# POLITECNICO DI TORINO

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# High level analysis to support preliminary design of Hypersonic vehicle


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# ABSTRACT

This thesis deals with the definition of a methodology to support the conceptual design of trans-atmospheric vehicles, with a special focus on the stakeholders' analysis.
After a brief introduction describing the current market outlook and the research activities and projects currently under development, a stakeholder analysis is performed with the aim of eliciting the first list of high-level requirements, which, in the second part of this thesis, have been used as a starting point for the preliminary design of the aircraft. In particular, these high-level requirements represented the major drivers for the main trade-offs at system level. In particular, proper algorithms to suggest the optimal staging strategy, propulsion strategy, take-off and landing strategy as well as the aerothermodynamic configuration have been developed and applied to different reference case studies. Indeed, considering that trans-atmospheric vehicles, different missions may be envisaged: suborbital flights, point-to-point missions and reusable access to space missions. Specific variations of the algorithms allow to specialize the trade-off analyses for the different case studies.
In parallel, an ad-hoc built in Tool has been developed in Matlab aiming at supporting the designer during the conceptual design providing useful suggestions. This program has been developed with the purpose of facilitating the problem definition process, simplifying design iterations and providing further design support. Throughout the process, a crucial role is played by requirements. Indeed, the requirements generated during the stakeholder analysis becomes drivers for the following selection process, in a cascade effect.

Questa tesi si occupa della definizione di una metodologia per supportare la progettazione concettuale dei veicoli trans-atmosferici, con particolare attenzione all'analisi degli stakeholder.
Dopo una breve introduzione che descrive le attuali prospettive del mercato e le attività di ricerca e i progetti attualmente in fase di sviluppo, viene eseguita un'analisi degli stakeholder allo scopo di ottenere la prima lista di requisiti di alto livello, i quali nella seconda parte di questa tesi sono stati utilizzato come punto di partenza per la progettazione preliminare dell'aeromobile. In particolare, questi requisiti di alto livello rappresentato i principali elementi per i principali trade-off a livello di sistema. In particolare, sono stati sviluppati e applicati a diversi casi di studio di riferimento algoritmi appropriati per suggerire la strategia di allestimento ottimale, la strategia di propulsione, la strategia di decollo e atterraggio e la configurazione aerotermodinamica. In effetti, considerando i veicoli transatmosferici, possono essere previste diverse missioni: voli suborbitali, missioni point-to-point e accesso riutilizzabile alle missioni spaziali. Variazioni specifiche degli algoritmi consentono di specializzare le analisi trade-off per i diversi casi studio.
Parallelamente, in Matlab è stato sviluppato uno strumento incorporato ad hoc che mira a supportare il progettista durante la progettazione concettuale fornendo suggerimenti utili. Questo programma è stato sviluppato con lo scopo di facilitare il processo di definizione dei problemi, semplificando le iterazioni di progettazione e fornendo ulteriore supporto alla progettazione. Durante tutto il processo, un ruolo cruciale è svolto dai requisiti. In effetti, i requisiti generati durante l'analisi degli stakeholder diventano la guida per il seguente processo di selezione, in un effetto a cascata.

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# 1 INTRODUCTION

## 1.1 *Objectives and aim of the thesis*

This work focuses on the high level analysis to support preliminary design of an innovative aircraft, hypersonic aircraft. In particular, useful algorithms are defined and used to support the process of defining the architecture of the aircraft. The methodology is able to handle multidisciplinary issues in such a way to allow adequate levels of integration. In this thesis different trade-off algorithms are shown for the choice of the best staging strategy, propulsion strategy, take-off and landing strategy and aerothermodynamic configuration. Moreover, information about the fuselage and the wing is shown. After the main analysis of trade-off, some numerical estimates are made, in order to have an idea of the most important project parameters. Regarding the results obtained, they have been obtained both from existing mathematical formulations and from statistical analysis, referring to data relating to similar aircraft. Three different missions have been carried out, which see the hypersonic aircraft operating in three different scenarios. The missions dealt with are: Suborbital Flight, Point to Pont mission and reusable launchers. In this way it was possible to mark the importance of the stakeholders on the design of the aircraft; in particular, it has been noted that as the needs of the stakeholders change, the design of the aircraft changes. Eventually, an ad hoc developed tool to support the overall methodology will be presented. User, interacting with the GUI, makes the first selections, such as the type of mission required and the maximum number of Mach. This will start the general design process. In particular, starting from these choices, the software is able to generate a list of requirements, which will impact on design. Thus, the software will be able to provide the user with suggestions regarding: Propulsive Strategy, Staging Strategy, Take-off and Landing strategy, Aerothermodynamic configuration. Moreover, the tool will be able to provide useful suggestions for the conceptual design and sizing of fuselage and the wing, as a direct consequence of the requirements elicited during the stakeholder analysis.. This tool was born with the purpose of facilitating the problem definition process, simplifying design iterations and providing further design support.

## 1.2 *Overview of the most recent Hypersonics Research activities*

One of the most characteristic performance for a generic transportation system is its maximum achievable speed. As far as aerospace transportation systems are concerned, the Mach number is considered to suggest proper categorizations. Indeed, different motion regimes can be identified: subsonic regime for Mach <1, supersonic regime for Mach> 1. Moreover there is a conventional threshold that defines the hypersonic regime, Mach≥5. In hypersonic motion the physical phenomena that occur are characterized by viscous interaction, as viscosity has a strong influence on the external flow and on the shock waves. The hypersonic regime is characterized by a series of physical phenomena that are not found in other regimes: [18]

- The front of the shock wave: as the Mach increases, the density of the shock wave increases, and its volume decreases due to the law of mass conservation; as a result, the front of the shock wave also decreases.
- Entropy, which increases in the area of the impact front as a result of a high entropic gradient and strong vortex flows that interact in the boundary layer.
- Viscose interaction: a part of the high kinetic energy associated with hypersonic regimes is transformed into internal fluid energy due to viscous effects; this increase in internal energy translates into an increase in temperature. Although the pressure gradient perpendicular to the flow within the boundary layer is zero, the increase in temperature coincides with a decrease in the density of this layer, which can expand and merge with the shock wave.
- The high temperatures reached by the viscous interaction, which cause chemical imbalances in the surrounding environment, such as dissociations and ionizations of molecules, through convective motions and radiation.

The hypersonic flight is a subject which the efforts of basic and applied aerospace research have been focused on over the years. [19] The first hypersonic aircraft to be considered is the "antipodal Bomber", which was made in Germany by Eugen Sanger in the 1930. It was expected to reach speeds and altitudes near the orbital ones, from which to begin a long descent, with successive "bounces" back to the dense layers of the atmosphere, in order to obtain considerable autonomy. [19] This aircraft, although it has never been realized, turns out to be the true progenitor of hypersonic aircraft.

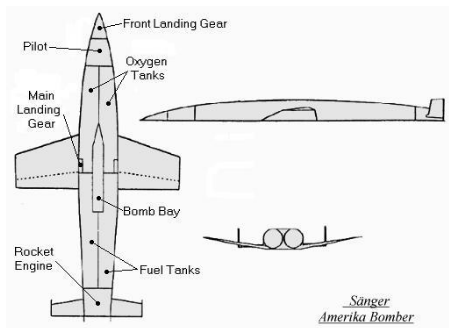


***Figure 1 Sanger Sub-Orbital BomberConfiguration***

Later there was a Soviet study strongly inspired by this aircraft, in this project we opted for a stratospheric cruise at hypersonic speed, rather than the suborbital trajectory for long distances. However, even this project has not been further developed. Only in the last 15 years of the twentieth century has there been a maturation of the Hypersonic Aircraft project, due to the need to expand the autonomy of the long-haul aircraft. Among these projects Particularly significant are the U.S. NASP X30, the English HOTOL and the German Sanger II. Unfortunately, none of Hypersonic Aircraft developed in the last years of the twentieth century have been realized. They were not realized for technical reasons and for financial reasons. [19]
In recent years there have been several research activities in this field. Below are some projects that were developed in 2000s.
"Space Ship One" is a spacecraft, in particular it is an experimental sub-orbital spacecraft equipped with a hybrid propellant rocket engine. In 2004 it made the first space flight developed, moreover it reached the altitude of 100 km twice in a two-week period with the equivalent of three people on board. The larger version "Space Ship Two / White Knight Two" suitable for regular space tourism flights. It is produced by The Spaceship Company, a Californian company. It is transported to its launch height by a Scaled Composites White Knight Two, before being released to fly into the upper atmosphere powered by its rocket engine. Moreover, this aircraft is able to perform a traditional landing. In 2013 he successfully completed his first motorized test flight. [19], [20]
Other airplanes projects for space tourism are XCOR Lynx. is a rocket space plane born in California to compete in the nascent suborbital space flight market. The Lynx had to carry a pilot, a passenger and payload above 100 km altitude. The concept was in development since 2003.In 2016 the project was interrupted. [21]
In addition, there are: SKYLON, LAPCAT A2, the project ZEHST-Zero Emissions Hypersonic Transport two to EADS.
SKYLON is an unmanned spacecraft under study at the British company Reaction Engines. This shuttle will be able to reach the Earth's orbit with a single stage, taking off and landing like a conventional airplane. The first test flight is scheduled for the year 2019. [22]

**Figure 2 SKYLON**

LAPCAT A2 is the project of a hypersonic scheduled airliner commissioned by the European Space Agency as part of the LAPCAT project and built by the British company Reaction Engines Limited. It was designed to take off from Brussels airport and then fly to the North Atlantic and reach Australia after flying over the North Pole in 4 hours 40 minutes. [23]
The Zero Emission Hyper Sonic Transport or ZEHST is a supersonic airliner of passenger aircraft fromEADS and Japan. It can be seen as a descendant of the Concorde airliner capable of flying more than Mach 4. The aircraft is designed to transport 50 to 100 people 32 km above the ground. Zehst would be able to fly from Paris to Tokyo in 2.5 hours, or from New York to London in an hour. [24]

***Figure 3 ZEHST***

## *1.3 Major challenges to be faced with in conceptual design*

The design of an airplane is a very complex discipline, as it requires the balancing of considerations of a variety of disciplines: aerodynamics, structure and weight, propulsion system, subsystems design and installations, stability and control, RAMS (Reliability Availability Maintainability and Safety) and costs. To allow adequate levels of integration, the following methodology is used to support the design process.
In particular, starting from an analysis of the stakeholders and their needs, the first list of requirements is derived. Each of these requirements must be linked to specific high-level system characteristics. As mentioned above, they affect the vehicle design, especially on the staging strategy, propulsion strategy, take-off and landing strategy and aerothermodynamic configuration. To choose the best solution, trade-off techniques are adopted, the possible alternatives are presented, highlighting the impact of each requirement on the choice. In this way, as mentioned previously, it is possible to reach an adequate level of integration.

## *1.4 Thesis overview*

In Chapter 2 the Stakeholders analysis is carried out. In particular, in the first part the methodology is presented, while in the second part the results of the application are reported. The stakeholder analysis is conducted for four different missions: Suborbital flight, Point to point mission, access to space with reusable transportation systems and Re-entry aircraft. A suborbital flight is a space flight that reaches the space, but whose orbit intersects the atmosphere, thus failing to make a complete revolution. Some suborbital flights were undertaken to test space vehicles and rockets for subsequent orbital flights. Other vehicles are specifically designed only for suborbital flights; examples include pilot vehicles such as the X-15 or SpaceShipOne, and unmanned vehicles such as intercontinental ballistic missiles and research rockets.

By definition, a suborbital flight (departing from the earth) reaches an altitude higher than 100 km (known as the Kármán line) above sea level. Suborbital flights can last for many hours. Typical mission consists in carrying out tests and demonstrations of aerospace technologies and also allows to carry out space experiences for astronaut training or for space tourism. This kind of aircraft will have take-off as a normal aircraft, it will have an Atmospheric ascent with airbreathing propulsion, a rocket powered ascent phase, a microgravity period and then there will be the landing phase.


***Figure 4 Example of suborbital flight***

The second mission, point to point mission, consists in reaching very distant points (usually the antipodes) on the globe in a very short time. The third mission allows to reach space using reusable transportation systems, instead of expendable launchers, in order to reduce launch costs and to reuse the same systems for multiple missions. Complementary, hypersonic speed can also be envisaged in missions enabling the return from the space. It shall guarantee the return of people and / or cargo. For each of these missions, specific Stakeholders may be identified, which are then mapped on the basis of their level of importance, which in turn is evaluated depending on their level of interest and influence. Then their Need and Values are identified and the QFD Analysis is carried out in order to identify the most important Stakeholders for that specific mission. Finally, the mission statement is developed and starting from it the high-level requirements are defined.

Chapter 3 focuses on the definition of architecture for hypersonic transportation systems, carrying out the first 3 types of mission mentioned above, in order to highlight how the architecture of the aircraft changes according to the needs of the Stakeholders. For each of these missions, the used trade-off algorithms and their results are shown for the selection of the best staging strategy, propulsion strategy, take-off and landing strategy and aerothermodynamic configuration. Moreover, information about the fuselage and the wing is shown.

In Chapter 4 the ad-hoc developed tool is presented, it allows an interactive use of the implemented functions, which starting from certain choices of the user will be able to provide in output

information on the design of the aircraft. In particular, results regarding the configuration, the fuselage and the wing will be provided.
At the end the conclusions are reported.

# 2 STAKEHOLDERS ANALYSIS

"Stakeholders are people, groups, or institutions which are likely to be affected by a proposed intervention (either negatively or positively), or those which can affect the outcome of the intervention" [1].

Performing stakeholder analysis means understanding who the stakeholders are and, understanding their role in the mission together with their major expectations.

