# APPENDICE 3

**AEROTECNICA MISSILI E SPAZIO**

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# AFFORDABLE SPACE TOURISM TRANSATMOSPHERIC PLANE

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**ABSTRACT**

*This work has a double purpose: to hypothesize an affordable future activity of space tourism and to present a particular application of a conceptual design methodology developed at the Aerospace Engineering Department of Politecnico di Torino.*

*This methodology has two main characteristics:*

1. *an intensive utilization of the modern 3D CAD parametric tool to model the concept of a plane, to study the mission feasibility and to size the aforesaid model (with the aid of parametric features of 3D CAD model);*
2. *the possibility of performing a quite good Risk Analysis starting by modeling several tools to evaluate Safety, Reliability, Maintenance and Cost characteristics at subsystems levels (expected to be accomplished in further developments) and also by taking into account the basic design choices.*

*As a particular and interesting case study we have developed the idea of an affordable plane to perform sub-orbital flights (reaching an height of more than 100 km) mainly devoted to tourism.*

*This implies that the plane cabin has room enough to host passengers and windows to enjoy the view of the Earth. As a trade off, the amount of propellant required and of power of the propulsion system, not sized to reach orbital speed, are reduced. For safety reasons, airbreathing engines have been foreseen to guarantee safe take-off, climb and landing and to have the possibility, during descent, of cruising to reach the desired or an alternative landing field.*

*Safety is very important because of the presence of passengers on board and cost-effectiveness is mandatory to perform a profitable operational life. Last but not least the social and cultural aspects have to be remembered: in fact space tourism could contribute to achieve more and more familiarity with space.*

## 1. INTRODUCTION

Space tourism is the term that is now commonly used to mean ordinary members of the public buying tickets to travel to space and back. Since Sputnik I was launched in 1957 most space activities have been funded by governments for scientific research and/or military purposes. The ideas of setting up commercial space tourism services and opening up space frontiers to all people (at least all people who can afford it!), and not just to astronauts, are totally new.

Market research has revealed that most people would like to take a trip to space, if it was possible. If a large-scale operation like airlines could be set up, the cost of space travels could be "greatly" reduced. One of the main obstacles is the conservatism of space industries. As the Cold War is over now, space agencies' budgets are being cut; therefore the development of a profitable business like space tourism could help them overcome future problems and fund their own research activities as well.

After some false starts in the '60s and '80s work towards realizing space tourism is finally becoming a reality. The main reasons why it is going to happen this time are:

- because people want it;
- because it is a realistic objective thanks to today technology;
- because by generating the large-scale launch activity needed to reduce cost, space activities can become profitable and the limitless resources of space can be finally exploited to solve our problems on Earth;
- because living in space involves every line of business from construction to marketing, fashion, interior-design and law;
- because it will be fun too.

By analogy with commercial developments in the past, one might reasonably expect the demand for space tourism services to evolve through several broad phases. Starting with a relatively small-scale and high-priced phase, the scale activity will grow and prices will fall as the space tourism matures. The target of the space tourism's development is a mass-market business like aviation is today.

The demand for launches has derived mainly from the request for satellites for communications, meteorology, surveillance, scientific research. The launch rate required for these purposes is about 100 launches per year worldwide. The cost of space transportation is strongly influenced by the rate of traffic. If much higher rates of launch traffic could be generated, the cost of development of a fully reusable launch vehicle could be justified. As a result, thanks to the use of this kind of space vehicles, launch cost could be substantially reduced below the present level of about $10000/kg. Space tourism has the potential to generate much higher rates of launch traffic. Considerable cost reduction can therefore be expected only by the development of future generation of launchers, which have extremely high launch rates and are fully reusable; moreover they should be operated with a minimum maintenance effort, comparable to today's aircraft fleets in the commercial airlines business. The development of a thriving passenger space travel business in the near future would also have a number of important social, educational and economical benefits. To conclude thanks to space tourism a new technical/industrial/commercial field could be entered and investigated.

