Successful collaboration & knowledge transfer amongst student space clubs – the SERA rockets

Robin Lenormand, Adrien Baras**, Timothée Aujames***, Arthur Lacombe**** and Julien Delpeyrat******
**Centrale Lyon Cosmos – rl576@alumni.cam.ac.uk*
*** Ipsa Space Systems - adrienbaras@hotmail.fr*
**** Centrale Lyon Cosmos – timothee.aujames@ecl14.ec-lyon.fr*
*****Supaero Space Section – arthur.lacombe@student.isae-supaero.fr*
******Supaero Space Section – julien.delpeyrat@student.isae-supaero.fr*

Abstract
The paper takes interest in how four French engineering student associations, along with industrial and research partners, achieved to design and launch supersonic rockets SERA-2&-3 in 2016 and 2017. In particular, it reviews how governance and management was carried, as well as knowledge transfer amongst the teams and throughout the years. Indeed, most students (~80 for each rocket) could only take part in one rocket during the course of their studies, helping them to develop skills and providing them a best-in-class aerospace experience.

1. Introduction

The SERA project is part of the PERSEUS program, an initiative from CNES, the French Space Agency. This program coordinates various innovative projects conducted by students from different universities. Since 2005, as part of the forward planning efforts of the Launch Vehicles Directorate, Perseus aims at stimulating innovative technical solutions. The four experimental supersonic rockets which constitute the SERA project (SERA-1 to SERA-4) were launched in 2015, 2016, 2017, and SERA-4 forecasted for April 2019; each of them building on theoretical, operational, and managerial experience gathered from previous rockets and models.
The current paper takes a particular interest in the SERA-2 and SERA-3 rockets in order to compare and explain how the knowledge gained from the former could be transmitted and reapplied to SERA-4, despite most of the teams composing of different people.
The successful launches of the SERA-2&-3 supersonic rockets in April 2016 & 2017 at the Esrange Space Center (Kiruna, Sweden) were the result of the collaboration of four French engineering student associations, namely, Supaero Space Section, Centrale Lyon Cosmos, IPSA Space Systems and OCTAVE, along with the Rymdgymnasiet High School in Kiruna, the Luleå University of Technology, and industrial and research partners. Those different teams representing various skills of the aerospace field worked jointly within the SERA project. Applying an industrial approach, the projects were structured by weekly videoconferences and several critical meetings supervised by CNES.
The SERA-2 launcher was composed of three composite cylinders adding up to a weight of 27 kg and a length of 2 m. Propelled with a Cesaroni Pro98 combined with a Pro38 starter kit, the experimental rocket reached an altitude of 5000 m and a maximum Mach number of 1.1. This nominal flight made it possible to obtain and analyze data from various inertial, vibration, and pressure sensors. In addition, the rocket was equipped with different cameras which allowed real-time broadcast footage, transmitted to the ground via a telemetric device.
SERA-3 was launched in April 2017, propelled with three Cesaroni Pro98 in a cluster configuration, largely benefiting from the knowledge gained from SERA-1&-2. It is the longest and heaviest rocket within the PERSEUS project as of today, with its 5-meter-length and 78.2 kg weight. It reached a top altitude of more than five thousand meters and a top speed of Mach 1.2. The SERA-3 rocket embedded twice as much of sensors than the previous SERA rockets and allowed to step up and develop skills in designing and operating more complex rockets.

For both rockets, all degraded flight cases were studied (non-nominal trajectories, critical wind effects, descent under parachutes) to ensure the Swedish Space Corporation that risks were mitigated and the rockets compliant for launch. The post-flight analysis brought new light on trajectory forecast, and led to reconsider or validate hypotheses and models, such as drag effects or yaw during transonic phase.

The insights gained from these projects served as a baseline for SERA-4. Moreover, the program has helped to develop skills and gave a best-in-class aerospace experience for all the students who were involved.

2. Organization & management

The SERA (Supersonic Experimental Rocket Ares) project is part of the PERSEUS program (Projet Etudiant de Recherche Spatiale Européen Universitaire et Scientifique), an initiative from CNES. Under the lead of recognized space professionals, the students involved conceive, develop, build and launch supersonic sounding rockets to test new technologies and gather scientific data during the flight. In addition, each rocket embeds one payload designed by a Swedish students team participating to the programme as a customer of the launch.
The programme is professionally oriented to provide the hundreds of students a deep insight of real-world space projects. Three SERA rockets have been successfully launched up to date (the fourth one is waiting for launch) with an average rocket development duration of one-to-two years.
By the number of students involved in different places all over Europe, each rocket project raised several issues be it on management aspects as well as technical ones. Processes have been put in place along the whole life of the project to ensure a good conduct and materialize enough knowledge transfer from one team to another but also between team projects all over the years.
Work packages were thus shared between student associations as followed:

