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HyImpulse Small Launcher SL1 – Access to Space with Hybrid Propulsion

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ABSTRACT

The Small Launcher SL1 is a hybrid propulsion based small satellite launch vehicle that is currently under development at HyImpulse Technologies GmbH, a New-Space startup, and a spin-off out of the German Aerospace Center (DLR). SL1 will be able to place payloads up to 400 kg into a 500 km SSO. Designed specifically for affordability, responsiveness and high launch cadence, SL1's salient characteristics derive from the usage of hybrid propulsion units in all its three stages. The first and second stages are powered by turbopump-fed 75 kN HyPLOX75 motors (8 and 4 numbers respectively). The third stage is powered by 4 25kN HyPLOX25 motors.

The HyPLOX75 motor has already been tested successfully in September 2020 and became the largest hybrid motor ever to be tested in Europe. Powered by paraffin wax (fuel) and liquid oxygen (oxidizer) as propellants, the motor can reach a high specific impulse like traditional KeroLOX liquid systems. Development of a fully carbon-neutral way to produce paraffin wax using the Fischer-Tropsch process is being prepared at HyImpulse and will be explained in the paper. A technology demonstrator in the form of a Sounding Rocket SR75 is being manufactured in parallel with key critical systems undergoing qualification tests. SR75 is slated to be launched in Q3 2021 and will flight validate the HyPLOX75 motor. The current paper will detail the results of the progress and advancements made in the design of SL1 and its key critical systems during the last year. In particular, details about SL1's design methodology and system architecture will be described. Additionally, progress on HyPLOX75 test firing, cryogenic LOX tank manufacturing, avionics and GSE development will also be described.

INTRODUCTION

Background of HIT

HyImpulse Technologies is a NewSpace company in southern Germany, a spin-off out of the historical chemical rocket propulsion research center of the German Aerospace Center (DLR) at Lampoldshausen. The founders of HyImpulse are five engineers who have a combined experience of more than 50 years in developing, testing, and launching rockets. HyImpulse's mission is to unlock the full potential of the commercial NewSpace industry by eliminating the current bottleneck of frequent, dedicated, reliable, affordable, and sustainable access to space for small satellites. Driven by maturation of miniaturization technologies, cost-effective off-the-shelf electronics and reduced barriers to entry, the small satellite (< 500 kg) market has seen an historic rapid growth in the recent years. This trend is expected continue as current forecasts estimate the requirement of 800 satellites to be launched every year for the next decade. This is an 100% increase in market volume compared to 2019 value. Meanwhile, there are not enough launch opportunities (both in volume and responsiveness) that cater to this rapid expansion of the small satellite market. Combined with the increasing strategic political interest in Germany and in Europe to support the development of a local small launch service, this presents an excellent business opportunity that HyImpulse will target.

The 60-member strong and diverse (from 12+ nations) HyImpulse team has over 250 years of combined experience in rocket engineering. The founders' have proven flight heritage having previously designed, developed, and flown the HEROS 3 sounding rocket, which still holds the world record for the highest altitude reached by an academic hybrid rocketry team. Advised by renown industry experts, the team is capable of meeting all the targets on time. Key partners supporting us on this endeavor include DLR and one of Europe's largest aerospace engineering companies – IABG, with all of which HyImpulse has proven working experience. The DLR Institute of Space Propulsion, with its test site is located only a 10-minute car drive away from HyImpulse's fully operational, 1000 m^2 production and assembling facility, ensuring a rapid technology development. Resilient partnerships in the supply chain have been established with all stakeholders in the launch service sector ensuring a capability to deliver a full suite of services right from payload pick up to post-mission support after orbital delivery. These unique strengths differentiate HyImpulse from its competitors and ensures a fast and competitive entry into the market for an industry leadership.

Market for Small Satellites

The growth of the Small Satellite Market segment in the last years can be attributed to its wide use for several purposes: Earth Observation, Communication, science, exploration and technology development. Small satellites are also used as test carriers for newly developed components that are to be installed on more critical satellites.

The defining trait of the space industry in the recent decades is the rise of 'NewSpace', a business environment increasingly dominated by private, commercial players. Fueled by lower costs of technological development, and reduced barriers to entry, a democratization of the space industry is currently in progress. One of the main drivers leading this revolution is the rapid growth of the number of small satellites (up to 500 kg) in Low Earth Orbits (LEO) and of downstream services associated with them, such as Earth Observation (EO), satellite-based internet and Internet of Things (IoT) connectivity.

In 2020, 1079 satellites have been launched worldwide, 1029 of which were smallsats, thus significantly growing compared to the previous record of 385 smallsats launched in 2019[1]. This growth trend is expected to continue: an estimated 8000+ small satellites will require launch within the next decade resulting in an average required launch of at least 800 satellites/year as highlighted in predictions of multiple space consulting and market research firms: Euroconsult[2], Northern Sky Research[3] and PwC[4].

Figure 1 and Figure 2 provide a visual representation of the trend from both historical launch data and future projections.

