ARES ROCKETS DEMONSTRATORS OF FRENCH SPACE AGENCY PROJECT PERSEUS

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ABSTRACT

ARES (Advanced Rockets for Experimental Studies) macro-project is part of the PERSEUS (Projet Etudiant de Recherche Spatiale Européen Universitaire Et Scientifique) initiative set up by the French Space Agency (CNES – Centre National d'Etudes Spatiales).

ARES main objective is to build small modular rocket demonstrators in order to study supersonic flight domain (SERA), two-stage flight configuration, airborne launch from a dedicated unmanned carrier EOLE, and to be used as PERSEUS flying test-bed for Hybrid rocket engine, for instance. Its final goal is to build a suborbital rocket with a culmination above 100 km.

The project is based on an organization with students associations, school projects and research laboratories, working on the innovating ARES modular architecture.

1. PERSEUS PROJECT

1.1. Presentation

Launched during the 2005 Paris Air Show, PERSEUS (Projet Etudiant de Recherche Spatiale Européen Universitaire Et Scientifique) initiative was set up 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 level.

To achieve this objective, PERSEUS is pursuing an original approach in which postgraduate students, university space club members and lecturers/researchers are coordinating their efforts to build technology demonstrators. The long-term goal is a detailed preliminary project of a small launch vehicle able to put 10-kilogram nanosatellites in low-Earth orbit. A step-by-step approach is the best way to succeed, with managements and procedures derived from the aerospace industry where it is widely used. PERSEUS is a project which is able to delete barriers between education, training and research.

Work is coordinated together with different partners (Bertin Technologies, GAREF Aérospatial, MI-GSO, ONERA (the French Aerospace Lab – Office National d'Etudes et de Recherches Aérospatiales), Planète Sciences, Roxel France and the University of Evry-Val d'Essonne). In the last five years, the PERSEUS university network has attracted more than 1000 students, working on 250 projects, and some studies extend now beyond France, reaching students, researchers and space industries from different places in Europe.

1.2. Management

Project management is a major task 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.

PERSEUS' management specifications have been adapted from the CNES' simplified normative guide and the practical experience in management of some of our student projects.

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.

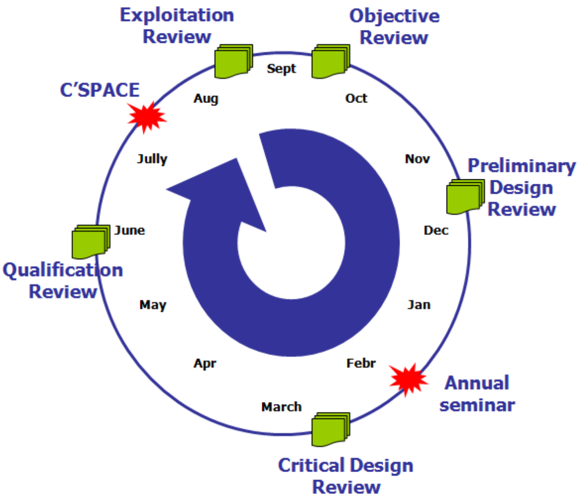

Figure 1. Typical year organization

1.3. Flight Demonstrators

Flight demonstrators are important stakes in PERSEUS. Two categories of flight demonstrators are studied:

- Ground launch demonstrators
- Air launch demonstrators

Ground launch demonstrators are rockets launched from different places depending on the performance of the rocket. Main objectives are to prepare more powerful rockets and test technologies suitable for very small launch vehicle. This paper deals particularly with these demonstrators.

Air launch demonstrators are rockets launch under an automatic and reusable carrier developed inside PERSEUS project. The carrier, EOLE, drops the rocket at about 6 000 m. The objectives of these demonstrators are to evaluate different drop out sequences.

Figure 2. PERSEUS flight demonstrators program

2. ARES ROCKET

2.1. ARES Objectives

ARES objective is to study and build small modular rocket demonstrators in order to:

- be used as flying test-bed for technologies developed in other PERSEUS macro-projects, for instance Hybrid rocket engine.
- qualify PERSEUS procedure for atmospheric dimensioning test cases of a future launcher : transonic flight and maximum of dynamic pressure
- finalize a two-stage flight configuration
- study airborne launch

It focuses on innovation and modularity. A particular study concerns mass optimization of structures and electrical systems.

All ARES rockets are defined around a common basis:

- Ø 160mm body Outside Diameter
- Recovery system by axial separation
- External support structure made of composite tubes
- Easy assembly/removable light fins
- Use of PERSEUS launcher (for launches operated from ground)

Some combinations can be performed.
In short terms, one of the performance objectives, is to reach max speeds around Mach 1.5 with culmination altitude close to 12km in a two-stage configuration.