Table 1: Work distribution amongst groups

Entity	Subject of studies
Centrale Lyon Cosmos (from Centrale Lyon Engineering School based in Lyon, France)	Development of acoustic experiments under the nose cone Trajectory forecast computing Postflight analysis
IPSA Space System (from IPSA based in Paris, France)	3D CAD modelling of rocket elements and fabrication (tubes, fins, nose cone, ...) Development of electronic cards
GAREF Aerospatial (based in Paris, France)	Development of main electronic systems (Onboard computers, cameras, radio transmission, ...), assembly and testing Point of convergence of all students during rocket assembly and flight mock-up test before sending the rocket to Sweden
OCTAVE (from Evry University based in Evry, France)	Testing of elements, development of the recovery system.
SUPAERO Space Section (from ISAE-SUPAERO Engineering School based in Toulouse, France)	3D CAD modelling of rocket elements, cabling, development of aerodynamic measurements Trajectory analysis Preliminary post flight analysis

Students teams in charge of developing payloads experiments involved:

- TechForSpace
- Lulea University
- KTH University
- Rymdgymnasiet High School in Kiruna

2.1 Conception and development phases

During the conception and development phases, work is divided between the student associations as mentioned above and regularly followed by the PERSEUS/CNES management team. Weekly meetings (videoconference, phone calls, …) were put in place between the different team leaders to encourage a continuous work all along the project. Frequently (up to 1-2 times per month), students gathered at GAREF Aerospatial headquarters in Paris to integrate, test and assemble rocket elements.

The projects' lives were punctuated by reviews, similarly to the space industry standards: PDR (preliminary definition review), CDR (critical definition review), QR (Qualification Review), BFR (Before flight review) before sending the rocket to the launch base (Kiruna, Sweden). Most of the reviews took place at CNES/Launch Directorate location in Paris. Reviews welcomed the students, the PERSEUS/CNES management teams and experts from CNES, ONERA and other space professionals.

2.2 Launch campaigns

All SERA rockets were launched from Esrange Space Center, managed by SSC in Sweden; their apogee altitude of more than 5000 m made it impossible to launch them in France.

The launch campaigns took place at Esrange (Sweden) in April 2016 and 2017, with more than 40 people involved, including nearly 30 students. Only a part of involved students on the design of the rockets had the opportunity to participate to this launch campaign, mostly for logistics and budget reasons. It would then be a reward for their work on the rocket and a chance to be an actor of the flight. Each of the students integrated a team among the following: launch infrastructures, quality, telemetry, assembly, payload, chronology, recovery and communication. The campaigns were decomposed in two parts:

A first week of "Pre-campaign", with a reduced team of four people, in order to prepare the logistics, safety issues and to finalize organization of the launch campaign

A second week of "Launch campaign" with the rest of the operational team during which the rocket needed to be assembled, tested for flight acceptance, launch, recovery and preliminary post flight analysis. Due to the short time frame and dependency upon weather conditions, the week is intensive but provided a good overview of what a launch campaign consists of. Daily morning meetings prepared the work to be done on the day and created a coherent timeframe for activities. Late afternoon meetings were used to discuss difficult points. ONERA was a key partner during both the development of powered stages and launch campaign by providing its key skills in pyrotechnic manipulations.

Both launches happened to be successful with nominal trajectory. SERA-2 took off at second attempt as the ignition system had slightly moved while raising the launch pad vertically.

The teams were congratulated by the launch base for the degree of professionalism, as well as their reactivity to provide suitable and complex answers in a timely manner to SSC.

2.3 Quality follow-up

Thanks to the experience gained with the first SERA rocket launched on May 7th, 2015, quality management methods and assurance were put in place for SERA-2 and SERA-3. Main activities consist in tracking changes, issues (mechanical, electrical, …) and establishing procedures for fabrication, assembly, and operations. The implementation of the measures has helped to enhance rocket quality, repair, maintenance and ensure the successful flights of both SERA-2 and SERA-3 in spite of the critical new design and parts of the sounding rockets.

The quality methodology consisted in creating quality files and anomaly reports by identifying the issue, the people responsible of the part, the solution adopted and recommendations for preventing the event.

The definition file is the main document which gathers all the information needed for conception, fabrication and performance. Each test and assembly procedure has been added as appendices to this document.

During the launch campaign, dedicated students were assigned to the role of quality managers and followed the assembly and launch operations to mitigate risks associated to non-predicted stress or manipulation.