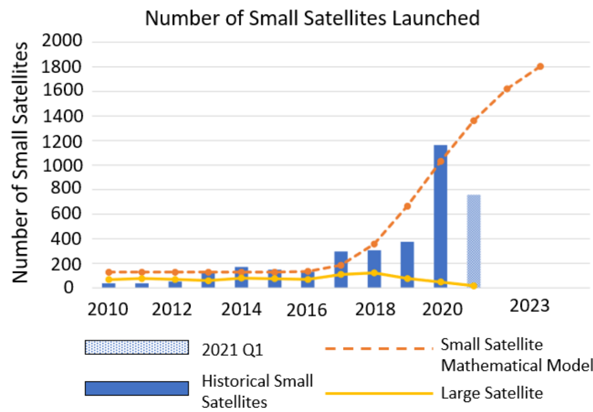

Figure 1: Future Development Launched Smallsats[1]

However, the main bottleneck towards the growth of this estimated $1T industry[6] remains the limited availability of launch services for small satellites. The small satellite companies essentially have only two choices when it comes to getting into space. They can 'rideshare' on a launch that is carrying other payloads, or they can purchase a dedicated launch. Though cheaper, rideshares come with significant disadvantages for satellite operators: the ridesharing satellite needs to wait, until the launcher's payload capacity is filled, the operator cannot freely choose the target orbit, and in case off-nominal behavior might threaten the main (biggest) payload, the ridesharing small satellite might get sacrificed to save the main payload. 'Dedicated' launches on the other hand are more expensive, but they avoid these problems of rideshares. Currently, there is a widening gap between the demand and supply of launch services with the demand exceeding the supply – and the gap is even bigger in the dedicated launch segment. Figure 2 shows that all smallsats in the last 5 years faced delays in getting launched, of which 40% were waiting for an affordable launch[7]. While waiting for affordable launches that meet their exact requirements satellite companies continue to lose potential revenue,[8] all of which stifles the evolution of the whole space economy. This creates a significant business opportunity in the NewSpace business environment.

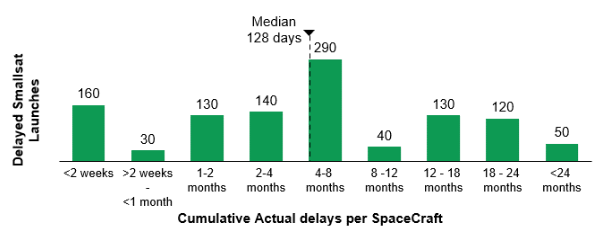

Figure 2: Waiting Times for Smallsat Launches[7]

HYBRID PROPULSION TECHNOLOGY

Hybrid rocket engines are the third alternative for chemical propulsion, next to liquid and solid engines, as shown in Figure 3. Hybrid propulsion is defined as the type of rocket engine, that uses a solid and a liquid propellant component. Typically, the fuel takes the role of the solid, whereas the oxidizer takes the role of the liquid component.[9]

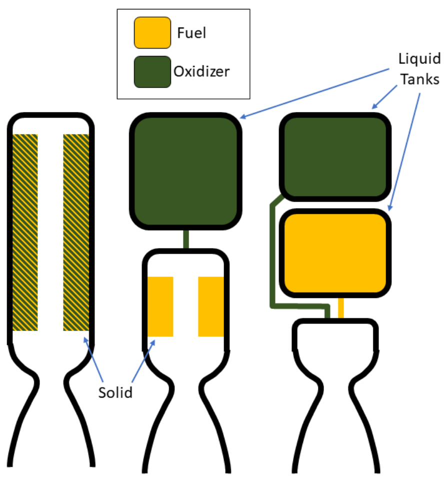

Figure 3: Types of Chemical Rocket Propulsion: (from left to right) solid, hybrid, and liquid rockets

Regarding its properties, hybrid rocket propulsion in many ways falls in between liquid and solid rocket propulsion: the required system complexity is in between solid and liquid (bipropellant) motors, since only one fluid needs to be handled.[9] The specific impulse of hybrid rockets is higher than that of solid rockets, since it can utilize the more energetic oxidizers like liquid oxygen (LOX).[9] The $\boldsymbol{I_{sp}}$ that can be achieved is however lower than that of liquid rocket motors based on low-molecular weight fuels like liquid methane and liquid hydrogen. Hybrid propellants can however match the specific impulses of kerosene-LOX liquid rocketry.

Hybrid rockets motors offer larger operational flexibility compared to solid rocket motors due the possibility of throttling down, which can be achieved by controlling the liquid oxidizer mass flow rate. Re-ignitable motor designs are possible with hybrid rocket engines as well. Additionally, hybrid rocket motors offer the largest flexibility when choosing propellants, since both liquid and solid substances can be utilized.[9]

The area where hybrid rocketry outperforms both liquid and solid rocketry is regarding handling and operational safety. Unlike with solid propellants, the fuel and the oxidizer are physically separated until they meet inside the combustion chamber during nominal operations. On top of that, the liquid component does not yet have to be present when personnel are working near/at the rocket propulsion system. This is an advantage over solid rocketry, that hybrid rocket propulsion shares with liquid rocketry. In liquid propulsion systems, there is however the possibility of fuel and oxidizer mixing rapidly, which allows for an explosive combustion in case of a tank rupture. Since one of the components in hybrid rockets is solid, this rapid mixing cannot occur. Therefore, even if ruptures can still happen, a full-on explosion is impossible. This higher safety, combined with the (compared to liquid rocketry) lowered system complexity, promises lowered cost of operations, due to a significant reduction on the amount of effort that needs to be put into safety precautions.

Typical hybrid rocket systems have been utilizing polymeric fuels like HDPE (high density polyethylene), HTPB (hydroxyl-terminated polybutadiene) or PMMA (polymethyl-methacrylate), which are pyrolyzed by the combustion heat and deliver fuel-gas into the combustion zone. This combustion mechanism has been plagued with low burn (regression) rates of the fuel, which lead to a lowered fuel mass flow, which in turn lead to a lowered thrust density of the motors.[10] Workarounds have been proposed including fuel additives, vortex injection or more complex fuel grain geometries, but all these solutions impact either the motors' burnout masses, the I_{sp}-performance, or combustion stability.

