocks that have been selected for a phase A design.

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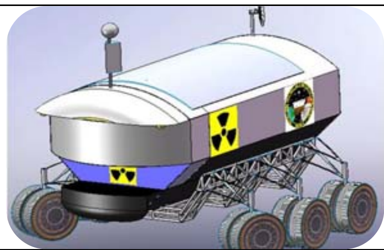
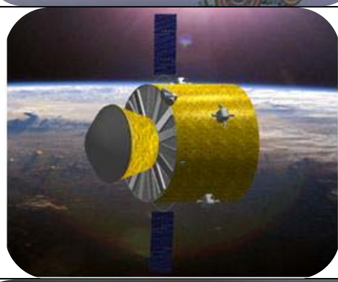
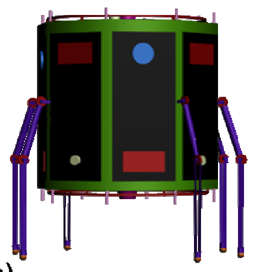
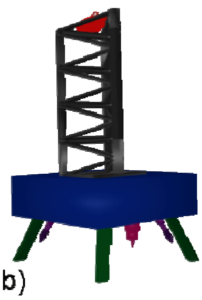
| **ELENA, Elements of a Lunar Enhanced Navigation Architecture, and CECILIA, Communications Elements for Caravan Long range and Inter-elements Activities**<br>**(designed in Toulouse)**<br><br>ELENA and CECILIA are, respectively, a navigation and communications architecture based on a lunar satellites constellation of 8 satellites on two orbital planes that provide continuous coverage of the lunar surface, supported by a beacons network on the Moon surface [6]. |  |
| **Mobile Nuclear Power Plant**<br>**(designed in Toulouse and Turin)**<br><br>The Mobile Nuclear Power Plant is in charge of providing the power required to all of the caravan elements [6]. |  |
| **SRV, Moon Sample Return Vehicle**<br>**(designed in Bremen)**<br><br>SRV shall bring safely to Earth from the lunar surface the most valuable samples collected during ALICE exploration campaigns [6]. |  |
| **CRC, Crew Residence Camper**<br>**(designed in Turin)**<br><br>ALICE caravan is composed of 2 trains of 4 elements each. All those elements perform a precise set of functions, which are in most cases highly redundant in the frame of ALICE scenario. In particular CRC, the logistic core of ALICE caravan, is a pressurized rover, able to host 4 crew members, enabling human exploration activities [6]. |  |

Table 4. ALICE building blocks selected for a phase A design

In the fifth and last edition the Project Work has focused on a human mission to an asteroid, which has been named AENEA, humAn Exploration of a Near Earth Asteroid. AENEA Mission Statement is reported hereafter: "*To safely transport humans to a Near Earth Asteroidin an international frameworkperforming extra-vehicular activities on its surface, scientific experiments and technological tests to extend the human scientific knowledge and capabilities in space exploration and utilization".*

Table 5 briefly describes the building blocks that have been selected for a phase A design.

<table>
<tr>
<td>SIBILLA, Smart hybrId roBot for the InternaLanaLysis of an Asteroid and MIDAS (Modular drIll anD sAmpler collector Segment)<br><br>(designed in Toulouse)<br><br>A robotic system shall explore the asteroid's surface for a high resolution mapping of it, shall accurately measure its gravity field, shall perform analysis for determining the internal structure of the body and shall perform drillings for taking samples and leaving attached to the soil structures to support the astronaut's descent on the asteroid's surface. The robotic system consists of an exploring robot (SIBILLA, a)) and a drilling machine (MIDAS, b)) [7].</td>
<td><br>a)</td>
<td><br>b)</td>
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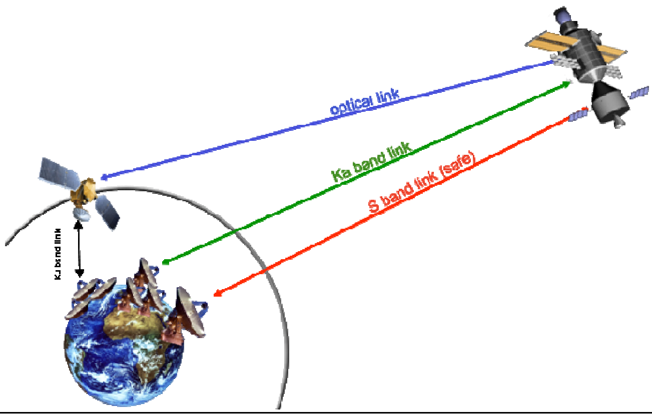
<td>HERMES, Human ExploRation coMmunications intEgrated System (designed in Toulouse)<br><br>HERMES consists of the Ground Segment, which includes the Deep Space Network and a dedicated network of 18 diameter antennas, the Space Segment, represented by a satellite in geostationary orbit, and the spacecraft antennas, which are located on the HAB. HERMES provides communications between the astronauts, the spacecraft and the Earth, allowing accurate TT&C, storage and transmission of scientific data and multimedia broadcast to the Earth [7].</td>
<td colspan="2"></td>
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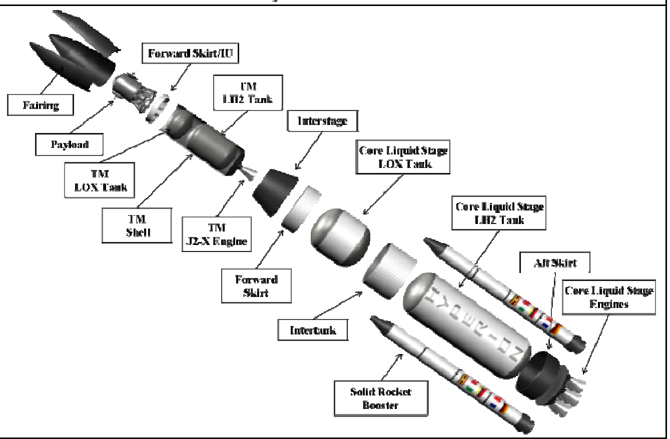
<td>HYPERION, Heavy Lift Launch Vehicle (designed in Bremen)<br><br>HYPERION shall provide the $\Delta V$ needed to perform the transfer from ground to the assembly in LEO, to perform the transfer from the LEO assembly to the Near Earth Asteroid and to perform the transfer from the Near Earth Asteroid to the Earth's atmosphere reentry interface [7].</td>
<td colspan="2"></td>
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| HAB, Habitation Module (designed in Turin) | |
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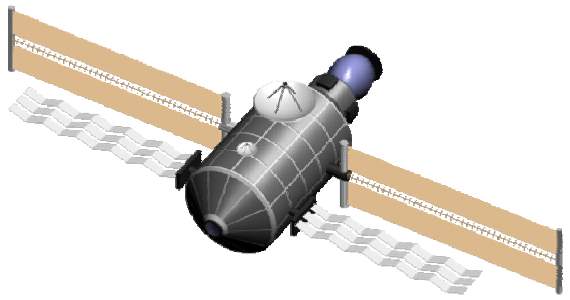
| HAB shall provide 4 crewmembers with a safe and comfortable environment for a 186 days mission to a NEA (Near Earth Asteroid), providing them with resources, protecting them against the external environment, supporting IVAs (Intra Vehicular Activity) and EVAs (Extra Vehicular Activity) [7]. |  |

