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Research Article

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Hyplane: Challenges for Space Tourism and Business Transportation

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Abstract

In the present work a preliminary study on a small hypersonic airplane for a long duration space tourism mission is presented. It is also consistent with a point-to-point medium range (5000 km) hypersonic trip, in the frame of the "urgent business travel" market segment. Main idea is to transfer technological solutions developed for aeronautical and space atmospheric re-entry systems to the design of such a hypersonic airplane. A winged vehicle characterized by high aerodynamic efficiency and able to maneuver along the flight path, in all aerodynamic regimes encountered, is taken into consideration.

Rocket-Based Combined Cycle and Turbine-Based Combined Cycle engines are investigated to ensure higher performances in terms of flight duration and range. Different flight-paths are also considered, including sub-orbital parabolic trajectories and steady state hypersonic cruise. The former, in particular, takes advance of the high aerodynamic efficiency during the unpowered phase, in combination with a periodic engine actuation, to guarantee a long duration oscillating flight path. These trajectories offer Space tourists the opportunity of extended missions, characterized by repeated periods of low-gravity at altitudes high enough to ensure a wide view of the Earth from Space.

Keywords: Space tourism; Hypersonic cruise; Combined-cycle propulsion systems

Introduction

In recent years some private enterprises have been approaching Space flight with a relatively low-cost philosophy, in great contrast with the one followed by government agencies in past years. In fact, some examples of small reusable airplane-like vehicles have been developed to perform sub-orbital missions, which could represent a first step towards a safer, more comfortable and less expensive access to Space in the near future. Main idea is to merge part of technological solutions developed for aeronautical and atmospheric re-entry purposes in order to design such vehicles, as also discussed in [1-3].

The Scaled Composite launched for the first time the Space Ship One (SS1) in 2004. The vehicle reached 100 km altitude on a suborbital trajectory 36 years after the X-15, developed by NASA at the turn of 50s and 60s. The company is presently test qualifying an enlarged version of the SS1, named SS2, which is intended to carry passengers for a short-duration Space flight at a fare of about 200 k$ with first commercial flights in early 2014. This suborbital flight should allow passengers to experiment weightlessness for a few minutes and to see a large area of the Earth, along with its curvature [4]. Other projects which are included in this frame are the BSP Ascender, the EADS spaceplane and the XCOR Lynx [4-6], all of which could be used even for technological flight test [7].

Recent survey studies assessed the potential market for suborbital vehicles [6,8]. The one performed by EADS and IPSOS [6] shows that there is a sizable market for suborbital tourism and that people willing to pay around 200 k€ for that could be in the order of 50000, just 16 years after the market start. This market is of course much larger than the one related to orbital Space tourism missions on the ISS. In this case, in fact, only 7 people had the opportunity, up to now, to perform this experience paying from 20 M$ to 40 M$. It is obvious that these fares can be paid only by the so called Ultra High Net Worth Individuals (UHNWI).

Suborbital Space tourism may also be seen as an intermediate step towards a novel concept of orbital Space tourism, based on reusable winged vehicles. Indeed, the employment of reusable components could strongly reduce the cost per seat up to 2 orders of magnitude, depending on the number of flights scheduled. In addition, the development of a winged re-entry vehicle could represent a safer and more comfortable way to cross the atmosphere [9-12].

A longer term perspective for commercial sub-orbital human spaceflight, as shown in Figure 1, is also characterized by point-to-point hypersonic transportation.

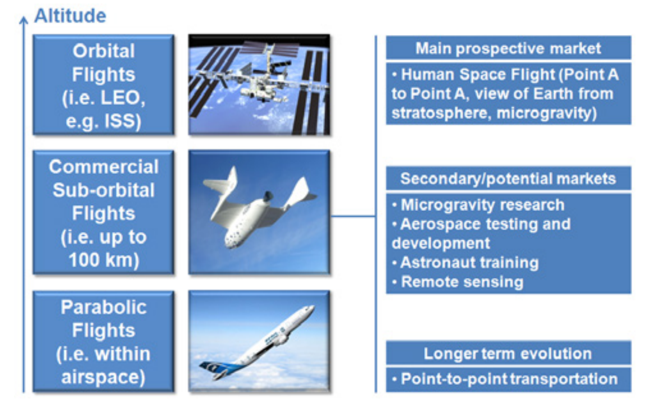

Figure 1: Commercial Suborbital Spaceflight and prospective market.

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This work reports a feasibility study for a new vehicle concept under development at the University of Naples "Federico II" in the wider frame of the Space Renaissance Italia Space Tourism Program [13], with the support of other universities and small and medium enterprises.

The study refers in particular to a six seats hypersonic airplane-like vehicle, named HyPlane for a long duration Space tourism mission. It is also consistent with a point-to-point hypersonic trip, whose concept was amply discussed [14] in the frame of the "urgent business travel" market segment.