| Company name | Space Vehicle name | Launch | Landing | Propulsion | N° stages | Aerial refueling |
|---|---|---|---|---|---|---|
| Scaled Composites, Inc. | SPACE SHIP ONE | Air Launch from a conventional turbofan aircraft as a first stage | Conventional Runway (Horizontal Landing) | Turbojet (first stage)/Rocket Power(second stage) | 2 | No |
| Pioneer Rocketplane, Inc. | PATHFINDER | Conventional Runway (Horizontal Take-Off) | Conventional Runway (Horizontal Landing) | Rocket Power | 1 | Yes |
| AeroAstro, LLC | PA-X2 | Vertical | Horizontal Landing with Airbags | PA-E LOX/Kerosene Rocket Engine | 1 | No |
| Advent Launch Services | ADVENT | Water, Vertical | Water, Horizontal (like a seaplane) | Oxygen/Natural Gas Rocket | 1 | No |
| Discraft Corporation | THE SPACE TOURIST | Conventional Runway (Horizontal Take-Off) | Conventional Runway (Horizontal Landing) | Blastwave-Pulsejets | 1 | No |
| Mr. Mickey L. Badgero | LUCKY SEVEN | Vertical | 1. parachute<br>2. parasail landing | Rocket Engines | 1 | No |
| Bristol Spaceplanes, Ltd. | ASCENDER | Conventional Runway (Horizontal Take-Off) | Conventional Runway (Horizontal Landing) | Jet and Rocket Engines | 1 | No |
| Pablo De Leon & Associates | GAUCHITO | Vertical | Parachute | Rocket Engines | 1 | No |
| Lone Star Space Access Corporation | COSMOS MARINER | Conventional Runway (Horizontal Take-Off) | Conventional Runway (Horizontal Landing) | Jet and Rocket Engines | 1 | No |
| Pan Aero, Inc. | XVan | Vertical | Vertical | Jet and Rocket Engines | 1 | No |
| Starchaser Industries | THUNDERBIRD | Vertical | Vertical | Turbofans and LOX/Kerosene Rockets | 1 | No |
| Dr. Graham Dorrington | GREEN ARROW | Vertical | Parachute | Kerosene and Hydrogen Peroxide Rockets | 1 | No |
| Kelly Space and Technology | ECLIPSE ASTROLINER | Air Towed from a 747 | Conventional Runway (Horizontal Landing) | LOX/Kerosene Rocket Engines | 1 | No |
| TGV Rockets | MICHELLE-B | Vertical | 1. flexible aero-shield<br>2. Vertical with reduced engine power | Pressure fed kerosene-oxygen engines | 1 | No |
| Cosmopolis XXI | COSMOPOLIS XXI | Air Launch from M-55 "Geophisika" HALE turbofan powered ac as a first stage | Airplane style, or parachute | Rocket Engines | 2 | No |
| The daVinci Project | DAVINCI | Air launch from hot air balloon | Parachute | Liquid Oxygen/ Kerosene Rocket Engines | 1 | No |

**Table 1: Some X-Prize competitors**

The first phase of space tourism will have some reduced critical technical aspects, such as the short suborbital flight, typical of this phase, while others will be pronounced, such as the safety requirements for ordinary passengers. These safety requirements will have to be fulfilled on three different levels:

- the vehicle and its facilities have to be safe;
- significant health risks have to be avoided;
- the likelihood of damage from collision with other spacecraft or debris have to be insignificant.

Chances are that already in this decade suborbital flights will play a major role as precursors to initiate tourist space trips: they either consist of a vertical ascent into space or end after one orbit around Earth with a landing at the departure airport.

The X-Prize competition has played an important role in stimulating the study of a new generation of reusable launch vehicles to carry passengers into space. Table 1 shows different configurations proposed by X-Prize competitors. The X-Prize competition is now over as on October 4, 2004, SpaceShipOne (see figure 1), a two-stage system designed and manufactured by Scaled Composites, claimed the $10 million prize. In order to win the prize, a private organization or company had to build its own space vehicle able to fly up to a minimum altitude of 100 km, carrying at least three adults, within the span of a 14 day period. It can thus be said that SpaceShipOne has become the first private manned spacecraft.


**Figure 1: SpaceShipOne**

On September 27, 2004, a multimillionaire hotel owner, Robert Bigelow, announced a $50 million prize, called "America's Space Prize," for the first successful vehicle capable of carrying up to seven astronauts to an orbital outpost by the end of the decade. The America's Space Prize witnesses a thriving enthusiasm in space tourism.
However, as far as the space tourism is concerned, even the "easy" suborbital flight appears to be very interesting. This fact has led our AeroSpace Systems Engineering Team (ASSET), working at DIASp, (Politecnico di Torino), to investigate the feasibility of a vehicle, which, potentially, could be considered as a competitor of SpaceShipOne, in spite of their diversity. Unlike SpaceShipOne, the space vehicle we have studied is a Single Stage: this avoids the usually highly risky separation's manoeuvre and reduces the logistic effort of managing two different vehicles.

## 2. HYPOTHESIS FOR A SPACE TOURISM VEHICLE

In order to develop such a project, the research activity of ASSET, has been focusing for a few years now on the development of aircraft/spacecraft's conceptual design efficient computerized methodologies, which allow us to accomplish the studying and the technological assessment of new aerospace systems concepts.
It is quite easily understood that nowadays an interesting field to investigate is space tourism: as above described, innovative concepts, turned towards a new exploitation of space resources, are becoming popular. Advanced reusable space vehicles have to be studied and implemented to let the space tourism start.
In this paper we present our first hypothesis for a fully reusable tourism sub-orbital vehicle.

### 2.1. Requirements and layout choices

We have thought that the above mentioned X-Prize competition could be considered as a useful frame for our work. Therefore the target we were willing to achieve was the development of an aerospace system able to:

- perform suborbital flights attaining an height of 100 km (First Requirement);
- carry a minimum of three adults (Second Requirement).

Moreover, bearing in mind the X-Prize reusability and supportability requirements, the craft must be flown twice within two weeks and the second flight has to demonstrate the economical vehicle reusability (no more than 10% of the vehicle's first-flight non-propellant mass may be replaced between two flights), thus reducing the turnaround time too.

