European University and Scientific Space Research Program PERSEUS (Projet Etudiant de Recherche Spatiale Européen Universitaire et Scientifique)

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Abstract

Launched at the 2005 Paris Air Show, the Perseus initiative was conceived by the French Space Agency (CNES). As part of the forward-planning efforts of its Launch Vehicles Directorate, this project is looking to spur innovative technical solutions in all areas related to launchers, aimed chiefly at students in higher education.

Work is coordinated together with different partners and a dedicated organization has been established. System studies have given the basis of our work. They led us to two main concepts: our range of experimental rockets ARES and our final demonstrator of assisted launch by automatic reusable carrier, EOLE.

1. Introduction

PERSEUS is giving an answer to the need to involve students and higher education in industrial space projects. This project is issued from different reflections and working groups. Their conclusions led to the long-term PERSEUS project, set up in 2005 by the Launch Vehicles Directorate of CNES which is based on three main objectives:

- To stimulate innovation and advance technologies applicable to launch systems;
- An educational initiative for students and a motivation for future generations to take up careers in the space sector;
- To realise the design project (phase 0/A) for a nanosatellite launch system (10kg payload on a polar, circular orbit at 250km).

Thanks to these objectives, the involvement of inexperienced members of higher education, without any preconceived notions on the subject, encourages the creation of new ideas as well as motivating these younger generations to acquire a hands-on, professional experience. What's more, the project federates the different actors of universities as well as it fosters relationships with other institutions, associations, companies and public agencies.
The difficulties introduced by reducing the size of a typical launcher to this scale, whilst remaining economic, mean that innovation is not only a goal for PERSEUS but that it is the key to the project's success.
To achieve these objectives, Perseus is pursuing an original approach in which students, lecturers/researchers, postgraduate students and university space club members are coordinating their efforts to build technology demonstrators. The long-term goal is to develop a launcher for 10-kilogram nanosatellites in low-Earth orbit. A step-by-step approach is the best way of getting there, with the kind of oversight and procedures widely used in the aerospace industry. PERSEUS is a project which is able to cut across the barriers between education, training and research.

Since 2005, a long road has been gone through. Organisation has been settled up, partners took place, more than 1,000 students have been working on about 250 projects and some studies extend now beyond France. Studies of support for ground demonstrations have been developed: avionics and electrical technologies for NLV (Nanosatellite Launch Vehicle) applications, advanced propulsion technologies, materials technologies.
In order to qualify these concepts and technologies, different flight demonstrators are developed by students and associations within the framework of PERSEUS. The results of the last national campaign are encouraging and the projects planned for the next national campaign will be based on the technological headways qualified during this 2010 campaign.

2. Organisation of the project

2.1 Means of innovation: students and implementation of Higher Education

The first principle of the project is based on the realisation of every elementary activity by students from Higher Education, within the framework of their university programme. The second principle consists in the completion of the activities by material realizations, followed by trial campaigns, on the ground or in flight. These are the better ways to get:

- good supervision by teachers-researchers
- support of activities by joined researches, allocation of research grants
- the interest of students for material realisation until flight tests directly connected to industrial needs
- innovation comes out as a challenge for the students

Finally, this way to get students involved contributes to the promotion of technical jobs, more specifically space and launchers business. The innovation and the implication of the students also present a particular interest for the small and medium-sized companies which take an increasing role in the project.

2.2 A PERSEUS Project Office and different partners

CNES leads this project and its team. The French Launcher Directorate is also responsible for programmatic synthesis.