Previous supersonic or hypersonic commercial designs 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 and sustainable operational concept, because of the system high complexity, requiring very long time to reach the sufficient technology readiness level. A small passenger hypersonic plane may take advantage of previous experiences and represent a first step towards development of larger complex systems, but at the same time it may open new markets and applications.

A trade-off study between Rocket-Based and Turbine-Based Combined Cycle engines (RBCC and TBCC, respectively) is performed to ensure higher performances in terms of flight duration and range, for a given propellant mass.

The work begins with the description of the vehicle configuration. On the basis of an aerodynamic database obtained by means of engineering tools, the main flight performances for different mission scenarios are presented and discussed. A preliminary mass budget is also reported. Finally, the main conclusions and future developments are presented.

System Configuration and Mission Profile

HyPlane is a new concept of hypersonic transportation system able to offer access to stratospheric and space flights as safe, convenient and commonplace as today's commercial air transportation, by integrating state-of-art aeronautic and space technologies.

HyPlane analysis team includes experts of universities; research Centers, small and medium enterprises, involved in thermodynamics, aerodynamics, propulsion, trajectory and performance analysis, structural analysis and system engineering. Analyses are performed using academic and industry proven tools.

By combining education, experience, proven software, and creative thinking, the HyPlane analysis team has created the required models, simulations, and analyses to confirm design elements and suggest improvements in an efficient and cost effective manner.

A preliminary vehicle configuration is shown in Figure 2. The vehicle is a six-seat small-sized spaceplane with a high performance wing and a tail providing good flight 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. It will be constructed with many of the systems normally employed on business jet aircraft, but it will also include state-of-art technologies required for its flight into the stratosphere at hypersonic speed.

The vehicle, powered by turbo-ramjet and/or rocket engines, will perform Horizontal Takeoff and Horizontal Landing (HTHL) on ordinary runways, taking advantage from the lift forces resulting from the relatively large wing surface, and will be accelerated to speeds above Mach 4 to execute point-to-point suborbital parabolic flights, providing the sensation of weightlessness for some minutes, or hypersonic cruise transportation over transcontinental distances.

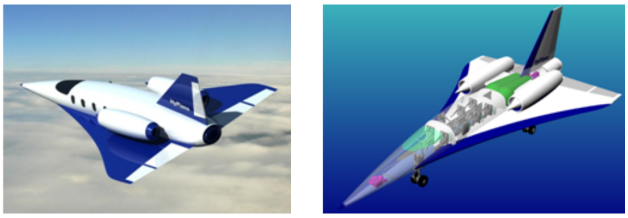

Figure 2: HyPlane hypersonic vehicle.

The spaceplane conceptual design is defined by the complex interplay of aerodynamics, atmospheric heating, materials and structures, propulsion, fuel selection, cabin, tank and subsystems sizing.

The HyPlane mission profile begins with a takeoff from a conventional runway, taking advantage from the two air-breathing engines. The total weight of the vehicle at takeoff is about 18000 kg. Then, an ascent phase is performed to reach suitable conditions for the suborbital parabolic maneuvers or for the hypersonic cruise. When the aircraft reaches a sufficient altitude and speed with the dual mode-engine, then the engine operating mode undergoes a transition to pure ramjet. After performing its nominal mission, the aircraft glides and performs a traditional aeronautics landing on a conventional runway.

In summary, the mission specifications include:

- Horizontal takeoff with engines operating preferably in turbojet mode
- Subsonic ascent to altitudes between 5 and 10 km
- Acceleration through the transonic speed range and climbing along a constant dynamic pressure trajectory using combined cycle engines (maximum sensed acceleration on ascent around 1.2 g)
- Hypersonic cruise using high specific impulse ramjet engines (transcontinental range around 5000 km) or sequence of suborbital parabolas Gliding descent and powered horizontal landing
- Total duration less than 2 hours

As it is in most hypersonic planes designs, the aircraft needs to have a relatively high lift-to-drag ratio. This is meant for two reasons. First, the requirement to fly in the atmosphere using also rocket engines forces the designers to minimize the required thrust, so that the propellant mass at takeoff can be small. Second, the maneuvering performances are improved if the aircraft has a high enough lift-to-drag ratio. The wing area is large enough to aerodynamically sustain the aircraft gross takeoff weight with relatively low velocities and to reduce, at relatively high altitudes, aerodynamic heating and sonic boom during cruise and supersonic descent approach (efficient overland routes) and the consequent environmental impact. High altitude flight, possible due to the low wing loading, offers also a better Earth view and may open to new applications (e.g. remote sensing, high altitude technological demonstrations, etc.). The spaceplane features a proper design to maximize internal volume. The variable-delta planform of the wing is combined with the fuselage shape to provide aerodynamic stability and maneuverability over a broad speed range, and also enough space to hold propellants. The center of gravity has not significant excursions as propellant is consumed during the flight.