Thust, the main propose of the process dealt with in this chapter is to identify who the Stakeholders are and how they intend to use the product. [2]

## *2.1 Methodology*

### 2.1.1 Stakeholders identifications

Stakeholders identification is an iterative process that must be done throughout the project life cycle.
The promotion of new programs and projects can come from many organizations. These include Presidential directives, Congress, Public Agencies, Private Companies, Academy of Sciences and many other groups in the science and space communities. These organizations are commonly called "Stakeholders".
A Stakeholder is a group or individual who is affected or in some way responsible for the outcome of a business. Stakeholders can be classified as customers and other interested parties. Customers are the ones who will receive the goods or services and are the direct benefits of the work. Other Stakeholders are those interested in the project by providing broad and general constraints within which the needs of customers must be met. These parts may be affected by the resulting product, by the way the product is used or responsible for providing life cycle support services.[2]

To identify the Stakeholders, it could be helpful answering the following questions:

- Who are the people / groups / institutions that are interested in the planned initiative? What is their role?
- Who are the potential beneficiaries?
- Who could be negatively affected? Who has restrictions on the initiative?
- Who can influence the initiative?

Moreover, Stakeholders can be divided into primary and secondary ones depending on their power on the definition of mission objectives and constraints.
In order to identify the primary Stakeholders, the following questions must be answered:

- Who has the idea?
- Who finances it?
- Who approves it?
- Who works for the purpose?
- Who works there, organizes it, manages it?
- Who publicly approves or opposes it?

While among the secondary Stakeholders there are:

- People who experience the effects of work on the project or its result, even if they have a low or even zero degree of influence
- Their satisfaction can be decisive for the success of the project. [1], [3]

### 2.1.2 Mapping of Stakeholders

Stakeholders are divided into categories based on their influence and interest in that particular activity. They are also mapped in order to better understand which one are the main ones.


***Figure 5 Example of mapping of Stakeholders***

They are divided into:

- Promoters: high interest and power to help or to derail the activity; they have to be must fully engage and keep satisfied;
- Defenders: high interest but low influence; they have to be adequately informed about the activity process;
- Latent: low interest but high power and influence if they become interested; they must be keep satisfied;
- Apathetic: low interest and low influence; they have to be monitored but with minimum effort.

All this can be done by answering question.

- Who has more decision-making power?

Based on the answers, scores can be assigned in order to define an adequate ranking of influence. In particular, a score from 1 to 10 to each Stakeholders suggested for the purpose of define a suitable hierarchy of influence.
After that they must be positioned on a map in such a way as to better understand the roles.
The mapping is a crucial point as it visually summarizes the entire analysis of the influence of the Stakeholders. [2], [4]

### 2.1.3 Need and Values Analysis

Each stakeholder has several pecular expectations on the product or on the final provided service.
The importance of each stakeholder determines the degree to which the company seeks to meet the needs during the planning of its actions. The goal is to obtain the point of view of all the Stakeholders in every phase of the system's life, in order to consider a complete set of Needs.
Values identify the utility, benefit, or reward for the Stakeholders in exchange for their contributions to the project, they can summarize the Needs of the Stakeholders, but they can be in conflict or in a positive relationship. [4]

### 2.1.4 QFD Analysis

The Quality Functional Deployment tool (QFD) allows identifing and ranking the objectives of stakeholders and the importance of those objectives together with the engineering features associated to the objectives. Moreover, the QFD process helps to identify areas of conflicts between the needs and the values obtained from the need analysis.

It correlates the two previous points and verifies the correlations, assigning objectives and priorities for the system requirements in the end.
The Quality Function Deployment is built on the House of Quality matrix, which is a diagram split in different areas which are:

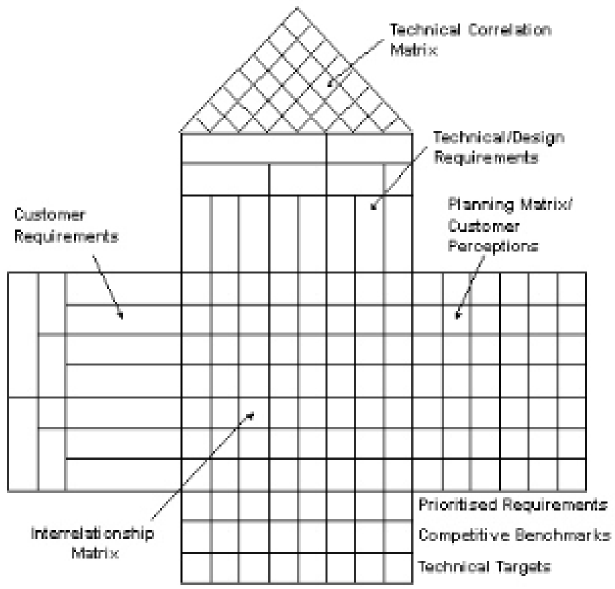


***Figure 6 House of Quality***

- Customer requirements
- Planning matrix
- Technical requirements
- Inter-Relationships Matrix
- Roof
- Targets

<u>Customer requirements</u>
Generally, this is the first portion of the HOQ matrix to be completed and also the most important. It documents a structured list of the stakeholders requirements described in their own words.

<u>Planning matrix</u>
Attached on the right side it serves several purposes. Firstly, it quantifies the customers' requirement priorities and their perceptions of the performance of existing products; secondly it allows these priorities to be adjusted based on the issues that concern the design team.
The most important measure in this section is the Importance Weighting which quantifies the relative importance of each of the stakeholders requirements from the customer's own perspective.

<u>Technical requirements</u>
This section describes the mission in the terms of the team and identifies all the measurable characteristics of the mission which they perceive are related to meeting the specified customer requirements

Inter-Relationships
This section forms the main body of the HOQ matrix. Its purpose is to translate the requirements as expressed by the customer into the technical characteristics of the product; its structure is that of a standard two-dimensional matrix with cells that relate to combinations of individual customer and technical requirements. It is the task of the QFD to identify where these inter-relationships are significant.

Roof
The roof matrix is used to identify where the technical requirements that characterize the mission, support or impede one another. The information recorded in the roof matrix highlights where a focused improvement could lead to a range of benefits and it also focuses attention on the negative relationships in the design.

Targets
This is the final section of the HOQ matrix to be completed and it summaries the conclusions drawn from the data contained in the entire matrix.

To build the HOQ two steps have been done.

The first one was to build:

- a matrix, where the left column is occupied by the STs and the upper line by the needs identified in the previous section;
- a roof, where the left column is occupied by the needs related to themselves, in order to understand which needs could be positively or negatively affect by each other

The second one was to assign particular scores to complete those matrix and obtain reasonable numerical values for the analysis.

Matrix
The level of inter-relationship discerned is weighted usually on a three point scale (High, Medium, Low) where each point has an assigned score chosen to suit the individual QFD project that may be varied later if necessary.
In the target section, the relative importance of each technical requirement of the mission in meeting the stakeholders' needs is simply calculated from the weightings contained in the planning and interrelationship matrix sections. Each interrelationship weighting is multiplied by the weighting from the Planning matrix; later these values are summed down to give a priority score for each technical requirement.

Roof
To complete the roof matrix the following question needs to be answered:
"Does improving one requirement cause a deterioration or improvement in the other technical requirement?"
When the answer is a deterioration the symbol "-" is entered in the cell; when improving one requirement leads to an improvement in the other requirement the symbol "+" or "++" is entered. [3], [4]

### 2.1.5 Mission objectives/Mission statement development

Define mission objectives is the beginning of the mission analysis because they describe what the mission will have to accomplish without include lower level implementation aspects. The first step is to answer a series of questions:

- What is the main problem?
- How can we solve the problem?
- Are there any other significant objectives imposed by the scenario?
- Who is the end user?
- Are there any constraints?

The second step is going to write the Mission Statment, going to identify the high-level objectives. The information in the MS will be sufficient to start the requirements generation process.
Requirements are written as instructions, because they must be easily legible and understood. A good requirement must be verifiable and quantifiable. [2], [4]

## *2.2 Results of the application*

### 2.2.1 Suborbital flight

Stakeholders identification

This chapter focuses on the Stakeholder Analysis and the case of the suborbital flight is used as an explanatory study case.
This mission shall allow testing and demonstration of aerospace technologies and to make spaceflight experiences for tourism and training. Furthermore, it could also be used to perform research in space environment and microgravity and remote sensing.

On the basis of the influence matrix, Stakeholders can be divided into primary and secondary.
In order to identify the primary Stakeholders, the following questions must be answered:

| | |
|---|---|
| **Who has the idea?** | Public Agencies |
| | Private Companies |
| **Who finances it?** | Financial institutions |
| | Actionist |
| **Who approves it?** | Safety managers |
| | Regulatory/Certification organism |
| **Who collaborates for the purpose?** | Universities |
| | Research Organizations |
| **Who works there, organizes it, manages it?** | Consultant |
| | Employee |
| **Who publicly approves or opposes it?** | Public Office |

***Table 1 Primary Stakeholders, case of suborbital flight***

While among the secondary Stakeholders there are:

| | |
|---|---|
| **People who experience the effects of work on the project or its result, even if they have a low or even zero degree of influence** | Consumers/Users |
| **Their satisfaction can be decisive for the success of the project** | Consumers/Users |
| | Public Agencies |
| | Private Companies |

***Table 2 Secondary Stakeholders, case of suborbital flight***

Also, to identify the Stakeholders, the following questions are answered:

| | | |
|---|---|---|
| Who are the people / groups / institutions that are interested in the planned initiative? What is their role? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the |

| | | |
|---|---|---|
| | | unique properties of the space environment and the microgravity. |
| | • Public Office | They promote and present this activity. |
| | • People intellectually attracted by the aerospace world | They are people who keep themselves informed about the aerospace world, they are very interested in these technologies, they are very interested in increasing their knowledge, but they do not give us any contribution for the development of these technologies. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Consultant | They manage the initiative. |
| | • Employee | They work on this initiative, they are engineers, workman, etc. |
| | • Consumers/Users | (Tourism, public companies, private companies, government, armed forces, training of space personnel, technological tests and demonstrations, image acquisition of the earth or of the solar system for commercial, civil, military, governmental, military surveillance) use this service. |
| Who are the potential beneficiaries? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Consumers/Users | (Tourism, public companies, private companies, government, armed forces, training of space |

| | | |
|---|---|---|
| | | personnel, technological tests and demonstrations, image acquisition of the earth or of the solar system for commercial, civil, military, governmental, military surveillance) use this service. |
| Who could be negatively affected? Who has restrictions on the initiative? | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| Who can influence the initiative? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
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| | • Actionist | They finance the initiative. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |

***Table 3 Stakehoders identfication, case of suborbital flight***

Please, notice that each entity can have different roles in the project. Of course, depending on the role, the stakeholder can express different expectations and can have a different impact on the mission.

## Mapping of Stakeholders

On the basis of what is presented in the previous paragraphs, Stakeholders can be divided into categories based on their influence and interest in that particular activity. They are also mapped in order to better understand which one are the main ones.

| STAKEHOLDERS | LEVEL OF IMPORTANCE |
|---|---|
| PUBLIC AGENCIES | 10 |
| PRIVATE COMPANIES | 8 |
| UNIVERSITIES | 7 |
| RESARCH ORGANIZATIONS | 7 |
| PUBLIC OFFICE | 5 |
| PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD | 2 |
| CONSUMERS/USERS | 6 |
| SAFETY MANAGERS | 9 |
| REGULATORY/CERTIFCATION ORGANISM | 9 |
| FINANCIAL INSTITUTIONS | 8 |
| ACTIONIST | 8 |
| CONSULTANT | 6 |
| EMPLOYEE | 4 |

***Table 4 Stakehoders, case of suborbital flight***

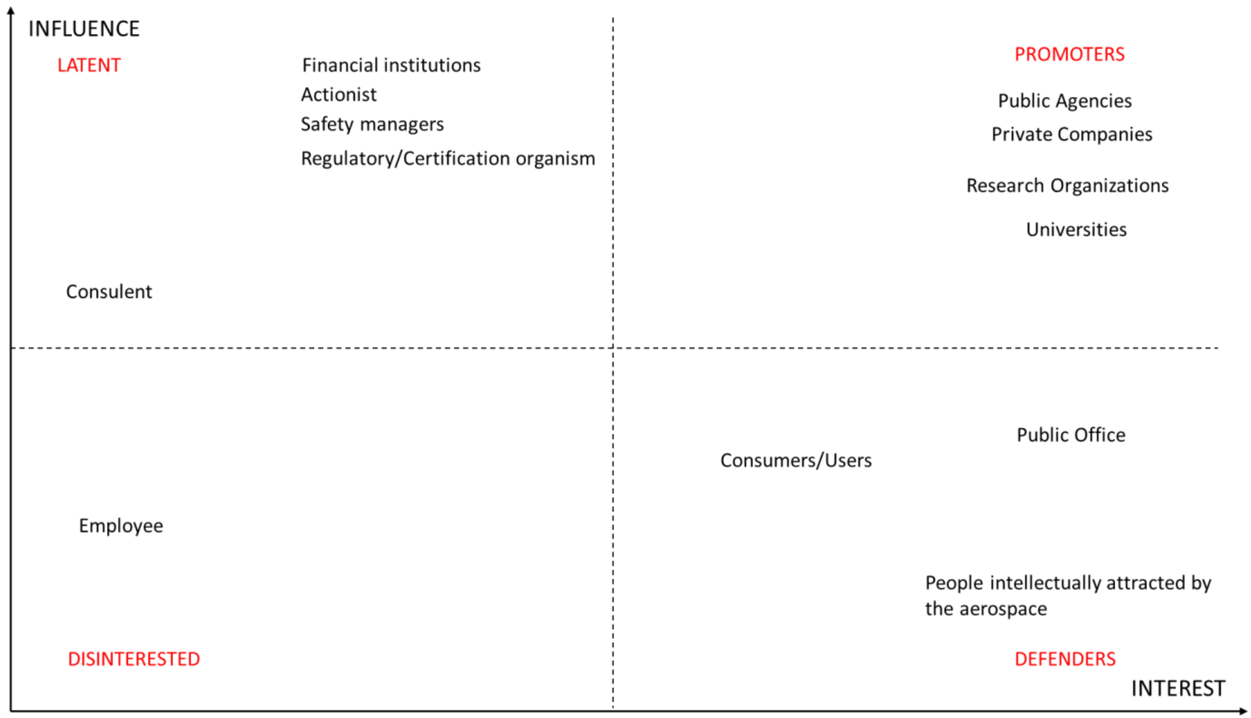



***Figure 7 Stakeholders map, case of suborbital flight***

## Need and Values Analysis

Each stakeholder has several pecular expectations on the product or on the final provided service.
The importance of each stakeholder determines the degree to which the company seeks to meet the needs during the planning of its actions. The goal is to obtain the point of view of all the Stakeholders in every phase of the system's life, in order to consider a complete set of Needs.
Values identify the utility, benefit, or reward for the Stakeholders in exchange for their contributions to the project.

