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# SMALL INNOVATIVE LAUNCHER FOR EUROPE: RESULTS OF THE H2020 PROJECT SMILE

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**Abstract**

Today's market for small satellites is expanding, but there is little capacity for affordable, dedicated launches. Launch costs of less than €50,000 per kg are required to compete with piggyback options and ride-shares; hence, cost reduction is essential. Fourteen European companies and institutes have joined forces in a Horizon2020 project called "SMall Innovative Launcher for Europe" (SMILE). The project aims at designing a launcher for satellites up to 70 kg and a European launch facility in northern Norway. Furthermore, the readiness level of critical technologies on propulsion, avionics, and cost-effective manufacturing is increased.

As the development time of small satellites can be quite short, the launch rate (time-to-launch) is considered a key requirement. An effective and efficient organisation, including supply chain, is needed to maintain the launch cadence and to reduce operational cost, both of which are needed to deliver a commercially viable service.

Both liquid and hybrid rocket engines are considered for this small launcher. The reusable LOX/kerosene liquid engine, for which hot firing tests have been performed in September 2018, uses a ceramic-based, transpiration cooled combustion chamber and a 3D-printed injector. The H2O2/HTPB hybrid engine technology offers simplicity of the architecture and uses green, storable propellants, and was successfully tested in July 2018. Upgrades from the existing engines have been performed, increasing the performances and reducing the dry mass.

With a choice of two types of engines, different configurations have been analysed in a two- or three-stage set-up using a multidisciplinary design approach including steps from geometry set-up to trajectory optimisation. Preliminary cost estimations and readiness levels are used as complementary metrics. A trade-off was performed to select materials and structural elements to withstand the most demanding loading cases. To minimise the mass, composite sandwich structures have been selected. A suitable automated manufacturing process will increase cost-effectiveness. To accommodate both CubeSats and micro-satellites, a flexible payload adapter has been designed.

The use of COTS for the avionics will further reduce cost, with low-cost MEMS gyroscopes competing with high-performance fibre optic gyroscopes. High-performance multi-processor System-On-chips can combine processing power, real-time control, and high number of interfaces into a single board. Finally, a new launch site design, including preliminary ground and flight safety analysis, has been performed for the launch base in Northern Norway, currently already used for sounding rockets launches.

**Keywords:** launch vehicle, hybrid rocket, liquid engine

## 1. Introduction

The space market faces an evolution towards nano- and micro-satellites, that are more and more performant for all kind of purposes. This trend has expanded into small satellites constellations, a market which many (former start-up) companies are already investing in, e.g. Skybox, BlackSky Global, Spire and Planet. They are claiming their spot on the podium next to the established large companies by responding to market needs much faster as well as by providing affordable satellites for high-definition imaging, climate data acquisition, maritime shipping assets tracking, and In Orbit Demonstration and Validation (IOD/IOV). Their business concept seems to completely out-compete the established players and they are attracting venture capital as well as the attention of big multinational enterprises not normally active in the space business.

All these new satellites need an affordable way to get into space, and since their key features are responsiveness, low-cost, and flexibility, the same has to be applied to their launch service. So far, most of the new satellite companies have to rely on the big players to get their access to space through hitchhiking as secondary payloads on large institutional launchers.

The need for a dedicated launch service for these ever more powerful microsats, is quite clear to everybody in the space community. The challenge lies in their limited launch mass, which represents the low-end of the satellite mass range for which no institutional launchers have been developed.

In response to this need, several commercial space companies are ready to offer to the market their own version of such a new launch service, i.e. China’s Kuaizhou-1A and Kaituozhe-2, Virgin Orbit's LauncherOne, Rocket Lab’s Electron, with others at various levels of development. Worldwide many companies are developing new small launch vehicles.

*1.1 Small Innovative Launcher for Europe (SMILE)*

Fourteen European companies and institutes have joined forces in 2015 for a Horizon2020 programme called “SMall Innovative Launcher for Europe” (SMILE). The project aims at designing a small launcher for satellites up to 70 kg, demonstrating critical technologies on propulsion, avionics, and production for cost-effective solutions, and designing a European-based launch facility in Andøya in northern Norway, where a launch base for sounding rockets already exists: Andøya Space Center (ASC). Part of the work is dedicated to business development and economic viability.

Fig. 1: SMILE consortium

The technology in the SMILE context involves:

- Reusable liquid rocket engines;
- Low cost hybrid rocket engines;
- Low cost automated manufacturing of composites and advanced materials;
- Low cost avionics equipment;
- Efficient, easy-to-use payload deployment system;
- Low cost ground segment.

The SMILE project has held the last design review in July 2018 and will have the Final Review on 10 & 11 December 2018 at NLR.

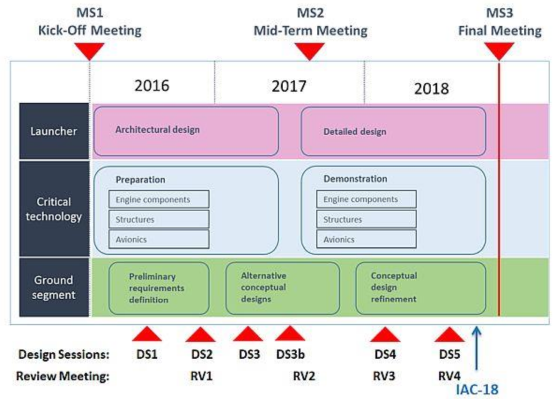

Fig. 2: SMILE planning and status

*1.2 Market Analysis*

To properly gauge the demand for small-lift launch vehicles, a detailed assessment of the launch demand components (by mass vs orbit altitude, by inclination, by country, by sector, etc.) was performed using a database from ASC with launched satellites. Current and future competitors were also identified to have an indication for how accessible the specific target market will be by the time SMILE project reaches fruition.