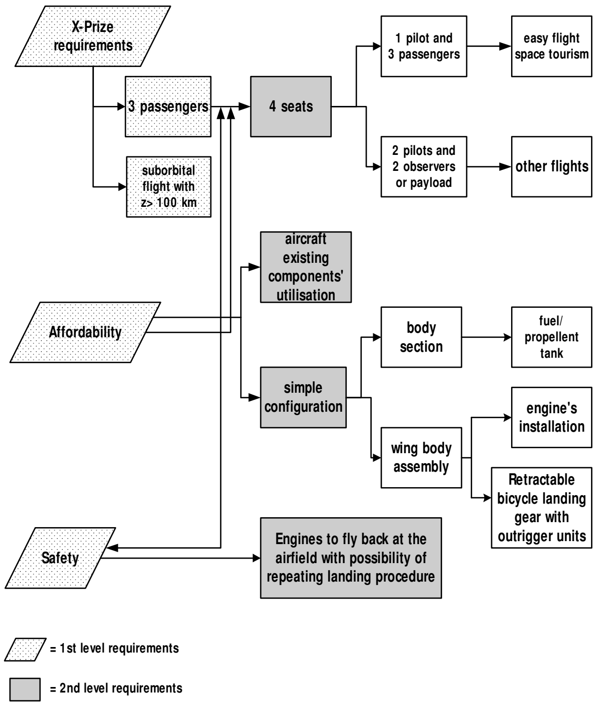



**Figure 2: Space vehicle requirements**

These first considerations have paved the way for drawing up a logical path which has led us to the definition of more detailed and specific requirements. The logical definition process has evolved through the following steps:

- high importance has to be attached to affordability not to compromise the possibility of a thriving beginning of space tourism. In fact too much high launch cost as well as the limited budgets of small or medium companies (see Table 1), which are likely to be in charge of carrying out space tourism's vehicles, could seriously frustrate any attempts of achieving space tourism's goal. It has to be remembered that the previously mentioned reusability and supportability fall within affordability (Third Requirement);

- a high safety level (Fourth Requirement) has to be guaranteed since ordinary members of the public will be carried into space.

Figure 2 shows how a set of technical requirements, defined as “second level requirements”, have stemmed from the four above mentioned basic requirements.

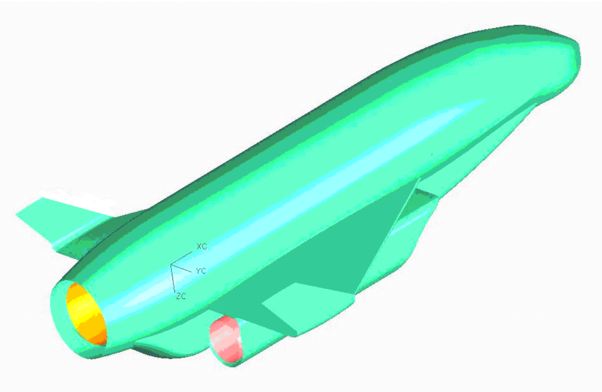


**Figure 3: 3D-CAD model of the space vehicle**

Thus the space vehicle’s configuration (see figure 3) appears to be defined this way:

a) crew/passengers compartment is located in the front fuselage area. The four seats are arranged in two rows, each one constituted by two seats side by side;

b) the central body has a circular section and it hosts the fuel/propellant tanks;

c) one rocket engine is located in the rear fuselage; it is supported by a bulkhead, which is one of the main structural elements;

d) a delta-wing configuration was employed and its center section was connected to the lower side of the fuselage;

e) two airbreathing engines are hung from the wing center section. They are enclosed in a volume which extends out of the lower side of the fuselage and can be considered as a continuum of the fuselage itself from the aerodynamic point of view, but not from the structural one (see figure 4). Apart from the two airbreathing engines, the two elements of the by-cycle landing gear and a great part of the on-board systems are contained into this volume as well thus attaining a good accessibility level. It has to be remembered that the easier the maintenance work can be performed the better the affordability requirement and the short turnaround time requested by the X-Prize Competition can be achieved;

f) small vertical surfaces at the wing tips are devoted to directional stability and yaw control. Moreover these surfaces may increase the aspect ratio with benefits for the subsonic flight;

g) there are three tanks hosted inside the fuselage: the LOX and the LH2 tanks for the rocket engine and one tank for the airbreathing engines’ fuel (i.e. JP4).

Figure 5 schematically shows how the JP4 and rocket propellant quantity and hence the fuselage length affect the wing surface and the wing aspect ratio. An important role is also played by the Mach cone (corresponding to the maximum Mach number, M=2.8, which is the same for all configurations foreseen) during the ascent as a constraint for the wing geometry. A further constraint for the space vehicle geometry is given by the abscissas of the center of gravity and the aerodynamic center (see figure 6).