| STAKEHOLDERS | NEED | VALUES |
|---|---|---|
| **PUBLIC AGENCIES** | Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies. | New Technologies. |
| **PRIVATE COMPANIES** | Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies. | New Technologies. |
| **UNIVERSITIES** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |

| | | |
|---|---|---|
| **RESARCH ORGANIZATIONS** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **PUBLIC OFFICE** | Promote and present hypersonic aircraft. | Provide them with more information about these aircraft. |
| **PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD** | Being involved, receiving information about new technologies. | Involve them more, providing more information about this new technology. |
| **CONSUMERS/USERS** | Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity (biological and physical research, earth sciences, space sciences, research on physiology and psychology), tests and demonstrations of aerospace technologies, remote sensing (acquisition of images of the earth or the solar system for military, commercial and governmental civil use). | Hypersonic aircraft. |
| **SAFETY MANAGERS** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **REGULATORY/CERTIFICATION ORGANISM** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **FINANCIAL INSTITUTIONS** | Investing on new products, new technologies. | Give them a product to invest in. |
| **ACTIONIST** | Investing on new products, new technologies. | Give them a product to invest in. |
| **CONSULTANT** | Work, economic agreements. | Give them an initiative to manage. |
| **EMPLOYEE** | Participate in the design, development and implementation. | Give them a technology to work on. |

***Table 5 Need and Values, case of suborbital flight***

<u>QFD Analysis</u>

For the identified case study, the most important Stakeholders results to be:

- Public agencies and private companies
- Security Managers and Regulatory/Certification organism

The HOQ is shown below, it is split for reasons of space.

| STEKEHOLDERS / NEEDS | Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Agencies | H | H | M | L | H | H | H | M | H | 10 | |
| Private Companies | H | H | M | L | H | H | H | M | H | 8 | |
| Universities | H | H | L | L | H | H | M | M | M | 7 | |
| Resarch Organizations | H | H | L | L | H | H | M | M | M | 7 | |
| Publc Office | M | L | H | M | M | M | L | L | L | 5 | |
| People intellectually attracted by the aerospace world | M | M | L | H | M | L | L | L | L | 2 | |
| Consumers/Users | H | M | L | L | H | H | H | L | L | 6 | |
| Safety managers | H | L | M | L | L | H | L | L | L | 9 | |
| Regulatory/Certification organism | H | L | M | L | L | H | L | L | L | 9 | |
| Financial institutions | M | L | L | L | L | M | H | M | L | 8 | |
| Actionist | M | L | L | L | L | M | H | M | L | 8 | |
| Consultant | L | H | L | L | L | L | L | H | M | 6 | |
| Employee | L | M | L | L | L | L | L | M | H | 4 | |
| Normalization | 0,174389 | 0,121945 | 0,070774 | 0,032332 | 0,116853 | 0,172352 | 0,128564 | 0,089358 | 0,093432 | | |
| Ranking | 1 | 4 | 8 | 9 | 5 | 2 | 3 | 7 | 6 | | |
| Score | **685** | **479** | **278** | **127** | **459** | **677** | **505** | **351** | **367** | **TOT** | **3928** |

**Figure 8 HOQ Matrix, case of suborbital flight**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies. | | | | | | | | | |
| Being involved in the study, in the project of new technologies.Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | | | | | | | | | |
| Promote and present hypersonic aircraft. | | + | | | | | | | |
| Being involved, receiving information about new technologies. | | + | + | | | | | | |
| Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing. | ++ | | | | | | | | |
| Maintain a high level of safety, ensuring that the various standards are respected. | | | | | | | | | |
| Investing on new products, new technologies. | | | | | | - | | | |
| Work, economic agreements. | | + | | + | | | ++ | | |
| Participate in the design, development and implementation. | | ++ | | + | | | | + | |
| Direction of Improve: Minimize (↓), Maximize (↑), or Target (X) | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |

| STEKEHOLDERS / NEEDS | Human spaceflight experences for tourism or for training, tests and demonstrations of aerospace technologies. | Being involved in the study, in the project of new technologies.Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance |
|---|---|---|---|---|---|---|---|---|---|---|

**ROOF:**

**++** Strong positive

**+** Positive

\- Negative

**DIRECTION OF IMPROVEMENT:**

↓ To decrease

↑ To increase

**RELATIONSHIP:**

**H** High=10

**M** Medium=5

**L** Low=1

***Figure 9 HOQ Roof Matrix, case of suborbital flight***

Mission objectives/Mission statement development

| QUESTION | ANSWER |
|---|---|
| WHAT IS THE MAIN PROBLEM? | Need to perform tests and demonstrations of aerospace technologies. |
| HOW CAN WE SOLVE THE PROBLEM? | Suborbital flight with new technologies, hypersonic aircraft. |
| ARE THERE ANY OTHER SIGNIFICANT GOALS IMPOSED BY THE SCENARIO? | Increase searches in such a way that you can use this technology for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications). |
| WHAT IS THE END USER? | Tourism, public companies, private companies, government, armed forces; for space personnel training, technological tests and demonstrations, image acquisition of the earth or solar system for commercial, civil, military, governmental, military surveillance. |
| ARE THERE ANY CONSTRAINTS? | The aircraft must be able to take off and land from existing runways.<br>This does not preclude vertical take-off. |

***Table 6 Mission Statement Development, case of suborbital flight suborbital flight***

Mission statement:

*"The mission shall allow testing and demonstration of aerospace technologies. It shall make human spaceflight experiences for tourism or training, using new technologies. The spacecraft shall perform take-off and landing from existing runways, and can also perform vertical take-off and landing. The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications)."*

Mission Requirements:

| ID | REQUIREMENT |
|---|---|
| MIS-1 | The aircraft shall do suborbital flights. |
| MIS-2 | The aircraft shall be a hypersonic aircraft. |
| MIS-3 | The aircraft shall allow aerospace testing and demonstration. |
| MIS-4 | The aircraft shall allow space flight experiences. |
| MIS-5 | The aircraft shall be used for training space personnel. |
| MIS-6 | The aircraft shall allow take-off and land on existing runways. |
| MIS-7 | The aircraft shall allow vertical take-off and vertical landing. |
| MIS-8 | The aircraft shall allow research, in spatial environment and in microgravity, in different fields. |

***Table 7 Mission Requirements, case of suborbital flight suborbital flight***

### 2.2.2 Point to point mission

Stakeholders identification

This mission shall allow to reach distant points on the globe in a short time. The aircraft can be used for the transportation of cargo or human, military use, surveillance. Furthermore, it could also be used to perform research in space environment and microgravity and remote sensing.
On the basis of the influence matrix, Stakeholders can be divided into primary and secondary.
In order to identify the primary Stakeholders, the following questions must be answered:

| | |
|---|---|
| **Who has the idea?** | Public Agencies |
| | Private Companies |
| **Who finances it?** | Financial institutions |
| | Actionist |
| **Who approves it?** | Safety managers |
| | Regulatory/Certification organism |
| **Who collaborates for the purpose?** | Universities |
| | Research Organizations |
| **Who works there, organizes it, manages it?** | Consultant |
| | Employee |
| **Who publicly approves or opposes it?** | Public Office |

***Table 8 Primary Stakeholders, case of flight point to point***

While among the secondary Stakeholders there are:

| | |
|---|---|
| **People who experience the effects of work on the project or its result, even if they have a low or even zero degree of influence** | Consumers/Users |
| **Their satisfaction can be decisive for the success of the project** | Consumers/Users |
| | Public Agencies |
| | Private Companies |

***Table 9 Secondary Stakeholders, case of flight point to point***

Also, to identify the Stakeholders, the following questions are answered:

| | | |
|---|---|---|
| Who are the people / groups / institutions that are interested in the planned initiative? What is their role? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or |

| | | |
|---|---|---|
| | | projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Public Office | They promote and present this activity. |
| | • People intellectually attracted by the aerospace world | They are people who keep themselves informed about the aerospace world, they are very interested in these technologies, they are very interested in increasing their knowledge, but they do not give us any contribution for the development of these technologies. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done |

| | | |
|---|---|---|
| | | in accordance with the rules. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Consultant | They manage the initiative. |
| | • Employee | They work on this initiative, they are engineers, workman, etc. |
| | • Tourism | They are the direct beneficiaries of the work, they can reach distant points on the globe in a short time. |
| | • Armed Forces | They are interested in the application of these aircraft in the military field, a hypersonic aircraft could penetrate any enemy airspace in the planet in no time. |
| Who are the potential beneficiaries? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Tourism | They are the direct beneficiaries of the work, they can reach distant points on the globe in a short time. |
| | • Armed Forces | They are interested in the application of these aircraft in the military field, a hypersonic aircraft could penetrate any enemy airspace in the planet in no time. |
| Who could be negatively affected? Who has restrictions on the initiative? | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| Who can influence the initiative? | • Public Agencies | They promote new programs or projects, in addition they deal |

| | | |
|---|---|---|
| | | with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |

***Table 10 Stakehoders identfication, case of flight point to point***

Please, notice that each entity can have different roles in the project. Of course, depending on the role, the stakeholder can express different expectations and can have a different impact on the mission.

Mapping of Stakeholders

On the basis of what is presented in the previous paragraphs, Stakeholders can be divided into categories based on their influence and interest in that particular activity. They are also mapped in order to better understand which one are the main ones.

| STAKEHOLDERS | LEVEL OF IMPORTANCE |
|---|---|
| PUBLIC AGENCIES | 10 |
| PRIVATE COMPANIES | 8 |
| UNIVERSITIES | 7 |
| RESARCH ORGANIZATIONS | 7 |
| PUBLIC OFFICE | 5 |
| PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD | 2 |
| TOURISM | 4 |
| ARMED FORCES | 4 |
| SAFETY MANAGERS | 9 |
| REGULATORY/CERTIFICATION ORGANSM | 9 |
| FINANCIAL INSTTUTIONS | 8 |
| ACTIONIST | 8 |
| CONSULTANT | 6 |
| EMPLOYEE | 4 |

***Table 11 Stakehoders, case of flight point to point***

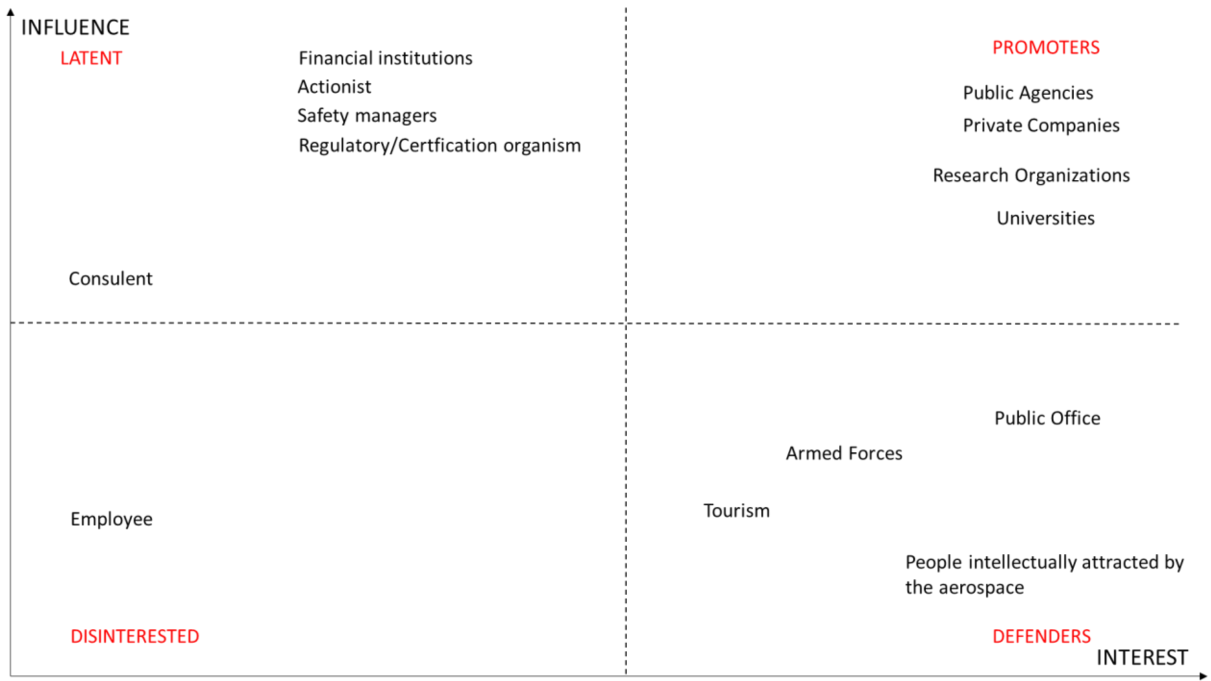



***Figure 10 Stakeholders map, case of flight point to point***

<u>Need and Values Analysis</u>

Each stakeholder has several pecular expectations on the product or on the final provided service. The importance of each stakeholder determines the degree to which the company seeks to meet the needs during the planning of its actions. The goal is to obtain the point of view of all the Stakeholders in every phase of the system's life, in order to consider a complete set of Needs. Values identify the utility, benefit, or reward for the Stakeholders in exchange for their contributions to the project.