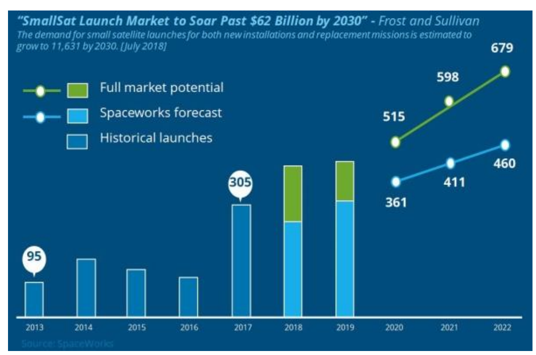

Fig. 3: Market forecast (source SpaceWorks)

According to various market studies, such as the one by SpaceWorks Enterprises, the number of small satellites under 50 kg being developed will continue to increase, such that over the next 5 years, over 2500 nano- and micro-satellites will require a launch.

Despite such impressive figures for the total available market for small sat launches, the demand specific to the accessible target market needed to be assessed.

A full assessment of the demand for launch broken down by mass vs orbit altitude and inclination was therefore performed using ASC's proprietary database of previously-launched satellites. The historical data were used to extrapolate trends and percentages that were then applied against forecasts for total launch demand for small satellites below 50 kg. It was clear that within the range of small satellites, there exists a much higher launch demand for nano- and micro-satellite mass classes to orbits achievable from ASC.

From this assessment, it can be reasonably concluded that there will be a real demand for small satellite launches under 50 kg into near polar or polar orbit in the near future. This is particularly true due to the significant launch capability gap for small satellites that strongly characterises the current launch services market. In fact, the launch demand for low orbits is expected to significantly increase in the near future due to the predicted availability of new small dedicated launchers, which are anticipated to stimulate further demand through the enabling of new missions to these orbits and lower launch costs.

Until now, most small satellites are launched as secondary payloads (either ridesharing or piggyback) and there often is a long waiting period before an appropriate launch opportunity can be found. The already limited supply of secondary payload launch opportunities is set to dramatically decrease after 2020, since some of today's launch vehicles used for small sat launches are converted military missiles (e.g. Rokot, Shtil, and Cosmos), whose availability is limited due to ageing (expiration of missile life service) and their rapid dwindling of stocks.

To take advantage of this timely business opportunity, new medium and heavy lift launchers are being developed that should eventually offer more secondary launch opportunities to small satellites. However, the additional rideshare or piggy-back opportunities are only substitutes for the actual need expressed by satellite companies: dedicated and frequent launches.

The desired service of satellite companies can only be met by dedicated small-lift class launchers. This brand new market segment is opening up, with i.e. China's Kuaizhou-1A, Virgin Orbit's LauncherOne, Rocket Lab's Electron. Worldwide over 30 organizations are developing new small launch vehicles, including several European companies as PLD Space, SpaceLS and Orbex [16]. This companies are at various levels of development, from concept design to operational. This high number of small-lift launch vehicles under development is unprecedented and demonstrates how much growth is anticipated in the small satellite market from one side and, from the other side, the extent of the current launch capabilities gap recognised by the launch services market.

It must be noted that despite the identified high number of small launchers under development, historically, the percentage of launchers successfully reaching the market is statistically very low. It is therefore important to distinguish between actual future competitors already on or about to enter the market and only future potential competitors, since the credibility of each member in the latter group will need to be individually evaluated.

For a European small-lift launcher, it is equally important to assess the availability of launch sites from which small lift launchers could launch small satellites into near polar orbit. A review of launch sites around the world yielded the following findings:

- Currently, besides ASC, there are no commercial launch sites existing in Europe that can already offer dedicated launch opportunities to near polar or polar orbit. There are currently 11 launch sites in the world with SSO and Polar Orbits injection capability for secondary payloads;
- The only European launch site with (near) Polar orbit capability offering launch opportunities for secondary payloads is Centre Spatial Guyanais, located in Kourou, South America, far from continental European;
- There are several other potential competing launch sites in Europe for vertically-launched vehicles that are currently being assessed or under development, including Esrange (Sweden) and the recently selected A 'Mhoine peninsula in Sutherland, right at the top of Scotland. Also, Spain and Portugal are looking into a setting up a launch base.

### *1.3 Launch Service*

The launch service needs to cope with different types of payloads, both standard CubeSats and non-standard microsats, as well as the different development times associated with them. This complexity makes it difficult to achieve a high throughput of launches, unless the complete organisation is designed for it.

Standardization can be the solution for many of the issues encountered, not only technical standards, but also on the level of the provided service and timelines. A standard schedule of operations is comparable to airline flight schedules, where subsequent flights follow a pre-coordinated schedule, which is insensitive for passenger induced delays. The way passenger delays are dealt with is by moving them to a next flight, with potential financial consequences on customer's side. In principle, the flight slots themselves do not move.

The second way of 'standardization' is comparable to the airline industry: the 'seating arrangement'. There are only two or three classes (service products) to choose from, and with those the price and the service obtained are fixed.

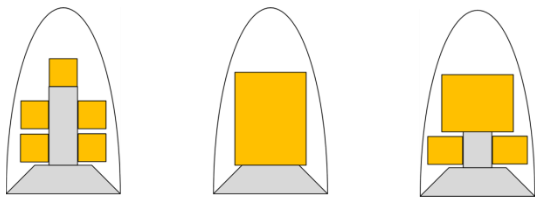

Fig. 4: Various types of payload

The operational strategy is treated according to its four main constituents:

1. The organisation;
2. The logistics of the vehicle, customer satellites etc.;
3. The production and assembly of the vehicle;
4. The execution of the launch campaign.