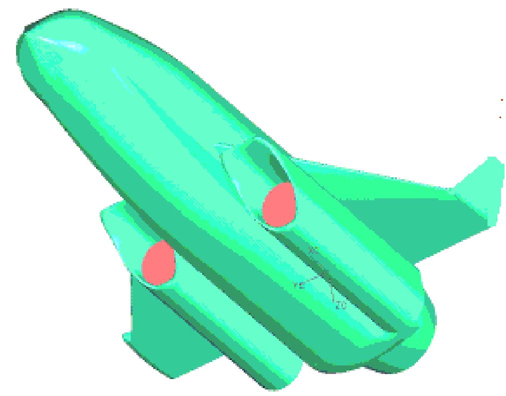


**Figure 4: Space vehicle bottom view**

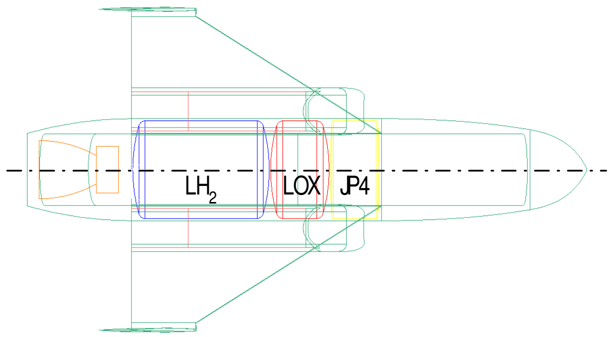



**Figure 5: Space vehicle plan view**

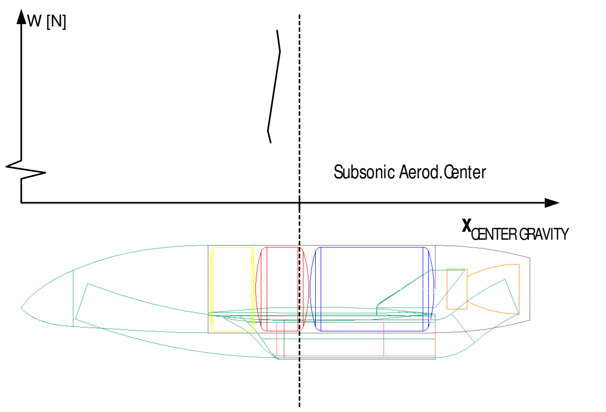



**Figure 6: Study of the CG abscissa variation**

In order to obtain a convenient variation of the center of gravity abscissa, we have thought that the LOX tank should be located between the JP4 and the LH2 tanks. This configuration seems to be the best one to guarantee an adequate static margin, considering the variation of the aerodynamic center abscissa, throughout the flight. The going backwards of the aerodynamic center abscissa in supersonic flight can be reduced thanks to the lifting contribution of the fore part of the vehicle's body. It has to be remembered that the variation of the center of gravity abscissa is one of the driving factors for the choice of the location of the main landing gear that can be retracted forward, like the nose landing gear. The forward retraction is convenient for the center of gravity's abscissa variation and for assuring the landing gear extraction even without the availability of hydraulic power.

### 2.2. Dimensioning activity of the configuration

A 3D CAD parametric model has been built to illustrate the architectural layout obtained on the basis of the configuration's choices. The parametric nature of our 3D CAD drawing is essential to improve and simplify the sizing activity within the conceptual design methodology recently developed at DIASP [1], [2].
The first step to take to apply this methodology (see figure 7) to the case study consists in making a first attempt in choosing the engines (kind and size) and the tanks capacity. The methodology lets the 3D CAD parametric model to be dimensioned and consequently a weight estimation becomes possible.

### 2.3. Propulsion system

The power plant configuration adopted is constituted by two airbreathing engines and one rocket engine. Safety has been the driving factor of our choice because of the presence of passengers on board. The airbreathing engines guarantee safe take-off and landing procedures, which are similar to civil aircraft's ones. The possibility of igniting the airbreathing engines during the approach phase allows to choose the landing field depending on different necessities.
Table 2 shows the three hypothesized airbreathing engines and the rocket engine.

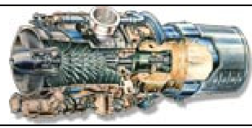
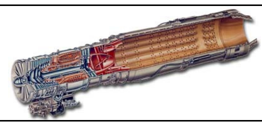
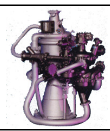
| | | |
|---|---|---|
| **AIRBREATHING ENGINES** | | |
| ***n°2 WILLIAMS ROLLS FJ44 TURBOFAN*** | |  |
| **<u>Engine data</u>:** | W = 1982 N | **<u>Features:</u>** |
| T = 2*10240 N = 20480 N | Isp = 7660 sec | It is used up to z=8000m of height and M=0.7 of velocity. |
| Length = 1199 mm | Diameter = 551 mm | |
| ***n°2 ROLLS-ROYCE VIPER 600 TURBOJET*** | |  |
| **<u>Engine data</u>:** | W = 3689 N | **<u>Features:</u>** |
| T = 2*17795 N = 35590 N | Isp = 3830 sec | It is used up to z=10600 m of height and M=0.95 of velocity. |
| Length = 1806 mm | Diameter = 624 mm | |
| ***n° 2 GENERAL ELECTRIC J85 TURBOJET WITH AB*** | |  |
| **<u>Engine data</u>:** | W = 3689 N | **<u>Features:</u>** |
| T = 2*17795 N = 35590 N | Isp = 1622 sec (with AB) | Two different uses foreseen:<br>➢ Up to z=15700 m of height and M=1.1 of velocity (third configuration).<br>➢ Up to z=14300 m of height and M=1.57 of velocity (fourth configuration); |
| Length = 1806 mm | Diameter = 624 mm | |
| **ROCKET ENGINE** | |  |
| ***RL10A-5*** | | |
| **<u>Engine data</u>:** | W = 1402 N | **<u>Features:</u>** |
| T = 64700 N | Isp = 373 sec | It is ignited when the airbreathing engine has been switched off and it is used up to M=2.8. |
| Diameter = 800 mm | | |

**Table 2: Engines' data and features**

By combining the three airbreathing engines with the rocket engine four different propulsion system's configurations have been foreseen:

1. FJ44 turbofan + RL10A-5 rocket (first configuration);

2. Viper 600 turbojet + RL10A-5 rocket (second configuration);
3. J85 turbojet with AB + RL10A-5 rocket (third configuration);
4. J85 turbojet with AB + RL10A-5 rocket (fourth configuration), used up to a height and a Mach number different from the third configuration.