2.2. Organization

As all PERSEUS Macro Project, ARES is coordinated by a project manager. In this case, a specific link is guaranteed between the Mechatronics Laboratory of IPSA (Institut Polytechnique des Sciences Avancées) and the PERSEUS project team.Project manager assumes coordination between different participants and manages the macro-project organization.

The macro-project is principally based on student teams which work as part of their school year projects, on specific ARES developments and studies, or on student associations' team members who work on rocket conception.

School research laboratories also take part in technology developments of the macro-project and in students project supervision.

2.3. Developed technologies

There are many technological developments for ARES demonstrators. The small size of the rockets doesn't often allow the use of existent technologies or systems at affordable price or sufficient light weight.

ARES modular architecture is divided into several parts. Each of these parts is the subject of specific studies (support structure, fins, nosecone, recovery system, motor section, electronic bay, roll control system, etc…).
Next subsections present three main studies of ARES macro-project.

2.3.1. Innovating composites structures

The Mechatronics Research Laboratory of IPSA works on an innovative manufacturing process of ARES composite structure. The main goal is to improve structural factor.

Because of the "small size" of ARES demonstrators, we can reduce mass by reducing the carbon layer thickness of the support structure. There is, however, an impact on tubes rigidity and technological limits.

The solution is the use of sandwich technology. This technology allows to increase rigidity while reducing the final mass. But it is not so easy to produce according to a constant quality without industrial capacities. One of our main objectives is to be innovative. To this end, we developed a cheap and "easy" full "cold process" used to manufacture our sandwich carbon composites with core made "in-situ".

Heaviest parts of a sandwich composite 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 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.

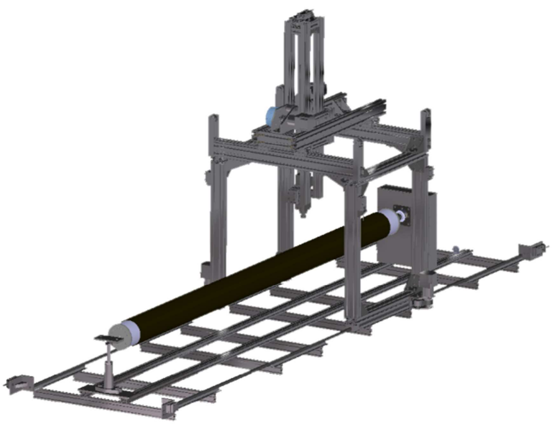

Figure 3. IPSA 4 axis dedicated mill machine

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.

2.3.2. Supersonic composite fins

ISAE students are working, during their school projects, on supersonic capability composites fins.

Since 2010 student teams of ISAE (Institut Supérieur de l'Aéronautique et de l'Espace) has made a first differential approach between two different stability systems, fins and a "rear 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 in August 2010 on the Ares-α prototype in subsonic speed and since confirmed on all Ares rockets. It led to a reduction of 50% of the mass of fins, compared with aluminum 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 then, 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.

Testing on samples and fin prototypes has been conducted in order to verify the potential differences with simulation models.

Figure 4. Composite sample testing

A first operational test in flight will occur in 2014 on Ares11S-SERA1 rocket.

2.3.3. Electrical integrated systems

This thematic is studied in coordination with the AETNA macro-project, macro-project dedicated to electrical system studies. Its main goal is to define modular electrical architecture and electronic systems adapted to every ARES demonstrators needs. It also has to anticipate next size demonstrators' needs.

There is two ways of specification for ARES electrical systems. The first concerns hardware specifications like:
- using validated boxes
- connector types
- components package

All those characteristics are defined around common ambient values measured on previous PERSEUS launch and in literature.

The other specification is about a common electrical architecture of each demonstrator. One of the objectives is to reduce as maximum cables weight by using communication buses derived from industry or automobile domains.

Ground connectivity takes also part of this specification with a common mechanical interface, a ground station, energy and batteries management, etc...

GAREF Aerospatial, is developing a S-Band telemetry system with 1Mbits of data transfer capacity. It uses a commercial 2200MHz 1W emitter and is studying a patch antenna that could be mounted around the rocket.

This telemetry allows us to use conventional telemetry receiving system of many international launch sites for future ARES demonstrators.

Students of ESIEE (Ecole Supérieure d'Ingénieurs en Electronique et Electrotechnique) are working on a IMU. This module is based on Mems technology (Micro Electro-Mechnical System). It includes: accelerometers, gyroscopes, 3 axis-magetometers, and temperature sensor. Integrated to IMUs are different sensors: absolute analogical pressure, numerical pressure, differential analogical pressure (to measure dynamic pressure from Pitot tube), and GPS (Global Positionning System).