A remedy to this traditional draw-back of hybrid rocket propulsion has been found in so called "liquefying fuels". This new class of solid fuels melt before they pyrolyze, so that a liquid layer forms on top of the solid fuel grain. Due to the oxidizer flow over the liquid surface, waves are formed, and fuel-droplets are entrained into the gas flow, so that an additional fuel transport mechanism into the flame is established. The process is depicted in Figure 4. With this, the regression rate can be increased 2 to 5 times over that of conventional hybrid fuels.[11]

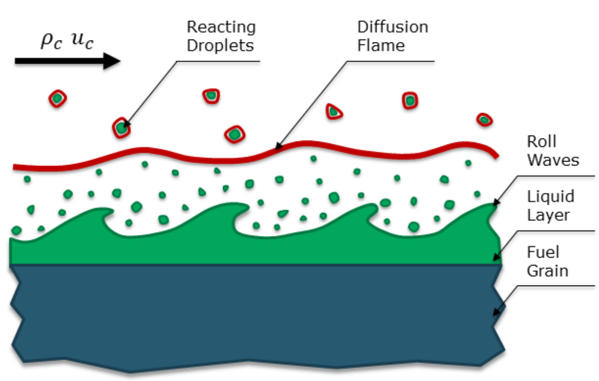

Figure 4: Entrainment Process of Liquefying Fuels[12]

Paraffin wax is one material that belongs to this category of fuels and has quickly been identified as such once the phenomenon was discovered. Due to its general properties and due to the experience of HyImpulse's founders with the development of paraffin-based hybrid rocket fuels, this substance was selected as the solid component of the rocket engines.

For the selection of the liquid oxidizer, an analysis was conducted.[13] Most commonly, hybrid rockets use liquid oxygen (LOX), hydrogen peroxide, or various nitrous oxides as their oxidizer. Of these LOX has been selected, due to performance (see Figure 5), cost, and safety (hydrogen peroxide and nitrogen oxides can decompose exothermically).

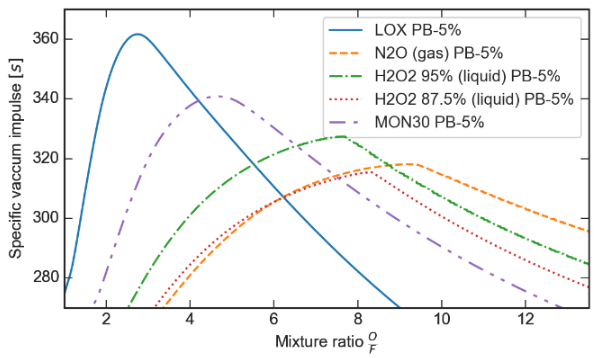

Figure 5: Specific Impulse for an expansion ratio of 60 and a chamber pressure of 15 bar[13]

Typically, LOX has a tendency of causing instabilities in hybrid rocket motors, but HyImpulse has developed engine designs that can ensure stable paraffin-liquid-oxygen-(ParaLOX-)combustion. This design has been successfully demonstrated in over 75 sub-scale (10kN) tests (see Figure 6) and is currently in the process of being qualified for full-scale (75kN) operations.

Figure 6: Test of the 10 kN Demonstrator Motor

CARBON-NEUTRAL FUEL

From an environmental point of view, the ParaLOX-combustion is comparatively clean, emitting mostly carbon dioxide (CO_2) and water. Conventional paraffin is however a byproduct of raw-oil-refining, so that the CO_2 emitted in rocket motor operations stems from fossil sources and thus contributes to global climate change. In order to overcome this disadvantage, HyImpulse is investigating options for a renewable method of obtaining paraffin. Since CO_2 always will be a product of the combustion process, the paraffin needs to be generated from the CO_2 already present in the atmosphere. This way, no new CO_2 will be added.

An established methodology for synthesizing various hydrocarbons from smaller molecules is found in the Fischer-Tropsch-Process (FTP), which follows the reaction equation of:

$$n\,CO + 2n\,H_2 \rightarrow (CH_2)_n + n\,H_2O \qquad (1)$$

where CO is carbon monoxide, H_2 is hydrogen, $(CH_2)_n$ is an alkane of chain-length n and H_2O is water.[14]

FTP has been in use for around 100 years and commonly produces hydrocarbons like gasoline, diesel, kerosene, or fuel oil from so-called syngas (a mixture of carbon monoxide and hydrogen). This syngas can easily be obtained from fossil sources like coal or natural gas.[15] Despite its long history of utilization, FTP has so far only proven economically viable in circumstances of oil-scarcities or overabundance of coal/natural gas.[14] The increased attention paid to the dangers of global climate change has renewed the interest in FTP in recent years, since the process itself is independent of the source of the syngas. This allows a replacement of the traditional syngas sources with renewable ones, for example from biomass or via extraction from the atmosphere.[15]

FTP runs by exposing the syngas to metallic catalyzers at temperatures between 220 and 350 °C and under varying pressures. The composition of the produced hydrocarbon mix can be optimized by varying the process temperatures and pressures and by adjusting the catalyzers.[14] Paraffins are typically mostly a side-product in FTP as it is utilized currently, so the parameters of a process optimized for paraffin-output are the goal of HyImpulse's research activities in this area. Alternatively, reprocessing of the side-products of bigger FTP-operations (e.g., production of carbon-neutral kerosene for commercial aviation) might also yield an effective hybrid rocket fuel.