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Aerodynamic Performances

Preliminary aerodynamic performances of the HyPlane configuration are shown in Figure 3, for different flight regimes. The aerodynamic database is evaluated by means of semi-empirical aerodynamic prediction codes, including DATCOM, that offer the possibility too quickly and economically carry out aerodynamic analyses of aircrafts. These methods are particularly suitable during conceptual and preliminary design phases. The aerodynamic data include aerodynamic and moment coefficients, stability and control derivatives (longitudinal and lateral-directional, static and dynamic), longitudinal trim conditions. These results can be also obtained varying the flight parameters (angle of attack, sideslip angle, Mach number, altitude, control surface deflections) for subsonic, transonic, supersonic and hypersonic regimes.

The engineering codes have been validated against experimental and numerical aerodynamic results available in literature over hypersonic configurations, including NASA experimental vehicles (e.g. X-15).

Typical results are shown in Figure 3 in terms of drag coefficient and aerodynamic efficiency. The vehicle exhibits a hypersonic aerodynamic efficiency around 4 that ensures good performances.

The behaviour of stability and control derivatives not reported here, are continuously determined during the configuration upgrading in order to ensure longitudinal and lateral-directional performances around trim conditions.

CFD methods based on the solutions of Navier-Stokes equations with negligible real gas effects and finite volume approach are used to accomplish a more accurate aerodynamic analysis of the vehicle configuration and to completely assess the flow field in the critical flight conditions.

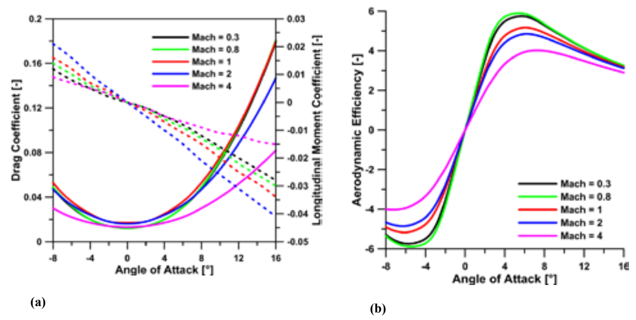

Figure 3: Drag (solid lines), longitudinal moment (dashed lines) coefficient (a) and aerodynamic efficiency (b) as a function of angle of attack, for different Mach numbers.

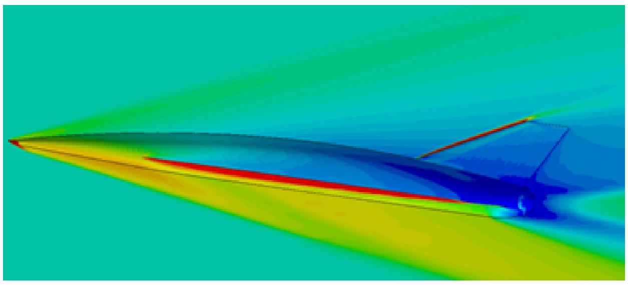

Figure 4: Computed pressure distribution for CFD three-dimensional simulations over 32 millions cells computational grid.

Figure 4 shows the computed pressure distribution in a typical hypersonic flight condition for a simulation over a 32 million hexahedral cells computational grid.

Propulsion System

HyPlane takes advantage from state of art airbreathing hypersonic propulsion. Current design is based on combined-cycle propulsion systems (Rocket-Based Combined Cycle engines, RBCC and Turbine-Based Combined Cycle engines, TBCC).

It is here taken into account that RBCC engines can operate as a pure rocket, in ejector (ducted rocket) and ramjet modes. During operation in the ejector mode, RBCC engines use the jet pumping effect of the rocket exhaust to collect and compress atmospheric air into the mixing duct. The collected air and rocket exhaust streams mix and increase the total mass flowrate, resulting in a thrust increase.

In the late 1950s and through the 1960s, the Marquardt Corporation conducted research on combined-cycle engines with their ground breaking study of different combined-cycle engine models under NASA contracts [15]. To the authors' knowledge, this remains the most comprehensive hardware testing and development program for ramjet and RBCC engine systems to date that is available in the literature.

Turbine-based combined cycle engines operate by using a gas turbine propulsion cycle which passes to a ramjet cycle at high Mach number. In this condition, in fact, the air-flow bypasses the turbomachinery, because pressure, temperature, and flow velocity would make such turbine impractical, redundant, or both.