The real-time operational organisation is working on several complex technical projects in parallel to suit its purpose: build, test, and operate launch vehicles at a high rate. The organisation consists of several functional teams of about 20 persons that handle all necessary technical and non-technical operations.

The logistics of a launch campaign are important as they are a source of cost and complexity and covers:

1. Preparing and packing flight hardware for transport to launch site;
2. Loading the hardware on a vehicle of transport, and any intermediate transfer loading;
3. Environmentally controlling the cargo;
4. Moving staff (and customers) to the launch site and accommodating them;
5. Unloading and unpacking the hardware;
6. Moving all non-flight components of the logistics campaign back to their place of origin.

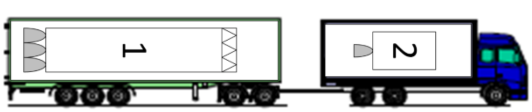

Fig. 5: Transportation example

The overall launch campaign is a combined effort of the launch service provider and the launch site and consists of pre-launch activities, the operational scenario, and post-launch activities.

## 2. Launcher Design

### *2.1 System Requirements*

The Netherlands Aerospace Centre NLR leads the concurrent design team that is responsible for the launcher design. Instead of a waterfall process, where strict requirements can lead to costly design solutions, the launcher requirements are defined in a flexible way, keeping the main goal of being low cost in mind. The main cost drivers are:

- The production of the launcher (size, complexity, tools, materials);
- The handling, storage, and transport of the launcher (size, sensitivity, materials);
- The organisational structure of the launch provider (facility, logistics, launch preparation, number of employees).

This means that the design of the launcher is driven by low-cost production methods, restrictions on logistics, minimising the personnel involved, and reduction of the overhead whilst upholding a high level of quality and safety.

The launcher is broken down into three major subsystems Engines, Structures, and Avionics, each of which comprises a number of subsystems of its own. The launcher requirements are defined on both system level and subsystem level.

To create a process that focuses on cost reduction, the concurrent design process involves not just the obvious multi-disciplinary domains such as propulsion, aerodynamics, and trajectory analysis, but also the manufacturing and logistics on a detailed level, resulting in a concurrent top-down and bottom-up approach.

### *2.2 Multidisciplinary Design Approach*

The design of a launcher is a multidisciplinary challenge that consists of an iterative process between launcher stage sizing and flight trajectory simulation to converge to a launcher design solution that reaches the target orbit.

The design approach focuses on bottom-up design, manufacturability, and cost effectiveness and is based on three consecutive phases:

1. Get it Working;
2. Get it Right;
3. Get it Optimised.

For this first phase, the collaborative design steps are as follows:

1. Initial sizing for the launcher stages, mass breakdown, and trajectory flight data is supported by hybrid and liquid engine sizing (including turbopump design).
2. Subsystem design, analysis, and subsystem mass breakdown.
3. Updating the stage sizes for total launcher mass breakdown to calculate launcher payload capacity and sensitivity analysis by trajectory optimisation calculations.

At the start of the project, several configurations were assessed, but in the end only two configurations remained: a three-stage hybrid launcher and a three-stage liquid launcher.

The (bottom-up) design rationale for the three-stage hybrid configuration is mainly driven by the limits of having a maximum burn time of around 90 seconds and of providing at least 100 kN of thrust (vacuum).

The selected number of unitary engines for the first stage is four to achieve an acceptable thrust-to-weight ratio of about 1.6 for the 20 ton launcher. Furthermore, the selection of four engines results in a stage diameter of 1.8 m which still is an acceptable size for the production of composite cylinders. Due to the high rate of oxidizer flow, the engines are fed by a turbo-pump.

For the second stage, a single unitary hybrid engine is selected to maintain acceptable accelerations during flight. However, at the end of the burn time throttling is required to limit the acceleration level. This engine is also fed by a turbo-pump.

This architecture allows having the same motor design in both the first and the second stage, with only a modification of the nozzle geometry to adapt to the different ambient atmosphere. This has a major advantage for the cost of the launcher as only one big hybrid motor needs to be developed and qualified. Also, the recurring cost can be reduced thanks to a higher production rate and the reliability increased by a more automatic manufacturing process.

The diameter for the payload bay inside the fairing is set to 1.4 m to accommodate enough volume to host single satellites as well as in combination with multiple smaller satellites with a payload capacity of 70 kg to 600km SSO. The length of the fairing is set to 2.0 m to achieve a good aerodynamic shape for drag losses and heating. The upper stage engine is pressure-fed.

The diameter selection also determines the diameter for the third and second stage to standardize the manufacturing for structure components (i.e. interstages and separation systems). By keeping the second stage and third stage diameter fixed to 1.4 m, the diameter of the first stage varies from 1.8 m (hosting the engines and turbopump) to 1.6 m (hosting the oxidiser tank) to 1.4 m (interstage) to use similar structures and systems for each stage separation.

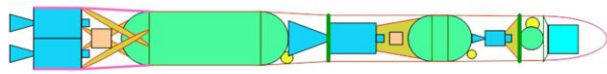

Fig. 6: Architecture of the hybrid launcher

The concept rationale for the three-stage liquid configuration is largely based on the same individual component design of the hybrid concept. Using a 1.4 m stage diameter for the first stage and 1 m for the second and third stage. Using similar design for the hybrid and liquid launcher allows interchanging components.

