

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 conceived 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, two-stage flight configuration, airborne launch from a dedicated unmanned carrier EOLE, and to be used as Perseus flying test-bed for Hybrid engine, for instance. Its final goal is to build a suborbital rocket.

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, the Perseus (Projet Etudiant de Recherche Spatiale Européen Universitaire Et Scientifique) 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.

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 launcher for 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.

In order to simplify the design of the final launch concept, it was divided into a launch system and its subsystems (like propulsion, structures, ground systems, etc...).

In the PERSEUS project, various systems and subsystems have been classified in several groups of projects, called macro-projects.

There are four main categories of macro-projects (here are some examples)

NLV (Nano Launch Vehicle) 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

1.2. Management

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.

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 macro-project.

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 and 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. Procedures seem a bit heavy to apply by now but are indispensable for the continuation of the project, 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.

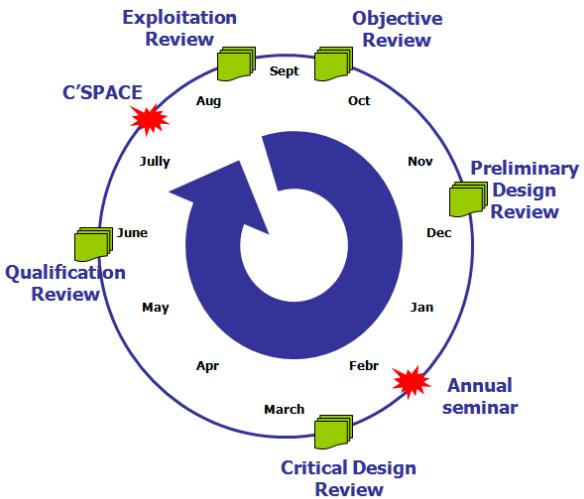


Figure 1. Typical year organization

2. STATE OF THE ART OF THE PROJECT

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

2.1. 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 (NLV-CHIMERA, NanoLaunchVehicle) or by an airborne carrier for L3AR.

2.2. Software development and studies

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

2.3. Ground demonstration

Through the AETNA macro-project, an OBC (On-Board Computer) 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.



Figure 3. Tank, combustion chamber and nozzle - PEGASE



Figure 2. On-Board Computer card for ARES

Since 2006, PEGASE macro-project has developed and realized structures for hybrid propulsion. Several engineer schools and universities from Bordeaux have been working on this project, implying about forty students each year. Every year brings an evolution to technical specifications and a level of additional difficulties.

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 realized by ONERA and tested on experimental rockets, using N_2O and polyethylene or paraffin. 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 liquid 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,...).

Before any flight integration, technologies are first developed on ground and then updated for flight.

2.4. Flight demonstrations

The first hybrid rockets were launched in 2007 and 2008. They essentially gave the opportunity to demonstrate hybrid propulsion technologies in flight. But they also led, step by step, to better structural and electronics knowledge. PERSEUS rockets launched in 2009 and 2010 showed how these technologies are now controlled.

In 2010, the project embedded two different IMUs in the 3 PERSEUS rockets, so that each rocket had similar set of IMUs. The objective was to obtain a comparison

between the different flights, to validate trajectories restitution and flights analysis, and to qualify the different IMUs in their environment for later flights.

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.

Indeed, EOLE is our L3AR demonstrator. It is 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 ...

3. 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 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 equipment.

All ARES rockets are defined around common characteristics:

- 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 launch pad (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.

4. MACRO-PROJECT ORGANIZATION

As all PERSEUS Macro Project, ARES is coordinated by a project leader. In this case, a specific link is guaranteed between the Mechatronics Laboratory of IPSA (Institut Polytechnique des Sciences Avancées) and the EPIP (Equipe Projet Intégrée PERSEUS) team. He 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.

5. 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.

5.1. Innovating composites structures

The Mechatronics Research Laboratory of IPSA works on an innovating 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 increasing 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 ($\varnothing 160\text{mm}$) and presents a capacity to produce 3m tubes for the future ARCADIA ($\varnothing 250\text{mm}$) and even bigger (max $\varnothing 500\text{mm}$). This machine is modular: it

gives the possibility to increase the tube length capacity, depending on the internal mandrels rigidity.

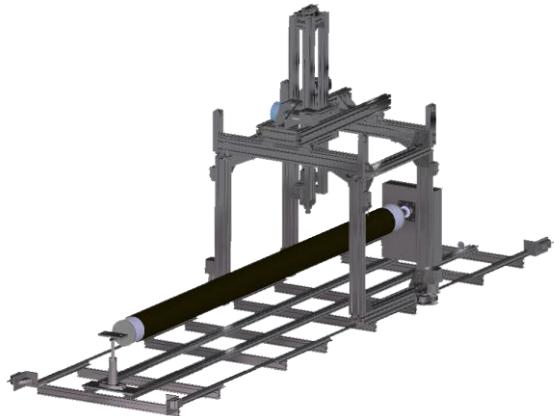


Figure 4. IPSA 4 axis dedicated mill machine

On each tube we can choose the number of layers, the fibers 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.