Turbojet propulsion systems are generally limited to Mach 3, due to the rise in inlet temperature present at the compressor face. Turbine engines are more limited in altitude with respect to RBCC and also produce a much lower thrust. On the other hand, they provide more efficient operations in term of specific impulse, in particular at low altitudes and Mach numbers.

TBCC engines have been tested in flight and qualified much more than RBCC engines. An example of operative TBCC engine is the J-58 utilized in the Lockheed SR-71 Blackbird, working in multiple cycles depending on the flight regime (with cruise conditions of approximately Mach 3.2 at an altitude of 23 km). More recent advanced hypersonic systems, such as the DARPA Blackswift, have proposed using TBCC-class propulsion systems [16].

Using turbine-based engines, the thrust-to-weight ratio in the ascent phase is between 0.5 and 1. This is not true when relatively strong acceleration are necessary to climb very rapidly using rocket engines, characterized by larger fuel consumptions. In this case thrust-to-weight ratios should be higher than 1 (maximum thrust in the order of 250 kN for the case under investigation). The average performances of different classes of engines, selected for the present work, are summarized in Table 1.

Preliminary Budgets

Mass budget

The weight buildup of the vehicle determines whether it is possible to enclose the required volume of propellant and passengers' cabin in an aircraft with a sufficiently small weight to permit the mission accomplishment on the basis of the main requirements. The assumptions that are made for the vehicle are to apply advanced structural technologies making use of lightweight materials (titanium

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Engine Type	Average Specific Impulse [s]	Average Thrust [kN]
Turbo-Ramjet	1730	100
Rocket	330	230
Ejector-Rocket	830	175
Ramjet	1700	90

Table 1: Engines main performances.

alloys and/or composites) for the wing/body structure of the aircraft. Special thermal protections are only required for localized elements (e.g. nose cap, wing leading edges and control surfaces).

A preliminary mass budget has been elaborated in order to assess the feasibility of the vehicle configuration, according to the main mission requirements. The study is based on both statistical correlations and engineering design of specific subsystems. These models, taking also into account heavier vehicles designed in past years, provide preliminary results, which can be useful in the first stages of the iterative design process.

Some assumptions have been made in order to obtain the vehicle mass budget and the mass breakdown among its main subsystems, in particular:

1. the payload and crew weights have been determined from the given requirements, considering the worst case scenario of all adult and male passengers travelling in winter (i.e. 100 kg per person, according to the Federal Aviation Administration);

2. the fuel weight depends on the aircraft configuration and on the mission requirements;

3. the vehicle empty weight can be estimated from statistics on the basis of the HASA model proposed in literature [17].

According to the statistical model, the overall vehicle weight has been computed by iteratively solving a number of equations for different parameters, including the total volume and the total gross weight of the vehicle.

The different steps include:

1. preliminarily definition of the flight mission profile, in order to identify the vehicle geometrical and aerodynamic configurations;

2. identification of the overall weight and volume of the payload;

3. estimation of the overall fuel weight necessary for the mission;

4. assignment of proof values for some parameters, in particular total gross weight and total volume of vehicle;

5. comparison between the assigned and the computed value of each parameter;

6. iteration (from step 4) until a sufficient accuracy is reached.

After having added a proper mass design margin, the method has an overall accuracy around 10% for the total gross mass estimation, while the errors regarding the mass breakdowns are estimated to be larger [17].

In the present analysis 6 passengers, 2 crew members and a propellant mass of about 50% of the total gross weight have been considered.

In Figure 5 the total vehicle mass breakdown is shown, while Figure 6 reports the structural mass distribution.

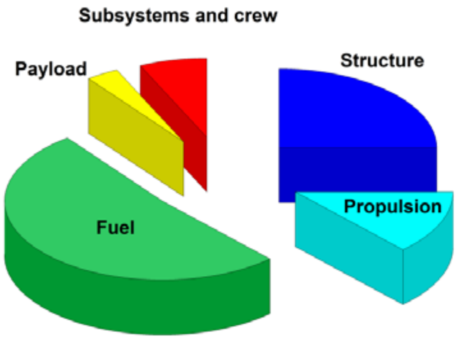

Figure 5: Total mass breakdown.

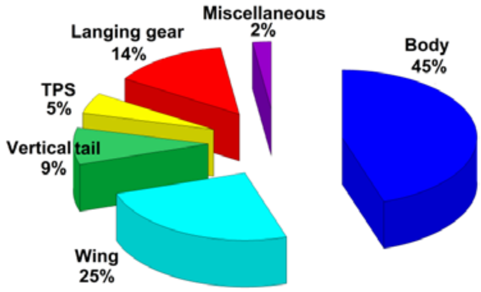

Figure 6: Structural mass breakdown.