By considering a higher specific impulse and a lower dry mass fraction, the liquid concept outperforms the hybrid concept with a total mass of about 15 ton and higher payload capacity of about 150 kg to 600 km SSO.

The liquid launcher houses less powerful engines but are more efficient than the hybrid counterpart. This results in a longer flight time, the unthrottled burn times are respectively 150 s, 90 s and 230 s. The three-stage liquid configuration is also based on a unitary engine concept, the vacuum thrust level is 67.5 kN. The first stage houses four engines therefore the thrust-to-weight ratio is about 1.45. The second stage houses only one engine and has a higher efficiency due to the better expansion of the flow in the nozzle.

The third stage deviates from the unitary engine concept, it houses a smaller engine with a thrust level of 1.5 kN. This allows for better orbit control and orbit insertion. Due to the low thrust level of the third stage engine the third stage flight takes relatively long (also because there is a long coasting phase), as cryogenic propellants tend to evaporate during long flights therefore, the propellant type was changed to a storable monopropellant HPGP.

The first stage has a 1.4 diameter cross-section and the second and third stage a 1 meter cross-section. At the narrowing, between the first and second stage, there is little space for the second stage engine nozzle to separate from the first stage. To accommodate the separation guiding pins are introduced for a smooth transition between the first stage flight and the second stage flight.

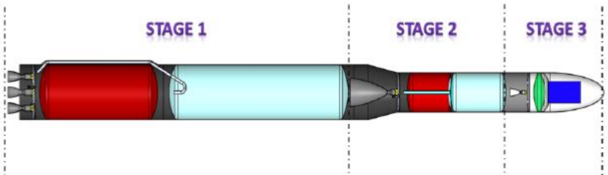


Fig. 7: Architecture of the liquid launcher

Regarding safety, several analyses have been performed to assess the impact zone of the stages, to learn for historical launcher failures, and to safely deorbit the upper stage.

*2.3 Trajectory Optimization*

INCAS, the Romanian aerospace institute, has developed a trajectory optimization tool to assess the maximum possible payload mass for any launcher configuration [17]. It employs a genetic algorithm in order to search in a global manner a solution for the following control problem:

*Find the optimal control functions that minimize a performance index f while satisfying a given set of equality and inequality constraints.*

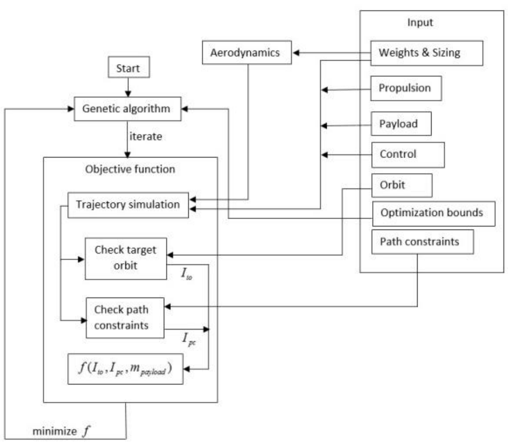


Fig. 8: Trajectory optimization tool

The genetic algorithm initiates an inner iteration loop that evaluates at every iteration the objective function f (the fitness function) attempting to minimize it. The objective function includes a 3DoF trajectory simulator. The output from the trajectory simulation is used to check the orbit and path constraints defined by the input, after which all performance indices together with the payload are combined in the objective function.

Then, the genetic algorithm generates a new set of decision variables (optimization variables) within the bounds defined in the input file, based on the history of the performance indices encountered during all the previous iterations, until the optimum for a direct ascent to orbit is found.

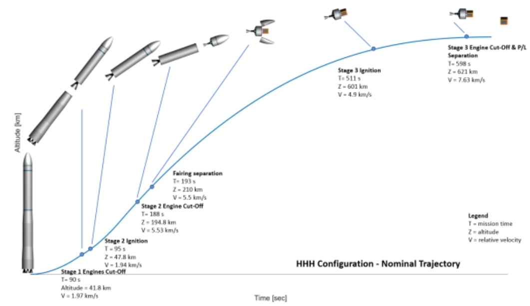


Fig. 9: Example trajectory of the hybrid launcher

*2.4 Propulsion System*

*2.4.1 Hybrid Engine*

The hybrid propulsion system is based on a modular concept from Nammo Raufoss, a Norwegian defence and aerospace company, consisting of hybrid rocket motors clustered together. Modularity is obtained at different levels: at component level, at the propulsion level and at the level of the stages. For the intended market, cost is essential. Using common components, volume production is possible, thus reducing the cost. Reliability can then be increased by automated production.

The reuse of the propulsion is primarily based on a high thrust motor for the 1st and 2nd stage. For an upper stage, a high performance engine with a more moderate thrust requirement and longer burn-time is needed to obtain orbit insertion. The hybrid rocket motors are throttleable and capable of repeated stop and restart, characteristics that become a hard requirement for the third stage engine in order to enable accurate orbit insertion and further deorbit manoeuvres.

