HiSST: 2nd International Conference on
High-Speed Vehicle Science Technology

11–15 September 2022, Bruges, Belgium

CEAS
Council of European Aerospace Societies

Single Stage Suborbital Vehicle (S3V) demonstrator

G. Russo[1], *C. Voto*[2]

Abstract

The mid-to-long term perspectives of suborbital hypersonic spaceplanes require the availability of ultra-fast, winged vehicles, characterized by low wing loading, streamlined fuselages, sharp nose and wing leading edges, able to manoeuvre along flight trajectories at small angles of attack. From another point of view, the cost associated with sub-orbital space access flight is strongly conditioned by the still small dimension of its market and accessibility to critical technologies. Therefore, hypersonic technologies suitable for this market as well as for point-to-point fast transportation can facilitate the endeavour.

HYPLANE is a HTHL Mach 4.5 bizjet-size aerospaceplane conceived by Trans-Tech and University Federico II of Naples and under study within the industrial-academic ecosystem of the Campania Aerospace District (DAC), believing it to be more affordable than larger hypersonic airplanes and with a larger dual-use market. HYPLANE has the aim to offer very fast suborbital flight for space tourism, microgravity experimentation and training, and also shortening time to connect two airports within the door-to-door scenario. The concept is based on the access to stratospheric altitudes (30+km) and suborbital flights as safe as today's commercial air transportation by integrating state-of-the-art enhanced aeronautics and space technologies. Essentially, HYPLANE is mostly based on already relatively high TRL technologies which guarantees a sufficiently short time to market.

The low wing loading configurations and designed ability to manoeuvre along the flight trajectories at small angles of attack, allow HYPLANE to guarantee accelerations and load factors of the same order as those characterizing the present civil aviation aircraft (FAA/EASA specifications). Thanks to its technical features, it may operate from/to more than 5000 airports all over the world even using short runways to take-off and land, which for point-to-point business aviation is paramount. Furthermore, characteristics such as small dimension, configuration and high cruising altitude determine reduced noise in the airports surrounding and low sonic boom impact on ground. These conditions will further facilitate not only the development of the commercial use of such kind of transportation mean, but also its social acceptability.

With the aim to validate the developed technologies on a multi-mission flying vehicle embarking leading-edge aviation and space technologies, a demonstrator is proposed.

DAC is parallelly supporting the development of Grazzanise military airport to become an experimental spaceport, within the frame of the promoted development of the Suborbital Experimental Polygon to be established between Campania and Sardinia regions, and including PISQ (inter-forces polygon of Salto di Quirra). This Suborbital Experimental Polygon will make available the perfect operational scenario where to test and make use of the supersonic/hypersonic demonstrator.

This paper intends to update the status of the HYPLANE project as reported in [1].

Keywords: hypersonics, suborbital flight, demonstrator, single stage, spaceport

---

[1] *Campania Aerospace District, DAC, Via Coroglio 57, 80124 Naples - Italy, g.russo@daccampania.com*

[2] *Campania Aerospace District, DAC, Via Coroglio 57, 80124 Naples - Italy, c.voto@daccampania.com*

Acronyms/Abbreviations

ATC	Air Traffic Control
ATM	Air Traffic Management
CAGR	Compound Annual Growth Rate
CFD	Computational Fluid Dynamics
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FL	Flight Level
HASA	Hypersonic Aerospace Sizing Analysis
HTHL	Horizontal Take-off Horizontal Landing
L/D	lift-over-drag ratio
MTOW	Maximum Take Off Weight
SERJ	Supercharged Ejector Ram-Jet
STEP	Suborbital TEst Polygon
TRL	Technology Readiness Level

1. Introduction

In recent years, some private enterprises have been approaching Space Flight with a relatively low-cost philosophy. Available survey studies assessed the potential market for suborbital vehicles, showing that there is a potential sizable market for suborbital tourism. Number of people willing to pay tickets in the range of 200 k€ for this experience could be in the order of 50000 in some 15 years after the market start. Secondary markets directly linked to the commercial sub-orbital flights will include microgravity research, high altitude aerospace technological testing and development, astronauts training, remote sensing but also entertainment, movie making and publicity.

Although many believes that such situation will rapidly evolve toward much more interesting business numbers, this market size still does not support definitively the development of a new aircraft/spacecraft, and this is the reason why only pioneering enterprises are playing this role today.

On the other side, business world is becoming faster and faster and it requests a transportation system to adequately follow these needs. Up to 2017, the business jet market was the one with the highest growing rate in the aviation industry. The event of the COVID-19 pandemic changed drastically the overall general aviation scenario. In particular, high-speed point-to-point flights address in large part the segment of urgent business travel for passengers as well as fast cargo transportation for special goods/products such as mail and express, pharms, valuables live, perishable goods, transcontinental organ transport.

Despite the sharp reduction from 2019 to 2020, the worldwide Business Jet market confirms the trends in private travel vs. commercial ones and continue to maintain a trend of about 750 new aircraft deliveries per year in 2021 and 2022-Q1[3]. Even more, the market for the business jet was valued at USD 15.25 billion in 2020 and has already reached about USD 13.7 billion in the first quarter 2022. It is anticipated to register a Compound Annual Growth Rate (CAGR) of 2.50% during the forecast period (2021-2026), thus going in 2026 beyond the market dimension of 2017-2018, the years of the last revision of HYPLANE market analysis.

Most of supersonic or hypersonic commercial designs have tended toward large aircrafts, characterized by hundreds of tons of mass and hundreds of passengers. This has resulted in great difficulty in determining a valid sustainable operational concept, because of very large costs. In addition, the system concepts were often very complex, requiring very long time to reach the required TRL.

The HYPLANE concept was originated in the perspective to satisfy very special requirements of both sub-orbital space flight and ultra-fast transportation [1-4], addressing the action "safer and greener aviation in a smaller world", inspired by the following targets of the European Commission's Space Strategy for Europe[4] and Aviation Vision[5]:

---

[3] GAMA - General Aviation Manufacturers Association Report 2022 First Quarter (issued on 2022-05-19)

[4] Space Strategy for Europe, COM(2016) 705 final *https://stip.oecd.org/stip/interactive-dashboards/policy-initiatives/2021%2Fdata%2FpolicyInitiatives%2F26561*

[5] Flightpath 2050 - Europe's Vision for Aviation, Maintaining Global Leadership & Serving Society's Needs, European Commission Policy, 2011, doi: 10.2777/50266

- Maximise the benefits of space for society and the EU economy, by promoting the exploitation of altitudes between FL600 (= 18km) and 100km, which are currently underused;
- Contribute to a more competitive European aerospace sector, through the development of a very innovative concept for commercial aerospace transportation;
- Reinforce Europe's competitiveness and autonomy in accessing high altitudes in a safe and environmentally friendly manner, by making aircraft cleaner and quieter to minimise transport's systems' impact on climate and the environment;
- Make Europe the safest air space in the world and provide the best products and associated services in air transport, carrying travellers and their baggage from door-to-door, safely, affordably and quickly.

2. The HYPLANE aerospaceplane family

HYPLANE (see Fig. 1) is a new concept of ramjet-based hypersonic small transportation system conceived to offer suborbital space flights for space tourism perspectives as well as very fast flights, shortening time to connect two airports within the door-to-door scenario in the frame of the "urgent business travel" market segment. The concept is based on the access to space from stratospheric reference altitudes (30+km) as safe as today's commercial air transportation.