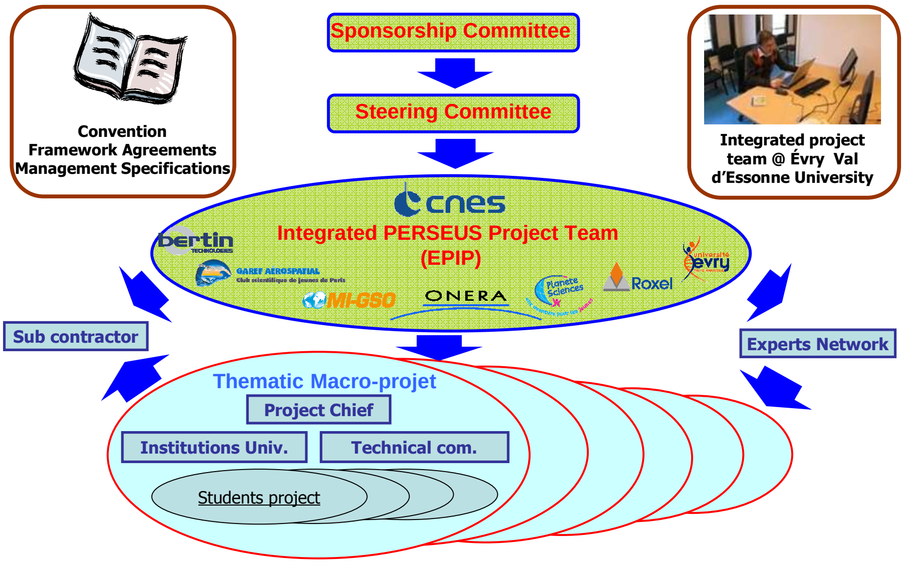

Figure 1: PERSEUS organisation

Eight partners are now involved in the project:

- industrial partners :
  - **Bertin Technologies**: methodological assistance to innovation, coordination and support for software, synthesis on technologies and innovative concepts
  - **MI-GSO**: quality, project management and internal communication
  - **ONERA**: system studies, multidisciplinary optimisation, study of L3AR concepts (assisted launch by automatic reusable carrier), hybrid propulsion research programs, links with ISAE (Institut Supérieur de l'Aéronautique et de l'Espace) and its campus in Toulouse

  ○ **Roxel France**: pilot of propellant systems conception, coordination of associated research activities, supervision of propellant systems testing, propulsion and pyrotechnics expert
- university :
  ○ **University of Evry-Val d'Essonne** (UEVE): support of its association, coordination of university partnerships, educational and research program on launch systems, provision of offices for the project team.
- associations :
  ○ **GAREF Aérospatial**: coordination of electrical systems activities, draft studies on demonstrators and launch systems, assisting French Guyana, Paris and its suburbs
  ○ **Planète Sciences**: L3AR demonstrators operations, supervision of experimental activities of young people, implementation of its national and expert network, promotion towards young people and scientific associations.

A convention, applicable to all the participants of the project, defines the rights and duties of all the participants: partners, students, associations, CNES,…

2.3 Technical structure of the project – macro projects

In order to simplify the design of the final launch concept, it was divided into a launch system and its subsystems (propulsion, structures, ground systems, etc..). So, in the PERSEUS project, various systems and subsystems have been classified in several groups of projects, called macro-projects (MP). There are four main categories of macro-projects:

○ NLV (Nano Launch Vehicule) concepts:
- ALBION : Assisted launch under balloon
- CHIMERA : Multi-stages with boosters
- L3AR : assisted launch by automatic reusable carrier

○ Studies or software developments:
- THEMIS : Technological Help for Education to Management of Innovation and Survey
- SELENE : Launch site research
- ULYSSE : Ultimate Liquid hYbrid Solid launch System Evaluation

○ Ground demonstrators:
- AETNA : Avionics and Electrical Technologies for NLV Applications
- HERA : Hybrid Engine for Research Activities
- APTEROS : Advanced Propulsion Technologies for Rocket engine systems
- PEGASE : Studies and realizations of engine structures
- MINERVA : Innovative experimental engine

○ Flight demonstrators:
- ARCADIA : Advanced Rocket for Academic and innovation activities
- ARES : Advanced Rocket for Experimental Studies
- EOLE : Demonstrator of separation sequences for L3AR
- mini-L3AR demonstrators

2.4 Management specifications

Project management is major for projects in cooperation. It also corresponds to the "launchers" culture and to the foundation of every big aerospace project. Finally, it presents an educational interest for the young people attracted by space technologies. At CNES, different management specifications are applied, in particular Ariane's management specifications and the ECSS (European Cooperation for Space Standardization). But they are too complex, unsuitable and dissuasive to students and volunteers.
PERSEUS' management specifications have been adapted from the CNES' simplified normative guide and the practical experience in management of some of our student projects, especially in PEGASE MP.