5.2. Supersonic composite fins

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

A student team 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 "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 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 they made a first estimation of material thickness, number of carbon layers, reinforcement zones and mounting system.

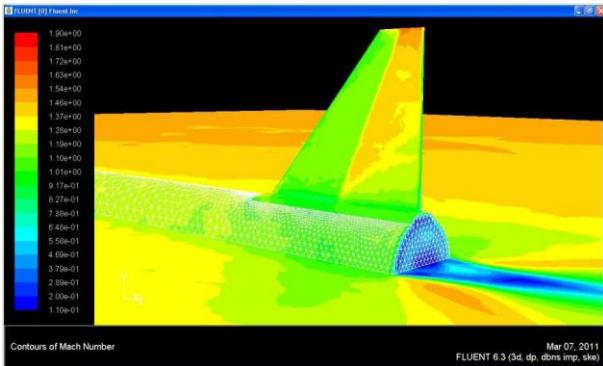


Figure 5. Supersonic composite fins simulation

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 Ares06S rocket.

5.3. Electrical integrated systems

This thematic is studied in coordination with the AETNA macro-project. 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 specification 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 Aerospace, 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-Mechanical System). It includes: accelerometers, gyroscopes, 3 axis-magnetometers, 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 Positioning 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.

6. LAUNCHES

Flights of experimental rockets have been carried out since 2007, within the PERSEUS project. They enable to define a rocket prototype which has been successfully launched in 2010 and led to establish ARES bases.

Four launches are scheduled this summer at the 2011 C'SPACE campaign in order to demonstrate a modulated hybrid motor, a two stages first full flight, a new recovery system with two successive parachutes and a first step of roll control system.

Future objectives of launch are still established as supersonic single and two-stage rockets, and airborne launches from the dedicated unmanned carrier EOLE, which is under construction.

6.1. Previous experimental launches

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 in La Courtine. It was based on a medium weight composite structure with Ø120mm of external diameter and aluminum fins. It was propelled by N₂O and Polyethylene and was the first hybrid rocket ever developed in France.

Rockets FH-02 to FH-05 was based on existent but heavier weight composites tubes with external diameter of Ø159mm and aluminum 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 Biscarrosse. 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).

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

- Ares- α , ARES rocket prototype
- FSP-05, a reconditioned version of FH-05 rocket with a Cesaroni Pro54-5G solid motor
- EVE2, a Fusex (experimental rocket) demonstrator of OCTAVE, the space club of Evry's University based on a medium weight composite structure, aluminum fins and Ø140mm of external diameter

These three rockets have two embedded common IMUs. They gave the opportunity to compare the results, coming out from the different rockets and 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.

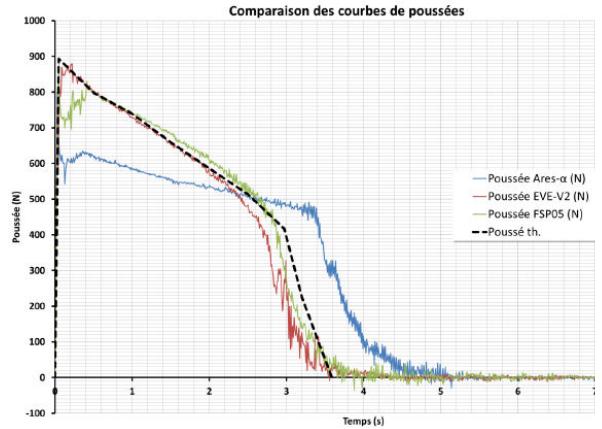


Figure 6. Thrust curves comparison of 2010 demonstrators' engines

6.2. Ares- α prototype in 2010

Ares- α (alpha) is the first ARES family rocket in PERSEUS launched at the French National Campaign (C'SPACE 2010) in Biscarrosse. It has been built by AeroIpsa students and Mechatronics Research Laboratory of IPSA.

The main objective was to demonstrate new structure conception and technologies in order to establish a first ARES reference. The work has been focused on:

- a new modular architecture 40% lighter than previous FH rocket demonstrators,
- composites fins 50% lighter than previous aluminum equivalent
- a new recovery system with axial separation.



Figure 7. Ares- α at C'SPACE 2010 in Biscarrosse

Powered by a Cesaroni Pro54-5G solid motor, Ares- α has reached an altitude of 1250m and a maximum speed

of 180m.s^{-1} . Without the propellant system, the mass of this demonstrator reached less than 7kg and consisted of 1kg of electronics for a 2,35m length and a 160mm body diameter.

Two IMU were embedded as passengers and gave the opportunity to determinate the flight performances with good precision. The use of data from the Pitot tube also gave the opportunity to restore the longitudinal velocity and to compare it with inertial data. Besides, it was a good way to compare altitude measurement between absolute and differential pressure sensors. Finally, we got to define GPS performances, with helical antenna.

The recovery system tested on ground has been successfully tested in flight.

A secondary objective of Ares- α was to anticipate the future first ARES two-stage rocket, since its second stage will be closely similar.