| STAKEHOLDERS | NEED | VALUES |
|---|---|---|
| **PUBLIC AGENCIES** | Reach distant points on the globe in a short time. | New Technologies. |
| **PRIVATE COMPANIES** | Reach distant points on the globe in a short time. | New Technologies. |
| **UNIVERSITIES** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **RESARCH ORGANIZATIONS** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |

| | | |
|---|---|---|
| **PUBLIC OFFICE** | Promote and present hypersonic aircraft. | Provide them with more information about these aircraft. |
| **PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD** | Being involved, receiving information about new technologies. | Involve them more, providing more information about this new technology. |
| **TOURISM** | Reach distant points on the globe in a short time, safety, improve the way you travel. | Hypersonic aircraft. |
| **ARMED FORCES** | Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time, make inspection. | Hypersonic aircraft. |
| **SAFETY MANAGERS** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **REGULATORY/CERTIFICATION ORGANISM** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **FINANCIAL INSTITUTIONS** | Investing on new products, new technologies. | Give them a product to invest in. |
| **ACTIONIST** | Investing on new products, new technologies. | Give them a product to invest in. |
| **CONSULTANT** | Work, economic agreements. | Give them an initiative to manage. |
| **EMPLOYEE** | Participate in the design, development and implementation. | Give them a technology to work on. |

***Table 12 Need and Values, case of flight point to point***

QFD Analysis

For the identified case study, the most important Stakeholders results to be:

- Public agencies and private companies
- Security Managers and Regulatory/Certification organism

The HOQ is shown below, it is split for reasons of space.

| STEKEHOLDERS \ NEEDS | Reach distant points on the globe in a short time. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Reach distant points on the globe in a short time, safety. | Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Agencies | H | H | M | L | H | H | H | H | M | H | 10 | |
| Private Companies | H | H | M | L | H | H | H | H | M | H | 8 | |
| Universities | H | H | L | L | H | H | H | M | M | M | 7 | |
| Resarch Organizations | H | H | L | L | H | H | H | M | M | M | 7 | |
| Public Office | M | L | H | M | M | M | M | L | L | L | 5 | |
| People intellectually attracted by the aerospace world | M | M | M | H | M | M | L | L | L | L | 2 | |
| Tourism | H | L | L | L | H | M | H | H | L | L | 4 | |
| Armed forces | H | L | L | L | M | H | H | H | L | L | 4 | |
| Safety managers | H | L | M | L | L | L | H | L | L | L | 9 | |
| Regulatory/Certification organism | H | L | M | L | L | L | H | L | L | L | 9 | |
| Financial institutions | M | L | L | L | L | L | M | H | M | L | 8 | |
| Actionist | M | L | L | L | L | L | M | H | M | L | 8 | |
| Consultant | L | H | L | L | L | L | L | L | H | M | 6 | |
| Employee | L | H | L | L | L | L | L | L | M | H | 4 | |
| Normalization | 0,158036 | 0,106927 | 0,06456 | 0,028917 | 0,102892 | 0,102892 | 0,156243 | 0,117687 | 0,07913 | 0,082717 | | |
| Ranking | 1 | 4 | 8 | 9 | 5 | 5 | 2 | 3 | 7 | 6 | | |
| **Score** | **705** | **477** | **288** | **129** | **459** | **459** | **697** | **525** | **353** | **369** | **TOT** | **4461** |

***Figure 11 HOQ Matrix, case of flight point to point***

| STEKEHOLDERS / NEEDS | Reach distant points on the globe in a short time | Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity | Promote and present hypersonic aircraft | Being involved, receiving information about new technologies | Reach distant points on the globe in a short time, security | Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time | Maintain a high level of safety, ensuring that the various standards are respected | Investing on new products, new technologies | Work, economic agreements | Participate in the design, development and implementation | Importance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reach distant points on the globe in a short time | | | | | | | | | | | |
| Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity | | | | | | | | | | | |
| Promote and present hypersonic aircraft | | + | | | | | | | | | |
| Being involved, receiving information about new technologies | | + | + | | | | | | | | |
| Reach distant points on the globe in a short time, security | ++ | | | | | | | | | | |
| Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time | ++ | | | | ++ | | | | | | |
| Maintain a high level of safety, ensuring that the various standards are respected | | | | | + | | | | | | |
| Investing on new products, new technologies | | | | | | | - | | | | |
| Work, economic agreements | | + | | + | | | | ++ | | | |
| Participate in the design, development and implementation | | ++ | | + | | | | | + | | |
| Direction of Improve: Minimize (↓), Maximize (↑), or Target (X) | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | |

**ROOF:**

**++** Strong positive

**+** Positive

**-** Negative

**DIRECTION OF IMPROV**

**↓** To decrease

**↑** To increase

**X** Not given

**RELATIONSHIP:**

**H** High=10

**M** Medium=5

**L** Low=1

***Figure 12 HOQ Roof Matrix, case of flight point to point***

Mission objectives/Mission statement development

| QUESTION | ANSWER |
|---|---|
| WHAT IS THE MAIN PROBLEM? | Impossibility to reach distant points on the land surface in a short time. |
| HOW CAN WE SOLVE THE PROBLEM? | Develop new technologies able to do this; hypersonic aircraft. |
| ARE THERE ANY OTHER SIGNIFICANT GOALS IMPOSED BY THE SCENARIO? | Increase searches in such a way that you can use this technology for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications). |
| WHAT IS THE END USER? | Tourism, as to allow travelers to reach a distant point on earth in a short time. Armed forces, as to be able to penetrate any air space in the planet in a short time. |
| ARE THERE ANY CONSTRAINTS? | The aircraft must be able to take off and land from existing runways.<br>This does not preclude vertical take-off, which could be very useful especially in the case of military application. |

***Table 13 Mission Statement Development, case of flight point to point***

Mission statement:

*"The mission shall allow to reach distant points on the globe in a short time using hypersonic aircraft. The aircraft can be used for the transportation of cargo or human, military use, surveillance. The spacecraft shall perform take-off and landing from existing runways, and can also perform vertical take-off and landing.*
*The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications)."*

Mission Requirements:

| ID | REQUIREMENT |
|---|---|
| MIS-1 | The aircraft shall reach a point on the globe in (TDB) time. |
| MIS-2 | The aircraft shall be a hypersonic aircraft. |
| MIS-3 | The aircraft shall allow the carriage of cargo. |
| MIS-4 | The aircraft shall allow the carriage of passengers. |
| MIS-5 | The aircraft shall allow take-off and land on existing runways. |
| MIS-6 | The aircraft shall allow vertical take-off and vertical landing. |
| MIS-7 | The aircraft shall allow research, in spatial environment and in microgravity, in different fields. |

***Table 14 Mission Requirements, case of flight point to point***

### 2.2.3 Reusable launchers

Stakeholders identification

This mission shall allow to reach the space using reusable aircraft, in order to reduce the costs of launching and reusing the aircraft for multiple missions. Furthermore, it could also be used to perform research in space environment and microgravity and remote sensing.

On the basis of the influence matrix, Stakeholders can be divided into primary and secondary.
In order to identify the primary Stakeholders, the following questions must be answered:

| | |
|---|---|
| **Who has the idea?** | Public Agencies |
| | Private Companies |
| **Who finances it?** | Financial institutions |
| | Actionist |
| **Who approves it?** | Safety managers |
| | Regulatory/Certification organism |
| **Who collaborates for the purpose?** | Universities |
| | Research Organizations |
| **Who works there, organizes it, manages it?** | Consultant |
| | Employee |
| **Who publicly approves or opposes it?** | Public Office |

***Table 15 Primary Stakeholders, case of reusable launchers***

While among the secondary Stakeholders there are:

| | |
|---|---|
| **People who experience the effects of work on the project or its result, even if they have a low or even zero degree of influence** | Consumers/Users |
| **Their satisfaction can be decisive for the success of the project** | Consumers/Users |
| | Public Agencies |
| | Private Companies |

***Table 16 Secondary Stakeholders, case of reusable launchers***

Also, to identify the Stakeholders, the following questions are answered:

| | | |
|---|---|---|
| Who are the people / groups / institutions that are interested in the planned initiative? What is their role? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |

| | | |
|---|---|---|
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Public Office | They promote and present this activity. |
| | • People intellectually attracted by the aerospace world | They are people who keep themselves informed about the aerospace world, they are very interested in these technologies, they are very interested in increasing their knowledge, but they do not give us any contribution for the development of these technologies. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a |

| | | |
|---|---|---|
| | | lot, could block it if it is not done in accordance with the rules. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Consultant | They manage the initiative. |
| | • Employee | They work on this initiative, they are engineers, workman, etc. |
| | • Consumers/Users | Space agencies, private entities such as Google, agencies dealing of telephony, TV, internet services, land control, etc. |
| Who are the potential beneficiaries? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Consumers/Users | Space agencies, private entities such as Google, agencies dealing of telephony, TV, internet services, land control, etc. |
| Who could be negatively affected? Who has restrictions on the initiative? | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| Who can influence the initiative? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important |

| | | |
|---|---|---|
| | | for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |

***Table 17 Stakehoders identfication, case of reusable launchers***

Please, notice that each entity can have different roles in the project. Of course, depending on the role, the stakeholder can express different expectations and can have a different impact on the mission.

<u>Mapping of Stakeholders</u>

On the basis of what is presented in the previous paragraphs, Stakeholders can be divided into categories based on their influence and interest in that particular activity. They are also mapped in order to better understand which one are the main ones.

| STAKEHOLDERS | LEVEL OF IMPORTANCE |
|---|---|
| PUBLIC AGENCIES | 10 |

| | |
|---|---|
| PRIVATE COMPANIES | 8 |
| UNIVERSITIES | 7 |
| RESARCH ORGANIZATIONS | 7 |
| PUBLIC OFFICE | 5 |
| PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD | 2 |
| CONSUMERS/USERS | 6 |
| SAFETY MANAGERS | 9 |
| REGULATORY/CERTIFICATION ORGANSM | 9 |
| FINANCIAL INSTTUTIONS | 8 |
| ACTIONIST | 8 |
| CONSULTANT | 6 |
| EMPLOYEE | 4 |

***Table 18 Stakehoders, case of reusable launchers***

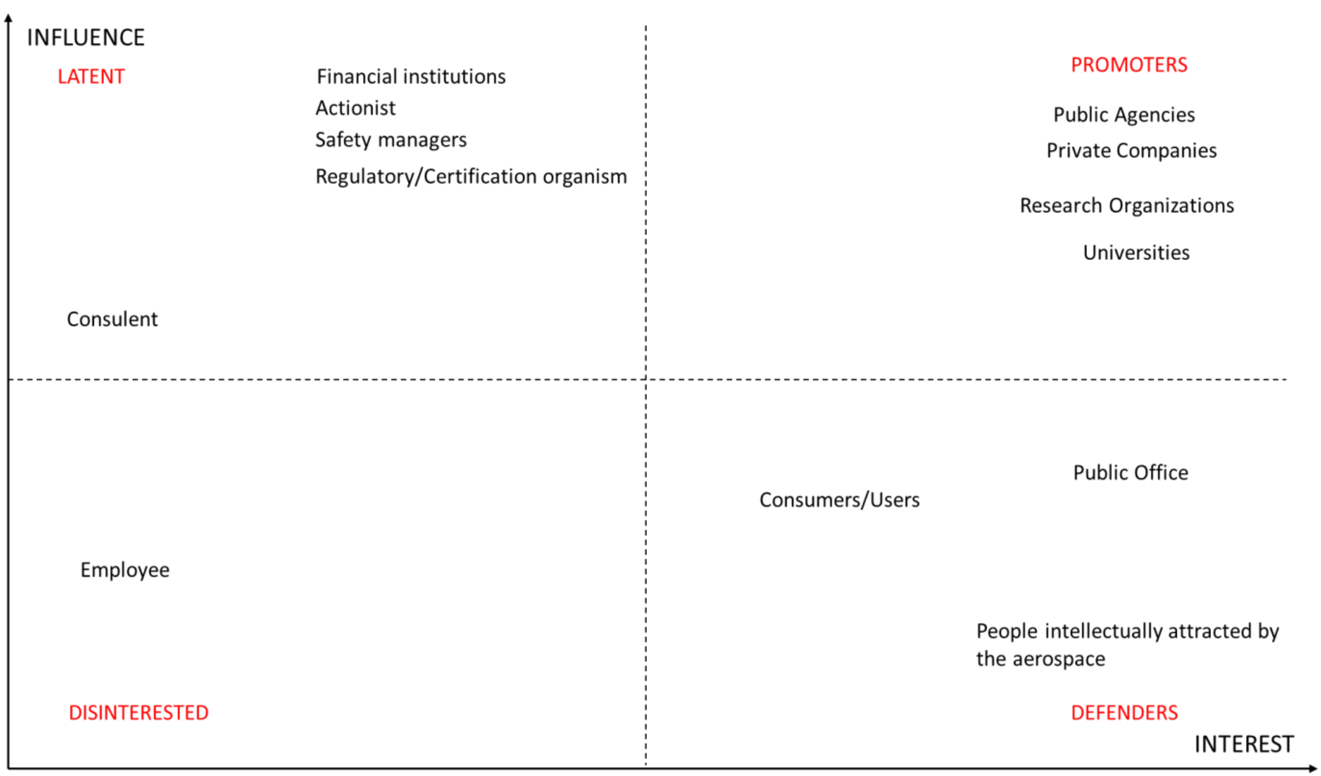



***Figure 13 Stakeholders map, case of reusable launchers***

Need and Values Analysis

Each stakeholder has several pecular expectations on the product or on the final provided service.
The importance of each stakeholder determines the degree to which the company seeks to meet the needs during the planning of its actions. The goal is to obtain the point of view of all the Stakeholders in every phase of the system's life, in order to consider a complete set of Needs.
Values identify the utility, benefit, or reward for the Stakeholders in exchange for their contributions to the project.