First objective is to restore precisely by means of hybridizing methods, the rocket trajectory in three dimensions and the rocket attitudes and flight environment. A second objective is to anticipate future trajectory control system for future advanced ARES rockets.

In order to compare the measurements, an IMU made by SYSNAV Corporation, a French start-up issued from l'Ecole des Mines de Paris, is embedded on each flight demonstrator as a black box.

After data restore, comparison is done between the two IMU systems and as possible with launch site external measurement systems. It gives very interesting results: we obtain correct attitude, velocity and height estimations, which are coherent to visual observations and data obtained from other sensors.

It is a good way to guarantee the integrity of attitude and velocity parameters, necessary for safety during separation and ignition of a second stage. Nevertheless, inertial navigation is deviating by nature. For longer flight, it will be necessary to use sensors of better quality or to use readjustments by hybridization.

Vibration tests will be systematically realized on all developed modules in order to qualify the hardware. Tests are made with domain's experts to be sure of the results availability.

2.4. Launches

At this day, twenty PERSEUS rocket demonstrators have been successfully launched during the annual French National Campaigns since 2007.

Since the beginning of ARES, thirteen rockets have been initiated, including four in 2013-2014: the first PERSEUS supersonic demonstrator SERA1, an airborne launch demonstrator Ares10Eole and two rockets that will be launched this summer during the French National Campaign at DGA-EM in Biscarrosse, Ares12-MasterLeia and Ares13-EVE5.

Ares12-MasterLeia will conduct tests on an active roll control system. ISAE-Supaero students are developing this demonstrator on the basis of two ARES rockets launched in 2010 and 2011 which experimented a passive roll control system.

Ares13-EVE5 will be an opportunity to flight test some technology modules destined to future ARES supersonic demonstrators. Two major sub-systems will be tested, a dual-parachute recovery system and a special nose cap made by laser fusion that integrates pressure measurement for speed and incidence restitution.

The airborne launched rocket, Ares10Eole, is in preparation and will hopefully fly in 2014. It will be embedded under Eole carrier and will be dropped at 4000m of altitude on a 45° ramp. A ingnition sequence will be tested on a small Pro54-5G solid motor and culmination point should be 8000m.

Figure 5. Ares rocket under Eole Carrier

3. SERA1 Rocket

3.1. Overview

In order to achieve the 100km suborbital flight goal, a new series of rockets are currently under development. These rockets, called SERA (Supersonic Experimental Rocket ARES) are supersonic rocket developed inside ARES macro-project that can't be launched from metropolitan France due to the higher altitude expected. The main objective is to validate technologies that allow flights at supersonic speed and altitudes greater than 5 km.

SERA1 is part of the EASP initiative (Esrange Andoya Special Project) and will be launch in May 2014 from Esrange (Kiruna, Sweden).

SERA1 will be the first French supersonic rocket developed by students since 1998 and the 20th rocket developed inside PERSEUS.

The particularity and the interest of this project is the strong implication of students in the design, development, realization and operations associated with a multidisciplinary PERSEUS project team to ensure the good realization of the project.

Two students' teams are primary involved in SERA1 and are in charge of the conception, the development and a part of the operations of the rocket:

- S3, non-profit students association inside the "Institut supérieur de l'aéronautique et de l'espace" (ISAE)
- OCTAVE, non-profit students association inside University of Evry Val d'Essonne

In addition, several projects are made in different university to help the definition of the rocket.

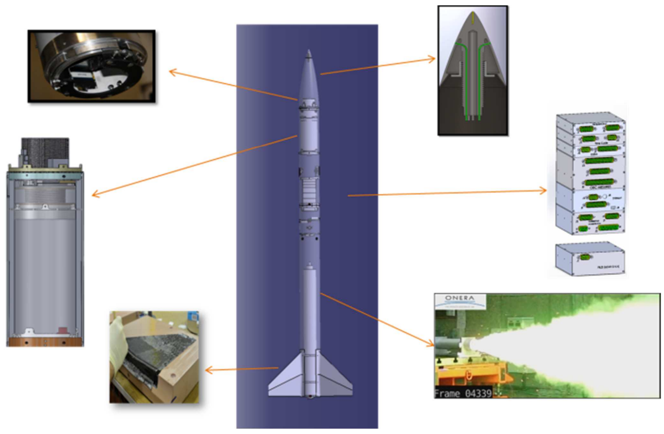

Figure 6. Ares technological decomposition

3.2. Technical characteristics

SERA1 is characterized by:

- Off-the-shell engine : CESARONI PRO98 6G Green 3
- Lightweight rocket (full composites materials)
- Complete restitution of the trajectory
- Use of past experience and elements developed in previous ARES Rockets

Figure 7. SERA1 external layout

PRELIMINARY MASS BUDGET	
Fairing	0,6 kg
Carbon fiber tubes	2,2 kg
Fins	1,8 kg
Electrical systems	2,9 kg
Recovery system	1,7 kg
Separation system	0.8 kg
Propulsion system	13,5 kg
Payload (experience)	0,5 kg
Margin	1 kg
Lift-off Mass	**25 kg**

3.3. Measurements plan

In order to ensure the validation of technologies, SERA1 will be fully instrumented:

- two different inertial unit measurements,
- one vibration sensor in the fairing,
- 5 pressure sensors: 3 in the fairing, one on the side of the rocket and one at the aft end.
- two video cameras, one that films the top and the other the bottom.