2.4 Knowledge management

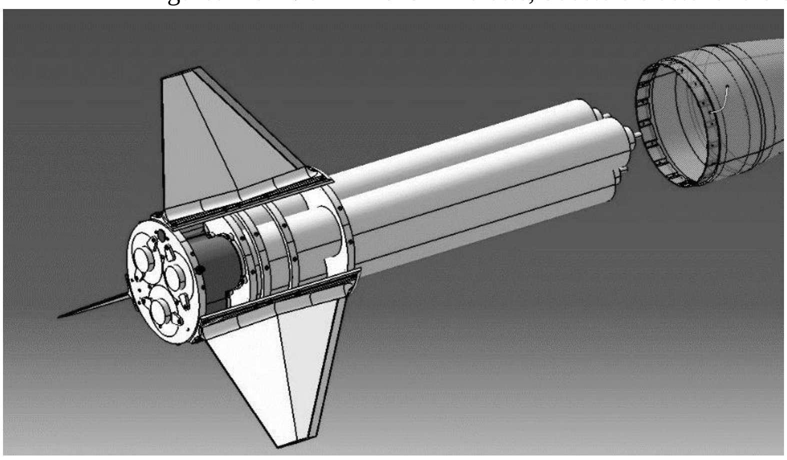
To enhance communication and successful key document transmission, a dedicated online platform was created. It allowed students to look for technical documents from current and past projects.
Ensuring continuity between students' generation is challenging due to huge turnover each year. That is why student association gathering younger and more experienced students are essential to the project. By organizing different activities outside the PERSEUS project, they transmit valuable knowledge to the newest ones. More experienced students that have yet conceived and launched rockets help, encourage, and advise the newest one in their projects. The implication of this experienced members is key for the success of future projects since it can prevent future project to fall short in the same issues and can bring additional value in problem solving.
Addionally, the PERSEUS project organizes workshop to accelerate the knowledge transmission and create team spirits among the diversity of students.
Another key aspect of knowledge management is the PERSEUS seminary taking place once a year which gather all the students working within the whole PERSEUS project. Such an initiative can create synergy to finally converge to more innovative and performing systems.

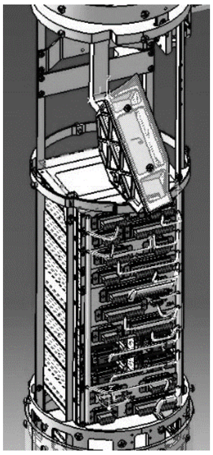
3. From SERA-1 to SERA-3

The SERA (Supersonic Experimental Rocket Ares) rockets are the result of years of ARES rockets (Advanced Rocket European Students) designed and launched by students under the supervision of Perseus, a CNES entity. During more than twenty years and step by step, global architecture and exhaustive avionics was developed, improved and operated by students. The GAREF partner is among else in charge for the ground installation and telemetry. The structural consistency of these rockets was verified by using a mechanical test bench which can generate loads on the structure which intensity is a direct result of global loads analysis. These demonstrators would reach an altitude of 2 km and a subsonic Mach number of 0.6. These regular launches enabled to test a lot of technologies such as: sandwich composite structure for the structure and fins (a patent was filed); aluminum 3D additive process with laser fusion for fins, or rocket top head including pressure canals; thin circular antenna for full 3D clear emission of telemetry; roll control was tested with canard fins.
Hence, SERA were derived from ARES subsonic experimental in order to achieve in the long term a 100km suborbital flight goal. The development of SERA-1 was the opportunity to: validate technologies that allow flights at supersonic speed, reach altitudes greater than 5 km, and prepare the development of more powerful rockets. SERA-2, in this respect, had the same design than SERA-1 but was more complex on a system level, due to new sensors and live HD camera broadcasting. It aimed to secure and validate the capability of PERSEUS to management with high consistency the design, manufacturing and launch of supersonic rockets. SERA-3's aim, which was launched one year later than SERA-2 and two after SERA-1, was to demonstrate similar flight performance with a new rocket design, three times heavier, equipped with three times more thrust. It would use SERA-2 body as a first stage, and a propelling stage made of a cluster of 3 Cesaroni Pro-98 engines (which were the same than used on SERA-1&-2). On top of drastic shape adjustments, the developed measurement plan included, in addition to the SERA-2 measurements:

- Pressure measurements integrated in two fins: incidence restitution
- A common motherboard for pressure and vibration board data
- Acoustic ambient measurement under cover
- Inter-stage deformation modulus
- A payload ambient recording module

Figures 1 & 2: SERA-3 CAD views, boosters cluster and electrical motherboard





Key elements compared to SERA-1 and SERA-2 count:
- Ensure the simultaneous ignition of the three engines in a cluster configuration
- Check the structural strength of the skirt from a diameter of 250 mm to 160 mm.
- Manage the interfaces of this new configuration with respect to the ramp, the umbilical tearing system
- Adjust the parachute descent

Table 2: Final mass budget (kg)