The principles of PERSEUS rules are:
- management by phases with associated reviews, taking into account the different aspects of human, financial and calendar resources. The management of documentation, the traceability of the projects are included in this project management.
- the application of PERSEUS management specifications is adapted to each project : realizations, duration, investment costs, relation with other projects,…
- at least 4 milestones spread out all along the activity of each project : annual objective review, preliminary design review, critical design review, exploitation review

The first use of these management specifications was applied on macro-projects: organization notes, functional specifications, road map,… Two documents describe the specifications which have been defined, and a documentary basis is proposed to the projects. The requirement documentation is more rigorous for demonstrator projects.
A first experience feed-back has shown that the rules were appreciated and followed in a variable way. The perception of these specifications is quite different between teachers, students, and volunteers. The procedures seem a bit heavy to apply by now but are indispensable for the project continuation, in particular for EOLE or ARCADIA. These management methods are limited by actors' cohesion: the most resistant are sometimes the most effective and creative…

Nevertheless, project management remains a necessity for such a cooperative project. We thus maintain the requirements, and aim towards their intensification, trying to use as much persuasion, diplomacy, and pedagogy as possible. We just know that cooperation risks being more difficult with some volunteers, who are not still the worst.

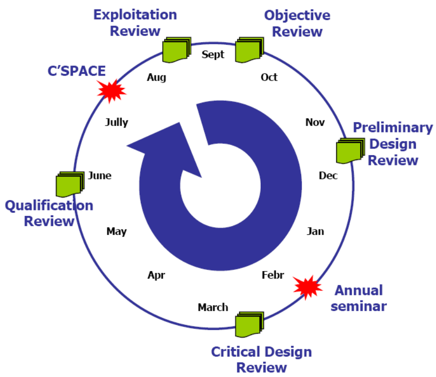

Figure 2: Typical year organisation

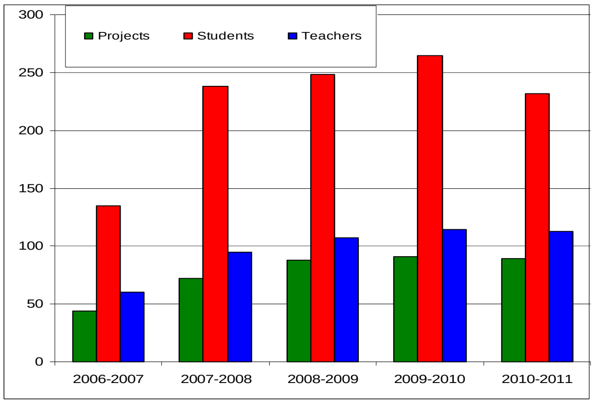

Figure 3: Number of projects, students and teachers evolution

3. State of the art of the project

Following to the first studies presented in 2007 and 2008 (reference [1], [2] and [3]), we have far much knowledge about the different concepts that we studied. Calculations were deepened and led towards more advanced technological works.

3.1 System studies

Preliminary design studies led to the conclusion that a two-stage launcher is not viable, due to a bad structural factor. Nevertheless, a three-stage launcher would be too complex for a 10 kg payload. Consequently, we turned to a two-stage solution, assisted either by boosters for ground lift-off or by an airborne carrier for L3AR.