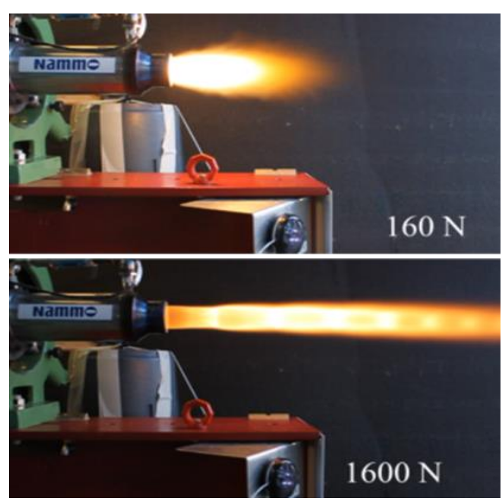


Fig. 10: Throttleability of Nammo's hybrid motor

Nammo's hybrid technology has matured since 2003 through several research and technology programs, either nationally or in collaboration with international partners ([11]). The motors use high concentration hydrogen peroxide (87.5% H2O2) as oxidizer and hydroxyl-terminated polybutadiene (HTPB) rubber as fuel and as such combine environmental friendliness and cost effectiveness with a high regression rate and an excellent overall combustion efficiency (up to 98%).

Figure 11 shows the working principle of Nammo's hybrid technology. The incoming liquid oxidizer is first decomposed by a catalyst bed into hot steam and gaseous oxygen at a temperature of 670°C.

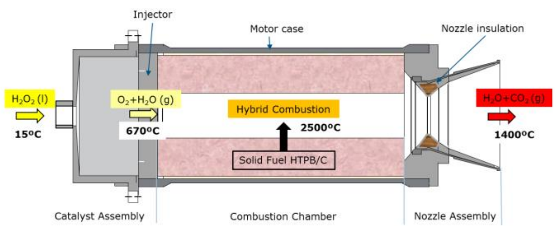


Fig. 11: Working principle of hybrid motor

It then continues through the injector and enters the combustion chamber in hot gaseous form, where ignition of the propellants occurs instantly without any dedicated ignition device due to the high temperature vaporizing the solid fuel. Vortex injection helps in maintaining a high heat flux into the fuel surface and in achieving appropriate mixing of the reactants. Ultimately, this allows sustaining high combustion efficiency. The hot combustion gases are then expelled through a standard bell nozzle, generating the thrust.

Compared with solid rocket motors, the hybrid motor designed by Nammo has a rich set of attractive features:

- Self-ignition increasing engine start reliability and enabling an unlimited restart capability;
- Wide range throttling with limited performance losses;
- Green life cycle and exhaust properties;
- Solid inert fuel and high-density green storable oxidizer;
- High engine combustion efficiency, performance and stability;
- Simplicity of a single circular port and single feedline configuration;
- Low development and operational costs.

The aforementioned features are implemented in Nammo's currently developed hybrid motor, a 30 kN-class engine named the Unitary Motor 1 (UM1). More details about the UM1 and the results of performed test campaigns until 2017 can be found in reference [13]. In July 2018 the motor was ignited and burnt for 40 seconds, until full depletion of the oxidizer and gas tanks [18]. This successfully tested Europe's first hybrid space rocket that now it's ready for launch.

Fig. 12: Firing of flight-weight UM (July 2018)

While being primarily developed for sounding rocket applications, the technology matured through the Unitary Motor 1 and the clustering concept can be directly implemented for a microsatellite-launcher, for which the cost effectiveness of the propulsion system is just as important as shear performance.

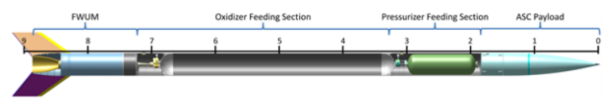


Fig. 13: Sounding rocket design with hybrid UM

Firstly, a trade-off at system level has been made between thrust, burn-time, and motor envelope for a given total impulse provided by the motor. The burn time has an impact on the diameter of the motor and thus the stage. The thrust level is limited by the acceleration loads.

Secondly, where the optimisation of the dry mass is not so critical for a sounding rocket, it becomes quite the opposite in a launcher. Using new technologies (3D printing, composite materials) as well as the know-how acquired with the latest engine tests, the mass of the catalyst assembly and that of the motor case has been reduced significantly.

Finally, the oxidizer feed system must be adapted to the size and the requirements of a microsatellite-launcher. Up to a certain level of oxidizer mass-flow, e.g. for the upper stage, a pressure fed-system can be considered. With the hybrid motors operating at a somewhat low pressure (20-40 bars), the required pressurization system can remain quite small.

The first stage engines need to be fed by a turbo-pump due to the high mass-flow and overall size of the otherwise pressurized oxidizer tank.

*2.4.2 Liquid Engine*

Usually, the propulsion system is the most expensive part of the launcher. Thus, it would be beneficial to retrieve the engines back after each mission. In contrast to solid, hybrid or classical liquid engine approaches, liquid engines based on ceramic matrix composite (CMC) materials are very promising candidates with respect to reusability aspects as they offer [4][5][6]:

- Improved lifetime;
- Thermo-shock resistance;
- Thermal-cycling ability;
- Reliability and damage tolerance;
- Reduction in structural weight;
- Increased oxidation resistance;
- Potential fail-safe operation;
- High specific strength at elevated temperatures;
- Low thermal expansion.

Hence, this specific kind of propulsion system using ceramics is well suited and applicable as it can be thermally cycled without degradation, which is not the case for metallic approaches.

Especially in combination with the transpiration cooling technique and the use of fibre reinforced material, the structural weight can be reduced significantly. Liquid propulsion is a reliable technology that is quite flexible as the engines can be throttled to a wide range (5-100%) and are easily re-ignited.

The German Aerospace Centre DLR Stuttgart is developing a LOX/Jet A-1 engine with transpiration and film cooling to make it reusable. Jet A-1 is a worldwide available, very affordable fuel that can be easily stored, and with the active cooling system for the combustion chamber, soot is less of a problem [6][9][10].