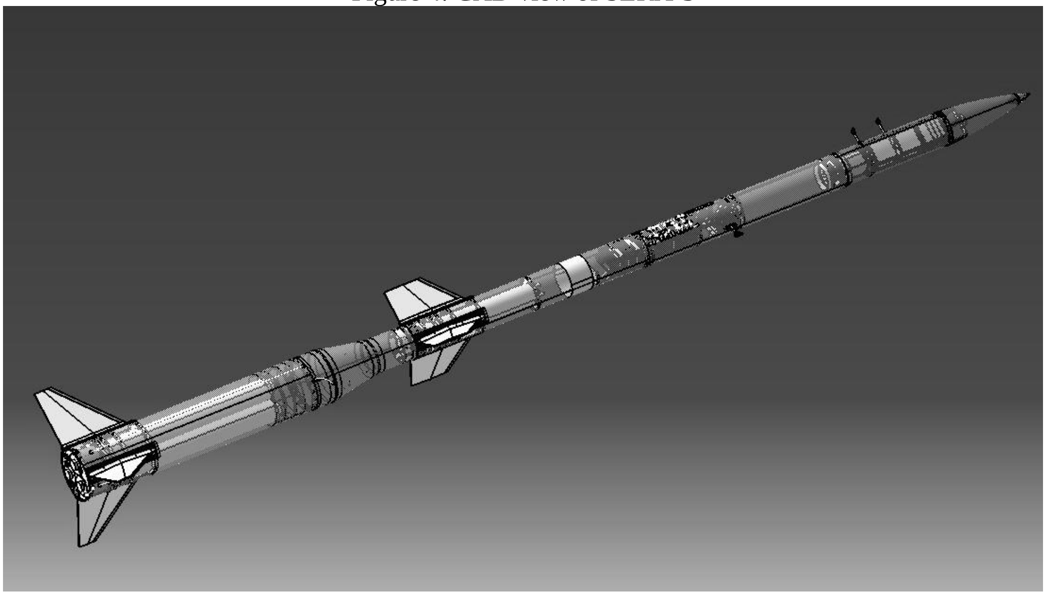
Rocket	**SERA-1**	**SERA-2**	**SERA-3**
Payload	0.25	0.5	1 + 12.6 (upper mock-up engine)
Upper part (inc. Fairing & P/L support)	0.75	0.75	3.6
Carbon fibre tubes	2.9	2.95	7.8 (including the skirt)
Composites Fins	1.9	1.87	4.8
Separation system	0.7	0.8	0.9
Recovery system	1.7	1.7	2.6
Electrical systems	2.8	2.8	4
Pressure & Vibrations deported sensors	0.5	0.6	0.8
Cameras	0.3	0.3	0.3
Telemetry	0.25	0.24	0.24
Engine (loaded)	13.2	13.2	39.6
TOTAL	25.3	25.7	78.2
Mass w/o engine	12.1	12.5	38.6

Figure 3: SERA-2&-3 badges and CAD models

4. Design, manufacturing and trajectory forecast

As already introduced, SERA rockets are the result of more than twenty years and rockets overseen by PERSEUS. Though each rocket would have a particular improvement developed by students, the core structure would be passed so that each team could start on a proper and reliable basis.
SERA rockets were only one project out of the dozen PERSEUS carried. Hence, the SERA body structure was not developed by its team but designed and formalized by another project which had a much tighter focus on strength of materials (in this particular case, a master's study project at ISAE-Supaero). SERA manufacturing team at IPSA used their work to build the structure for the rockets
Hereafter are detailed some works the co-authors have realized in their team, namely on trajectory forecast, parachute studies, loads simulations and post-flight analysis.

Figure 4: CAD view of SERA-3



4.1 Trajectory forecast

During the preliminary phase of the project, two simple Excel based tools developed by Planètes Science, Stabilito and Trajecto, were used to respectively evaluate roughly the stability of the rocket in the lift gradient coefficient vs. static margin diagram and compute an estimate of the ballistic trajectory in order to assess the performance (apogee and ground range). Though weak, that information is crucial to evaluate the acceptable weights of the different systems that would be integrated in the rocket. Moreover, it gave to the students nice figures (Mach, altitude, size, flight duration) which helped to grasp the reality of the rocket and keep them motivated throughout the project. Indeed, most students had a restricted field of study (telemetry, sensors, systems integration, etc.), hence such numbers reminded them of the overall shared goal of the project.

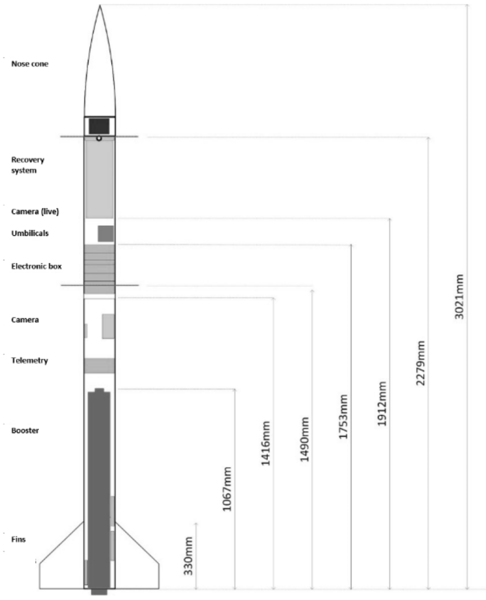
After those first calculations, the Andromede software was extensively used. Created by PERSEUS in 2006 for PERSEUS, its objective was to meet two essential needs: the study of launcher performance - which requires the study of flight path - and the study of rocket stability - which is necessary to obtain authorization to launch the rocket.
Andromede is therefore a configurable software, so that it can be easily adjusted to each PERSEUS project. This software allows to determine very reliable approximations of the trajectory and general forces from the following data:

- Flight sequencing
- Rocket geometry and inertia
- Propeller and atmosphere characteristics
- Ramp configuration and launch site

Concretely, the trajectory analysis establishes the curves (and value tables) of data such as altitude, inclination, dynamic pressure, speed, acceleration and Mach number (...) as a function of time.