6.3. C'Space 2011 launches

Four ARES rocket demonstrators are prepared to be launched this summer at the French National Campaign (C'SPACE 2011).

Students of Supaero Space Section (S3), ISAE space club, are working on Ares01H3-1 as a modulated hybrid engine flying test-bed.

Students of AeroIpsa, IPSA space club, are working on Ares02Bi-P1P1, a two-stage active rocket.



Figure 8. Ares02Bi-P1P1-AéroIpsa

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 flight in cooperation with Delft University in May 2011.

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.

6.4. Future launches

All future launches of ARES demonstrators are not yet scheduled, but we already have defined some of the next short term demonstrators.

6.4.1. Ares05Eole-static

First of airborne launched ARES rocket demonstrators, Ares05Eole will be used to test and qualify the EOLE unmanned demonstrator until active launch.

Ground tests will estimate vibrations interferences with the release system and then will validate all EOLE flight characteristics in complete configuration.

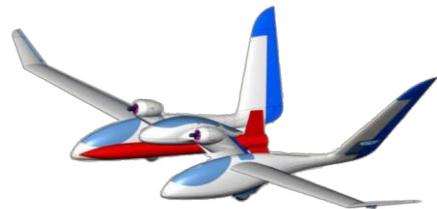


Figure 9. Ares05Eole rocket under EOLE demonstrator

Ares05Eole is a non-propelled rocket, but it will take on board the full motor ignition automatic system (derived from Ares two-stage rocket) in order to simulate every release sequences.

An IMU and a telemetry system will also be embedded to return every rocket's attitudes during the flight.

The rocket has 3 trapezoidal fins in order to avoid ground contact during the take-off rotation. The rocket's gravity centre has to be positioned at the same horizontal location than EOLE's.

After all non-propelled tests, Ares05Eole will be upgraded with a Pro54-5G Cesaroni motor for a first active airborne launch with no slope.

At midterm, the objective of Airborne launched ARES rockets is a 45° angle airborne launch at an altitude of 4km with roll control and propelled by a Pro98-3G "Moon Burner" motor (12s burn time, $\sim 6000\text{N.s}$ of total impulse). The rocket would reach an altitude of 8km, with a non-supersonic maximum speed (around Mach 0.8).

6.4.2. Ares06S-P9

Ares06S will be the first supersonic ARES demonstrator. This will allow us to test our supersonic designed carbon composites technologies for fins, nose and structures in flight.

The performance should be the followings: reaching an altitude of 5km with a maximum speed of Mach \sim 1.4. The rocket will be propelled by a Pro98-6G “Green3” Cesaroni motor (\sim 14200N.s total impulse, 7.2s of burning time).

This engine has a progressive thrust during major part of the burn time. The rocket will progressively accelerate between the lift-off (\sim 60m/s 2) and 2/3 of the motor burn time (max \sim 100m/s 2). Maximum acceleration of an experimental rocket with a solid propellant is usually at lift-off and decreases after.

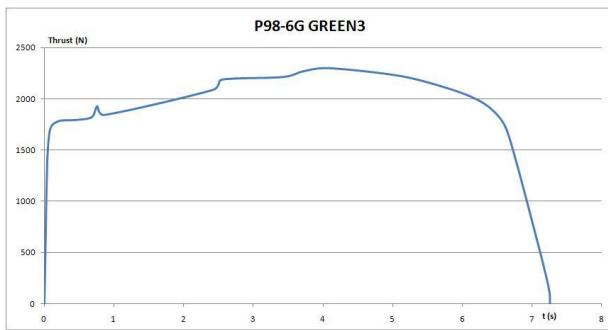


Figure 10. Thrust curve of a Pro98-6G “Green3”

The particular thrust curve of Ares06S-P9 allows us to make a parallel with full size launcher.

6.4.3. AresxxBi-P9P7MB

This rocket is the next two-stage ARES demonstrator. The objective is to reach an altitude superior to 10km with two Pro98-6G Cesaroni motors:

- Pro98-6G “White” for the first stage (\sim 6s burn time)
- Pro98-6G “Moon Burner” special high altitude long burn version for the second stage (\sim 11s burn time)

Launch weight should get around 40kg with \sim 25kg of motor weight, 3kg of electronics, and a capacity of embedded passenger up to 1kg.

The rocket would reach an altitude of 10 to 12 km and a maximum speed of Mach 1.5.

Inter-stage separation sequence will be subsonic and the maximum acceleration would not exceed 10g during the entire flight.

The second stage structure and fins will be directly derived from Ares06S rocket.

7. CONCLUSION

During these five years, a real progress in the PERSEUS project has been observed. Thanks to management specifications and to the involvement of numerous volunteers, teachers-researchers and partners, results are to match our ambitions.

Much progress is highlighted by the exploitation of demonstrators data, the precision of the documentation provided by students, the deepening of technical subjects and 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 organization and research resources, especially in propulsion, since safety requirements in respect with students work are more complex. Nevertheless, the organization of our different projects gives solid basis for the development of our two future demonstrators, ARES and EOLE.

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