Fig. 1. HYPLANE Configuration 3.2 rendering

The reason to propose the flight demonstrator S3V of the HYPLANE is based on the maturity of the concept [4] and its technical/economic credibility: the significant amount of study carried out in the years, with technical, economic and technological evaluations presented worldwide at various international conferences [1, 2, 4, 7, 8], demonstrated its feasibility (which mainly derives from the integration of state-of-the-art enhanced aeronautics and space technologies) and resulted in the fact that its technological and market readiness is easy within reach. Essentially, HYPLANE is mostly based on already relatively high TRL technologies which guarantees a sufficiently short time to market.
Thanks to its technical features, it may operate from/to more than 5000 airports all over the world even using short runways to take-off and land, which for point-to-point flight is paramount. Furthermore, characteristics such as small dimensions, slender configuration and design flight trajectories determine reduced noise in the airports surrounding and low sonic boom impact on ground. These conditions will further facilitate not only the development of the commercial use of such kind of transportation mean, but also its social acceptability.

Thanks to its great concept versatility, a family of applications has been introduced as shown in Fig. 2, ranging from the above mentioned original HYPLANE target missions of suborbital flight and stratospheric cruise, to the military surveillance and interceptions missions (tagged HYPERION), to the semi-reusable/reusable space launch capabilities from 50-60km altitude (tagged HYLAUNCH).

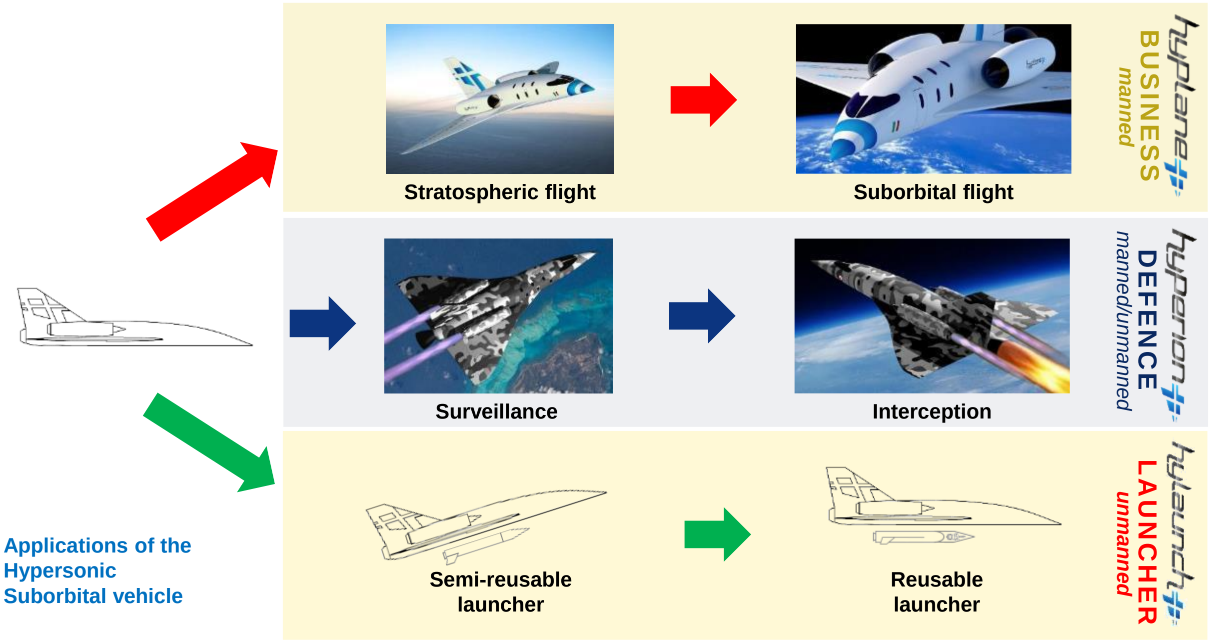


Fig. 2. HYPLANE family of applications

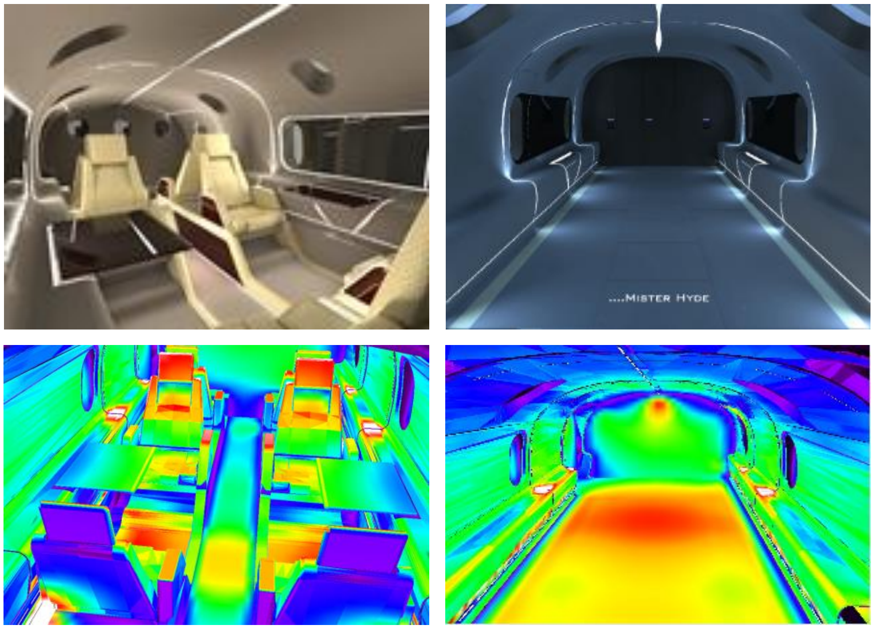
3. Main Characteristics

3.1 Configuration

The 27.5t MTOW vehicle configuration is characterized by a 140 m^2 wing area, high lift-over-drag ratio and low wing loading to guarantee a very low operational load factor all along the flown trajectories. The propulsion system is based on combined cycle turbo-ramjet engines associated with a booster capability. It is a six-seat small-sized (24.7m long, wingspan 16.3m) spaceplane with a high-performance wing and a vertical tail providing good flight stability characteristics both in subsonic and super/hypersonic regimes. The cabin environment is designed to maintain a comfortable temperature and pressure for the occupants, while providing an excellent view of the Earth from space. To allow best use of the cabin during the microgravity conditions along the suborbital trajectory, the cabin is automatically reconfigurable from the seat to the empty configuration and back. It is thus called "*Dr Jekyll and Mr Hyde*" (Fig. 3).

During the last design iteration in 2021-2022 some modifications have been introduced to strengthen aircraft characteristics. They can be summarized as follows:

- the GOE9K aerodynamic wing section has been adopted
- the wing has been moved in its lowest possible configuration with respect to the fuselage (low-wing configuration), with the aim to reduce structural interferences between fuselage-wing structures and cabin space
- the wing has been moved 1m forward for a better position of the vehicle Centre of Mass
- a $\Gamma=5°$ dihedral angle has been introduced
- the vertical tail has been modified to have a bit more surface area and moved 1m backward to have a larger distance from the Centre of Mass, with the aim to increase stability and manoeuvrability
- the two airbreathing engines have been moved 1m upward to reduce the aerodynamic complexities associated with the very tight configuration of fuselage-wing-engine.



Dr Jekyll

Mr Hyde

Fig. 3. Reconfigurable "Dr. Jekyll and Mr. Hyde" passenger cabin (top) and related lighting rendering (down)

The new HYP4.0 configuration shown in Fig. 4 has resulted and is actually subject to further analysis. Studies are ongoing also on other aspects of the interiors (e.g., galley and lavatory, hold luggage, external service access, etc.), as shown in Fig. 5.