Sourcing of the syngas might present the second research goal for HyImpulse's carbon-neutral fuel production, in case HyImpulse runs its own paraffin-optimized FTP. Two main options present themselves for this purpose, extracting the syngas from biomass (together with FTP known as “Biomass to Liquid”) or extracting it from the atmosphere using energy (together with FTP known as “Power to Liquid”).[15]

The carbon-neutral fuel development currently is in its early planning stages. Once cooperation partners have been determined and resources become available it can be implemented quickly, due to the high maturity of the technologies involved.

RECENT DEVELOPMENTS AT HYIMPULSE

Two key technical developments have been ongoing at HyImpulse are the development of the HyPLOX75 (75 kN Hybrid Paraffin LOX) motor, that will power SL1’s first two stages, and the development of a sounding rocket (sub-orbital technology demonstrator) called SR75 (75 kN Sounding Rocket) that will also use this motor.

HyPLOX75 Development

The HyPLOX75 motor is the full-scale version of the 10 kN demonstrator that has been successfully tested over 75 times. This full-scale version of the hybrid motor is intended to be utilized on both the SR75 and SL1 (with some adaptations for the different uses).

The development test campaign of the HyPLOX75 has been conducted at DLR rocket propulsion test site Lampoldshausen in September 2020, as can be seen in Figure 7. The tests were successful and served to demonstrate the operation of this scaled-up version of the established 10 kN-hybrid rocket motor.

Figure 7: HyPLOX75 Development Tests in Sep 2020

The first of a series of qualification tests has been conducted in May 2021, this time at Shetland Space Center (see Figure 8). With this campaign, nominal operation of the flight motor has been successfully confirmed. The next test campaign is planned for later this summer, before the flight of the Sounding Rocket SR75.

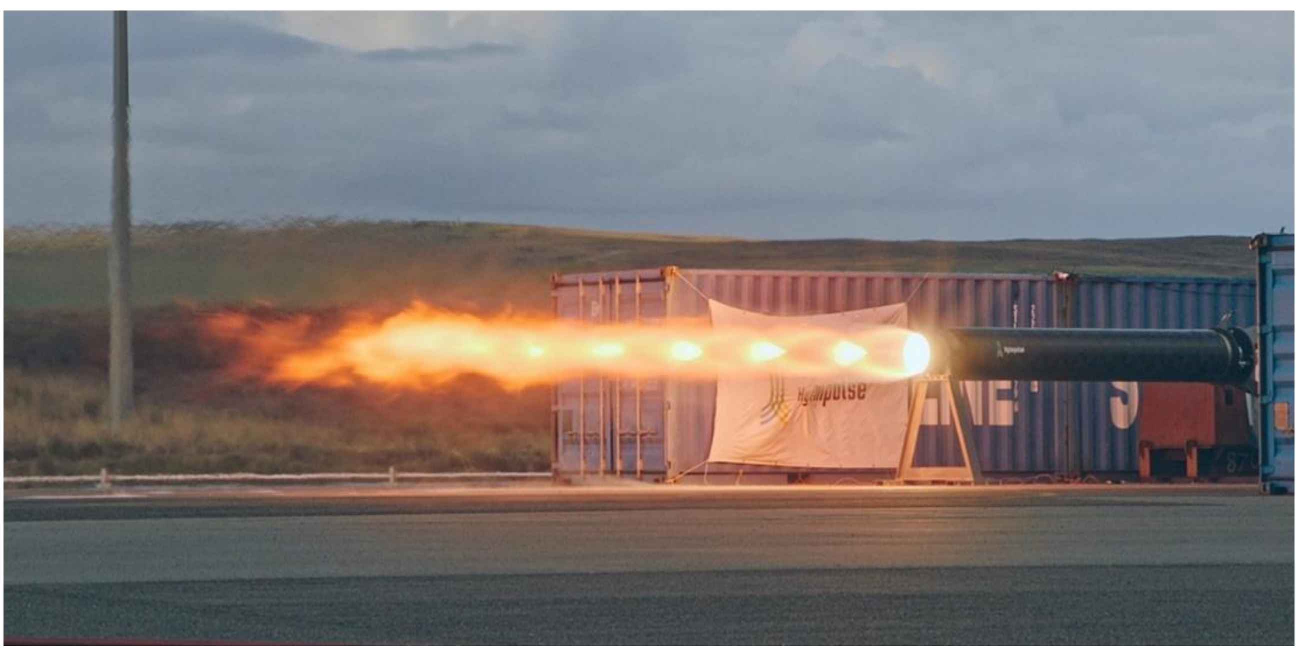

Figure 8: HyPLOX75 Qualification Tests at Shetland Space Center in May 2021

After this, continued effort will be put into engine testing in order to upgrade the design to the configuration of the small launcher (including turbopump feeding and thrust vector control). The integrated powerpack test is planned for Q2 2022.

SR75 Flight Preparation

The sounding rocket SR75 (see Figure 9) uses the HyPLOX75 motor in a pressure-fed configuration to propel a payload of 350 kg to an altitude of 200 km on a sub-orbital trajectory. This will provide a microgravity environment (< 1E-5 g) for a duration of around 5 minutes.