Table 5. AENEA building blocks selected for a phase A design

## III. FUTURE SPACE WORKFORCE

The results of five years of SEEDS may be expressed both in terms of number and nationality of the enrolled students and in terms of the current employment status of the students themselves. Fifty four students have attended SEEDS, taking into account all SEEDS editions. As far as the students' nationality is concerned, the vast majority of the students have been Italian with small contributions from other European countries, specifically France, Germany, Spain and Rumania, and also from non European countries, like Uganda and Venezuela (see Figure 1).

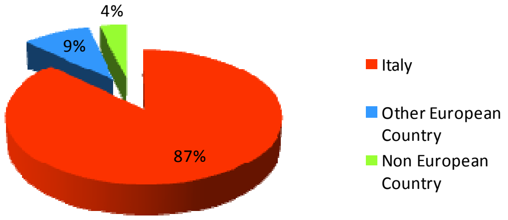



Figure 1. Five years SEEDS students' nationality

Eventually, as far as the current employment status of former SEEDS students is concerned, it is worth highlighting that almost 75% of the students have been employed in aerospace industries just few months after the end of SEEDS. This stunning result testifies the success of the SEEDS initiative. The remaining 25% of the SEEDS students have been partly employed in other fields, in space agencies or have applied at universities for a PhD position. This last option actually represents a very small percentage but it is worth mentioning it because it is a very interesting case of perfect mixture between industry and aerospace, according to SEEDS approach, as the PhD fellowship is sponsored by an aerospace industry.

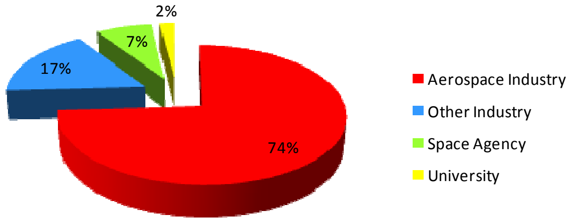



Figure 2. Current employment situation overview of five years SEEDS students

## IV. CONCLUSIONS

The first year of activity started in November 2005, with a Plenary Opening which took place at the ESA-ERASMUS Centre, Noordwijk, with the full support of the Human Space-Flight Microgravity and Exploration Directorate of ESA. Five years of activities have passed since then and five project works have been successfully completed, dealing with various space exploration themes. The positive experience of five years of SEEDS, in terms of project work activities and development of the future space workforce, has been brought to evidence. Eventually a few important lessons have been learned during these five years, as reported hereafter:

- the project work, where the students play the role of systems engineer or system specialist, is a fundamental step of the program, as it helps student develop their skills through the accomplishment of specific design activities;
- the enhancement of the students' team working capabilities through dedicated lessons and practical applications during the project work is very precious to prepare the students for the future real aerospace industrial world;
- blending together the industrial experience on real case-studies and the academic approach of university is an essential feature of the program, as it allows the students acquire both the knowledge coming from real design

cases and the tools and methodologies to face them;
- multidisciplinary teams of students are highly recommended to improve the quality of the systems engineering work, even though communications between the team members may be difficult at least at the beginning;
- internationality of both tutors and students have to be strongly enhanced to foster the exchange of knowledge, educational methods and design solutions.

After five years of activities, SEEDS initiative has been stopped for one year. Main reasons for this interruption have been the change of frame work, due to the end of collaboration with the University in Bremen, and to the need of gathering thoughts and drawing conclusions on future space exploration scenarios. Now that the first SEEDS cycle is over, SEEDS initiative is likely to start again in 2012. Main objectives of SEEDS will be once again human space exploration, systems engineer and internationality, even though the frame of work this time will be different because of the end of collaboration with the University in Bremen, as mentioned above, and thanks to the flourishing of activities with other new partners.

ACKNOWLEDGMENTS

The authors wish to thank all SEEDS students, teachers, academic and industrial tutors.

## VI. REFERENCES

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