| STAKEHOLDERS | NEED | VALUES |
|---|---|---|
| **PUBLIC AGENCIES** | Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | New Technologies. |
| **PRIVATE COMPANIES** | Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | New Technologies. |
| **UNIVERSITIES** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **RESARCH ORGANIZATIONS** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **PUBLIC OFFICE** | Promote and present hypersonic aircraft. | Provide them with more information about these aircraft. |
| **PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD** | Being involved, receiving information about new technologies. | Involve them more, providing more information about this new technology. |
| **CONSUMERS/USERS** | Perform space missions, send satellites in orbit with lower launch costs. | Hypersonic aircraft. |
| **SAFETY MANAGERS** | Maintain a high level of safety, ensuring that the various standards are respected. | _ |
| **REGULATORY/CERTIFICATION ORGANISM** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **FINANCIAL INSTITUTIONS** | Investing on new products, new technologies. | Give them a product to invest in. |
| **ACTIONIST** | Investing on new products, new technologies. | Give them a product to invest in. |
| **CONSULTANT** | Work, economic agreements. | Give them an initiative to manage. |

| | | |
|---|---|---|
| **EMPLOYEE** | Participate in the design, development and implementation. | Give them a technology to work on. |

***Table 19 Need and Values, case of reusable launchers***

QFD Analysis

For the identified case study, the most important Stakeholders results to be:

- Public agencies and private companies
- Security Managers and Regulatory/Certification organism

The HOQ is shown below, it is split for reasons of space.

| STEKEHOLDERS \ NEEDS | Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Perform space missions, send satellites in orbit with lower launch costs. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Agencies | H | H | M | L | H | H | H | M | H | 10 | |
| Private Companies | H | H | M | L | H | H | H | M | H | 8 | |
| Universities | H | H | L | L | H | H | M | M | M | 7 | |
| Resarch Organizations | H | H | L | L | H | H | M | M | M | 7 | |
| Publc Office | M | L | H | M | M | M | L | L | L | 5 | |
| People intellectually attracted by the aerospace world | M | M | L | H | M | L | L | L | L | 2 | |
| Consuners/Users | H | L | L | L | H | H | H | L | L | 6 | |
| Safety managers | H | L | M | L | L | H | L | L | L | 9 | |
| Regulatory/Certification organism | H | L | M | L | L | H | L | L | L | 9 | |
| Financial institutions | M | L | L | L | L | M | H | M | L | 8 | |
| Actionist | M | L | L | L | L | M | H | M | L | 8 | |
| Consultant | L | H | L | L | L | L | L | H | M | 6 | |
| Employee | L | H | L | L | L | L | L | M | H | 4 | |
| Normalization | 0,174567 | 0,12105 | 0,070846 | 0,032365 | 0,116972 | 0,172528 | 0,128695 | 0,08945 | 0,093527 | | |
| Ranking | 1 | 4 | 8 | 9 | 5 | 2 | 3 | 7 | 6 | | |
| **Score** | **685** | **475** | **278** | **127** | **459** | **677** | **505** | **351** | **367** | **TOT** | **3924** |

***Figure 14 HOQ Matrix, case of reusable launchers***

| STEKEHOLDERS / NEEDS | Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Perform space missions, send satellites in orbit with lower launch costs. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance |
|---|---|---|---|---|---|---|---|---|---|---|
| Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | | | | | | | | | | |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | | | | | | | | | | |
| Promote and present hypersonic aircraft. | | + | | | | | | | | |
| Being involved, receiving information about new technologies. | | + | + | | | | | | | |
| Perform space missions, send satellites in orbit with lower launch costs. | ++ | | | | | | | | | |
| Maintain a high level of safety, ensuring that the various standards are respected. | | | | | | | | | | |
| Investing on new products, new technologies. | | | | | | - | | | | |
| Work, economic agreements. | | + | | + | | | ++ | | | |
| Participate in the design, development and implementation. | | ++ | | + | | | | + | | |
| Direction of Improve: Minimize (↓), Maximize (↑), or Target (X) | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | |

**ROOF:**

- **++** Strong positive
- **+** Positive
- - Negative

**DIRECTION OF IMPROVEMENT:**

- **↓** To decrease
- **X** Not given

**RELATIONSHIP:**

- **H** High=10
- **M** Medium=5
- **L** Low=1

***Figure 15 HOQ Roof Matrix, case of reusable launchers***

Mission objectives/Mission statement development

| QUESTION | ANSWER |
|---|---|
| WHAT IS THE MAIN PROBLEM? | Impossibility to reach the space using reusable launchers. |
| HOW CAN WE SOLVE THE PROBLEM? | Develop new technologies that can be used as reusable launchers; hypersonic aircraft. |
| ARE THERE ANY OTHER SIGNIFICANT GOALS IMPOSED BY THE SCENARIO? | Increase searches in such a way that you can use this technology for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications). |
| WHAT IS THE END USER? | Space agencies, private entities such as Google, agencies dealing of telephony, TV, internet services, land control, etc. |
| ARE THERE ANY CONSTRAINTS? | The aircraft must be able to take off and land from existing runways.<br>This does not preclude vertical take-off. |

***Table 20 Mission Statement Development, case of reusable launchers***

Mission statement:

*"The mission shall allow to reach the space using reusable aircraft, in order to reduce the costs of launching and reusing the aircraft for multiple missions. The spacecraft shall perform take-off and landing from existing runways, and can also perform vertical take-off and landing.*
*The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications), human spaceflight experiences for tourism or training."*

Mission Requirements:

| ID | REQUIREMENT |
|---|---|
| MIS-1 | The aircraft shall reach the space. |
| MIS-2 | The aircraft shall be a hypersonic aircraft. |
| MIS-3 | The aircraft shall allow the carriage of satellites. |
| MIS-4 | The aircraft shall be re-usable. |
| MIS-5 | The aircraft shall allow take-off and land on existing runways. |
| MIS-6 | The aircraft shall allow vertical take-off and vertical landing. |
| MIS-7 | The aircraft shall reduce the launch costs. |

***Table 21 Mission Requirements, case of reusable launchers***

### 2.2.4 Re-entry aircraft

Stakeholders identification

This mission shall allow the return from the space. It shall guarantee the return of people and / or cargo.

On the basis of the influence matrix, Stakeholders can be divided into primary and secondary.
In order to identify the primary Stakeholders, the following questions must be answered:

| | |
|---|---|
| **Who has the idea?** | Public Agencies |
| | Private Companies |
| **Who finances it?** | Financial institutions |
| | Actionist |
| **Who approves it?** | Safety managers |
| | Regulatory/Certification organism |
| **Who collaborates for the purpose?** | Universities |
| | Research Organizations |
| **Who works there, organizes it, manages it?** | Consultant |
| | Employee |
| **Who publicly approves or opposes it?** | Public Office |

*Table 22 Primary Stakeholders, case of re-entry aircraft*

While among the secondary Stakeholders there are:

| | |
|---|---|
| **People who experience the effects of work on the project or its result, even if they have a low or even zero degree of influence** | Consumers/Users |
| **Their satisfaction can be decisive for the success of the project** | Consumers/Users |
| | Public Agencies |
| | Private Companies |

*Table 23 Secondary Stakeholders, case of re-entry aircraft*

Also, to identify the Stakeholders, the following questions are answered:

| | | |
|---|---|---|
| Who are the people / groups / institutions that are interested in the planned initiative? What is their role? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |

| | | |
|---|---|---|
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Public Office | They promote and present this activity. |
| | • People intellectually attracted by the aerospace world | They are people who keep themselves informed about the aerospace world, they are very interested in these technologies, they are very interested in increasing their knowledge, but they do not give us any contribution for the development of these technologies. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a |

| | | |
|---|---|---|
| | | lot, could block it if it is not done in accordance with the rules. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Consultant | They manage the initiative. |
| | • Employee | They work on this initiative, they are engineers, workman, etc. |
| | • Consumers/Users | (Public Agencies, Private Companies, ISS Crew) use this service. |
| Who are the potential beneficiaries? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Consumers/Users | (Public Agencies, Private Companies, ISS Crew) use this service. |
| Who could be negatively affected? Who has restrictions on the initiative? | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| Who can influence the initiative? | • Public Agencies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. |
| | • Private Companies | They promote new programs or projects, in addition they deal with operations, interventions, functions, maintenance and organization. They also deal with production, development and supply. |
| | • Universities | They collaborate to the aim, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies. Moreover, in |

| | | |
|---|---|---|
| | | this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Research Organizations | They collaborate to the purpose, deepen the studies in this field, they look for alternative solutions; they are very important for the study and development of these technologies; they increase knowledge, are key factors for the growth and development of society, as they provide innovation through the technological and organized application of scientific discoveries. Technical and scientific progress. Moreover, in this way they could do research in different fields, exploiting the unique properties of the space environment and the microgravity. |
| | • Financial institutions | They finance the initiative. |
| | • Actionist | They finance the initiative. |
| | • Safety managers | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |
| | • Regulatory/Certification organism | They take care of the security, they check that the norms are respected; influence the project a lot, could block it if it is not done in accordance with the rules. |

***Table 24 Stakehoders identfication, case of re-entry aircraft***

Please, notice that each entity can have different roles in the project. Of course, depending on the role, the stakeholder can express different expectations and can have a different impact on the mission.

Mapping of Stakeholders

On the basis of what is presented in the previous paragraphs, Stakeholders can be divided into categories based on their influence and interest in that particular activity. They are also mapped in order to better understand which one are the main ones.

| STAKEHOLDERS | LEVEL OF IMPORTANCE |
|---|---|
| PUBLIC AGENCIES | 10 |
| PRIVATE COMPANIES | 8 |

| | |
|---|---|
| UNIVERSITIES | 7 |
| RESARCH ORGANIZATIONS | 7 |
| PUBLIC OFFICE | 5 |
| PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD | 2 |
| CONSUMERS/USERS | 6 |
| SAFETY MANAGERS | 9 |
| REGULATORY/CERTIFICATION ORGANISM | 9 |
| FINANCIAL INSTITUTIONS | 8 |
| ACTIONIST | 8 |
| CONSULTANT | 6 |
| EMPLOYEE | 4 |

***Table 25 Stakehoders, case of re-entry aircraft***

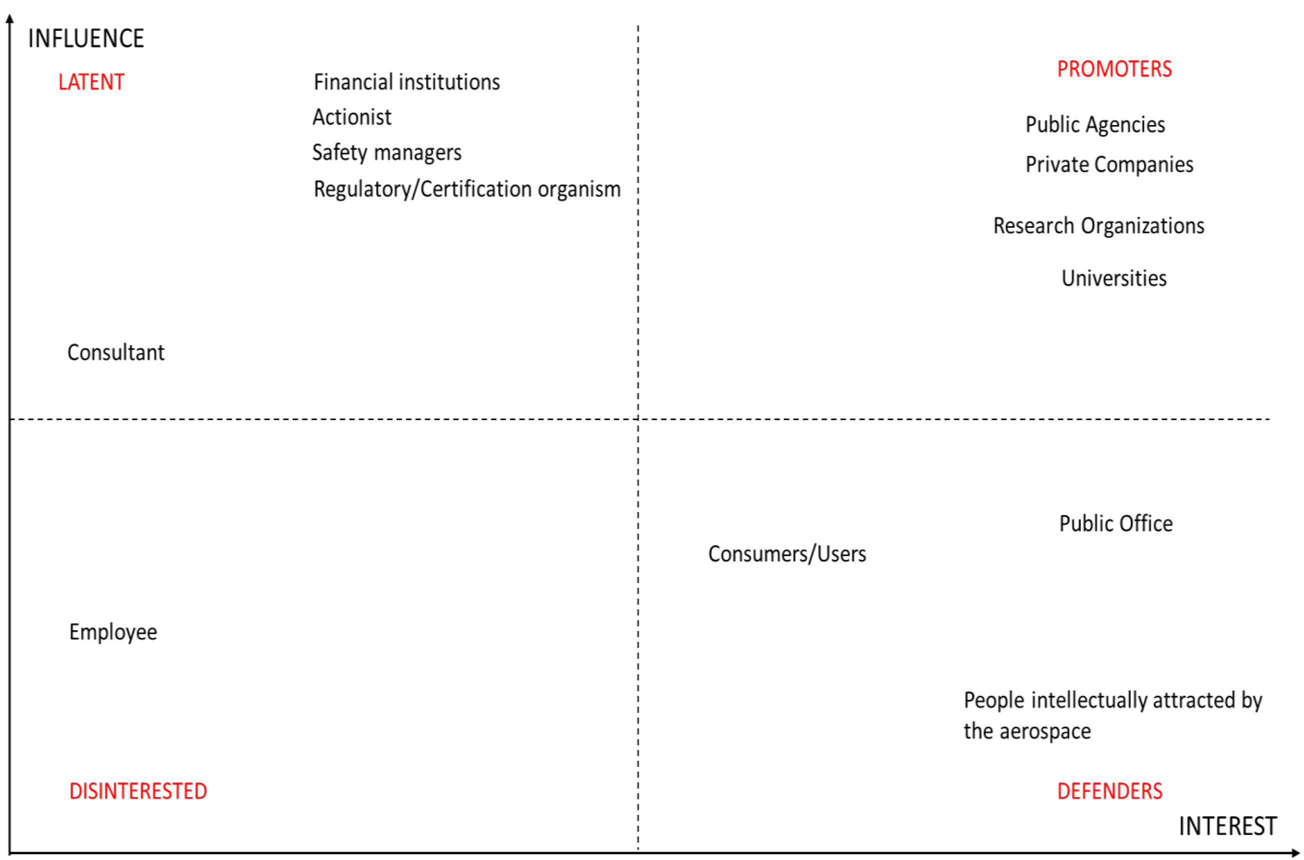



**Figure 16 Stakeholders map, case *of re-entry aircraft***

Need and Values Analysis

Each stakeholder has several pecular expectations on the product or on the final provided service. The importance of each stakeholder determines the degree to which the company seeks to meet the needs during the planning of its actions. The goal is to obtain the point of view of all the Stakeholders in every phase of the system's life, in order to consider a complete set of Needs. Values identify the utility, benefit, or reward for the Stakeholders in exchange for their contributions to the project.