Besides the combustion chamber, the C/C-SiC materials are used for nozzle as they have high resistance to high temperatures, high oxidation strength, high damage tolerance, low thermal expansion coefficient, and low density [7][8].

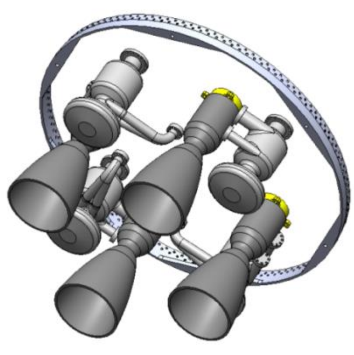

Fig. 14: First stage engine configuration

The modular engine design approach has the following advantages leading to reduced overall cost:

- The engine design is based on standardized and interchangeable components, lean manufacturing, and easier quality management;
- Clustering enables the usage of the same engine components for all of the three stages, e.g. injector, combustion chamber, and valves. Such components can be manufactured at low cost by 3D printing;
- Throttling capability in the first stages allows for gimbal-free thrust vectoring.

For the current configuration of the liquid rocket engine tests, all designs, manufacturing (except injector), machining, integration and qualification were performed by DLR, as well as the ceramic combustor liner, to ensure reusability. The injector is a complex design with separate feed lines for the transpiration cooling, film cooling, and propellants, and has been 3d-printed in Inconel 718 at low cost by 3D Systems in Leuven (Belgium) [20].

Fig. 15: Liquid rocket test configuration

Within the project, several test campaigns were performed at the test facility of PLD Space in Spain. Cold firing tests of the igniter and injector have been performed successfully in July 2017 and hot firing tests with a ceramic-based combustor were successfully conducted in early November 2017 [19] and September 2018.

*2.4.3 Turbo-pumps*

For the various hybrid and liquid engines, turbo-pumps have been designed by WEPA-Technologies from Germany, all of which are based on a common set-up using a gas-generator to drive the turbine, which in turn drives the oxidizer and fuel pumps. The impulse turbine preferably has a single rotor for simplicity, while minimising the loss in specific impulse.

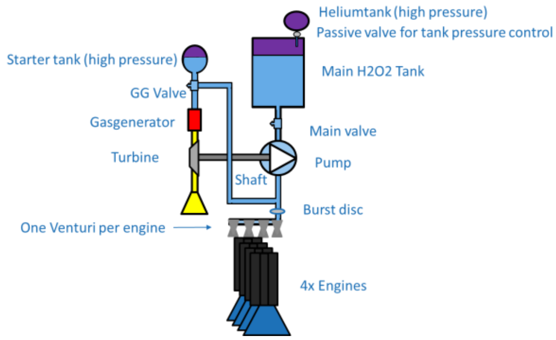


Fig. 16: Piping diagram for hybrid first stage

The design encompasses the properties of all pumps, such as rpm, flow rate, impeller-, inducer-, and blade geometry, required drive power including losses, mass and, build volume. It shows that the pumps are a small and lightweight solution for feeding the engines, compared to a pressure-fed system.

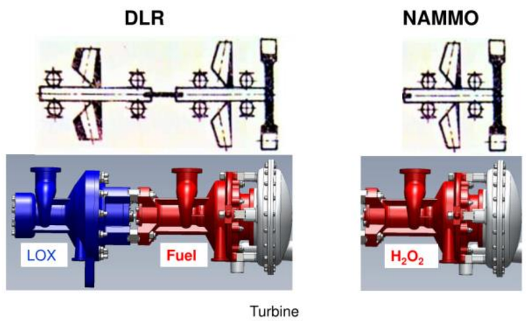


Fig. 17: Common design of the turbo-pumps

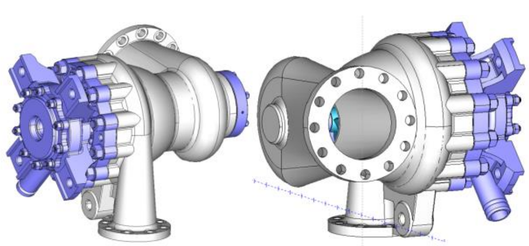

Fig. 18: Detailed design of the LOX turbo-pump

The mass flow of the propellants can be varied by controlling the mass flow of the turbine drive gas, which provides a simple but effective means of control, where the thrust is changed through the set point of the gas generator valve.

*2.5 Structures*

*2.5.1 Architecture*

NLR and Heron Engineering (Greece) are responsible for the structural design of the launcher. Each stage contains several structural elements:

- Nose fairing;
- Payload adapter;
- Inter-stage structure;
- Separation mechanism;
- Outer shell or hull;
- Tanks;
- Engine thrust frame.

For each structural element, materials are selected and manufacturing methods are investigated to support a cost efficient structure development process.

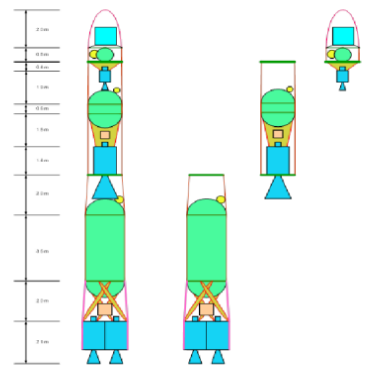

Fig. 19: Structural architecture of the hybrid launcher

As most load cases are driven by buckling, a carbon composite sandwich is selected for the load-carrying elements. Some of the tanks are integrated into the structure; others are non-load carrying. The cryogenic LOX tanks are made of carbon-composite to further decrease the structural mass.