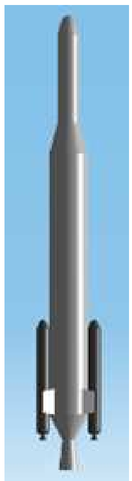

Figure 4 : CHIMERA : Two-stages with boosters :

- 1er stage : propulsion LOX/CH4
- 2ème stage : propulsion hybrid LOX/wax with additive
- Booster : solid propulsion

Global Characteristic :

- Weight : ~ 5 tonnes
- Height : ~ 11 m

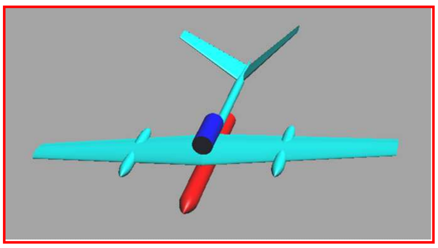

Figure 5 : L3AR
Global Characteristic :
- MTOW ~ 4,5tonnes - Launcher: ~ 3 tonnes - Span ~ 11m
- Separation at 15000 m - Hybrid propulsion

3.2 Software development and studies

System loops give the basis of the preliminary design, with trajectory computation. ULYSSE MP uses tools based on Excel tables and C++ programs giving the opportunity to calculate global loads, aerodynamics, structural constraints, and propulsive characteristics. Therefore, software was developed in order to simulate and optimize trajectories. Its use is adapted to any kind of launcher.

3.3 Ground demonstrations

Through the AETNA macro-project, an OBC (On-Board Computer – fig.6) was developed and realized with its IMU (Inertial Measurement Unit), for flight exploitation and long term flight control. Besides, we encourage associations to use USB sensors technologies on demonstrators.
Some studies are still in progress: wireless communication, as Bluetooth, zigbee,… And a functional model of a powerline data bus was realized.

Since 2006, PEGASE macro-project has developed and realised structures (fig.7) for hybrid propulsion. Several engineer schools and universities from Bordeaux have been working on this project, implying about 30 to 40 students and 10 volunteers each year. This MP was the first to introduce management rules. In order to stimulate innovation and boost competitiveness, the same problem is broken down into three different factors: performance, cost and "crazy idea". It is finally a good way to provide interesting results: since its beginnings, it has demonstrated an increasing evolution of results. Starting with cryogenic storage vessel units, it now studies combustion chambers, nozzles, wax casting process and uses several means of testing, including fire tests. Structural bonded connections and thermo mechanical damage influence on the composite material permeability have also been studied by two Ph'Ds for a couple of years.


Figure 6 : OBC for ARES


Figure 7: Tank, combustion chamber and nozzle – PEGASE


Figure 8: Buckling tank - ENSICA

As for propulsive systems, we encourage developments in hybrid propulsion (HERA), since it is less complex than liquid propulsion, and less dangerous than solid propulsion, as long as we involve students. By now, hybrid engines have been realised by ONERA and tested on experimental rockets, using N_2O and poly-ethylene or paraffin wax. PhD's are working at ONERA and PRISME Institute (Bourges and Orléans Universities), and experts from SPLab Milano are involved in these studies. Nevertheless, some projects are developed on MINERVA macro-project in order to realize ground demonstration of a 5-10kN engine, with the aim of an operational engine of 100kN, with storable fluid (Lox/ethanol).
Studies are also implemented for architectural choices (mass reduction, hybrid or bi-liquid stage, on ground or airborne configuration,…) and structural design (tanks, external skin, skirt and separation system , fins,… - fig.8). Before any flight integration, technologies are first developed on ground and then updated for flight.

3.4 Flight demonstrations

MPs of demonstrators, such as ARES or mini-L3AR, are places of expression for students and volunteers.