Figure 9:Sounding Rocket SR75

The SR75 flights allows HyImpulse to flight-qualify some of the hardware that will be used on the small launcher, as well as gaining some flight experience with the other components, which are still quite similar to what will be used on the SL1. Next to the HyPLOX75 motors, the light weight CFRP (carbon fiber reinforced plastics) structures, avionics, and many fluid components can already be demonstrated in a spaceflight-/launch environment.

Furthermore, the launch of the SR75 also allows HyImpulse a way of commercializing its technology before the development work on the small launcher has concluded. Sounding rocket flights offer a cheap access to microgravity and allow atmospheric researchers to access different layers inside the higher atmosphere, which cannot be reached by either balloons or satellites.

The maiden flight of the SR75 will be conducted in the third quarter of 2021 from Shetland Space Center. Later launches may be conducted from one of multiple different launch sites across the globe, for which a large amount of flexibility exists. SR75 requires only a suitable launch rail, a control room, a supply of LOX and pressurant gas, radio ground stations (including radar tracking), and access to deliver 40 ft-standard shipping containers. All ground support equipment (GSE) designed by HyImpulse has been designed with transportability in mind.

GSE Development

HyImpulse worked on testing and assembly of the GSE, whose purpose is to allow the loading of all propellants into the rocket and prepare it for the lift-off. The motor test campaign on Shetland gave an opportunity for a practical test of the systems developed so far, see Figure 10. The GSE includes most of the fluids components, the control box for the measurement, command, and control (MCC) system, which contains wiring, piping, and sensors for pressure, temperature, and mass flow rate. The GSE can handle fluids with temperatures between -180°C and 100° and a maximum pressure of 400 bar.

Figure 10: Ground Support Equipment (left) and the Shetland Test Campaign Setup (right)

On top of the electrical systems that are anyway part of the sounding rocket GSE, the scope of sensor and control units has been expanded, the hardware was assembled, and tested, including planning for electrical grounding and lightning protection. Ethernet LAN network infrastructure has been set-up and proven operational with data acquisition and control modules as well as with IP video cameras to be used for surveillance and test event live-streaming.

SMALL LAUNCHER 1 (SL1)

SL1 Development Status and Architecture

Concerning the SL1 development, HyImpulse is moving towards sub-system level technical studies of the Small Launcher SL1. SL1 is a three staged launch vehicle with a lift-off mass of around 48 tons and a total length of about 28 meters. It is capable of delivering 400 kg payload to a 500 km sun-synchronous orbit (SSO). The first stage consists of 8 HyPLOX75 motors.

The first stage feed system uses a Gas Generator (GG) cycle with one turbopump supplying 2 HyPLOX75 motors with LOX. A Helium tank is also required in order to pressurize the GG-fuel (ethanol) tank and to initially pressurize the LOX tank.

During the operation of the engine, the ethanol is pressurized with helium the whole time, while the extracted LOX-volume is replaced with gaseous oxygen. The hot exhaust gases from the turbine are used to vaporize a small amount of the high-pressure LOX in a heat exchanger, reducing the amount of external pressurization gas needed. The fuel rich combustion inside the GG results in a very clean exhaust gas with only minimal amounts of soot. The Gas Generator has already been tested, as shown in Figure 11.

Figure 11: Gas Generator Firing Test

The first stage will have thrust vector control on multiple rocket motors in order to control the attitude of the launch vehicle. Additionally, it is being considered to use aerodynamic stabilization with control surfaces on fins during the ascent in the atmosphere. It is possible to recover the first stage of the launcher by parachute. However, it will be assessed during development, if it is economically viable as the hybrid motors by design are single use.

The systems for fluid handling are currently in their design stages, and most of them can quite easily be adapted from the sounding rocket. The main changes to the architecture here lie in the turbopump-feeding, which reduces the pressure levels throughout most of the system and in the pressurization of the LOX-tank with gaseous oxygen from the heat exchanger. This adds more system complexity, but the mass and cost penalty of a bigger pressurization system can be avoided.

HyImpulse is also designing, developing and producing in-house composites tanks for liquid oxygen and the pressurant gas. Figure 12 shows the cryogenic test campaign conducted in March 2021.

Figure 12: Cryo-Testing of the CFRP Structures

Concerning the avionics, HyImpulse is designing and assembling avionics components that will be tested and validated during the first flight of the SR75. The avionics of SL1 will use identical/nearly identical components. Examples of the custom avionics-designs are given in Figure 13 and Figure 14.

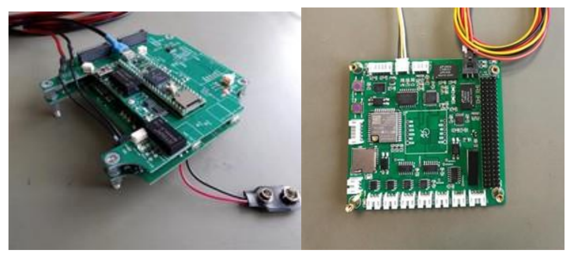

Figure 13: On the left Measurement Unit Power and micro-controller unit, on the right the in-house built interface board for COTS flight controller

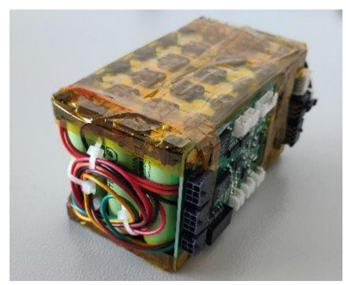

Figure 14: Li-Ion battery pack assembled and ready to be tested together with its electrical control unit