A finite element model has been generated by Heron Engineering to analyse a combination of load cases:

- Inertia loads: axial + lateral, from trajectory data;
- Aerodynamic pressure loads on the fairing at maximum dynamic pressure;
- Pressure inside the propellant tanks;
- Venting loads: 2.5 psi collapse pressure and 5.0 psi burst pressure.

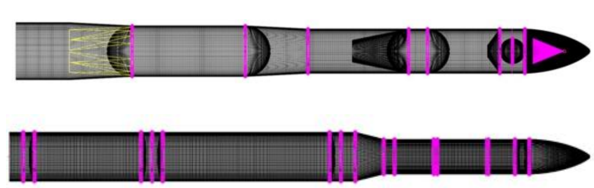

Fig. 20: Finite element models of both launchers

A linear static analysis (Nastran SOL 101) is used for deriving the static strength of the structures, whereas an Eigen-buckling analysis (Nastran SOL 105) is used for the buckling strength. From the FEM analyses, the optimal thickness (number of plies) of the composite sandwich can be deduced, resulting in an accurate estimation for the mass of the structural elements.

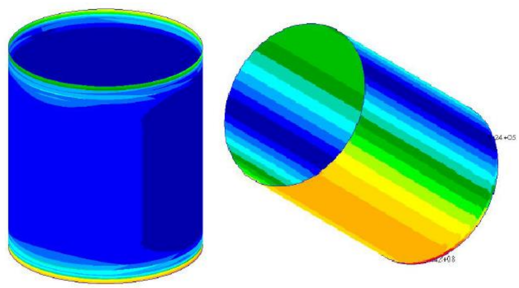

Fig. 21: Example of FEM results for liquid stage 2, fuel and liquid respectively

To put several types of payload (CubeSats as well as micro-satellites) into orbit, the Dutch CubeSat company ISIS is developing the flexible payload deployment system "MicroSatellite Separation System (M3S)" that can be adapted for any payload fitting in the fairing. It uses a standardised clamp points with a hold-down-and-release mechanism and a single centralised actuator.

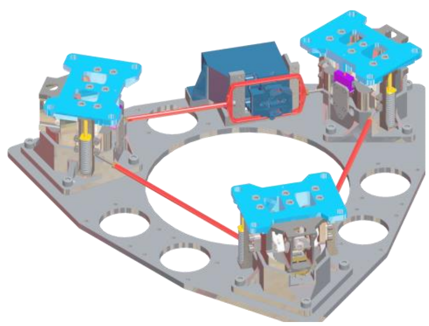

Fig. 22: MicroSatellite Separation System (M3S)

*2.5.2 Materials*

Several trade-offs have resulted in recommendations for decreasing the dry mass, for instance, using composite sandwich instead of a solid laminate for the fairing. However, the double-curved geometry of the fairing may not be suitable for low cost production.

To achieve a cost-effective solution, several composite technologies have been investigated by NLR and Tecnalia to exploit the potential of promising emerging materials and processes such as liquid moulding (infusion) and out-of-autoclave prepregs.

Tecnalia, a Spanish research institute, has also investigated the thermal protection materials for the nose cone and the base of the launcher, given that carbon composite materials are limited with respect to temperature.

*2.5.3 Automated manufacturing*

The other key aspect in the development of advanced, cost effective composite launcher structures is automation by means of robotics. Guidelines for structural designers are needed to ensure that the resulting composite launcher structures are fit for automated manufacturing.

The company Airborne Composite Automation from the Netherlands has been looking, together with NLR, at manufacturing methods for affordable production of the composite elements. With Automated Tape Laying (ATL), a single wide unidirectional prepreg tape can be laid down automatically, e.g. for the cylindrical and conical structures. Airborne has designed an in-house robotic-based ATL system specifically for affordable manufacturing of launcher structures. Currently, they have the second generation ATL system ready, which is designed as a production system.

Fig. 23: Airborne ATL Mk2

More complex structures, such as the double-curved fairing, can be made with a fibre placement machine.


Fig. 24: NLR Coriolis AFP

*2.6 Avionics*

The use of space-qualified avionics components typically leads to expensive subsystems. Experience with CubeSats has led to the conclusion that selected

Commercial-Off-The-Shelf (COTS) equipment can survive the launch and continue to function in a space environment. Today's rapid rise in computing power and advances made in sensor technologies open up alternative architectural solutions for the avionics.

Taking into account the relative short time frame in which the launcher will be active, the need for redundancy (and thus extra weight and power) needs to be reconsidered. If the (time-dependent) probability for critical failures of a launch is low enough, redundancy is not needed, or can be replaced by a form of checking.

To obtain a cost-effective avionics architecture, a practical approach with good engineering judgement should be applied to implement an architecture based on the following principles:

- Minimize direct redundancy / complexity;
- Use COTS components / systems instead of expensive space-qualified parts;
- Integrate as much as possible into a single box per stage, thus reducing the harness.

Other considerations that come to play are:

- It is foreseen to apply COTS components in the launcher. Then, obsolescence needs to be addressed as the life cycle of COTS devices is relatively short;
- Another issue with COTS systems is that they may not be suited for the harsh environment of a launcher. This may require ruggedization of the COTS devices in order to survive the launch. When a COTS manufacturer decides to change the design, it may affect the needed ruggedization;
- To test the suitability of ruggedized COST systems, the environment in which they are to be operated must be characterized. Obviously, a location near the engine thrusters is much worse than somewhere above a fuel tank.

The first two items may best be addressed by omitting the use of complete COTS systems and by applying COTS components into a dedicated design. This has several advantages:

- Separate ruggedization of mechanical interfaces is not required;
- The design can have a higher level of integration, i.e. less mass and less connectors;
- The architecture does not depend on the life cycle of commercial systems, as components tend to be on the market for longer periods than complete systems;
- The use of components provides a better control of the whole ruggedization process.