● **Rockets:** Since 2007, many rockets with many different characteristics have been launched in PERSEUS project.
FH (Fusex Hybride) is a family of PERSEUS rocket demonstrators destined to serve as flying testbed of Hera-F engine. FH-01 made the inaugural flight of a PERSEUS rocket demonstrator during the French National Launch Campaign of 2007. It was based on a medium weight composite structure and aluminium fins. It was propelled by N_2O and PolyEthylene and was the first hybrid rocket ever developed in France.
Rockets FH-02 to FH-04 were based on existent but heavier weight composites tubes and aluminium fins. They allowed testing Hera-F hybrid engine (especially paraffin wax) during the French National Launch Campaign of 2008 and 2009 in La Courtine and Biscarosse. The first European hybrid rocket composed with paraffin wax was

launched by PERSEUS in August 2008. FH rockets were made by a cooperation of Planète Sciences, GAREF and INSA Lyon (Institut National des Sciences Avancées) space club (Cles Facil).

Figure 9: FH01 (polyethylene) – 2007

Figure 10: Remote controlled model probationary of EOLE – 1/2.2 scale

● **Airborne:** In parallel, demonstrator projects are developed on mini-L3AR subjects. They present the interest to test separation sequences and flight control loops and to prepare studies for our dedicated L3AR demonstrator, EOLE (fig.10). Indeed, a model of EOLE was tested to qualify the carrier behaviour in flight. Following to this milestone, EOLE is now in progress at Aviation Design, a French model aircraft designer, and under the direction of ONERA. As soon as 2013, it will be used as flight test bed for separation, flight command, embedded experiment (such as 0G,..), release of touch down demonstrator,…

4. Present activities on PERSEUS

4.1 Remarkable flight results

Three rockets have been launched during the French National Campaign in Biscarosse last summer:

- Ares-α, ARES rocket prototype testing a new recovery system with horizontal separation
- FSP-05, a reconditioned version of FH-05 rocket with a Cesaroni Pro54-5G solid motor
- EVE2, a Fusex (experimental rocket) demonstrator of Octave, based on a medium weight composite structure, aluminium fins

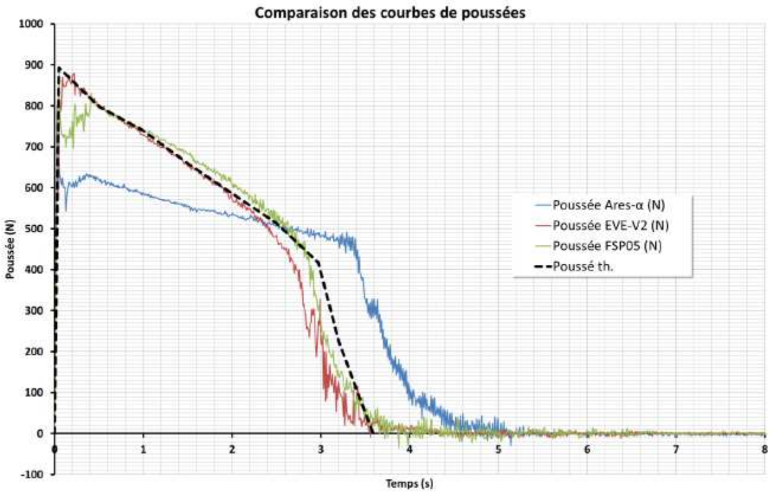

Figure 11: Thrust curves comparison of 2010 demonstrator's engines

These three rockets had two embedded common IMUs produced by ESIEE (Ecole Supérieure d'Ingénieurs en Electronique et Electrotechnique) and SYSNAV Corporation (a French start-up issued from l'Ecole des Mines de Paris). ESIEE's IMU is based on Mems technology (Micro Electro-Mechnical System). Its first objective was to restore precisely by means of hybridizing methods, the rocket trajectory in three dimensions and the rocket attitudes and flight environment. A second objective was to anticipate future trajectory control system for future advanced ARES rockets. System studies were performed with fallout analysis, in order to get comparison with experimental data. In order to compare the measurements between the different flights (fig.11), to validate trajectories restitution and flights analysis, and to qualify the different IMUs in their environment for later flights, SYSNAV's IMU was embedded as a black box. They both led to conclude that the 3 engines, supposed to be comparative, had some dispersion in thrust: one of them had a higher combustion time, even though the integration of its thrust is equivalent to others. A better knowledge of these propellants would be interesting for next flights.