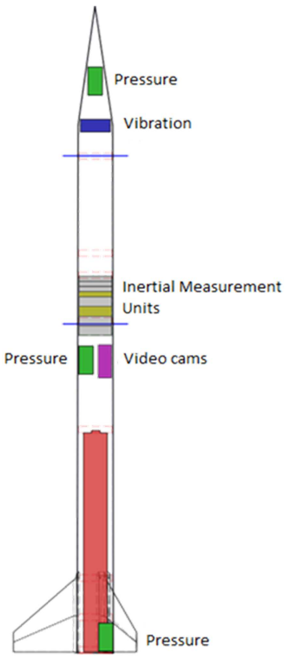

Figure 8. SERA1 measurement plan

3.4. Expected performance

Performance and design of the rocket have been made using PERSEUS home-made tools, trajectory is made with ANDROMEDE, an own made PERSEUS tool to simulate rocket trajectory.

Main results are shown below.

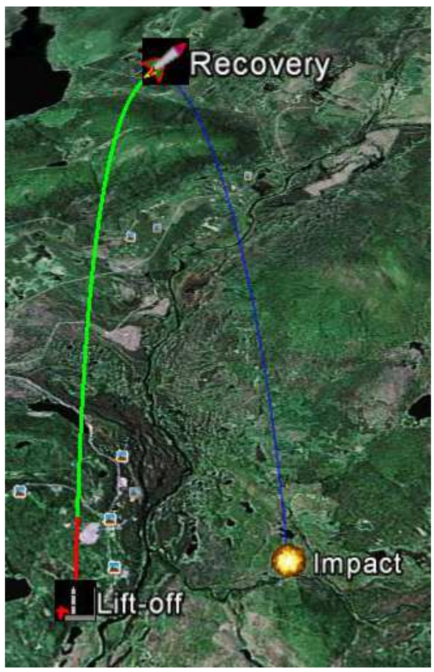

Figure 9. SERA1 GoogleEarth™ Trajectory

Mach Max	1.26	
Culmination	5 280	m
Max longitudinal acceleration	10.4	g
Max Dynamic Pressure	88.80	kPa
Max thermal flux Flux	37.26	MW/m²
Time to culmination	31.2	s
Exit launcher velocity	32.6	m/s

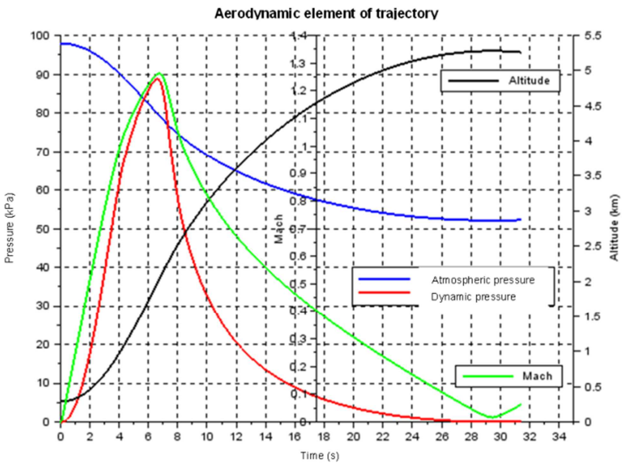

Figure 10. SERA1 expected performance graph

3.5. Status of the project

The Critical design review has been made in June 2013. First elements are under fabrication. Critical elements will be tested during the French launch campaign in August 2013 and a test campaign will occur at the end of the year.

3.6. Next Steps

The Next step is the development of a supersonic two-stage rocket for 2015. In parallel, a development of a liquid rocket engine is under progress. The objective is to integrate this engine in a SERA rocket in order to reach higher altitude and speed.

4. CONCLUSION

Since last publication of ARES rocket status, a significant step has been reach with the development of SERA1 rocket and the use of a professional launch site, Esrange.

Technologies developed in ARES rocket are also reached a maturity level both in structures and electrical systems.

Finally, with the development of SERA1 rocket, PERSEUS proposes a unique initiative to work on an entire supersonic rocket.

PERSEUS is always looking for motivated students' team to work on these projects.

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