Cost budget

A small hypersonic aircraft has to respond to several challenges to become one of the future air transportation systems. Spending less time in travel, creating better travel conditions over transcontinental and intercontinental distances, exploiting more efficiently the existing or new infrastructures, deploying an intelligent network system to achieve efficient and easy reservation services, including the possibility of shared travels, are some of the requirements for such vehicles.

The market for small hypersonic transportation system will strongly depend on the associated costs, on the safety and security aspects, on the possibility to seamless increase intermodal connectivity and to exploit flexible infrastructures and small airports.

An important market will be in the business segment. While demand for new aircraft orders will continue to come from established and developed markets, the growth potential in emerging markets such as China, India, Russia and Latin America is predicted to play an increasingly important role in the global aviation marketplace.

Considering the constant growth of fuel prices and environmental concerns, operators across industries continuously focus on fleet optimization and aircraft efficiency. For instance, the business aviation market continues to recover, and while current macroeconomic indicators are mixed, the overall trend for the world economy is stable to positive. It is expected that as confidence returns to world markets, aircraft orders and backlogs will expand and deliveries will grow.

Industries are confident in the strong, long-term potential of small intercontinental aircrafts for different applications. They forecast a total of 24000 business jet deliveries from 2013 to 2032 in the business jet segment, which represents approximately $650 billion in industry revenues. North America is expected to receive the greatest number of new business jet deliveries between 2013 and 2032, followed by

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Europe which, despite its continued economic challenges, remains the second largest market. China is forecast to become the third largest region in terms of deliveries over the next 20 years with 1000 deliveries from 2013 to 2022, and 1420 deliveries from 2023 to 2032. It is also expected that key growth markets including Brazil, India, Russia/the Commonwealth of Independent States (CIS), Mexico, and Turkey will receive a significant share of business jet deliveries during the next 20 years.

It is easy to consider that the availability of hypersonic business products may produce an increase of the above discussed forecast from one side, and may deviate a part of the mentioned deliveries and revenues to the hypersonic segment. If only 1% of the mentioned market would simply pass to the small high supersonic/hypersonic transportation sector, i.e. 240 deliveries with $6 billion revenues, it would comply with almost all the market studies performed during the last 8-10 years on the supersonic business jet market, that is as well a high-end business aircraft market.

An important and interesting element is the estimation of about 40% of the market to be held by fractional ownership, including:

- "time-share" airplanes;
- individual buys/leases portion of interest in single aircraft;
- access to vehicle for certain number of days/hrs.

In 2011 fractional ownership companies accounted for about 20% of global business jet fleet, a value moving since years along a strong increase tendency curve.

The potential small supersonic/hypersonic jet market may be therefore characterized by the following elements:

- growing importance of the Asian market;
- growing international freight market;
- growing fractional ownership in the future.

A preliminary cost budget has been carried out on the basis of a modified version of the model developed by Koelle and implemented by Snead [18].

The model is based on a statistical correlation between the vehicle mass and its development and production costs, expressed in terms of work years.

The work years obtained are multiplied by a number of coefficients taking into account the Technologic Readiness Level (TRL) of each component, the team experience on the development of such component and so on. The final cost depends on the cost of the average aerospace work year (in this case assumed equal to 100000 €, which seem to be a reasonable value for the average cost of work in Europe). In addition, the production costs are proportional to the number of vehicles which one intends to produce. In this case a fleet of 40 vehicles has been initially assumed.

On the basis of these assumptions and introducing correction factors to take into account the high conservativeness of the method, the development and production costs reported in Table 2 have been obtained. In particular, correction factors have been evaluated applying

Development cost [M€]	Production cost [M€]
≈ 2000	≈ 500

Table 2: Development and production costs obtained on the basis of a modified version of Koelle's model [18].

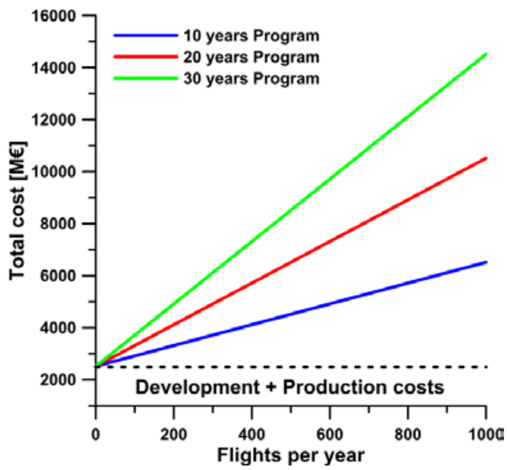

Figure 7: Total cost variation as a function of the number of flights per year and of the program duration.