| STAKEHOLDERS | NEED | VALUES |
|---|---|---|
| **PUBLIC AGENCIES** | Return people, cargo from space. | Technologies able to do this. |
| **PRIVATE COMPANIES** | Return people, cargo from space. | Technologies able to do this. |
| **UNIVERSITIES** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **RESARCH ORGANIZATIONS** | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Involve them in the project, in the study, in the research. Allow them to use new technologies to do research in different fields. |
| **PUBLIC OFFICE** | Promote and present these technologies. | Provide them with more information about these aircraft. |
| **PEOPLE INTELLECTUALLY ATTRACTED BY THE AEROSPACE WORLD** | Being involved, receiving information about new technologies. | Involve them more, providing more information about this new technology. |
| **CONSUMERS/USERS** | Return from space. | Technologies able to do this. |
| **SAFETY MANAGERS** | Maintain a high level of safety, ensuring that the various standards are respected. | _ |
| **REGULATORY/CERTIFICATION ORGANISM** | Maintain a high level of safety, ensuring that the various standards are respected. | – |
| **FINANCIAL INSTITUTIONS** | Investing on new products, new technologies. | Give them a product to invest in. |
| **ACTIONIST** | Investing on new products, new technologies. | Give them a product to invest in. |
| **CONSULTANT** | Work, economic agreements. | Give them an initiative to manage. |
| **EMPLOYEE** | Participate in the design, development and implementation. | Give them a technology to work on. |

***Table 26 Need and Values, case of re-entry aircraft***

QFD Analysis

For the identified case study, the most important Stakeholders results to be:

- Public agencies and private companies
- Security Managers and Regulatory/Certification organism

The HOQ is shown below, it is split for reasons of space.

| STEKEHOLDERS / NEEDS | Return people, cargo from space. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present these technologies. | Being involved, receiving information about new technologies. | Return from space. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Agencies | H | H | M | L | H | H | H | M | H | 10 | |
| Private Companies | H | H | M | L | H | H | H | M | H | 8 | |
| Universities | H | H | L | L | H | H | M | M | M | 7 | |
| Resarch Organizations | H | H | L | L | H | H | M | M | M | 7 | |
| Publc Office | M | L | H | M | M | M | L | L | L | 5 | |
| People intellectually attracted by the aerospace world | M | M | L | H | M | L | L | L | L | 2 | |
| Consumers/Users | H | M | L | L | H | H | H | L | L | 6 | |
| Safety managers | H | L | M | L | L | H | L | L | L | 9 | |
| Regulatory/Certification organism | H | L | M | L | L | H | L | L | L | 9 | |
| Financial institutions | M | L | L | L | L | M | H | M | L | 8 | |
| Actionist | M | L | L | L | L | M | H | M | L | 8 | |
| Consultant | L | H | L | L | L | L | L | H | M | 6 | |
| Employee | L | M | L | L | L | L | L | M | H | 4 | |
| Normalization | 0,174389 | 0,121945 | 0,070774 | 0,032332 | 0,116853 | 0,172352 | 0,128564 | 0,089358 | 0,093432 | | |
| Ranking | 1 | 4 | 8 | 9 | 5 | 2 | 3 | 7 | 6 | | |
| Score | **685** | **479** | **278** | **127** | **459** | **677** | **505** | **351** | **367** | **TOT** | **3928** |

***Figure 17 HOQ Matrix, case of re-entry aircraft***

| STEKEHOLDERS NEEDS | Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | Promote and present hypersonic aircraft. | Being involved, receiving information about new technologies. | Perform space missions, send satellites in orbit with lower launch costs. | Maintain a high level of safety, ensuring that the various standards are respected. | Investing on new products, new technologies. | Work, economic agreements. | Participate in the design, development and implementation. | Importance |
|---|---|---|---|---|---|---|---|---|---|---|
| Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | | | | | | | | | | |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | | | | | | | | | | |
| Promote and present hypersonic aircraft. | | + | | | | | | | | |
| Being involved, receiving information about new technologies. | | + | + | | | | | | | |
| Perform space missions, send satellites in orbit with lower launch costs. | ++ | | | | | | | | | |
| Maintain a high level of safety, ensuring that the various standards are respected. | | | | | | | | | | |
| Investing on new products, new technologies. | | | | | | - | | | | |
| Work, economic agreements. | | + | | + | | | ++ | | | |
| Participate in the design, development and implementation. | | ++ | | + | | | | + | | |
| Direction of Improve: Minimize (↓), Maximize (↑), or Target (X) | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | |

**ROOF:**

**++** Strong positive

**+** Positive

- Negative

**DIRECTION OF IMPROVEMENT:**

**↓** To decrease

**X** Not given

**RELATIONSHIP:**

**H** High=10

**M** Medium=5

**L** Low=1

***Figure 18 HOQ Roof Matrix, case of re-entry aircraft***

Mission objectives/Mission statement development

| QUESTION | ANSWER |
|---|---|
| WHAT IS THE MAIN PROBLEM? | Return from space. |
| HOW CAN WE SOLVE THE PROBLEM? | Using aircraft for space re-entry. |
| ARE THERE ANY OTHER SIGNIFICANT GOALS IMPOSED BY THE SCENARIO? | - |
| WHAT IS THE END USER? | Public Agencies, Private Companies, ISS Crew. |
| ARE THERE ANY CONSTRAINTS? | The aircraft must be able to return from space. |

***Table 27 Mission Statement Development, case of re-entry aircraft***

Mission statement:

*"The spacecraft shall allow the return from the space. It shall guarantee the return of people and / or cargo. It shall be able to re-enter ensuring a high level of safety for the safety of people on board."*

Mission Requirements:

| ID | REQUIREMENT |
|---|---|
| MIS-1 | The aircraft must return from space. |
| MIS-2 | The aircraft shall allow the carriage of cargo. |
| MIS-3 | The aircraft shall allow the carriage of passengers. |

***Table 28 Mission Requirements, case of re-entry aircraft***

### 2.2.5 Confront of the missions

The analysis of the stakeholders for various missions was conducted in the previous paragraphs.
The missions that have been treated are:

- Suborbtal flight
- Point to point mission
- Reusable launcher
- Re-entry aircraft

The first mission consists in carrying out tests and demonstrations of aerospace technologies and also allows to carry out space experiences for astronaut training or for space tourism.
The second mission consists in reaching very distant points on the globe in a very short time.
The third mission allows to reach the space using reusable aircraft, in order to reduce launch costs and to reuse the same aircraft for multiple missions.
The fourth is a mission that allow the return from the space. It shall guarantee the return of people and / or cargo.
As can be seen from the analyzes carried out in the previous paragraphs, most of the Stakeholders that come into play are the same, although many of them have different Needs, they impact differently and cover different roles depending on the mission.

For example, it can be observed that in the case of point-to-point flight, public agencies are involved in promoting the new project, while in the case of the launcher, as well as promoting the project, they will use the product themselves to send their astronauts to the space station.
Moreover, we must pay particular attention to the consumers of the various missions, in fact they are very different.
As for the suborbital flight the users are: tourism, public agencies, private companies, government, armed forces.
As for the point to point flight the users are: tourism and armed forces (see, as said before, how their needs and their positions vary according to the mission). Although tourism is present in both missions, in the first case its need is to make a space flight experience, while in the second case, its need is to reach a point far on the globe in a short time.
As for the reusable launcher and the return, the users are: Public Agencies, Private Companies, ISS Crew.
In conclusion, we can see how, although the Stakeholders are more or less the same, they go to cover different roles depending on the mission dealt with.

# 3 ARCHITECTURE DEFINITION

The definition of the architecture of an aerospace transportation system, trade-offs as well as the first design activities should be based on both qualitative and quantitative estimations.

The Stakeholder analysis, which is reported in the previous chapter, can be considered as the first step towards the definition of the best architecture for the transportation system. Starting from the analysis a first list of requirements can be elicited. Such requirements have to relate to specific characteristics of a high-level system, going through the definition of appropriate project variables.

In particular, the aim of this chapter is to highlight how these requirements may impact on the design of the vehicle.

Unlike the general procedure to solve a mathematical problem, which is structured in a compact form (the solution is unique), the design is not simple, as a single "correct" answer is rarely present. [5]

Furthermore, it should be able to handle multidisciplinary issues in order to allow adequate levels of integration.

The following diagrams summarize the main phases of the process, also providing useful elements to understand the main reports of the activities analyzed in this chapter with those that will be performed in the subsequent design phases, not covered in this thesis. [5]

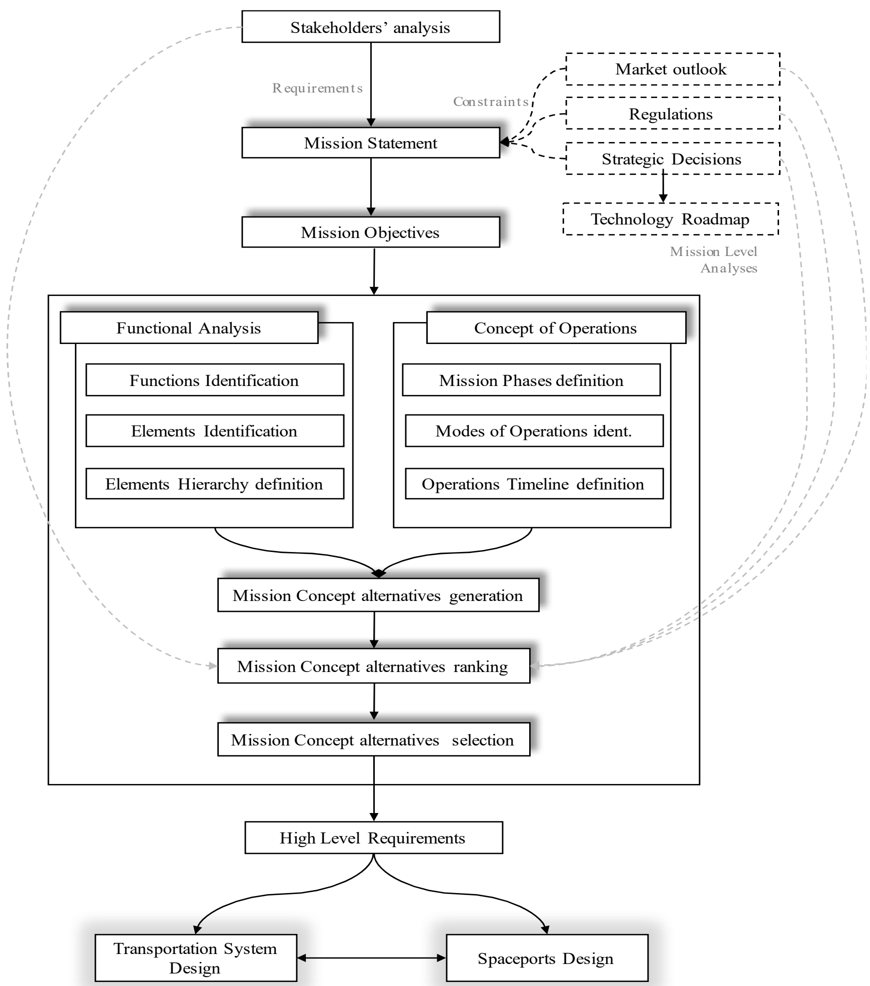



***Figure 19 From stakeholder analysis to high level requirements generation*** **[5]**

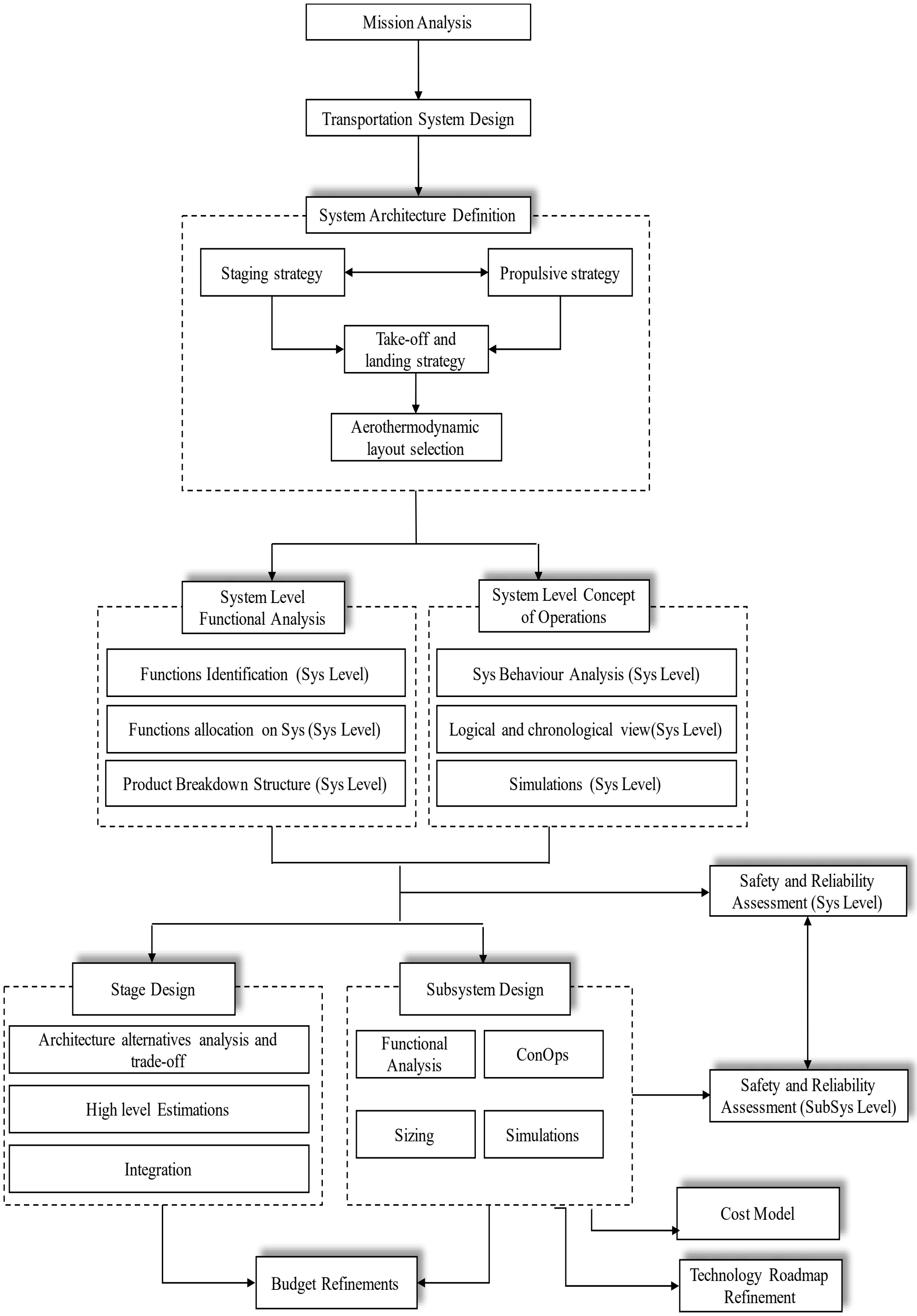



***Figure 20*** **From mission analysis to subsystems design and validation [5]**

## 3.1 Staging strategy

First of all, the staging strategy is defined. It is complex to understand, as it influenced by a lot of aspect of the mission. One of the major aspect that influenced the staging strategy is the way in which propulsive and propellant systems are integrated.