The second stage of SL1 uses 4 HyPLOX75 motors. Due to the higher expansion ratio, the thrust of each engine will be around 100 kN. The attitude control of the second stage again will be realized with thrust vector control. The second stage feed system is the same as the first stage and thus turbopump-based. The third stage of the small launcher will use 4 smaller HyPLOX25 motors and a pressure-fed system. The design parameters of the engines have been optimized according to the flight envelope for a payload of 400 kg to a 500 km orbit. Additional small thrusters are necessary for the attitude control and orbit circularization. Cold-Gas thrusters might be used for attitude control, using the already present pressurization gas. The orbit circularization can be done by a pair of small hybrid rocket motors. Alternatively, an integrated attitude and orbit control system using liquid propellants can be implemented for this smaller propulsive task. The payload, which can consist of a single or multiple small satellites, are connected to the upper stage via an adapter and an optional satellite dispenser.

A concept of the SL1 is proposed in Figure 15.

Figure 15: SL1 Configuration

A summary showing performance and design parameters of each stage is given below in Table 1:

Table 1: SL1 Configuration Overview

Parameter	Value
1st Stage	
Number of Hybrid Motors	8
Required Combustion time [s]	100 - 120
Average Pressure [bar]	60
Expansion ratio	16
Average Specific impulse [s]	~307
Average Sea Level Thrust [kN]	~657
2nd Stage	
Number of Hybrid Motors	4
Required Combustion time [s]	50 - 80
Average Pressure [bar]	60
Expansion ratio	41
Average Specific impulse [s]	~326
Average Vacuum Thrust [kN]	~412
3rd Stage	
Number of Hybrid Motors	4
Required Combustion time [s]	100 - 120
Average Pressure [bar]	11.5
Expansion ratio	30
Average Specific impulse [s]	~316
Average Vacuum Thrust [kN]	~27.5

SL1 Trajectory

Trajectory studies have been conducted in order to verify that the SL1 is able to deliver 400 kg to a 500 km SSO and to estimate the payload performances capability for the below listed orbits:

- SSO
- 80°
- 90°

Simulations have been conducted by considering the launch sites in Table 2:

Table 2: Launch Sites for Trajectory Simulation

Launch Site	Country	Latitude	Longitude
Lamba Ness	UK	60.82° N	0.76° W
Whaler's Way	Australia	34.91° S	135.65 E
Andøya	Norway	69.3 N	16 E

Example mission phases are reported in Table 3:

Table 3: Flight Phases

Mission Phase	Flight Time [s]	Altitude [km]	Flight Speed [km/s]
Lift-off	0	0	0
Pitch-over	4.3	0.04	0.02
Constant pitch	6.2	0.07	0.03
1st stage cut-off	108	38	1.5
2nd stage ignition	135	56	1.41
2nd stage cut-off	195	93	3.6
Faring jettison	238	113	3.5
3rd stage ignition	238	113	3.5
3rd stage cut-off	358	123	8.0
Orbit insertion	3002	500	7.56

An example of the flight profile and of the trajectory is depicted in Figure 16, 17, and Figure 18. They are based on Lamba Ness as launch site and for a 500 km SSO.

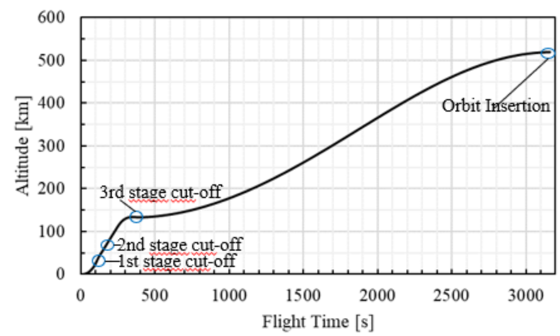

Figure 16: Ascent of SL1

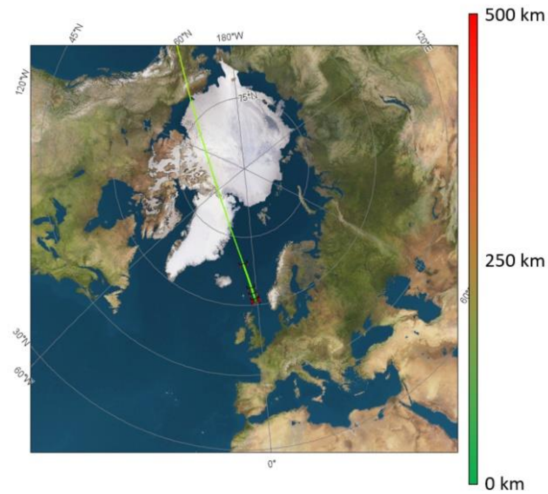

Figure 17: Flight Path from the Launch Site

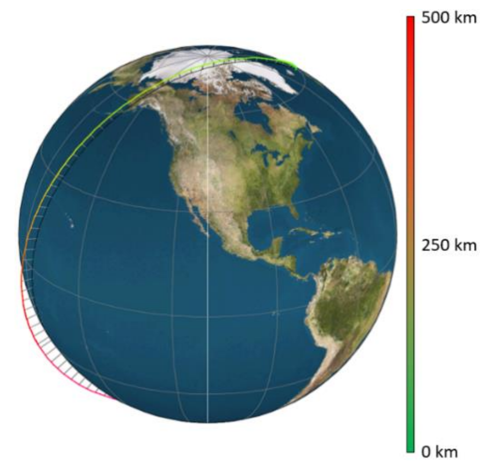

Figure 18: Flight Path Continued

SL1 Concept of Operations (ConOps)

After production of all components, assembled and tested subsystems of SL1 will be shipped to the launch site, where they are integrated as stages, which will then be integrated with one another. The payload will be prepared for launch and encapsulated into the payload fairing inside a clean-room environment, after which it is mated on top of the rocket. At each step along the way, the integrated system is checked to verify that critical systems are functioning nominally. The complete assembly is done in horizontal orientation.