Even though the third and the fourth configurations employ the same airbreathing engine, they are characterized by different tanks' capacity. Thus they can be considered as different configurations.

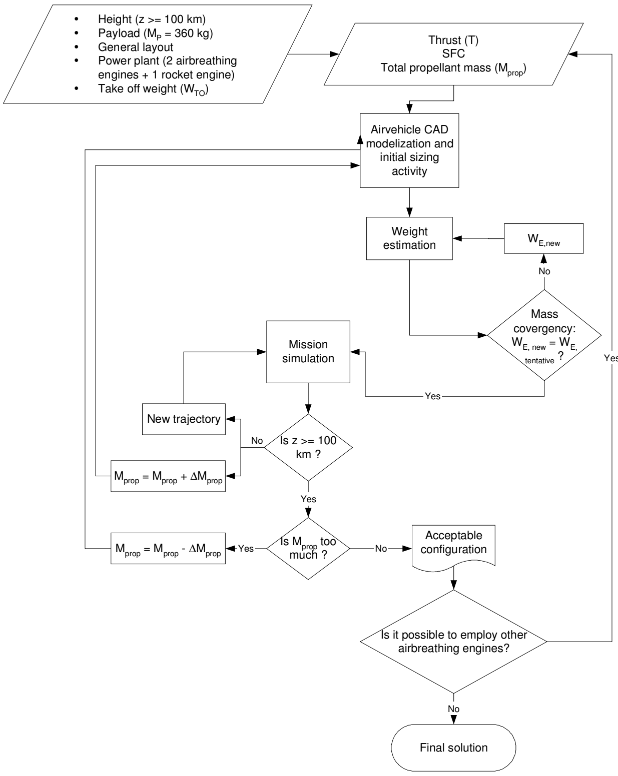



**Figure 7: Conceptual Design Methodology**

## 2.4. On-board systems' choices

A series of hypotheses about on-board systems has also been made. Thus the space vehicle's configuration is completely defined even if at conceptual level.

➢ **Electric system**

As the electric system's layout (see figure 8) is quite simple and the loads are not too big, the direct current is predominantly adopted. For all propulsive configurations foreseen, the electric system is constituted by two starter generators and a set of twenty-eight volt nickel-cadmium buffer batteries. As the air-breathing engines foreseen are reduced in size (see paragraph 2.3), they are set going by the batteries by means of the starter-generators. The batteries are then recharged by the engines while they are running. When the rocket engine is ignited and during descent, the batteries provide all electric loads with the electric power needed. As can be noted from the electric system's layout, two inverters have been foreseen for the alternate current required.

➢ **Hydraulic system and flight controls**

Two hydraulic pumps, driven by the air-breathing engines (see figure 9), set in action the control surfaces (elevons for pitch and roll, rudders for yaw), the aerodynamic brakes and the landing gear. When the rocket engine is ignited and during descent, the hydraulic power is provided by an electric driven pump: it sets going an high speed aerodynamic brake and two actuators for the rocket nozzle's control (see figure 8). In fact during these two flight phases the conventional flight surfaces are not effective because of low air density. Flight control is performed by employing thrust-vectoring of the rocket engine when it is ignited. During descent, when the rocket engine is switched off, flight control is guaranteed by aft steering jets until the aerodynamic control surfaces gradually become active. Anyway, if thrust-vectoring of the rocket engine was needed to perform flight control, the initial propellant's amount foreseen could be increased to allow the rocket engine to be ignited again though for a short time.

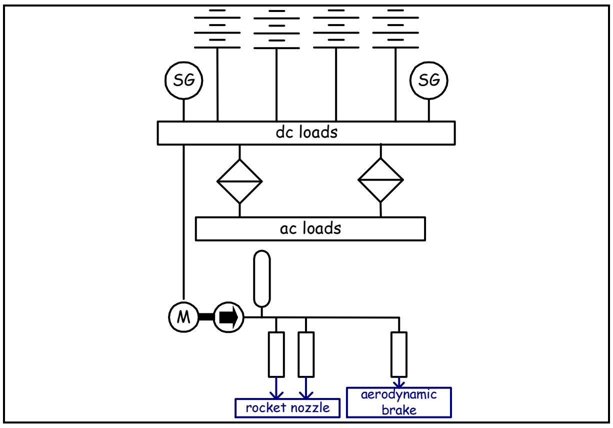



**Figure 8: Electric system**

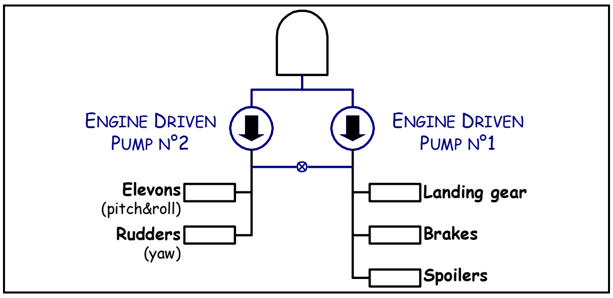



**Figure 9: Hydraulic system**

➢ **ECS (Environmental Control System)**

While air-breathing engines are running, warmer temperatures may be obtained in the cabin, if needed, thanks to the hot bleed. Whereas if colder temperatures are needed the rocket propellants, stored at very low temperature, can be used as cooling fluid.