There are different configurations:

- Single stage;
- Two stages;
- Three stages.

These configurations have positive and negative aspects. About the single stage configuration, the ideal case is considered; it can be observed that it consists of a single vehicle, which should contain all the subsystems. It is very similar to a conventional aircraft, thus avoiding the technical complexities linked to the integration of several stages and decreasing the risk linked to the separation phase. This configuration, however, compared to the other two, has a higher take-off gross weight. On the other hand, about the two-stage configuration, it represents the right compromise between weight reduction and increasing complexity. The first stage is a carrier, while the second stage is an aircraft. The first stage, typically, at take-off is responsible for the acceleration of the vehicle, at a certain point the second stage is detached from the first and carries out mission operations. An advantage, respect the single stage configuration, is that it will not be the whole mass of the system performing the mission. This can reduce costs. Moreover, compared to configurations consisting of three or more stages, there is a reduction in complexity and a smaller number of separation events, thus reducing costs and the risk of failure. However, the three or more stages configurations allow to increase the maximum altitude and payload capacities, desirable aspects for the missions dedicated to improving access to space possibilities, but difficult to achieve in suborbital or in a point-to-point mission. [5], [6]

Going into more detail on the two-stage configuration, it can be observed that various propulsive strategies may be present, which are shown in the following figure.

| | | First Stage | | | |
|---|---|---|---|---|---|
| | | Propulsive System only | Propulsive Sys and Propellant Sys(existing carrier) | Propulsive Sys and Propellant Sys (To be developed) | Propellant System only |
| Second Stage | Propulsive System only | Unfeasible | Unfeasible | Unfeasible | Conf. 3.1 |
| | Propulsive Sys and Propellant Sys | Conf. 1.2 | Conf. 2.2 (a) | Conf. 2.2 (b) | Conf. 3.2 |
| | Propellant System only | Unfeasible | Unfeasible | Unfeasible | Unfeasible |
| | No Propulsive and No Propellant systems | Unfeasible | Conf. 2.4 (a) | Conf. 2.4 (b) | Unfeasible |

***Figure 21 Staging strategies*** [5]

### 3.1.1 Staging strategy trade-off

Among the various possible alternative, the best configuration is selected, in particular it is chosen on the basis of the mission that the aircraft has to perform, and the expectations of the stakeholders must always be kept in mind.
The Analytic Hierarchy Process (AHP) is a multicriteria-based support technique which allows to compare multiple alternatives in relation to a variety of quantitative or qualitative criteria and to obtain a global assessment for each of them. This manages to order and select the best alternative.
First of all, it's important to identify a set of evaluation criteria for the decision-making alternatives (i.e. the Figures of Merit) and assign each criterion a normalized weight. Then a score that represents the impact of the criterion on the decision is assigned.
Trade-Off AHP Analysis can be conducted through two main ways: the Direct Analysis or the Indirect Method.
The first one derives from Game Theory, a branch of Statistics, Mathematics, Economics and Logic and it is also called Lottery Equivalent Probability or Direct Probabilistic Dichotomic Method:

- Direct: the values of the alternative choices are asked directly to the main actor of the game (in this case, to the customers, i.e. Stakeholders);
- Probabilistic: the importance of choices is calculated both with players' opinions (as described before), but also on the base of the risk (failure, complexity, difficulty to be put in practise) affecting the choice;
- Dichotomic: players must choose only between two alternatives and these ones always fork in other two ones.

This mission has not a real feedback coming from game players (Stakeholders) or a direct interaction with them, so the Indirect Method was chosen. This one is based on the Swinging Weights Method which is faster than Indirect Analysis.
This method is based on analyzing individual decisions and opinions and their impact on the mission. This method normalizes all mission priorities coming from different fields in terms of a simple vote weighted through the Figures of Merit.
From the Stakeholders analysis and the quality house, several needs / values have been obtained; which are very important to evaluate the relative weights of the merit figures.
The figures of merit are determined separately for each analysis and the relative weights have been calculated starting from the Needs previously found. To each of them was assigned a score that came out of the house of quality, starting from these have divided the Need in the figures of merit identified, and then divided the values obtained for the total score (as required by AHP).
After, votes were assigned from 0 to 5, and each of these votes were multiplied by the corresponding weights; from these a total sum was calculated by column, where the highest value corresponds to the winning design solution. [4], [7]

In this case the figures of merit that have been taken into consideration are:

- Complexity,
- Cost,
- Security.

The impact of design parameters on the figures of merit are summarized in the following table.

| Figure of Merit | Design Parameters impacting on the FoM evalutation |
|---|---|

| | |
|---|---|
| **Complexity** | Number of stages<br>Presence of propulsive system on each stage<br>Presence of propellant tanks on each stage<br>Presence of cross-feed between stages<br>Exploitation of existing first stage |
| **Cost** | Number of stages<br>Presence of propulsive system on each stage<br>Presence of propellant tanks on each stage<br>Exploitation of existing first stage |
| **Safety** | Number of stages<br>Presence of propulsive system on each stage<br>Presence of propellant tanks on each stage |

***Table 29 Impact of design parameters on the figures of merit***

<u>Suborbital flight</u>
First, we try to understand how the mission and the requirements go to influence the choice of the staging strategy.

"How do the mission and requirements affect the choice of the most suitable staging configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| ***Mission and requirements*** | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates;<br>Confort. |
| | Mission profile | Suborbital flight. | Mission profile influences:<br>Structural loads;<br>Thermical loads;<br>L/D, |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis, the Needs are divided into the various figures of merit:

- Safety:
  - Maintain a high level of safety, ensuring that the various standards are respected.
  - Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies.
- Cost:
  - Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity.
  - Promote and present hypersonic aircraft.

- Investing on new products, new technologies.
- Work, economic agreements.
- Participate in the design, development and implementation.
- Being involved, receiving information about new technologies.

- Complexity:

  Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing.

After the weights of the various figures of merit are evaluated, as explained above in figure 22:

| EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Suborbital flight** | | | | | | | |
| | | | | Figures of Merit | | | |
| Needs | Score | Ranking | | Safety | Cost | Complexity | TOT |
| Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies | 685 | 1 | | 1362 | 2107 | 459 | **3928** |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity | 479 | 4 | | 0,346741 | 0,536405 | 0,11685336 | **Weights** |
| Promote and present hypersonic aircraft | 278 | 8 | | | | | |
| Being involved, receiving information about new technologies | 127 | 9 | | | | | |
| Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing | 459 | 5 | | | | | |
| Maintain a high level of safety, ensuring that the various standards are respected | 677 | 2 | | | | | |
| Investing on new products, new technologies | 505 | 3 | | | | | |
| Work, economic agreements | 351 | 7 | | | | | |
| Participate in the design, development and implementation | 367 | 6 | | | | | |
| TOTAL | 3928 | | | | | | |

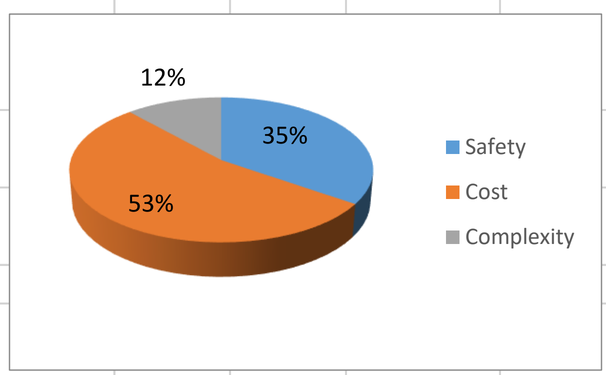



*Figure 22 Staging strategies, evalutation of weights, case of suborbital flight*

The requirements that have impacted on the choice are the following:

| *Requirement* | *Safety* | *Cost* | *Complexity* |
|---|---|---|---|
| *The aircraft shall do suborbital flights.* | | | ✓ |
| *The number of stages shall be reduced.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propellant tank.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propulsive system.* | ✓ | ✓ | ✓ |

***Table 30  Requirements that impact the staging strategy, case of suborbital flight***

The figure 23 shows which of the proposed configurations is the best for the mission.

| | **Weights** | **Single Stage** | **Two Stages Configurazione 2.2 (a)** | **Two Stages Configurazione 2.2 (b)** | **Two Stages Configurazione 2.4 (a)** | **Two Stages Configurazione 2.4 (b)** | **Two Stages Configurazione 3.2** | **Three stages** |
|---|---|---|---|---|---|---|---|---|
| Safety | 0,346741 | 3 | 4 | 3 | 5 | 4 | 4 | 3 |
| Cost | 0,536405 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| Complexity | 0,116853 | 5 | 4 | 4 | 3 | 3 | 4 | 2 |
| Score | | **3,233706721** | **2,927189409** | **2,580448065** | **3,157077393** | **2,810336049** | **2,927189409** | **1,81033605** |

***Figure 23 Staging strategies trade-off, case of suborbital flight***

Flight point to point

First, we try to understand how the mission and the requirements go to influence the choice of the staging strategy.

"How do the mission and requirements affect the choice of the most suitable staging configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| ***Mission and requirements*** | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates ;<br>Confort. |
| | Mission profile | Flight point to point. | Mission profile influences:<br>Structural loads;<br>Thermical loads;<br>L/D. |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis the Needs are divided into the various figures of merit:

- Safety:
    - Maintain a high level of safety, ensuring that the various standards are respected.
    - Reach distant points on the globe in a short time, security.
- Cost:
    - Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity.
    - Promote and present hypersonic aircraft.
    - Investing on new products, new technologies.
    - Work, economic agreements.
    - Participate in the design, development and implementation.
    - Being involved, receiving information about new technologies.
- Complexity:
    - Reach distant points on the globe in a short time.
    - Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time.

After the weights of the various figures of merit are evaluated, as explained above in fiigure 24:

**EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS**

**Flight point to point**

| Needs | Score | Ranking |
|---|---|---|
| Reach distant points on the globe in a short time | 705 | 1 |
| Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity | 477 | 4 |
| Promote and present hypersonic aircraft | 288 | 8 |
| Being involved, receiving information about new technologies | 129 | 9 |
| o Reach distant points on the globe in a short time, security | 459 | 5 |
| Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected | 697 | 2 |
| Investing on new products, new technologies | 525 | 3 |
| Work, economic agreements | 353 | 7 |
| Participate in the design, development and implementation | 369 | 6 |

| Figures of Merit | | | |
|---|---|---|---|
| **Safety** | **Cost** | **Complexity** | TOT |
| 1156 | 2141 | 1164 | **4461** |
| 0,259135 | 0,479937 | 0,260928043 | **Weights** |

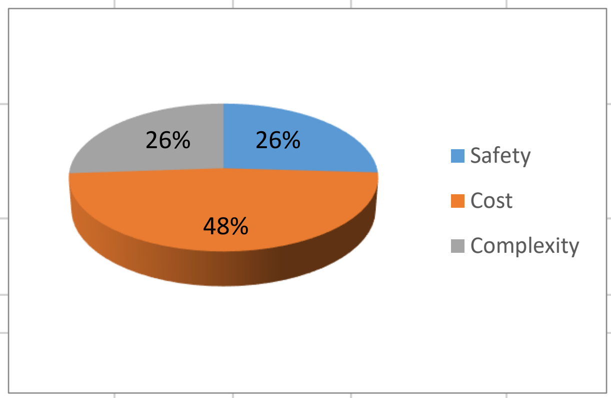



***Figure 24 Staging strategies, evalutation of weights, case of flight point to point***

The requirements that have impacted on the choice are the following:

| ***Requirement*** | ***Safety*** | ***Cost*** | ***Complexity*** |
|---|---|---|---|
| *The aircraft shall reach a point on the glob in (TDB) time.* | | | ✓ |
| *The number of stages shall be reduced.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propellant tank.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propulsive system.* | ✓ | ✓ | ✓ |

***Table 31 Requirements that impact the staging strategy, case of point to point mission***

The figure 25 shows which of the proposed configurations is the best for the mission.

| | Weights | Single Stage | Two Stages Configurazione 2.2 (a) | Two Stages Configurazione 2.2 (b) | Two Stages Configurazione 2.4 (a) | Two Stages Configurazione 2.4 (b) | Two Stages Configurazione 3.2 | Three stages |
|---|---|---|---|---|---|---|---|---|
| Safety | 0,259135 | 3 | 4 | 3 | 5 | 4 | 4 | 3 |
| Cost | 0,479937 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| Complexity | 0,260928 | 5 | 4 | 4 | 3 | 3 | 4 | 2 |
| Score | | 3,521856086 | 3,040125532 | 2,780990809 | 3,038332213 | 2,779197489 | 3,040125532 | 1,77919749 |

***Figure 25 Staging strategies trade-off, case of flight point to point***

Reusable launchers

First, we try to understand how the mission and the requirements go to influence the choice of the staging strategy.