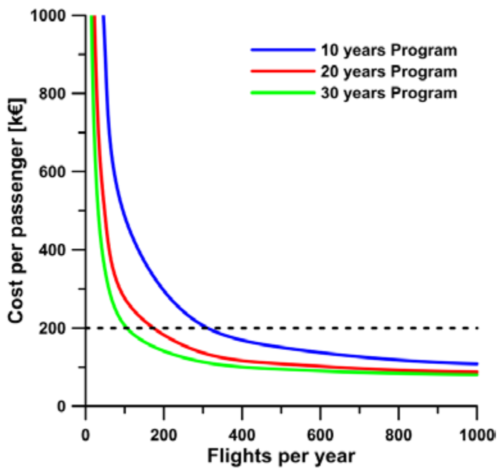

Figure 8: Cost per passenger as a function of the number of flights per year and of the program duration.

the conventional model reported in [18] to the Airbus A380 and dividing the values obtained by the real development and production costs of the vehicle. As result, the sum of development and production costs has been estimated in the order of 2.5 billion €.

On the other hand, the operational costs per flight (including maintenance, airport servicing, propellants, consumables and so on) have been preliminarily estimated around 400 k€. Varying the number of missions per year and the program duration, results plotted in Figure 7 have been obtained. As expected, the variable component of the total cost increases as the number of flights increases.

Conversely, dividing the total cost by the number of flights and passengers, it can be seen that the "cost per ticket" strongly reduces as the number of total flights increases, as reported in Figure 8. This is obvious if we consider that, as the number of flights increases, the fixed costs can be spread on a larger number of flights.

Figure 8 also reports the estimated cost for a typical Suborbital flight (as estimated for Space Ship Two and Rocketplane, for example). The Figure 8 shows that, thanks to the relatively large-scaled market, costs per passenger can be reduced also when compared with the fares foreseen for the other Suborbital flights. The cost reduction is much more dramatic if one considers the fare of a Space Tourism missions on the ISS (ranging from 20 M$ to 40 M$).

Finally, Figure 9 considers the influence of the number of vehicles on the cost per passenger, assuming a number of missions per year such that a time lapse of 2 weeks between two successive flights of each vehicle can be guaranteed.

As expected, the cost per passenger decreases as the number of vehicle increases, due to the larger cumulative number of flights. A number of vehicles around 40 seems to give a good compromise between the "cost per ticket" reduction and the increasing production costs.

Finally, on the basis of the above analysis, it has been estimated that producing 40 vehicles and assuming 1000 flights per year and a fare of 100 k€, the break-even point can be met in less than 15 years.

Flight Performances

Preliminary flight performances are reported in this Section in order to show the possibility to realize long duration missions, both for Space tourism purposes and for hypersonic cruises with a total range in the order of 5000 km. This can be achieved, as discussed in Section 4, optimizing the propulsion performances of the combined cycle engines in the different flight regimes.

Specific impulse variation has been obtained for the considered two classes of engine (RBCC and TBCC) assuming the possibility to transition between ejector rocket (or turbojet) and ramjet around a Mach number of 2.7. Trajectory simulations were performed to evaluate the flight profile in the ascent phases such that a Mach number of 4 at an altitude of 30 km could be achieved. In both cases the climbing phase begins at the altitude of 10 km and at a Mach number around 0.7. A level acceleration from the above mentioned conditions until the achievement of a constant dynamic pressure is considered. Then, the vehicle accelerates along a constant dynamic pressure to the maximum Mach number.

As shown in Table 3, the ascent profile with the TBCC engines is characterized by lower fuel consumption with respect to RBCC, due to the relatively higher specific impulse. However, due to the relatively low thrust-to-weight ratio, the climb angle is also lower and the final altitude is reached after 9 minutes with a fuel consumption of 3 tons. Conversely, using a RBCC engine, the ascent duration is less than 6 minutes and the fuel consumption amounts to about 3.8 tons.

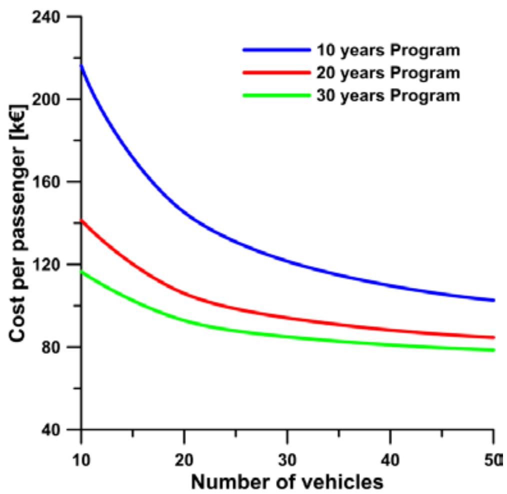

Figure 9: Cost per passenger as a function of the number of vehicles, assuming a 2 weeks time lapse between two successive flights per vehicle.