For general forces, the software determines the normal, sharp forces, bending moments and force flows at different points on the rocket, depending on their position relative to the bottom of the rocket.
The study of general forces therefore requires a preliminary study of the dimensioning cases to carry out calculations at relevant times.

Figure 5: SERA-2 Lay-out (Dimensions in mm)



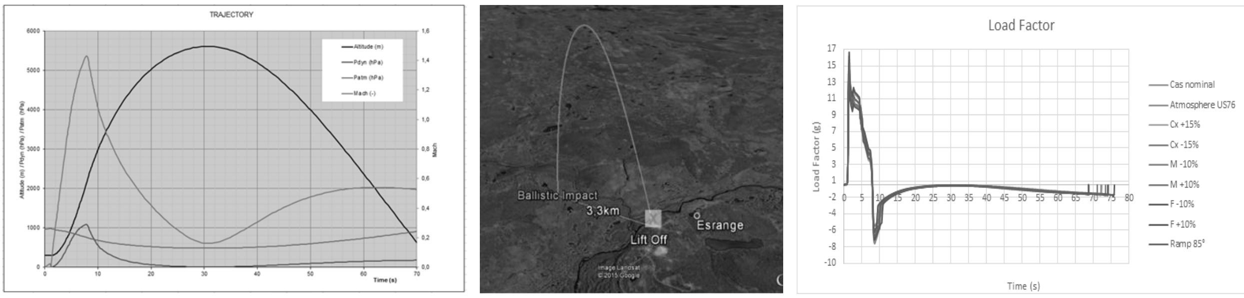
On a daily basis, Andromede is quite a heavy software to use, as it requires more than a hundred manual and variable inputs in both type and source:

- « AeroPerseus », an impressive spreadsheet requiring 38 rocket geometry input data allowing to calibrate 15 abacus tabs (Cx, Cn, Xcp depending on the machine) from off the shelf functions.
- Propulsion data file with time, thrust (kN), and remaining weight
- Atmosphere data file with at least altitude (m), pressure (bar) and dew temperature (K).

Andromede produces different outputs, namely:

- Andromede_Resultats : A spreadsheet with numerous charts to qualify the trajectory vs time (altitude, longitude, azimut, speed, latitude, acceleration, incidence, mass, local attitude, dynamic pressure, heat flow, ground distance, drag, lift, …)
- Andromede_EffortsGénéraux : A spreadsheet detailing normal force, shear force, bending moment observable (nominal, with constant wind, with wind gusts) during the flight, to meet specifications as well as results on the rocket stability.
- A Google Earth .kmz file, representing the trajectory as a 3D line from launch site.

Figures 6, 7 & 8: Andromede's outputs / Trajectory and performances



NB: Andromede would not calculate trajectories for the parachute descent in our study. For this part, a second study was to be carried out.

4.2 **Parachutes study on SERA-2: building on SERA-1 post-flight analysis**

An add-on was designed on MATLAB by a team member to forecast trajectory under parachutes.
This simulation was used before the launch in order to estimate more precisely the landing area, depending on the latest weather forecast. Moreover, if the landing site was identified as hazardous for the launch site ground installation or the rocket recovery, the trajectory could be modified by slightly changing the elevation (75-85°) and/or the azimuth of the launch pad. It was finally used as a basis for the helicopter when recovering the rocket after landing.

The main aim of the software was to determine at what time shall the second parachute be deployed (at 500 m above ground level). First simulations drew a lot of suspicion as descent rate was too low. Deploying at such a timing on SERA-1 would have crashed the rocket at 30 m/s. Hence a reverse study was done on SERA-1 post-flight trajectory results and showed that the actual drag coefficient of the first parachute mounted on SERA-1 was well below its theoretical value provided by manufacturer's booklet. Thanks to the similarities in shape and weight of SERA-1 and SERA-2, it was decided to pick the experimental value seen during SERA-1 flight, which resulted in an earlier opening of the second parachute, a safer option anyway.

Along with the following parameters were the final inputs for simulation.

Table 3: Parachute simulation inputs

Culmination time (1st parachute opening)	30 s after lift off
Culmination	5470 m above sea level
Dry mass of the rocket	17.15 s
Ground level	303 m above sea level
1st parachute surface	0.159 m²
1st parachute drag coefficient	Between 1.5 and 1.6
2nd parachute surface	1.815 m²
2nd parachute drag coefficient	2.2

4.3 **Astos simulations**

Motivations for a new software

The main simulation tool has changed to Astos with the SERA-3 project. Although the Andromede software used on the two previous rockets was satisfactory in terms of results and predictions, changes were mandatory for several reasons.