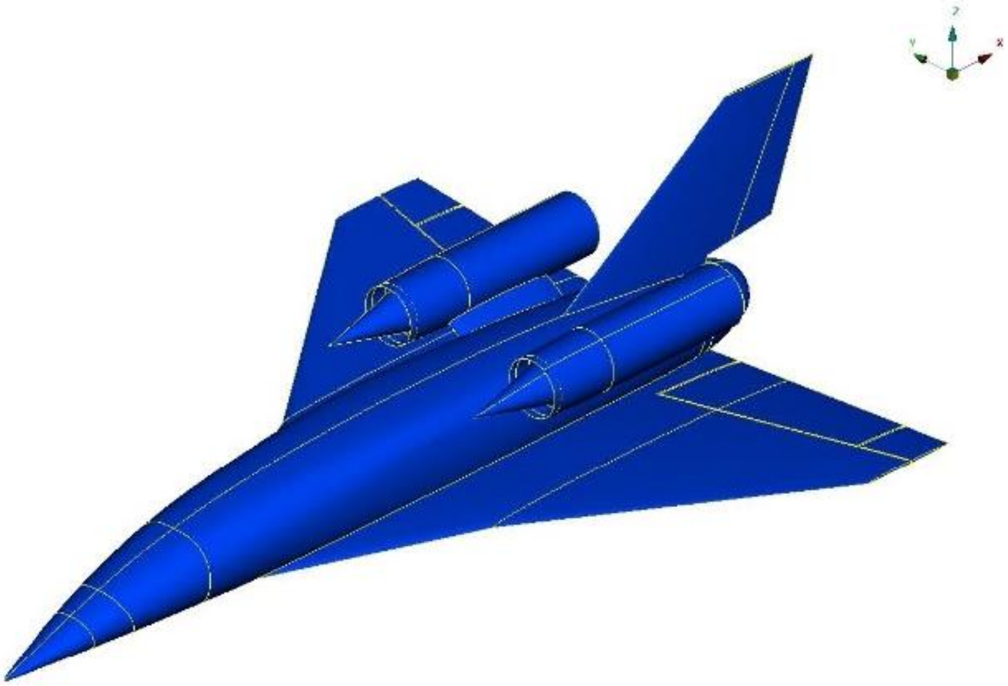


Fig. 4. HYPLANE Configuration HYP4.0

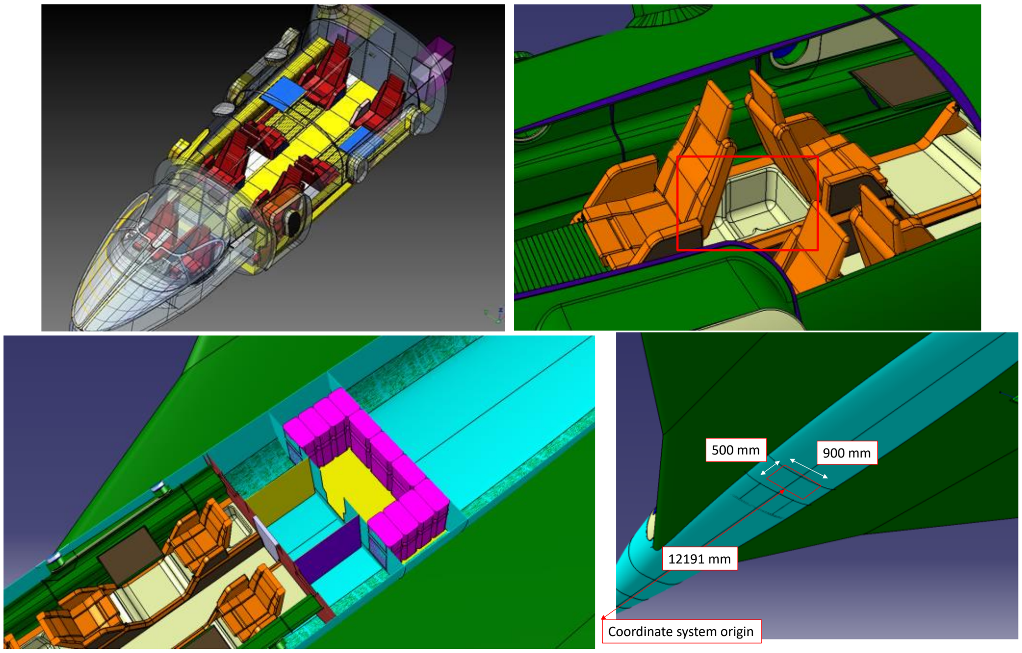
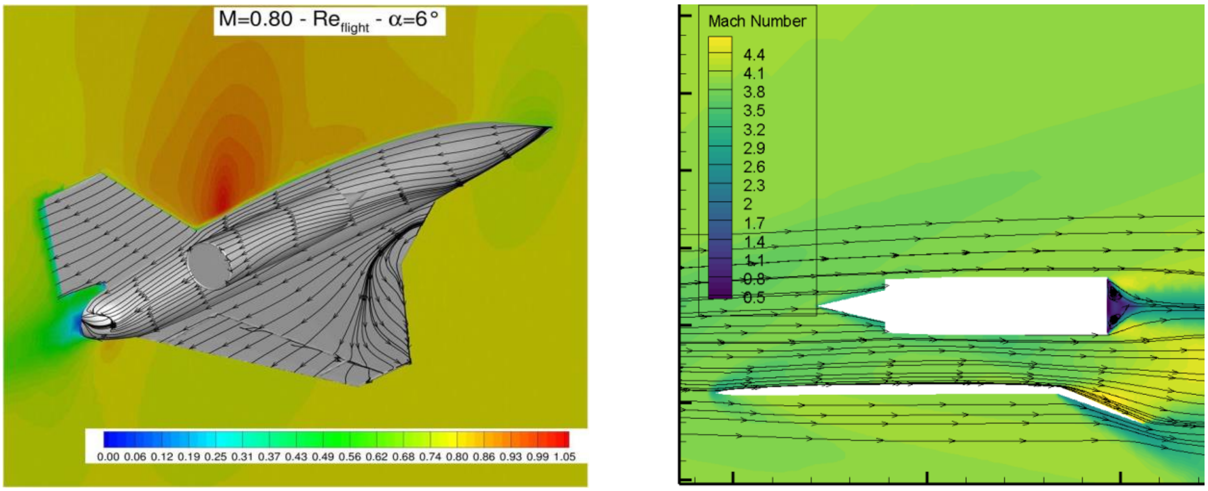


Fig. 5. Studies of cabin elements

3.2 Aerodynamics

The aerodynamic configuration is characterized by a lift-over-drag ratio L/D > 4.5 at 6-8 deg angle of attach and a low wing loading factor (between 85 and 130 kg/m^2) at hypersonic speed in order to guarantee operational load conditions around 1.2g along stratospheric point-to-point flight paths. The same vehicle will experience max accelerations around 4.2g during the pull-up manoeuvres associated with suborbital space tourism flights.

The large surface of the wing has the advantage to allow to take off and land at low speed (60 m/s). Thus, the spacecraft is able to perform a Horizontal Take off and Horizontal Landing (HTHL) on short-medium length runways (<1000 m). Figure 6 is an example of the subsonic aerodynamic characteristics of the clean HYPLANE configuration at α= 6 deg showing very smooth skin friction lines with the expected wing leading edge vortex.



a) b)

Fig. 6. Mach number contours: a) skin friction lines at subsonic speed; b) streamlines at supersonic speed in the wing-nacelle zone

Starting from the previous data [4, 5], the aerodynamic database of HYPLANE configuration HYP4.0 has been reassessed including aerodynamic and moment coefficients, stability and control derivatives, as function of flight parameters (angle of attack, Mach number, altitude, control surface deflections) for subsonic, transonic, supersonic and hypersonic regimes. The aerodynamic characteristics have been evaluated up to 100km altitude considering air rarefaction effects [8]. All the aerodynamic data have been then treated with regression/interpolation/extrapolation methods following the expected physical behaviour of the aerodynamic coefficients in order to achieve the best evaluation of them in all conditions of the manoeuvre diagram. Some of the characteristics of the Aero Data Base are given in Fig. 7.