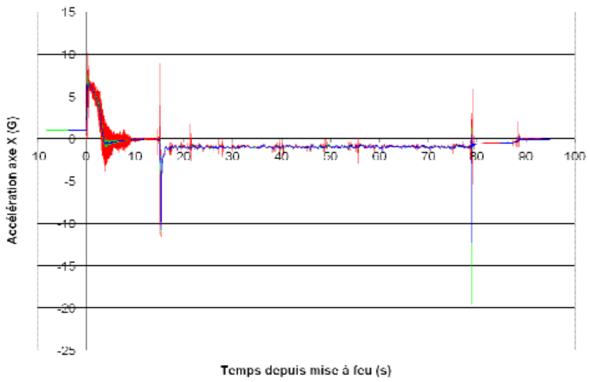

Figure 12: Acceleration (G) on X axis of SYSNAV (red), ESIEESPACE (green) and XSens (blue) IMUs

A third IMU (XSens central) was embedded on FSP05. It was a good way to compare the three IMUs and to qualify them. On figure 12, we notice an excellent superposition of the 3 acceleration curves (on X axis). Results are as much interesting for Y and Z axis. Only SYSNAV data are 8 times more numerous, since the IMU frequency is 8 times higher (800 Hz). The 3 first seconds correspond to thrust phase, and then we can notice the parachute opening at time 15.2s. At time 78.8s the rocket sticks its nose in the sand and at time 89s, it falls on its side.

These 3 IMUs include: accelerometers, gyroscopes, 3 axis-magnetometers, and temperature sensor. Integrated to IMUs were different sensors: absolute analogical pressure, numerical pressure, differential analogical pressure (to measure dynamic pressure from Pitot tube), and GPS (Global Positioning System).

Results obtained by these 3 demonstrators are very interesting; they lead to a correct estimation of attitude, velocity and height, which is coherent to visual observations and data obtained from other sensors. Nevertheless, inertial navigation is deviating by nature. For longer flight, it will be necessary to make readjustments by hybridization. These validated IMUs will now be embedded on next campaign demonstrators and will give the opportunity to get to a higher step on projects exploitation.

4.2 Innovation for next flights

These flights also have given the opportunity to test an innovating manufacturing process of ARES composite structure, whose main goal is to improve structural factor. Indeed, the Mechatronics Research Laboratory of IPSA (Institut Polytechnique des Sciences Avancées) developed a cheap and “easy” full “cold process” used to manufacture our sandwich carbon composites with core made “in-situ”. Since heaviest parts of a sandwich composite