The major one is the new architecture of SERA-3 with the three engines in a cluster configuration. The PERSEUS team wanted to reinforce the simulation part of the project with a first step towards a proper safety analysis. In case of failure of one of the engines, the outcome and trajectory would be much more uncertain compared to the previous rockets. Indeed, for SERA-1&2, if the engine had failed, it would have resulted in less or no thrust and overall degraded performances. On the contrary, for SERA-3 further investigation was needed to guarantee the safety of the launch and ensure the rocket would not be dangerous. A difference between the thrust of the engines would effectively create a torque, deviate the rocket with the risk of coming back towards the launch pad and Esrange facilities. It was therefore necessary to forecast trajectory deviations for degraded cases with only one or two active engines and make sure that the rocket would still head towards the allowed fallout zone. A simulation tool able to perform six degrees of freedom simulations, both position and attitude, was therefore required.

Another notable advantage of this new simulation tool is the possibility to simulate the descent under parachutes. All of the different scenarios, i.e. nominal case, with or without parachutes, and the different degraded cases can now be studied with only one software. Astos is not simpler in its utilization than Andromede but its ability to easily handle multiple scenarios resulted in a simplification of the operations during the launch campaign with a reduction of data transfer between softwares (previously between Andromede and MATLAB).

The change also aims at being durable as Astos is and will be used for future rocket, especially SERA-4 which is based on the same architecture than SERA-3. One can add that from SERA-4 on, the version of the software would be upgraded from the Astos Amateur Rocket edition to the professional Astos software.

Simulations before and after the flight

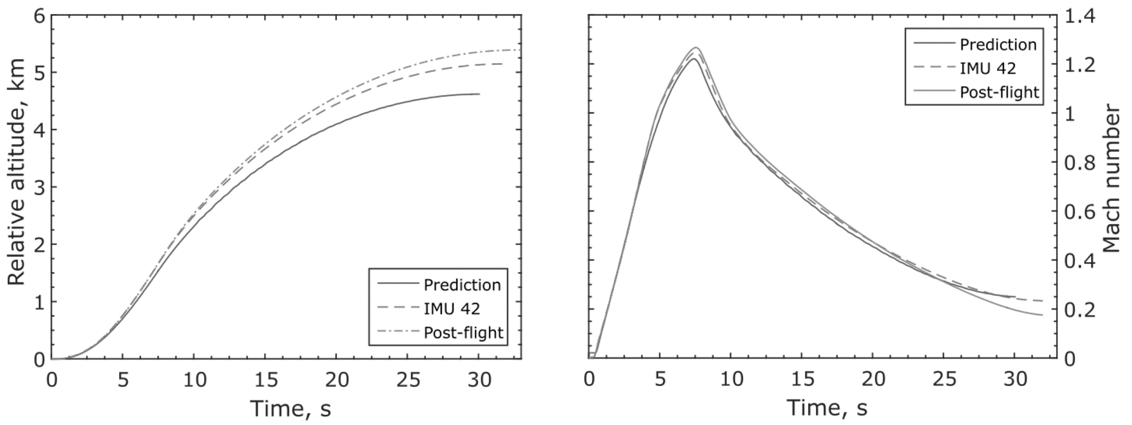
Andromede was still in use at the beginning of SERA-3 study, thus Andromede simulations for nominal ballistic trajectory were used as a reference for comparison with Astos. It enabled the team to validate the simulation scenario in Astos: once the transition to Astos effective, it could tackle simulations of descent under parachutes and most importantly, degraded cases.

Stronger safety studies were the opportunity for students to be in closer interaction with SSC safety team at Esrange. Besides the nominal and degraded cases, SSC was also closely interested in specific parametric studies regarding the

ballistic flight. More precisely, it consisted in evaluating the ballistic impact point, i.e. without the deployment of any parachutes, according to the influence of : (i) the presence of wind up to a given altitude, (ii) its direction, and (iii) the inclination of the launching rail.
These studies helped SSC assess the acceptable and most favorable conditions for the launch.

The last simulation before the flight is pictured in the Figures 9 and 10, with flight data processing, and a post-flight simulation for comparison.
After flight data analysis, new simulations were carried out considering new input data resulting from this analysis, such as the drag coefficient of the rocket as well as those of the parachutes, the time delay between the programmed and the effective opening times of the parachutes, an estimation of the thrust, etc. The main idea was to compare it with the prediction and the actual and see what could be said of the initial input data used for the prediction, their influence on the simulation, and also the scenario of simulation used in Astos. A detailed flight data analysis for SERA-3 only and the comparison with simulations has been presented at the 2018 SpaceOps Conference [1]. A more comprehensive data analysis is presented is the next section for the three SERA rockets; the authors want to inform that the results for SERA-3 are slightly different, because of the two studies being independent and the working hypothesis too (Mach number computation, noise reduction with moving average, etc.).
As it happens, the improvement is clear on the altitude, in the meaning of being closer to the actual flight, with the error on the altitude at apogee reduced to around 5%. The apogee epoch is also closer to the actual one. The difference is not so clear with the Mach number, even if the propelled phase, corresponding to roughly the first eight seconds of the flight, is slightly better reproduced. Note that the post-flight results tend to overestimate the performances and even though they are closer, they should be considered with caution. Finally, this loop between simulations and data analysis can only be fruitful and enriching for the project. The team took a critical eye at the developed model and simulations so that the resulting feedback could be meaningful for future rockets.