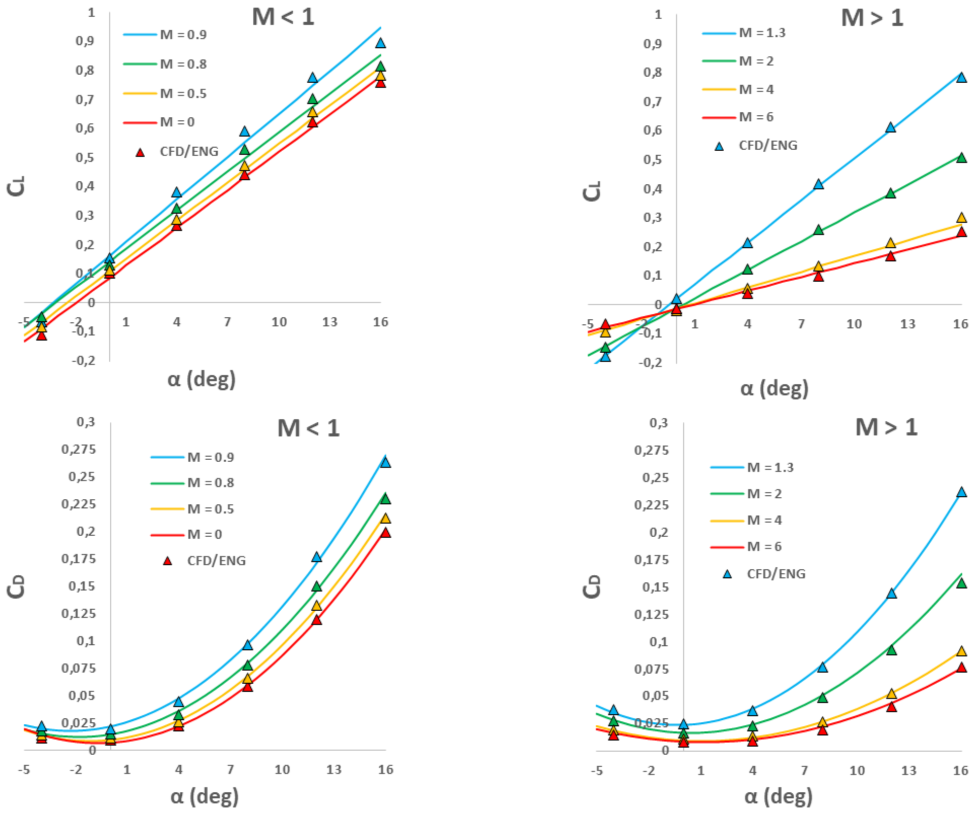


Fig. 7. Aerodynamic characteristics

3.3 Structures and materials

One of the most important problems during the hypersonic flight is the aerothermal heating. It is due to the high heat fluxes on the outer surface of the vehicle and the high ratio between surface and volume of the vehicle itself. In order to support proper material selection, different analysis of aerothermal environment was carried out by means of CFD simulations [1,2,4]. Figure 8 shows the surface temperature distribution for the new configuration obtained by imposing the radiative balance when cruising (steady state conditions) at Mach 4.5 and 30km altitude at an angle of attack α=5 deg. It is noted that areas of few centimetres in the stagnation flow zones reach temperatures not far from 600°C. Beyond these very hot areas, the windward side of the aircraft remains at an almost constant temperature of 330-360°C for an emissivity ε=0.8, which rises to 380-420 for ε=0.4. The temperature along the x-axis on the leeward side varies much more, ranging from 240 to 430°C for ε=0.8, and from 300 to 480 for ε=0.4.

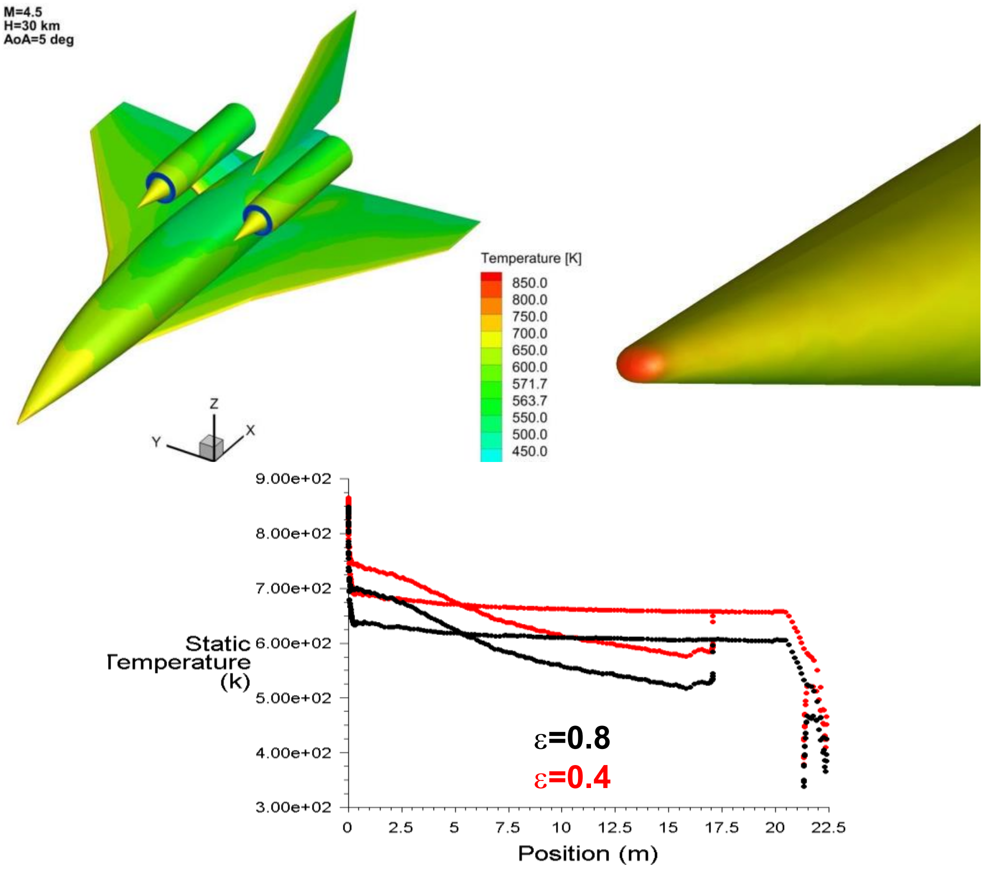


Fig. 8. Radiative equilibrium temperature at M∞=4.5 and H =30km altitude and for α=5 deg. (a) contours for ε=0.8 on the entire vehicle; (b) contours for ε=0.8 on the first 10 cm of the nose; (c) comparison of whole fuselage longitudinal temperature for ε=0.8 (black) and ε=0.4 (red)

Thus, it is possible to identify three different areas for material selection:

- Nose, wing and tail leading edges, engine inlet lip and spike nose, parts of control surfaces (flaperons and rudder), which reach temperatures above 550°C. For these areas high performance alloys (e.g., Inconel) as well as actively cooled or semi-passive solutions can be used. Alternatively, more sophisticated and performant ceramics materials with reinforcing fibres such as Boron Carbide (B4C) or Silicon Carbide (SiC) are applicable.
- Large parts of fuselage and wing windward surfaces are expected to reach temperatures in the range of 330-420°C. Titanium alloys are good solutions to implement.
- The rear parts of the fuselage and wings especially for the leeward side are estimated to be exposed to temperatures below 300°C; high temperature resistant carbon fibre composite materials can be used to save weight with respect to the already selected titanium alloys.