The GSE is installed inside 40 ft-standard shipping containers, in order to achieve good transportability. The containers are delivered to the launch facility and connected to the infrastructure already present. After this installation at the launch facility, the functionality and tightness of all connections is again verified. After this, the GSE awaits the connection of the SL1.

The vehicle is loaded on a Transport and Launcher Vehicle (TLV), which moves the integrated rocket out to the launch pad. Once there, the TLV rotates the rocket into its vertical orientation, Ground Support Equipment is connected, and after some final checks, fluids are loaded. Once complete, fluid lines are disconnected and the SL1 launches. An Overview on the full scope of activities at the launch site is given in Figure 20.

The first stage is optionally recoverable. After it separates from the second stage, it will return to earth on parachutes/gliders, from where it will be picked up, disassembled and reusable components are refurbished and reintroduced into HyImpulse's supply.

In order to ensure flexibility and a responsive access to space, HyImpulse plans to engage multiple launch sites around the world. It has already signed Memorandums of Understanding with SSC Esrange (Sweden), Shetland Space Center (UK), and Southern Launch Whaler's Way Complex (Australia). These locations and others that are currently under consideration are shown in Figure 19. Additionally, due to the increasing interest in small launchers in Germany, HyImpulse is also exploring opportunities of co-development for a naval launch platform in the North Sea.

Figure 19: Potential Launch Sites

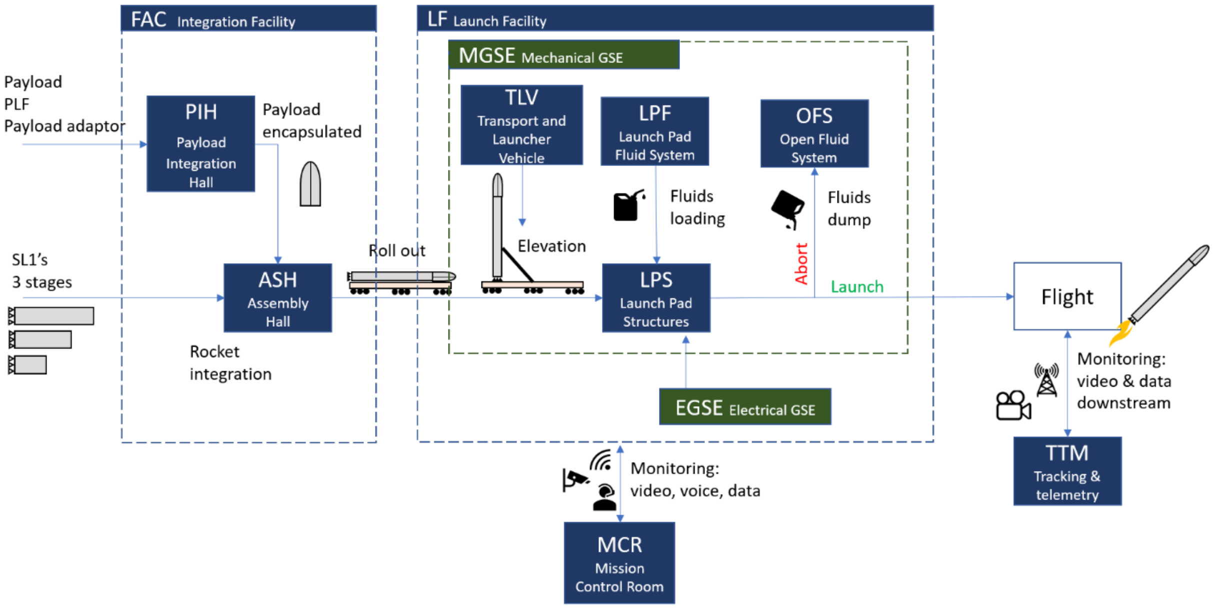

Figure 20: Overview of Launch Site Activities

SL1 Payload Capacity

As mentioned during discussion of the SL1's reference trajectory, the launcher is being designed for a payload capacity of 400 kg into 500 km SSO. Different orbits and launch sites have an impact on this number, as depicted in Figure 21, Figure 22, and Figure 23.