Figures 9 & 10: Altitude and Mach number of the SERA-3 rocket with respect to the launch pad as a function of time, according to (i) the last simulation made before the launch, (ii) the data processing of one of the Inertial Measurement Unit (IMU), and (iii) the post-flight simulation. Data from [1].



4.4 Parachutes sizing on SERA-3

Because SERA-3 has a drastically different geometrical configuration from the previous SERA-1&2 (which mimics future two-stage experimental rockets), a comprehensive rework of the parachute dimensioning was needed. Thanks to the experience acquired then, it was not a complete restart from scratch. The key parameters driving the study and the objectives were already clearly established. Because the descent under parachutes has proven satisfactory from a safety point of view, we aim at reproducing it and therefore adapting the parachutes accordingly.
The parachute system is still composed of a small parachute deploying at apogee and a much larger one opening 500 m above the ground. The vertical speed at the second parachute opening and at ground impact shall not exceed respectively 50 m s^{-1} and 10 m s^{-1}. We also consider their deployment times as part of the dimensioning work because they are scheduled in the rocket onboard electronics during the launch campaign and must therefore be determined as precisely as possible before the launch.
The first dimensioning occurred during the preliminary draft of the project with a simplified MATLAB tool compared to the add-on used previously. This would indeed not be used anymore for the final dimensioning due to the upcoming change to Astos as trajectory simulation tool. It mainly aims at determining the required surface of the parachutes to

meet the velocity requirements. Considering the doubts raised by the previous team on the effective drag coefficient of 2.2 announced by the manufacturer and also because of the new shape of the rocket that might disturb differently the parachutes aerodynamics, the Perseus team decided to consider the smaller one around 1.6 for safety purpose: this is the worst-case scenario. The choice of the new parachutes is also constrained by the available sizes in the manufacturer catalog. The first dimensioning was completely reassuring in regard to the feasibility.
The final dimensioning process with Astos is used with the chosen parachutes surfaces and is used to check that the vertical speed constraints are respected as well as to identify the opening times: the opening is automatically performed in the simulation and taken into account when the apogee is reached and at 500 m above the ground.
All of this finally conclude to the parachute characteristics shown in Table 4.

Table 4: Parachute characteristics on SERA-3

	Surface (m^2)	**Opening time (s)**
First parachute	0.46	31
Second parachute	4.67	144

4.5 Sensors & Post flight analysis

The rockets were equipped with various sensors. They allowed to gather huge amounts of information. The instrumentation plan had two main objectives:
Determine the performances of the launcher such as elevation, Mach number and drag coefficient.
Improve the understanding of the rocket behavior especially in transonic phase.
These sensors were pressure probes, accelerometers and gyrometers and vibration sensors.

Methodology

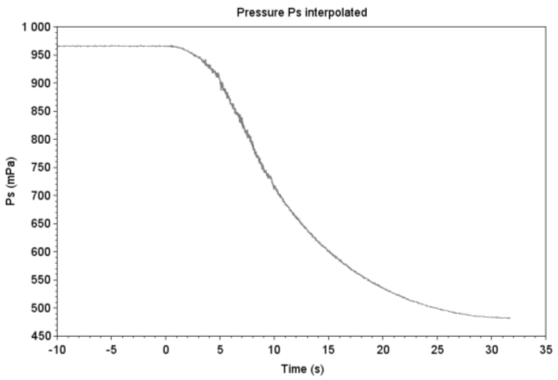
This part focuses on the process to determine the performance of the rockets. The estimation of the elevation, Mach number and drag coefficient are based on the data collected from accelerometers, gyrometers, and pressure sensors.

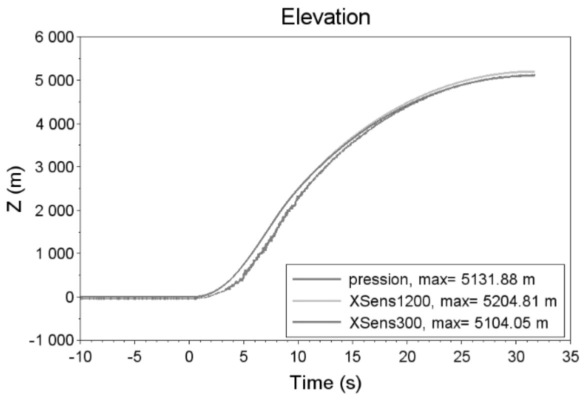
Estimation of the elevation

The elevation is defined as the altitude of the rocket from the launch pad. The instrumentation allows three estimations of this rate.

Firstly, two inertial measurement units are set up in the rocket. A double integration of these data leads to estimate the trajectory of the rocket. The altitude is one of the results.
Secondly, two pressure sensors were set on the side of the rocket. The average of these measures can be considered as static pressure. A sounding balloon was launched the same day of the flight. Thus, the relation between the altitude and the static pressure is well-known. The pressure sensors on the side of the rocket can be used as a barometer to determine the elevation.
Finally, three values of the elevation were estimated. The results are presented in the next figure. The curbs are regrouped and share a similar evolution. This fact assures a certain confidence in the result. For the SERA-3 flight; the rocket raised until almost 5150 m.