From the mechanical loads point of view, the aerostructures have been dimensioned on the basis of the following loading conditions:

LIMIT Loads	1* Gust Pull-Up (6.7 g) + 1* Aerodynamic Loads + 1* Thermal Loads
ULTIMATE Loads	1.5* Gust Pull-Up (6.7 g) + 1.5* Aerodynamic Loads + 1* Thermal Loads

3.4 Propulsion

High performance propulsion capabilities are required in order to guarantee high altitude and speed, necessary to achieve the double goals of sub-orbital flights and point-to-point stratospheric hypersonic trip. For that reason, the propulsion system is based on a twin axisymmetric combined cycle turbo-ramjet (30kN per engine at Mach 4.5 and 30km altitude) associated with a boosting function (overall 200kN at 30km altitude), which can be obtained by either an independent liquid rocket or an integrated Supercharged Ejector Ram-Jet (SERJ) configuration which was studied in 1960-1970 up to a subscale ground testing level. Having both a fan-supercharging turbine element and an internal rocket subsystem, SERJ comprises design features of both TBCC and RBCC engine types. It can be seen as the combination of traditional ROCKET and typical AIR-BREATHING propulsive elements into a single integrated engine, combining their most desirable characteristics.

Figure 9 shows the schematic of the SERJ propulsion system, which is characterized by the following subsystems:

- Adaptive supersonic inlet
- Fan
- Rocket
- Mixer/diffuser
- Diffuser
- Combustion chamber
- Variable exit nozzle.

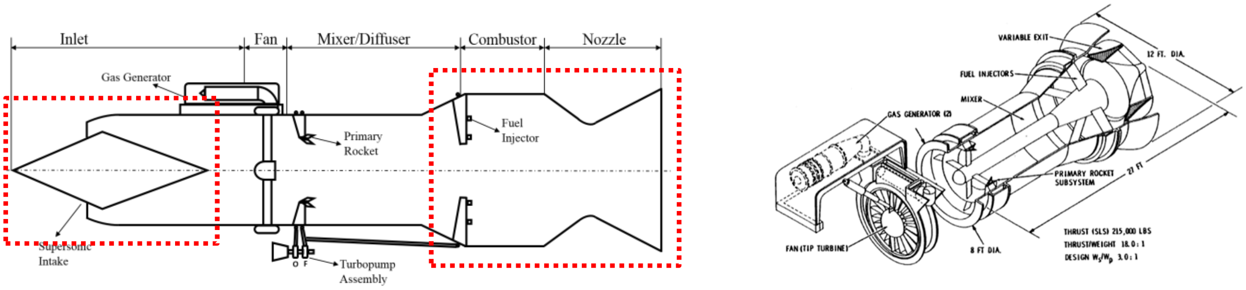


Fig. 9. Schematic of SERJ propulsion system

During take-off and acceleration, the engine works as a *fan-ramjet* or *ejector-ramjet*. As the aircraft accelerates through Mach 3, the fan or the ejector is shut down and the intake air is ducted, by guide vanes, straight into the afterburner, which becomes a ramjet combustion chamber.

In terms of fuels, adopting again the philosophy to use available or easy to reach technology, we assume the use of high-performance present aviation JP7 or JP10, or equivalent performance SAF. The lack of atmospheric oxygen during part of the suborbital flight is overcome with the use of 95% H_2O_2.

The SERJ cycle is shown in Fig.10 while its main thermodynamic characteristics at Mach 4 and 4.5 are given in Fig. 11.

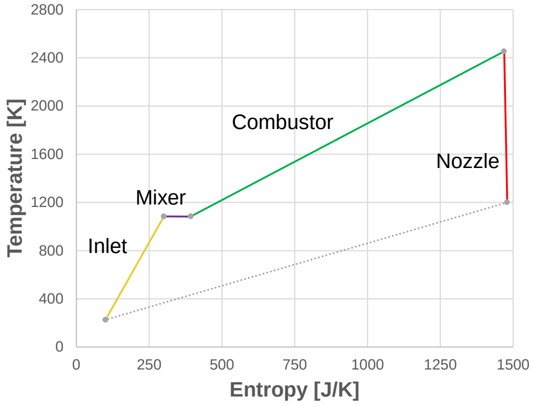


Fig. 10. SERJ thermodynamic cycle

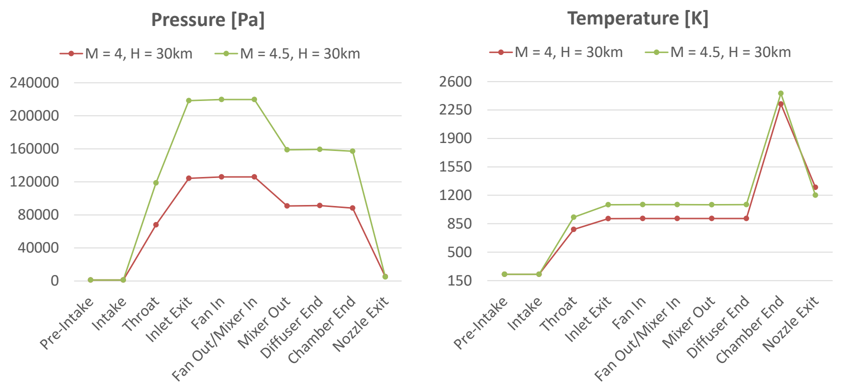


Fig. 11. SERJ ramjet mode thermodynamic properties

The operational modes of the SERJ propulsion system are [1,6]:

- Fan-ramjet
- Ramjet
- Supercharged Ejector Ramjet
- Ejector Ramjet.

Three main operating envelopes can be identified (Fig. 12):

- Fan Envelope limited by maximum Mach number and maximum altitude cruise efficiently at high Mach numbers like a ramjet
- Ramjet Envelope limited by minimum Mach number and maximum altitude
- Ejector-Ramjet Envelope covering the previous envelopes and higher altitudes (because of the rocket capabilities)

It combines the ability:

- to take off and climb like a rocket – for very demanding requirements, such as for super/hypersonic interceptor with a quick response time
- cruise efficiently at high Mach numbers like a ramjet
- to fly subsonic and loiter like a high bypass ratio fan - for low fuel-consumption subsonic cruise capability

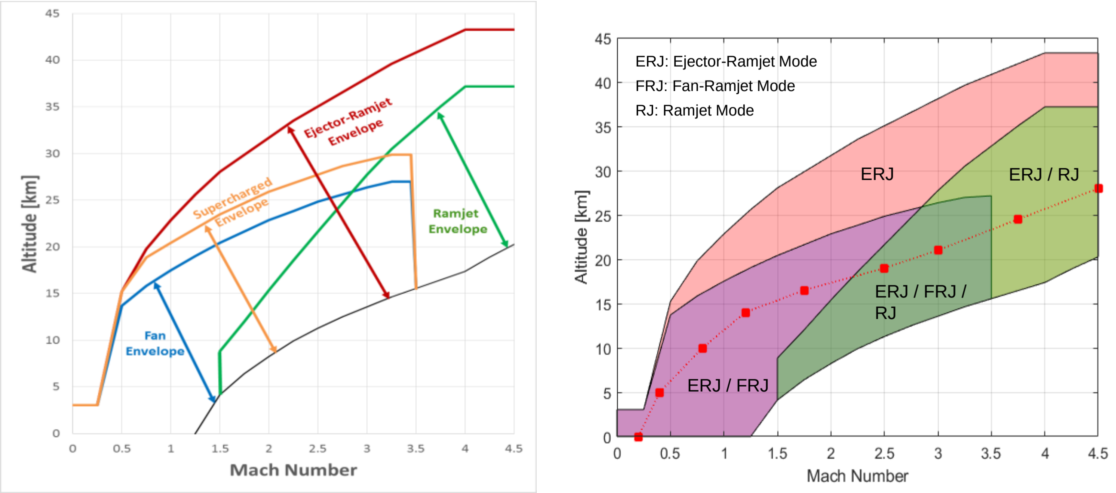
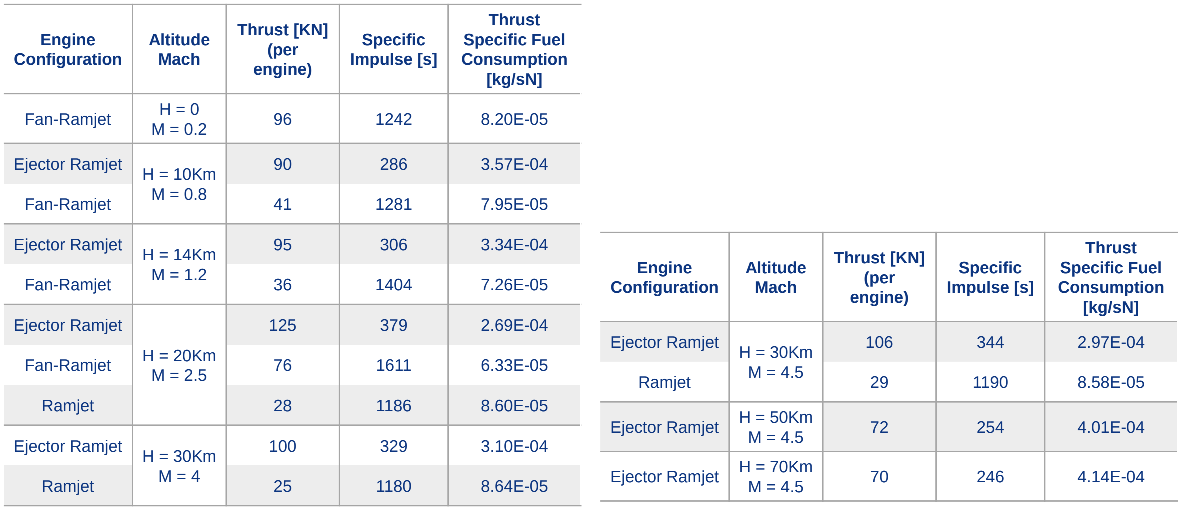