Taking into account the little time taken by the rocket ascent phase and by the descent (that is before the air-breathing engines are ignited again during approach and landing), we think that no serious problems concerning the ECS will arise. However, the possibility of lowering the temperatures is foreseen by exploiting the residual rocket propellant. Figure 10 illustrates the ECS.

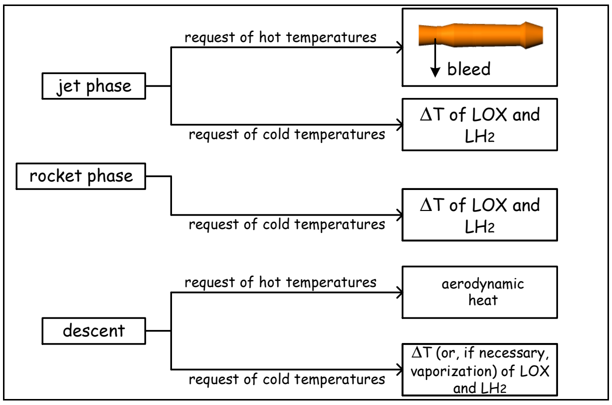



**Figure 10: ECS**

## 2.5. Weight estimation

An initial sizing activity and the airvehicle CAD modelization were carried out on the basis of the quantity and type of propellants, the capacity of the payload bay and the size of the foreseen engines. The outcomes were tentative values needed to begin working out the preliminary weight estimation, as described in Figure 7 [3]. The different weight values obtained (i.e. Empty Weight, Zero Fuel Weight and Take-Off Weight) let the simulations be performed.

An iteration process aiming at attaining more precise values for the vehicle's size could then begin and be pursued until convergence of values was reached. The dimensions and weights shown respectively in Figure 6 and in Table 3 represent the final values obtained and validated by the mission simulation's algorithm.

| | Different configurations | | | |
|---|---|---|---|---|
| | 1° | 2° | 3° | 4° |
| Weights | | | | |
| $W_{body}$ [N] | 5680 | 5680 | 5680 | 5680 |
| $W_{wing}$ [N] | 1717 | 1717 | 1717 | 1717 |
| $W_{vertical\ tails}$ [N] | 464 | 464 | 464 | 464 |
| $W_{l.gear/systems}$[N] | 4596 | 5804 | 5137 | 5130 |
| $W_{tanks}$[N] | 1311 | 1751 | 1695 | 1659 |
| $W_E$ [N] | 19134 | 24195 | 21413 | 21370 |
| $W_{payload}$ [N] | 3531 | 3531 | 3531 | 3531 |
| $W_{zero\ fuel}$ [N] | 22665 | 27726 | 24944 | 24901 |
| $W_{JP4}$ [N] | 1962 | 3983 | 7024 | 8525 |
| $W_{fuel\ rocket}$ [N] | 16000 | 20003 | 16196 | 14205 |
| $W_{TO}$ [N] | 40627 | 51712 | 48164 | 47631 |

**Table 3: Weight estimation**

## 3. MISSION SIMULATION

The next step is the implementation of the mission's simulation. As figure 11 shows, it is based on a flight mechanics simplified model. Once obtained the acceleration's components, the flight mechanics model gives the values of velocity and position through time integration.

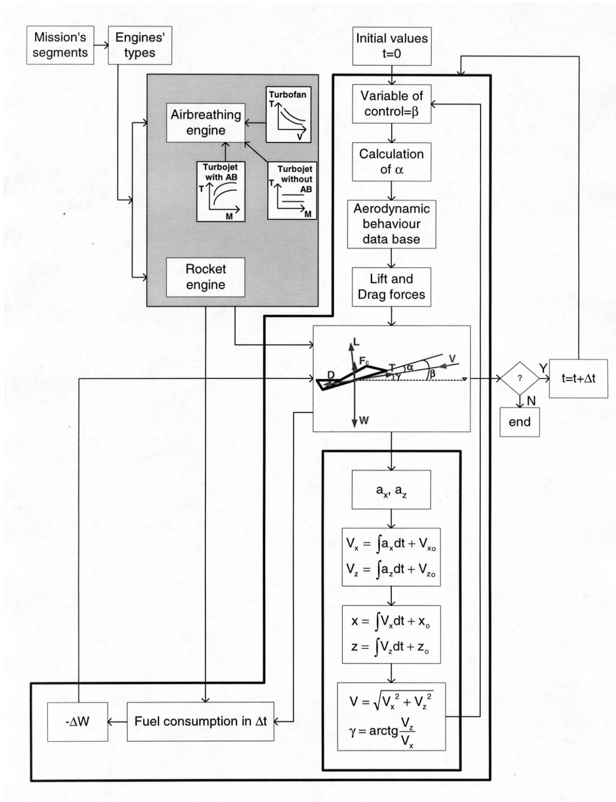



**Figure 11: Mission simulation program**

## 4. CONCLUSIONS

The results obtained in terms of fuel/propellant consumptions and significant flight times are expressed in Table 4.