Figures 11 & 12: Estimation of static pressure & elevation from SERA-3 flight.





Estimation of the Mach number

As for the elevation, three estimations of the Mach number were available from the exploitation of the data of the flight. Two are determined by integration of data from the two inertial measurement units. The acoustic velocity is provided by the meteorological data from the sounding balloon.

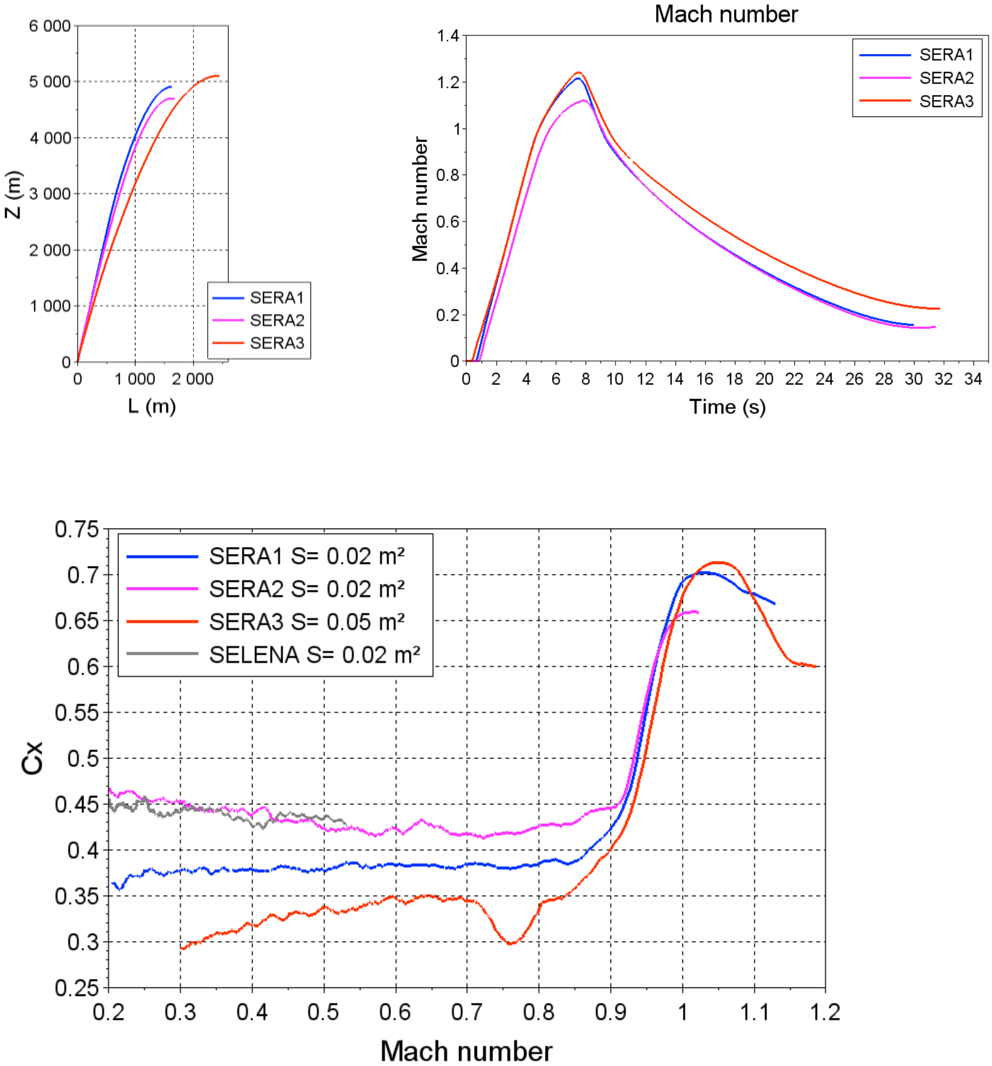
A third estimation used the pressure measurements. The static pressure is estimated from the pressure on the side of the rocket. A pressure is measured on the top of the nozzle. This measure is considered as the total pressure. However, this hypothesis may not be verified in the case of a detached shock wave. The calculation of the Mach number assumed an isentropic transformation between the total and static state :

$$\frac{P_0}{P} = \left(\frac{T_0}{T}\right)^{\frac{\gamma_{th}}{\gamma_{th}-1}} \quad , \quad M = \left[\frac{2}{\gamma-1}.\left(\left(\frac{P_0}{P}\right)^{\frac{\gamma-1}{\gamma}} - 1\right)\right]^{\frac{1}{2}} \quad and \quad \frac{T_0}{T} = 1 + \frac{\gamma_{th}-1}{2}.M^2 \quad with\ \gamma = \frac{C_p}{C_v} = \frac{c_p}{c_v}\ adiabatic\ index$$

Such a study allowed us to calculate that SERA-3 reached a Mach number of almost 1.24.

Compared performance of the SERA rockets

Figures 13, 14 & 15: Mach, Elevation and Drag coefficient for all SERA rockets and SELENA (subsonic rocket with SERA-1 design)



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