Fig. 12. SERJ Engine Performance. A typical ascent flight up to cruising Mach 4.5 is also shown

The performances of the engine at the reference characteristic flight conditions are given in Fig. 13, for a single engine.



Engine Configuration	Altitude Mach	Thrust [KN] (per engine)	Specific Impulse [s]	Thrust Specific Fuel Consumption [kg/sN]
Fan-Ramjet	H = 0 M = 0.2	96	1242	8.20E-05
Ejector Ramjet	H = 10Km M = 0.8	90	286	3.57E-04
Fan-Ramjet		41	1281	7.95E-05
Ejector Ramjet	H = 14Km M = 1.2	95	306	3.34E-04
Fan-Ramjet		36	1404	7.26E-05
Ejector Ramjet	H = 20Km M = 2.5	125	379	2.69E-04
Fan-Ramjet		76	1611	6.33E-05
Ramjet		28	1186	8.60E-05
Ejector Ramjet	H = 30Km M = 4	100	329	3.10E-04
Ramjet		25	1180	8.64E-05

Engine Configuration	Altitude Mach	Thrust [KN] (per engine)	Specific Impulse [s]	Thrust Specific Fuel Consumption [kg/sN]
Ejector Ramjet	H = 30Km M = 4.5	106	344	2.97E-04
Ramjet		29	1190	8.58E-05
Ejector Ramjet	H = 50Km M = 4.5	72	254	4.01E-04
Ejector Ramjet	H = 70Km M = 4.5	70	246	4.14E-04

Fig. 13. Performances of Different Engine Configurations (propellants: Hydrogen Peroxide-Kerosene)

3.5 Mass budget

A mass budget has been elaborated on the basis of statistical correlation and engineering design of specific subsystems. The following assumptions have been taken into account:

- According to the FAA, all persons (passengers and crew) are weighted 100 kg each, considering all adult, male and traveling in winter.
- The fuel weight depends on the aircraft configuration and on the mission requirements.
- Vehicle empty weight is estimated from statistics on the basis of HASA model proposed in literature.

The maximum weight of the spacecraft at take-off (MTOW) is estimated to be about 27500 kg, including 1300 kg for unforeseen elements and fuel as follows:

- suborbital flight: 7000 kg of kerosene (9000 litres) plus 8600 kg of oxidizer (12000 litres)
- stratospheric flight: 16000 kg of kerosene (21000 litres).

The structural weight is 5700 kg and the empty weight is 9400 kg. The system mass breakdown is shown in Fig. 14 for both the MTOW and EW.

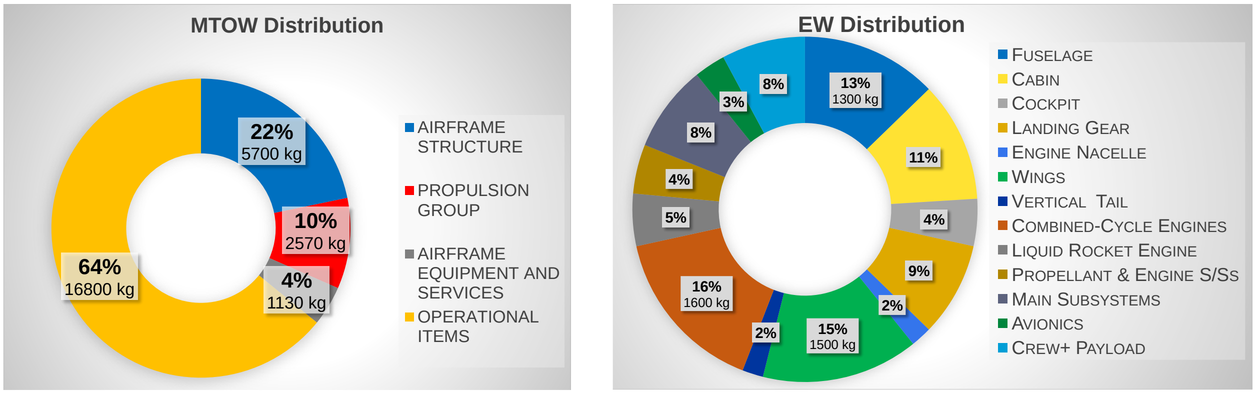


Fig. 14. System mass breakdown: a) maximum take-off weight, b) empty weight

The centre of gravity is located at X_{CG}=14.8 m from the nose apex (60% of the 24.7 m aircraft length) at take-off (MTOW). The spacecraft layout is such that, as the propellant is consumed during the flight, the centre of gravity has a limited excursion in the longitudinal direction reaching the position X_{CG}=13.4 m at zero-fuel (EW) conditions, while its variation in the vertical direction is negligible.

3.6 Reference mission profiles

A fundamental characteristic of HYPLANE is that it can make use of a great majority (80%) of existing airports, being able to take-off and land from less than 1000 m long runways. This gives HYPLANE a great advantage over many other proposed hypersonic spaceplanes.
According to both sub-orbital and stratospheric flight scenarios, a reference mission profile includes the following phases [1,2,3,4,5]:

- Horizontal take off at 60m/s from a conventional runway
- Subsonic climb to altitudes between 5 and 10km with speed up to 240m/s (Mach 0.8)
- Transonic–low supersonic climb from 10 to 20km altitude, speed from 240 to 740m/s or Mach from 0.8 to 2.5
- High supersonic climb from 20 to 30km, speed from 740 to 1370m/s or Mach from 2.5 to 4.5
- Depending on flight scenario:
  - Suborbital manoeuvre/s
  - Hypersonic cruise at 30km mean altitude and Mach 4.5
- Gliding descent from 30 to 5km altitude, speed from 1370 to 200m/s or from Mach 4.5 to Mach 0.6
- Final approach from 5 to 0km altitude, speed down to 100m/s
- Horizontal landing at 60m/s.