To verify the on-board units, NLR and the Danish company Terma are developing an Electrical Ground Support Equipment (EGSE) that can be reused during the complete life cycle of the launcher. The core of the EGSE is a 6DoF simulator with which the launcher control software can be tested both with and without hardware-in-the-loop (HIL). The HIL avionics EGSE concept has been demonstrated in July 2018

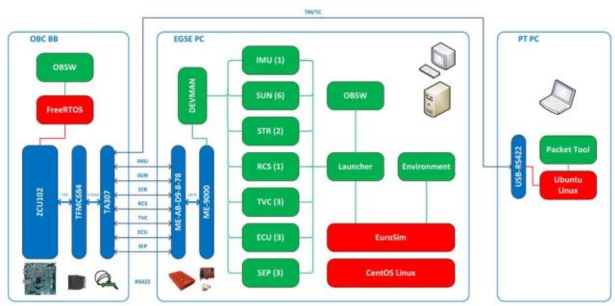


Fig. 25: HIL avionics demonstrator

Furthermore, NLR has developed a prototype avionics box that has been launched as a payload experiment on the Stratos III rocket from the Delft Aerospace Rocket Engineering (DARE) team [15]. This prototype box contains a Sensonor STIM300 MEMS IMU and a Septentrio Asterx4 GNSS receiver with a low-power Parallella board as the central node.

NLR has performed vibration tests of the Stratos III nose cone and the payload in June 2018 [21].

Unfortunately, Stratos III encountered a launch failure; 20 seconds into the flight the rocket disintegrated. Analysis of the anomaly is still on-going by the DARE team [22].

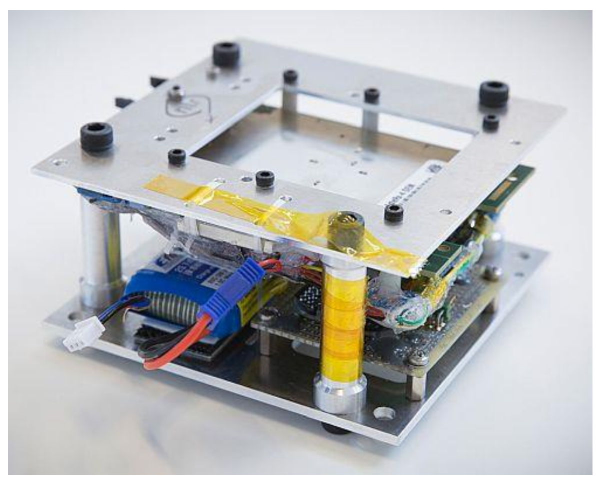

Fig. 26: Prototype avionics box

### 3. Launch Base

The Andøya Space Center (ASC) is located on a coastal island 2 degrees north of the Arctic Circle and is the world's northernmost permanent launch facility for sounding rockets with seven launch pads in the launch area. The launch complex currently offers different launch capabilities for sounding rockets up to 20 metric tonnes, wide-band mobile and stationary telemetry stations with a slant range system for tracking purposes, a large impact area, permitting a variety of launch directions and rocket configurations. Having conducted more than 1000 sounding rocket launches since 1962, it already provides complete services for launch, operation, payload data acquisition, recovery and ground instrumentation support.

Towards the end of 2014, the Polar Satellite Launch Service Programme was established to assess the technical feasibility and economic viability of a small satellite launch service from Andøya and in May 2018 the Andøya Spaceport was established, as a subsidiary of ASC.

Andøya benefits from a relatively mild micro-climate, due to its coastal location and the vicinity of the warm gulf current. Unlike other launch sites at similar high latitudes (Esrange and KLC), Andøya Island benefits from a relatively mild winter. Availability of existing infrastructures and services and the limited air and sea traffic are major competitive advantages, when comparing Andøya to other European location willing to host a Spaceport.

ASC has joint forces with the Norsk Romsenter (Norwegian Space Centre), with the objective to advance the development plans for the Andøya Spaceport.

## 4. Conclusion

*Project results*

This paper presented the results of the H2020 SMILE project, showing launcher concepts for a three-stage hybrid rocket as well as a three-stage liquid rocket.

As part of the technology development in SMILE, several prototypes have been developed, including a 3D-printed injector, flexible payload deployment system "MicroSatellite Separation System (M3S)", a COTS avionics box and an EGSE prototype (including HIL). Hot firing tests for hybrid and liquid engine have been performed successfully.

Business development is important driver to obtain an economically feasible overall concept. A market assessment to evaluate potential future benefits as well as a bottom-up cost estimation of launcher, ground segment, and operational organisation has been performed. A preliminary cost-benefit analysis shows that a micro-launcher can be commercially feasible. A realistic business plan – with companies willing and able to develop and integrate the complete launch system - is considered imperative to attract attention of European investors.

*Remaining activities*

With only a few months left before the end of the project, the following activities are remaining:

- Windtunnel testing of the nose cone and the launch vehicle to validate CFD models;
- Liquid engine testing and test assessment;
- Analysing and evaluating the data from the COTS avionics box;
- Manufacturing the upper stage structure prototype;
- Finalization of documentation;
- Preparation of the final review (December 2018).

*Way forward*

The results of the SMILE project will be beneficial for all participating organizations to continue their (technology) developments for small launchers. The knowledge and expertise that was further developed and combined in SMILE will function as a foundation towards the realisation of a small innovative launcher in Europe.

## 5. Acknowledgement

The SMILE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687242.

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