Engine Type	Ascent		Cruise		Descent
	RBCC	TBCC	RBCC	TBCC	Gliding
	Ejector-rocket/ Ramjet	Turbo-Ramjet/ Ramjet	Ramjet	Ramjet	-
Average Specific impulse [s]	1200	1715	1700	1700	-
Average Thrust [kN]	140	98	31	37	-
Duration [min]	5.8	8.7	51	57	18.8
Range [km]	305	375	3660	4110	415
Average TSA [g]	1.05	1.05	1.00	1.00	0.630
Maximum L/D [-]	6.0	6.0	3.8	3.9	5.3

Table 3: Main flight performances in the different flight phases.

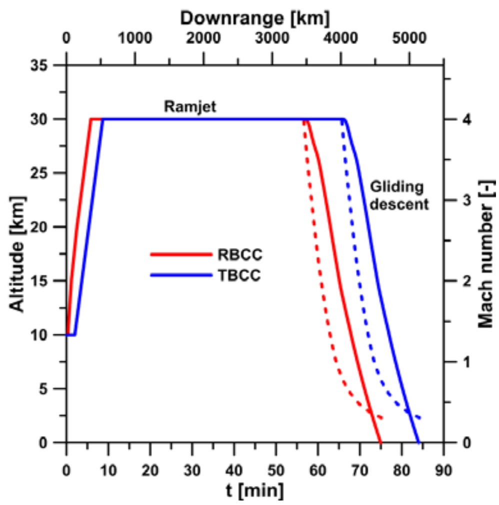

Figure 10: HyPlane trajectories in a hypersonic cruise scenario (dashed lines represent Mach number variation in the gliding descent phases).

In general, the TBCC system will be more efficient than the ejector ramjet mode of an RBCC for the subsonic and low-supersonic portion of the ascent. However, the RBCC could perform a very efficient, air breathing ascent well into the Mach 4-5 range, up to altitudes of 30-35 km. Additionally, the increased mechanical complexity of the TBCC system is eliminated in the RBCC, providing a further advantage. Another possibility is a combined system that uses both engine systems: a TBCC system for ascent to a mid-supersonic staging point, followed by an RBCC ramjet mode climb to high altitudes.

The high thrust available with the RBCC system becomes particularly important in a space tourism mission scenario, if relatively high accelerations are necessary to perform subsequent parabolas with lower altitude around 25-30 km and upper altitudes around 50-60 km.

The main performances of the HyPlane in a hypersonic cruise scenario have been plotted in Figure 10 and listed in Table 2, showing the main differences due to the propulsion system employed.

Similarly to subsonic airplanes performing parabolic flights, HyPlane will be also able to conduct specific mission profiles executing a series of sub-orbital jumps, each providing up to two minutes of reduced gravity. During this period passengers will be able to experience weightlessness conditions and to have a beautiful view of

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the Earth from the high stratosphere, as shown in Figure 11.

During a typical HyPlane flight the vehicle is able to execute about 5-6 parabolas. Before each sub-orbital jump, the airplane begins flying at hypersonic speed in a steady horizontal attitude, with an approximate altitude and speed of 30 km and Mach 4, respectively. During this steady flight the gravity level is 1g. Then the vehicle gradually pulls up the nose and starts accelerating along a climbing trajectory with flight path angle up to 30°. During this phase the passengers experience conditions of increased acceleration (~4.5 to 5 g), immediately prior to the two minutes of weightlessness. The peak of the sub-orbital free-fall ballistic trajectory is achieved at around 65 km altitude.

The extended duration low-gravity period is followed by another maneuver characterized again by hyper-gravity conditions, before the aircraft again flies a steady horizontal path. The downrange for each sub-orbital jump is about 300 km. In Figure 12 the mission scenario just described has been depicted, while in Figure 13 a possible parabolic trajectory is shown along with the corresponding Total Sensed Acceleration (TSA) profile.

HyPlane will be also the only HTHL sub-orbital vehicle able to provide users with the opportunity to execute microgravity research under repeated, relatively long duration conditions of weightlessness, offering ideal opportunity for precursor human, biological or physical research in preparation for long-duration missions onboard orbital space laboratories. In particular, this sub-orbital platform will be uniquely offering relatively extended duration of low-gravity conditions, typical of sounding rockets, together with a more flexible research approach, i.e. using typical laboratory-type instrumentation, participation of the research team on their experiments during flight, reusability.

Challenges

It is clear that the design and the development of the above

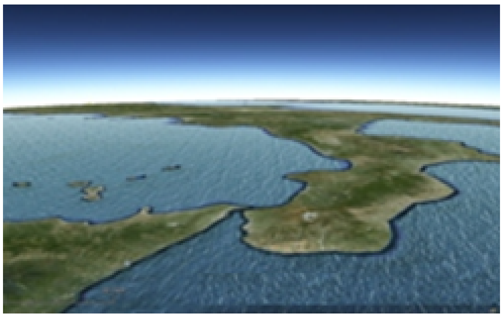

Figure 11: View of South Italy from the high stratosphere.