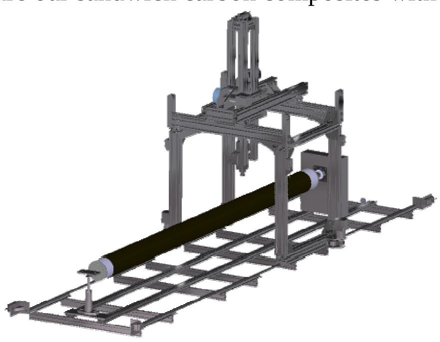

Figure 13: IPSA 4 axis dedicated mill machine

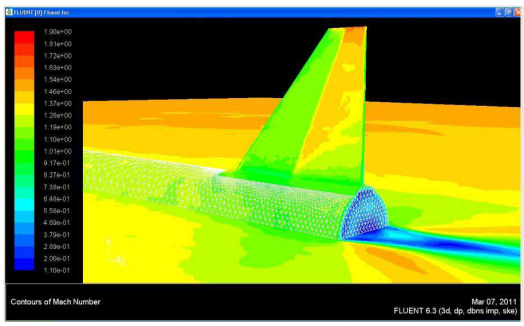

Figure 14: Supersonic composite fins simulation

are carbon layers, we decided to reduce as possible the carbon thickness and worked on a complex optimized core which presents many functions (reinforcement, vibrations absorption, etc...). The laboratory is developing, with IPSA students, a dedicated 4 axis mill machine (fig.13) that allows to manufacture 3 continuous meters of ARES composite tubes (Ø160mm) and presents a capacity to produce 3m tubes for the future ARCADIA (Ø250mm) and even bigger (max Ø500mm). This machine is modular: it gives the possibility to increase the tube length capacity, depending on the internal mandrels rigidity. On each tube we can choose the number of layers, the fibres orientation, and the core thickness and complexity. The process per rocket goes relatively quickly (between 1 and 1.5 weeks) and we can ensure an excellent final external aspect and geometric fidelity.

Besides, ISAE students are working, during their school projects, on supersonic capability composites fins (fig.14). A student team of ISAE has made a first differential approach between two different stability systems, fins and a “skirt” during transonic and supersonic flight. A more complete study has been realized on fins solution and students have worked on a process derived from SICOMIN technologies (French composite formulator) which are applied to boats. This technology of manufacturing has been first tested in flight on the Ares-α prototype in subsonic speed. It led to a reduction of 50% of the mass of fins, compared with aluminium fins traditionally used on small experimental rockets. It has especially demonstrated very good mechanical characteristics and robustness in regard to its light weight. These students determined, in two optimization loops, an adapted geometry to ensure stability of the future ARES supersonic rocket, and they made a first estimation of material thickness, number of carbon layers, reinforcement zones and mounting system. The two loops designs have been tested for different speeds, flight incidence and structural configuration in loads simulations and structural static and dynamic analysis. A next team will use these results and will manufacture prototypes in order to realize static, dynamic and wind tunnel tests. A first operational test in flight could occur in 2012 or 2013 on an ARES rocket ([5]).

4.3 Planned launches for 2011 C'Space

Two associations were born under the PERSEUS initiative: Octave from UEVE and SupaeroSpaceSection (S3) from ISAE. An older one, AeroIpsa from IPSA, is also well involved in the development of our flight demonstrator.
Four ARES rocket demonstrators are prepared to be launched this summer at the French National Campaign [6] (C'SPACE 2011):

- students of S3 are working on Ares01H3-1 as a modulated hybrid engine flying test-bed with a duration of engine combustion doubled compared to previous launches
- Students of AeroIpsa, are working on Ares02Bi-P1P1, a two-stage active rocket.
- Students of Octave, are working on Ares03Evo-P2. Its goal is to demonstrate a two successive parachutes recovery system. Their system was first tested during a successful flight in cooperation with Delft University in May 2011. They will also test a more powerfull engine, a PRO75 Cesaroni
- Students of S3 are also working on Ares04Evo-P1, a first step of a future active roll control system for some airborne launched ARES rockets.

In parallel, a campaign for airborne demonstrator (Mini-L3AR) is organised in the suburb of Paris at the beginning of July.

5. Conclusion

In the space of five years, PERSEUS project has much evolved. Thanks to management specifications and to the involvement of numerous volunteers, teachers-researchers and partners, the significant evolution of the results encourages us to continue in this way.
Much progress is to highlight in the exploitation of demonstrators data, in the precision of the documentation provided by students, in the deepening of technical subjects and in the cooperation between the different parties involved. Such cooperation is essential for the implementation of more complex projects, such as suborbital rocket or airborne launch demonstrators.
Some subjects are more difficult to develop, in terms of organisation and research resources, especially in propulsion, since safety requirements in respect with students work are more complex. Nevertheless, our two future demonstrators, ARES and EOLE, and the organisation of our different projects, allow us to be confident in the future. A promising strategy could be reviving European cooperation.

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