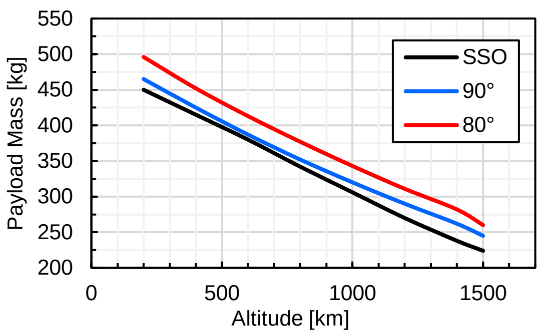

Figure 21: Shetland Payload Performances

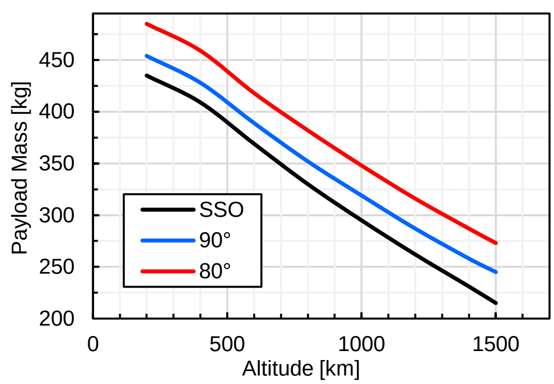

Figure 22: Whaler's Way Payload Performances

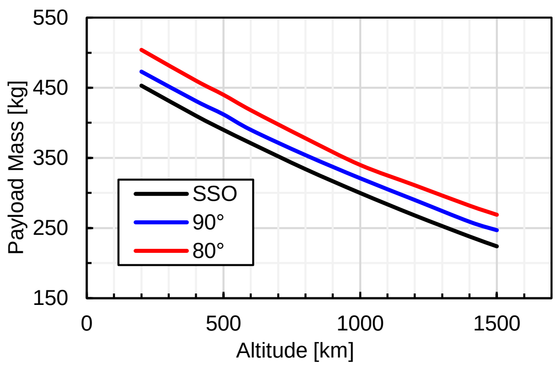

Figure 23: Andøya Payload Performances

SL1's payload volume is currently planned to provide the space depicted in Figure 24. The lower cylindrical section can potentially be extended from 0.2 m to 1.2 m length if necessary.

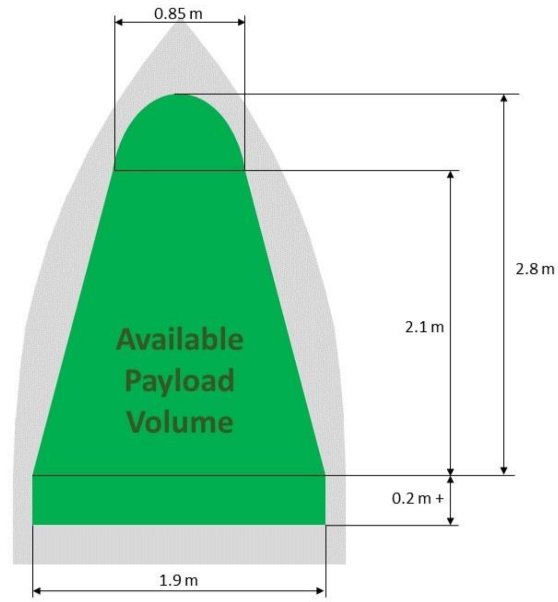

Figure 24: Geometry of Available Payload Volume

CONCLUSION

HyImpulse Technologies, a NewSpace company with its headquarters in southern Germany, counting more than 60 employees from all over the world, growing up to 100 by the end of the 2021, aims to provide dedicated, affordable, reliable, responsive, and environmentally compatible access to space using hybrid rocket propulsion.

This paper highlighted how the market of the small satellites is growing year by year and how it currently does not yet provide enough good launch opportunities for small satellites. It outlined the potential of rocketry to address this unsatisfied demand, by providing a simple, safe, and effective means of propulsion. The liquefying fuel technology utilized by HyImpulse overcomes the traditional draw-back of low thrust densities in hybrid rocket motors by significantly increasing the burn rate of the fuels. HyImpulse utilizes paraffin as fuel, which shows good performance, high safety and is widely available.

In order to combat global climate change, HyImpulse plans to implement a carbon-neutral fuel synthesis, in order to overcome the current drawback of paraffin, of being a product of fossil fuels. This can be accomplished combining the Fischer-Tropsch Process (a method which has been established 100 years ago and has seen some extend of large-scale operations since then) with a syngas-extraction from regenerative sources.

HyImpulse's development efforts regarding its launch service have been portrayed. This involves the first two test campaigns of the large hybrid rocket motor HyPLOX75, which have demonstrated and qualified it for the utilization on the sounding rocket SR75. The latter, having its maiden flight scheduled for the third quarter of this year is also in its final stages of development. The SR75-project serves to accelerate the small launcher's development by providing flight experience with the relevant hardware. The finished sounding rocket also allows HyImpulse a path to commercializing its technology before the end of its main product's development, thus generating additional funding for the small launcher development.

Development of the small launcher SL1 is well underway, and the rocket's architecture has been outlined. SL1 will utilize the HyPLOX75 motors in a gas-generator-driven turbopump-fed configuration on the first two stages (8 motors on the 1st stage, 4 on the 2nd stage) and pressure-fed HyPLOX25 motors (a scaled-down version of its sister engines) on the 3rd stage. Other system developments have been summarized, among which the testing of cryogenic compatible CFRP.

SL1's mission has also been summarized, demonstrating its payload performance into various orbits from relevant launch sites. Ground operations of the SL1 have a limited complexity and a high flexibility, enabling responsive and convenient access to space for HyImpulse's launch customers from one of multiple launch sites across the world.

HyImpulse's mission is to unlock the full potential of the commercial NewSpace industry by eliminating the current bottleneck for frequent, dedicated, reliable, affordable, and sustainable access to space for small satellites by using the in house developed technology based on hybrid propulsion.

Thanks to the rapid growth and to the rapid progress the company is making, a launch service can be provided using the SL1 small launcher from 2023 on. This launch service can cover multiple mission scenarios by operating form varying launch sites.

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