Figures 15 and 16 show respectively the mission profile for suborbital flight and point-to-point high-speed stratospheric cruise, where it is evident that the flight phases from take-off up to the reference flight condition (characterized by M=4.5 and H=30km) and back to landing are the same. In the suborbital flight situation, HYPLANE can perform either one parabola to the Karman line at 100km or up to three parabolas up to 70km in a single flight; a downrange of about 2500km is associated with a flight duration of 65 minutes. In the case of stratospheric hypersonic cruise, HYPLANE is able to fly an overall range of about 6500-7000km, covered in some 110 minutes (less than two hours).

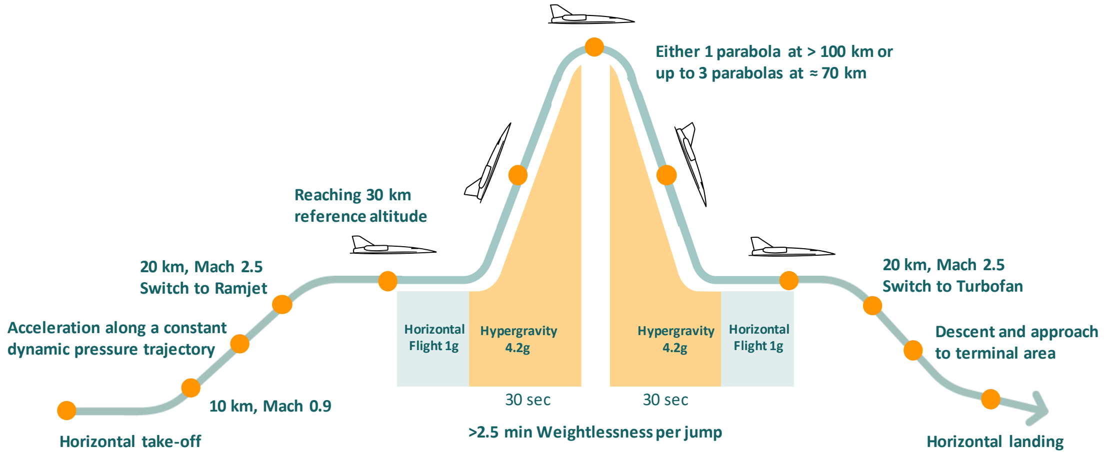


Fig. 15. Suborbital reference mission

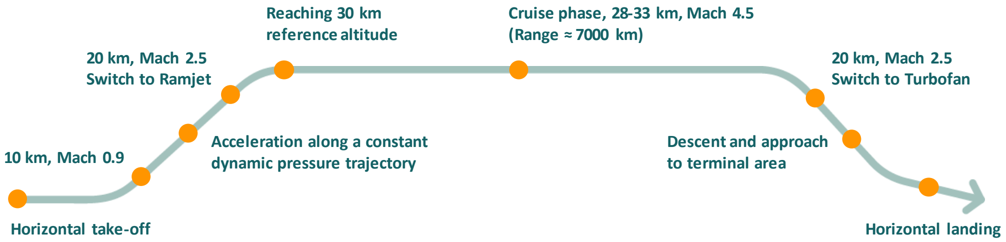


Fig. 16. Stratospheric cruise reference mission

An important challenge is represented by the integration of HYPLANE operations in the ATM/ATC, with the idea or eve requirement to minimize the impact on present commercial aviation. From the mentioned point of view, the ambitions of the HYPLANE project are:

A) Contribute to the introduction of small high supersonic or low hypersonic vehicle into the airspace (ATM) scenario as a pathfinder for the development of future larger supersonic/hypersonic airplanes operations.

B) Optimize the impact of this class of aircraft through a synergic and interdisciplinary approach that allows the design of low impact environmental aircraft and make them compatible with current or upcoming regulations.

C) Preparing the road map (methods and design tools) for new standards for certification of high supersonic aircraft.

With this ambition in mind, the HYPLANE reference missions have been studied and associated with the following operational scenarios:

City Pairs

The use of HYPLANE on a suborbital trajectory for medium range distances, not only aims to provide a flight experience at a speed of about 5,000 km/h, but would drastically reduce flight times (Fig. 17). The most appropriate and convenient operational scenario in this case is the so-called "City Pairs", with ad hoc procedures to be developed to guarantee interoperability of HYPLANE in the worldwide ATM scenario with specific regards to altitudes below FL600, considered today as the upper limit for controlled airspace (category A). Activities are going on worldwide (e.g., FAA and EASA) to define the new rules for aircraft which will occupy the "extended air space" above FL600.

Fig. 17. City-Pairs mission profile

Augmented Free Flight

The HYPLANE stratospheric cruise can be associated with the Augmented Free Flight. Airborne Self Separation, also called Free Flight, represents the most advanced ASAS application and corresponds to a complete delegation of responsibility to the pilot of the aircraft operating within a specifically designated airspace (FFAS, Free Flight Airspace). Within this specific airspace, the pilots - with the help of the ASAS on-board systems available - will maintain instrumental separation with the other aircraft. The ATC is expected to perform a back-up function and provide the alarm and information service within the FFAS. Compared to Managed Airspace (MAS) which includes both Fixed Route Airspace and Free Route Airspace, the roles and responsibilities of Air Traffic Control Services in Free Flight airspace are limited to supporting the aircraft in distress (control by exception), information provision, airspace density monitoring and assistance during the transition between FFAS and MAS. HYPLANE, extending into high-space through the development of curvilinear direct segments, will be able to adapt to the availability of airspace. This concept will therefore allow the pilot of the platform in question to freely decide the cheapest / fastest route within the Free Flight airspace.

Thus, a possible mission profile includes descent and ascent rates compatible with normal ATM operations around airports and beyond and an orthodromic track on the ground. The elevation and climb rate profiles of the proposed scenario are shown in Fig. 18.

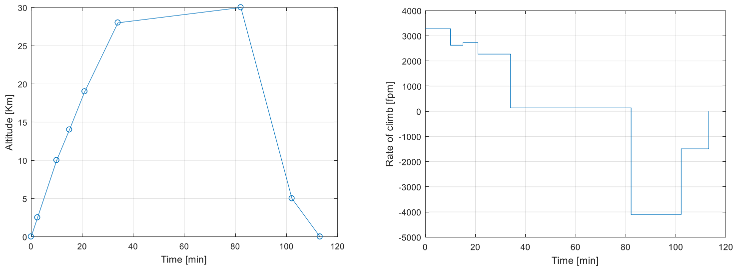


Fig. 18. Augmented Free Flight mission profile

The pilot can plan a route between a defined entry point and an exit point; this concept therefore allows you to choose a direct route without referring to the network of routes (where possible). The points mentioned, tagged as "Extended Supersonic Fixed Point (E-SFP)", define the "transition" from VFR (visual flight route) to IFR (instrumental flight route).

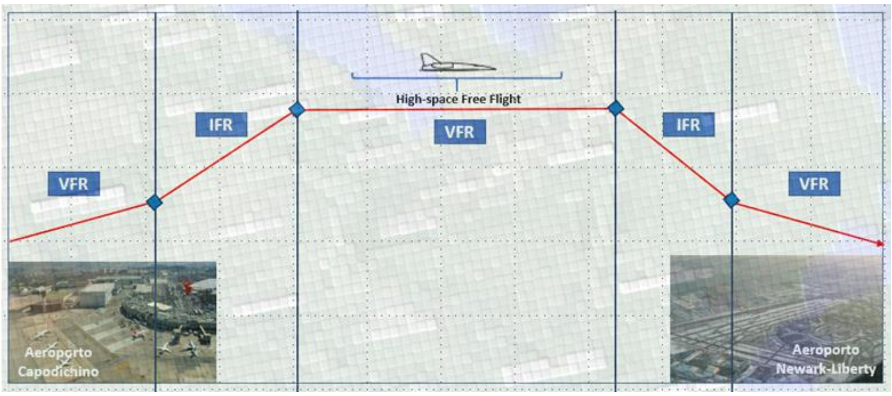


Fig. 19. E-SFP Free Flight

4. The demonstrator

As above said, the suborbital market estimates encouraging but still not robust because of lack of data (the segment is still at its inception). This is the main reason why the entire suborbital flight industrial scene is today dominated by few pioneering rich entrepreneurs.