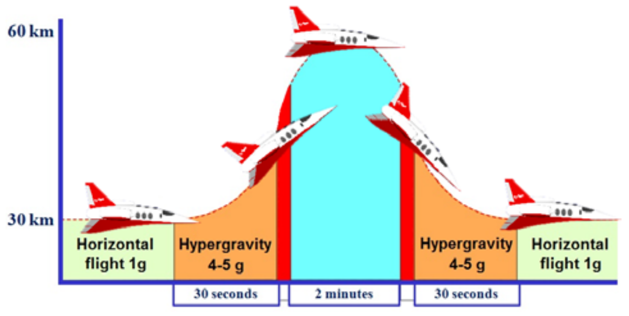

Figure 12: Sub-orbital flight maneuver profile.

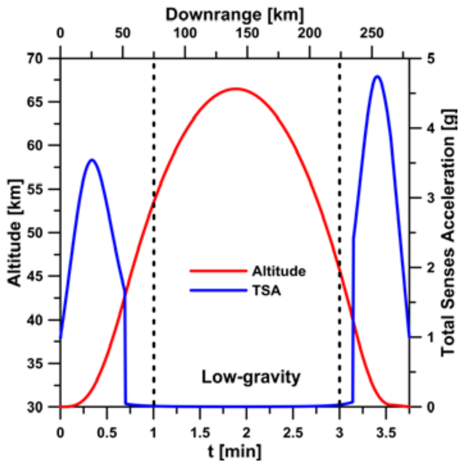

Figure 13: HyPlane trajectories in a suborbital parabolic scenario in terms of altitude and Total Sensed Acceleration (TSA) profiles.

discussed vehicle require facing with many challenges, regarding both the necessity to include such class of airplanes in a proper market (as already discussed in Section 5) and to face with some technological breakthroughs dictated by the hypersonic speeds.

The latter mainly regard the problems connected to a proper material selection, due to the peculiarities of the hypersonic flight and of the air-breathing hypersonic propulsion. In particular, material erosion and thermal resistance have to be considered, as also discussed in [19-21].

Material systems of interest for flight weight high-temperature hardware include Carbon-Carbon (C-C) materials coated with ceramics such as SiC, HfC, and ZrC, and Ceramic Matrix Composites (CMC's) such as SiC-SiC, C-SiC, CHfC, or C-ZrC as the primary candidates [19]. Some metal alternatives such as refractory metals (Niobium), superalloys (Inconel), and intermetallics (TiAl) also exhibit desirable characteristics such as strength/stiffness at high temperature and high melt/oxidation temperature thresholds. However, for higher-speed applications, the component mass penalty associated with increased density tends to make them not viable [19].

Of course the material requirements for each component vary with flight condition, whether or not the surfaces are actively cooled, and whether the intended mission requires an expendable

or reusable vehicle and have to take into account the thermal loads induced by "non-operational" phases [19]. In hypersonic regime local temperature enhancements due to the shock-shock interactions have also to be considered [20].

Also the material erosion is an important issue. Impact by liquid droplets and solid particles can in fact influence the characteristics of aero structures during the course of flight. This influence is governed by a number of vehicle parameters, such as the exposure time to the erodent, type of erodent, the synergy of different erodents and finally impact speed of the erodent, becoming therefore particularly important at hypersonic speeds [21].

Concluding Remarks

It is the older author's belief that aviation will relatively soon evolve to include very high speed systems. They will guarantee much better opportunities for fast transportation of individuals and goods not only using the world hubs, but also smaller new generation airports. Meanwhile, Space Tourism will spread all over the world guaranteeing much cheaper ticket costs than 200 k€/pers offered today. In this scenario, new hypersonic aircraft designers and manufacturers will emerge as well as new airline companies offering such capabilities.

Apart from the already running different studies related to hundred-seat high supersonic and hypersonic civil transport aircrafts, the authors share the vision and need of smaller hypersonic aircraft complementing the former ones for market segments like urgent business travel, taxi aircraft for persons, specific products, human organs, and so forth.

Looking then at the available technologies, coming from both the traditional aeronautic and space sectors, it is shown that the use of a proper mix of them makes technically feasible to design and realize a small Mach 4-5 aerospace vehicle able to take-off and land horizontally within the present set of rules governing common airports. Such a vehicle can either perform a series of parabolas dedicated to space tourism at maximum altitude above 65 km or fly 5000 km distances in less than 2 hours with cruise altitude of about 30 km.

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