| | Different configurations | | | |
|---|---|---|---|---|
| | 1° | 2° | 3° | 4° |
| Fuel/propellant consumption | | | | |
| JP4 [N] | 579 | 1530 | 4365 | 5945 |
| LOX+$LH_2$ [N] | 15382 | 19738 | 15725 | 13489 |
| $\frac{W_{total\_consumed}}{W_{total\_initial}}$ | 0.889 | 0.887 | 0.865 | 0.855 |
| Time | | | | |
| Mission [s] | 1466 | 1221 | 1256 | 1283 |
| Airbreathing engine ignition (climb) [s] | 465 | 326 | 340 | 381 |
| Rocket engine ignition (climb)[s] | 83 | 105 | 83 | 71 |

**Table 4: Obtained results**

As it can be noted the fourth configuration appears to be the best one from the point of view of fuel/propellant consumption (the value of the ratio of the total consumed fuel/prop. to the total initial fuel/propellant is the lowest).

| | Disadvantages | Advantages |
|---|---|---|
| First Configuration: **Turbofan** (FJ44) | ✓ Engines of a new generation: therefore they are **expensive.** | ✓ **Less consumption** of **JP4**, thanks to the low SFC of the turbofans.<br>✓ **Less consumption** of **rocket propellant**, thanks to the lower value of vehicle's mass at take-off and at rocket's ignition. |
| Second Configuration: **Turbojet** (Viper 600) | ✓ **More consumption** of **JP4** than the first configuration.<br>✓ The **consumption** of **rocket propellant** is **higher** than the consumption of all the other power plant's configurations, because of the high vehicle's mass at take-off. | ✓ **Old generation** engines, therefore they are cheaper. |
| Third Configuration: **Turbojet + AB, n°1** (J85) | ✓ **More consumption** of **JP4** than the first and the second configuration, because of the employment of the After Burner (high value of SFC). | ✓ Less consumption of rocket propellant because the **rocket** is **ignited for a reduced time,** if compared to the second configuration.<br>✓ **Old generation** engines, therefore they are cheaper. |
| Fourth Configuration: **Turbojet + AB, n°2** (J85) | ✓ The **consumption** of **JP4** is **higher** than the consumption of all the other power plant's configurations, because of:<br>▪ the employment of the After Burner;<br>▪ the highest ignition time. | ✓ Less consumption of rocket propellant because the **rocket** is **ignited for a reduced time,** if compared to the second and the third configurations.<br>✓ **Old generation** engines, therefore they are cheaper. |

**Table 5: Advantages and disadvantages of all studied configurations**

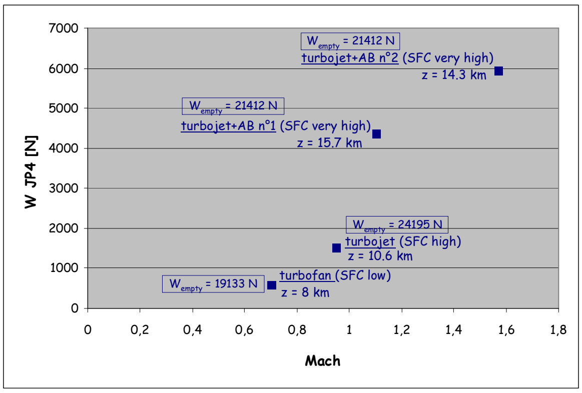



**Figure 12: Airbreathing engines' consumption (climb-1st segment)**

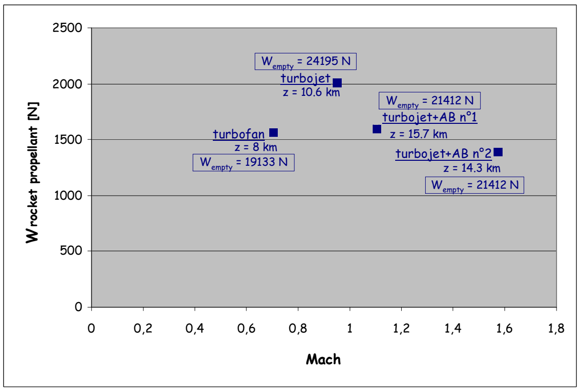



**Figure 13: Rocket engine's consumption (climb-2nd segment)**

Figures 12 and 13 compare the consumptions of JP4 and rocket propellant during ascent for all configurations foreseen. It has to be observed that the consumptions depend not only on Mach number, but also on height (z), empty weight ($W_{empty}$), Specific Fuel Consumption of the airbreathing engines and initial total fuel/propellant quantity.