The way to pursue the game is to reduce the initial investment by focusing on somewhat limited performances and non-certified commercial products. This is the case of flight demonstrators, which may also find contribution from institutional entities to support the development of advanced ideas, technologies, systems [3].

According to this logical line, the development of a demonstrator for HYPLANE has been already introduced in [1,8]. The S3V (Single Stage Suborbital Vehicle) is intended to demonstrate the aerospaceplane design and affordability while being used as an experimental spacecraft (in the logic of X-planes) for microgravity experimentation, training of pilots and astronauts, flight dynamics and other aerospace technologies testing, advancements in suborbital guidance and manoeuvres.

The following simplification will be implemented to use fully available technologies at the maximum possible extent and reduce development costs:

- Shape and scale: fully equal to HYPLANE
- Aerostructure: titanium alloys
- Propulsion system: twin EJ200 turbofan (from Typhoon) or RB199-34R (from Tornado) + rocket booster
- People on board: one experimental pilot or unmanned

The target demonstration missions to be:

- suborbital jump as high as possible towards 100km with some 400km downrange
- no more than 1000km stratospheric flight

The development cost is estimated to be about one tenth of the HYPLANE full development costs, i.e. about 200 M€. It is also estimated that the demonstrator could be built in about 4 years.

5. The Suborbital TEst Polygon (STEP)

One of the issues in developing the access to suborbital space is the identification of spaceports. The perimeter of spaceports in terms of requirements is very wide and still not fully standardized. A first distinction is done between institutional and commercial infrastructures, the first including all space launch site on Earth as well as those experimental airports (mainly military) from where specific flight campaigns have been conducted. After the first inception, many nations are promoting/proposing today the realization of spaceports, being them dedicated to vertical launches and/or horizontal take-off and landing. In Italy, the Grottaglie airport near the city of Taranto has been officially identified as the first Italian commercial spaceport. In the same time other initiatives exist in a similar direction.

So, the Campania Aerospace District is proposing and supporting the development of Grazzanise airport to become a HTHL suborbital spaceport. It has relevant specific characteristics that ease the safe operations (Fig. 20). In fact, the 3km runway is directed toward the Tyrrhenian Sea from which it is only 10km apart, with very few settlements and human activities on ground. Grazzanise is also a node in the national ATM network and this situation should facilitate the management of the activities with respect to the ordinary air traffic over the area.

Grazzanise Safe Spaceport	ICAO Indicator: LIRM 2990 x 30 m airway ATS Authority: Italian Air Force Special Rules for VFR Traffic: see ENR 6.3-9 Less than 10km away from the sea Few and scattered habitations

Fig. 20. Grazzanise proposed spaceport

On top of this, taking advantage from the specific relative position of the runways of Grazzanise and a couple of airports in Sardinia (Tortolì and Decimomannu, about 400km from Campania) on the other side of the Tyrrhenian Sea, the development of the Suborbital TEst Polygon (STEP) is proposed. Apart from the mentioned airports, STEP will benefit from the long-lasting operational PISQ (inter-forces polygon of Salto di Quirra) with a 50000+km^2 segregated areas between Campania and Sardinia regions. This Suborbital Experimental Polygon will make available the perfect operational scenario where to test and operate the S3V demonstrator, according to the indications given in the previous paragraph.

6. Conclusions

The Space Tourism market has started and is spreading around the world, with the perspective of a much cheaper ticket price than the one offered today. Meanwhile, it is clear that aviation will relatively soon evolve to include high speed systems. They will guarantee much better opportunities for fast transportation of individuals and goods using many of the world small-medium airports.

In this scenario, new aerospaceplane designers and manufacturers will emerge worldwide as well as new airline companies offering such capabilities.

Apart from the different running studies related to hundred-seat high supersonic and hypersonic civil transport aircraft, the opportunity of using smaller low-hypersonic aircraft exists for market segments like suborbital space tourism and experimentation, urgent business travel, taxi aircraft for persons, specific products, human organs, and so forth. They will stimulate the development and will complement larger and heavier systems. The HYPLANE project proposes a double-market oriented solution to target a more realistic market size, within a relatively short time. A flight demonstrator is identified to speed up development.

Acknowledgements

The HYPLANE project has been conceived by Trans-Tech and University of Naples Federico II who have conducted the feasibility and preliminary design activities, with the self-funded support by several public and private entities in Italy and abroad.
The part of this work related to the HYPERION version of the project is co-financed by the Italian Ministry of Defence under contract Repertorio n. 985 dated 13 Dec 2021.
The authors are specifically grateful to the members of the DAC Working Group Hypersonics, and among other: Alessandro Manzo (3DnA), Giorgio Fusco (Aerosoft), Aniello De Prisco (ATM), Michele Visone (Blue Engineering), Giovanni Maresca (BService-Eng), Michelangelo Giuliani (Caltec), Valerio Pisacane (Euro.Soft), Bonaventura Vitolo (Geven), Arturo Moccia (LeadTech), Roberto Vitiello (MBDA Italia), Mario Ciaburri (NAIS), Antonio Caraviello (Sòphia High Tech), Dario Castagnolo (Telespazio), Salvatore Cardone (Tecnosistem), Giancarlo Pagliocca (Trans-Tech), Francesco Monti (TSD), Sara Di Benedetto (CIRA), Pietro Ferraro (CNR-ISASI), Gabriella Rossi (ENEA), Rosario Mascolo (SSIP), Giuseppe Pezzella (Univ. Campania, L. Vanvitelli), Raffaele Savino (Univ. Naples Federico II).

References

1. Russo, G., Voto, C., Savino, R., "S4 – A Demonstrator of HYPLANE, a Single Stage Suborbital Spaceplane and a Hypersonic Business Jet", Acta Astronautica 183 (2021) 244–254, DOI 10.1016/j.actaastro.2021.03.025, presented at 71th International Astronautical Congress IAC2020, Cyberspace Edition, 12-14 October 2020
2. Russo, G., Savino, R., Pisanti, D., Saviano, M., Perrelli, F., "HYPLANE: The Future of Sub-orbital Space Access is Today", NEREUS Workshop on Commercialisation and Utilisation of Space Exploration Technologies, Turin, 15-16 March 2018
3. Russo, G., "HyPlane – A Solution for Ultra-Fast Air-Transportation", Advances in Aerospace Science and Technology, Chinese Society of Astronautics, Vol. 1, Nr 1, pp. 60-70, Mar 2017, ISBN 978-7-5159-1282-0
4. Savino R, Russo G, Carandente V, D'Oriano V. HYPLANE for Space Tourism and Business Transportation. 22nd Conference of the Italian Association of Aeronautics and Astronautics (AIDAA), 9–12th Sept 2013, Naples, Journal of British Interplanetary Society 2014; 67: 82-89. ISSN: 0007-084X
5. Zuppardi G, Savino R, Russo G. Aerodynamic Analysis of HyPlane in Supersonic Rarefied flow. Acta Astronautica 2016; 123: 229–238. DOI: 10.1016/ j.actaastro.2016.03.025
6. Todisco A. Propulsion Model of a Supercharged Ejector Ramjet for a Small Supersonic Airplane, Master Degree Thesis, Aerospace Engineering, University Federico II of Naples, 2014-2015
7. Russo G, Savino R. HyPlane: The Business Case of a Small Hypersonic Airplane for Point-to-Point and Space Tourism flights. 20th AIAA International Space Planes and Hypersonic Systems and Technologies Conference. 2015. Glasgow (UK).
8. Russo, G. et al., "Hypersonic Bizjet: A multi-mission technology demonstrator", 3rd International Symposium on Hypersonic Flight Naples, Italy, 30-31 May, 2019