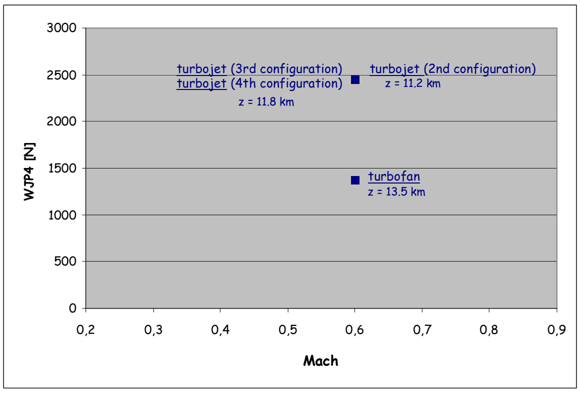



**Figure 14: Airbreathing engines' consumption (final descent phase and landing)**

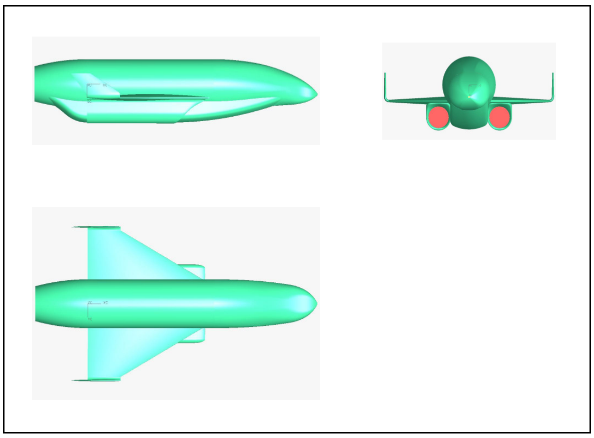


**Figure 15: Three-view drawing of the fourth configuration**

Figure 14 illustrates the residual amount of JP4 available for the approach/landing phase. The values of height and

Mach number highlighted in this figure refer to the ignition of the airbreathing engines during descent.
The available quantity of JP4 for the second, third and fourth configurations is the same because the during this phase the employment of the After Burner has not been foreseen. Thus the value of SFC for both turbojet configurations is of the same magnitude's order.
Table 5 sums up advantages and disadvantages for all studied configurations. Taking into account the consumptions and the engines' cost we think that the fourth configuration seems to be the more favorable.
Figures 15, 16 and 17 illustrate respectively the three-view drawing and the simulation's outcomes of the fourth configuration.

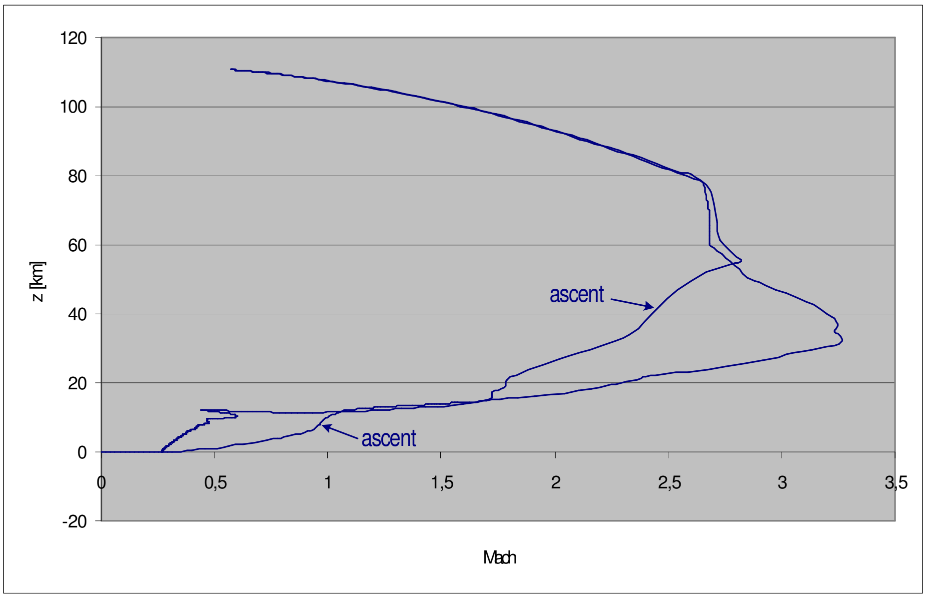



**Figure 16: z(M) graph for the fourth configuration**

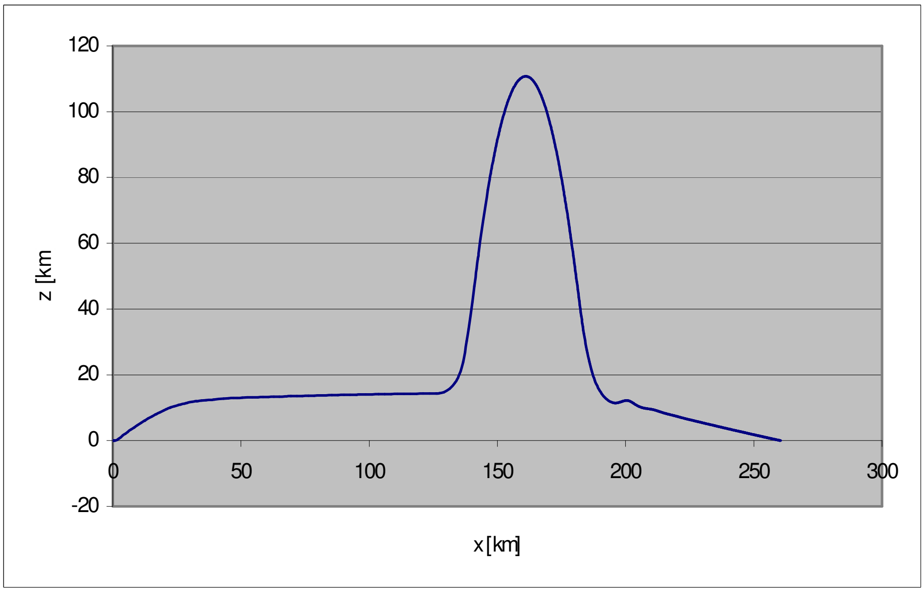



**Figure 17: z(x) graph for the fourth configuration**
**(without considering the airbreathing engines in the final descent phase)**

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