"How do the mission and requirements affect the choice of the most suitable staging configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| ***Mission and requirements*** | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates;<br>Confort. |
| | Mission profile | Reusable launchers. | Mission profile influences:<br>Structural loads;<br>Thermical loads;<br>L/D. |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis the Needs are divided into the various figures of merit:

- Safety:
  - Maintain a high level of safety, ensuring that the various standards are respected.
- Cost:
  - Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches.
  - Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity.
  - Promote and present hypersonic aircraft.
  - Being involved, receiving information about new technologies.
  - Investing on new products, new technologies.
  - Work, economic agreements.
  - Participate in the design, development and implementation.
- Complexity:
  - Perform space missions, send satellites in orbit.

After the weights of the various figures of merit are evaluated, as explained above in figure 26:

**EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS**

**Reusable launchers**

| Needs | Score | Ranking |
|---|---|---|
| Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches | 685 | 1 |
| Being involved in the study, in the project of new technologies.Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity | 475 | 4 |
| Promote and present hypersonic aircraft | 278 | 8 |
| Being involved, receiving information about new technologies | 127 | 9 |
| Perform space missions, send satellites in orbit | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected | 677 | 2 |
| Investing on new products, new technologies | 505 | 3 |
| Work, economic agreements | 351 | 7 |
| Participate in the design, development and implementation | 367 | 6 |

| Figures of Merit | | | |
|---|---|---|---|
| Safety | Cost | Complexity | TOT |
| 677 | 2788 | 459 | **3924** |
| 0,172528 | 0,710499 | 0,116972477 | **Weights** |

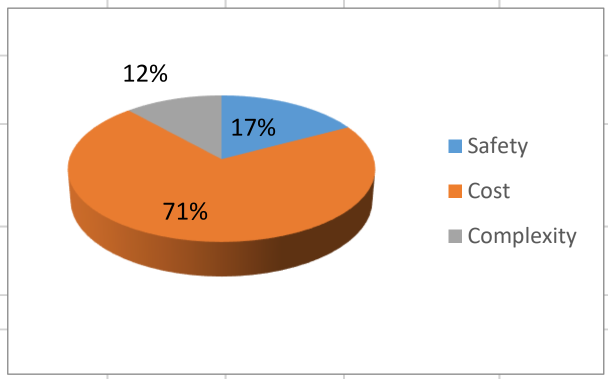



***Figure 26 Staging strategies, evalutation of weights, case of reusable launchers***

The requirements that have impacted on the choice are the following:

| ***Requirement*** | ***Safety*** | ***Cost*** | ***Complexity*** |
|---|---|---|---|
| *The aircraft shall reach the space.* | | | ✓ |
| *The number of stages shall be reduced.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propellant tank.* | ✓ | ✓ | ✓ |
| *The aircraft shall be equipped with a propulsive system.* | ✓ | ✓ | ✓ |

***Table 32  Requirements that impact the staging strategy, case of reusable launcher***

The figure 27 shows which of the proposed configurations is the best for the mission.

| | Weights | Single Stage | Two Stages Configurazione 2.2 (a) | Two Stages Configurazione 2.2 (b) | Two Stages Configurazione 2.4 (a) | Two Stages Configurazione 2.4 (b) | Two Stages Configurazione 3.2 | Three stages |
|---|---|---|---|---|---|---|---|---|
| Safety | 0,17252803 | 3 | 4 | 3 | 5 | 4 | 4 | 3 |
| Cost | 0,71049949 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| Complexity | 0,11697248 | 5 | 4 | 4 | 3 | 3 | 4 | 2 |
| Score | | 3,233944954 | 2,579001019 | 2,406472987 | 2,634556575 | 2,462028542 | 2,579001019 | 1,46202854 |

***Figure 27 Staging strategies trade-off, case of reusable launchers***

## 3.2 *Propulsive strategy*

The choice of the propulsive strategy is one of the first choices that is made when the mission profile has been defined. The choice of the propulsion system is strongly linked to two main aspects of the mission profile: the operating environments and the maximum expected number of Mach. In particular, in the case of hypersonic and trans-atmospheric vehicles, due to a wide range of speed regimes and different operating environments that shall be considered within each single mission, an integrated propulsion strategy can be adopted, combining together different propulsive technologies to be exploited to operate the vehicle during the different mission phases. [5]

The hypersonic aircraft tend to use rocket engines, scramjet engines or even a detonation wave. Vehicles driven by rocket engines, although technically feasible with today's technologies, would need a great deal of propellant to operate at speeds between Mach 8 and the orbital velocity. The use of scramjet at the moment does not seem a viable solution for passenger transport, while in Japan and Europe, precooled jet engines are being studied in which the air entering the compressor is passed into a heat exchanger that significantly lowers the temperature, allowing it to fly efficiently even at speeds above Mach 5.

Among the propulsive technologies that can be exploited in the field of hypersonic aircraft there are:

- Rocket propulsion: Most rocket engines are internal combustion engines. Rocket engines generally produce a reaction mass a high temperature, such as a hot gas. This is achieved by burning a solid, liquid or gaseous fuel with an oxidizing agent inside a combustion chamber. The extremely hot gas is then allowed to escape through a high expansion ratio nozzle. This bell nozzle is what gives a rocket engine its characteristic shape. The effect of the nozzle is to dramatically accelerate the mass, converting most of the thermal energy into kinetic energy. The discharge speed reaches up to 10 times the speed of sound at sea level. Rocket engines essentially provide the highest specific powers and high specific thrusts of any engine used for space vehicle propulsion. The ionic propulsion rockets can heat a plasma or gas loaded inside a magnetic bottle and release it through a magnetic nozzle, so that no solid substance must come into contact with the plasma. Of course, the mechanism to do this is complex, but nuclear fusion research has developed methods, some of which have been proposed for use in propulsion systems and some have been tested in a laboratory.
- Air-breathing propulsion systems: in contrast to a rocket engine that, in addition to fuel, carries an oxidant, an air-breathing propulsion system uses atmospheric air to oxidize the liquid fuel. Air-breathing propulsion systems include the jet engine, ramjet and scramjet. The field of air-breathing propulsion systems involves various scientific and engineering disciplines such as fluid dynamics, turbomachinery aerodynamics, thermodynamics and

materials and structures. Both turbojet and turbofan can be used at the beginning of the mission profile but must be supported by additional propulsion subsystems in order to achieve the desired Mach, such as ramjet and scramjet. The scramjet uses a slightly modified Brayton Cycle to produce energy, like that used for both classic piston engines and turbine engines. The air is compressed, the fuel injected, mixed and burned to increase the air (or more precisely, the products of combustion), temperature and pressure; then these combustion products are expanded. For the turbojet engine, the air is mechanically compressed by the work extracted from the combustor exhaust by means of a turbine. In principle, ramjet and scramjet work the same way. The forward movement of the vehicle compresses the air. The fuel is then injected into the compressed air and burned. Finally, high pressure combustion products expand through the nozzle, effectively thrusting the vehicle. This is a modified Brayton cycle because the final state in the scramjet nozzle is generally not environment. The specific impulse of the engine, or the efficiency of the ramjet, scramjet and turbine engines, with respect to the rocket is illustrated in the following figure. Note the significant improvement in the efficiency of air vent compared to a rocket. For example, the scramjet is about 7 times more efficient than the rocket on Mach 7. The revolutionary aspect of the scramjet is extending the engine of airbreathing far beyond the limits of traditional aircraft. The subsonic combustion in the ramjet produces high static pressure and temperature and a high heat transfer (heat load) to the engine combustor structure, especially to the highest Mach number. These static temperature and heat loads place a practical upper limit on the ramjet operation somewhere between Mach 6 and 8.The scramjet exceeds this limit using supersonic combustion. The supersonic combustion takes place at a static pressure and at a significantly reduced temperature and therefore at the thermal load of the combustor wall. The reduced static temperature allows the practical upper limit of the scramjet to be somewhere between Mach 13 and 15. At the lower limit, the scramjet can be operated under Mach 6 using mixed-mode combustion. The fact that a scramjet can be designed to work both in supersonic mode and in mixed mode, covering both the operating speeds of the ramjet and scramjet, has led to the scramjet dual-mode label. [5], [8]

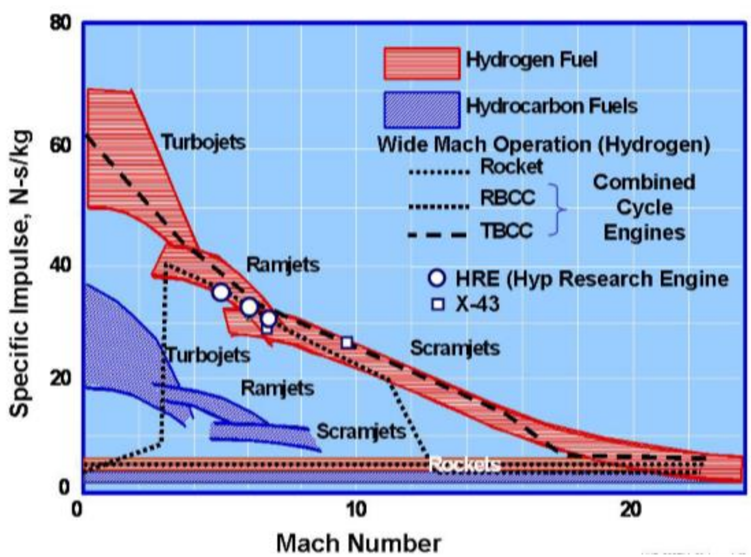


***Figure 28 Hypersonic Engine Efficiency*** [8]

The dual-mode scramjet can operate on the speed range of ramjet and scramjet, from about 3 Mach to at least 15 Mach. Any scramjet application will require an alternative means of accelerating scramjet acquisition rates. For an aeronautical application, an alternating power will be required to allow efficient operation under Mach 3-4 for take-off, acceleration and deceleration at motorized landing. It is worth noting that many research activities currently under development in the field of hypersonic speed propulsion are focused on the integration of individual components into different propulsive technologies. Some of them have a long historical route that dates back to the Second World War. They are known as combined engines or composite engines. [8]

Among the most relevant initiatives, it is useful to remember

- The Air Turbo Ramjet (ATR) a composite engine that behaves like a turbojet at very low speeds and as a rocket engine at higher speeds. Depending on the different applications, several variations on the theme have been developed, like:
    - the turbo ramjet rocket
    - the supercharged ejector ramjet (SERJ)
- The Dual Mode Ramjet (DMR) is a ramjet engine which can operate in both subsonic and supersonic combustion mode.
- Rocket Based Combined Cycle (RBCC)
- Turbine Based Combined Cycle (TBCC)

Other entirely separate classes of air-breathing engines specifically developed for the hypersonic application are the Liquid Air Cycle Engine (LACE) and the Inverse Cycle Engine. However, due to the relatively very low technology maturation. However, future technological developments will provide the designer to include these propulsion systems within the set of eligible technologies.
When defining the propulsion system, the best alternative for the different mission phases shall be chosen, trying to exploit the lowest number of deviating propulsive subsystems. The choice of the appropriate propulsion system architecture can not only be performed on the basis of some qualitative considerations, but it is important to include some high-level performance within the selection process. In particular, the minimum and the maximum Mach number achievable, the specific impulse, the thrust level and the current TRL will be considered correctly. [5]

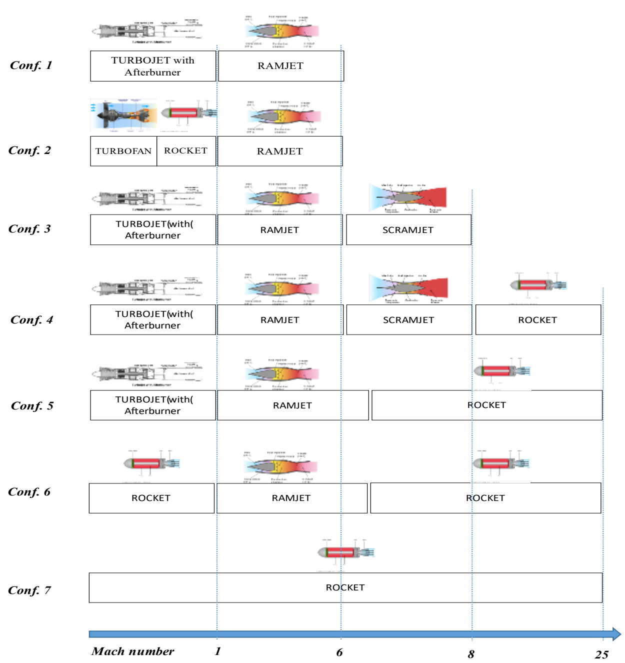



***Figure 29 Propulsive architecture alternatives*** [5]

### 3.2.1 Propulsive strategy trade-off

First of all, the technical areas and the technical aspects that influence the selection process are defined. And finally, the trade-off is executed.

| Figure of Merit | Design Parameters impacting on the FoM evaluation | Comments |
|---|---|---|
| *Safety* | Number of different propulsion systems | The highest is the number of different propulsion systems, the highest will be the impact on safety. |
| | Wall Temperature | The wall temperature is an indicator of the criticalities that characterize propulsion system structure and material. Indeed, the highest is the wall temperature, the heaviest will be the impact on safety. |
| | Presence of rotating machinery | The presence of rotating machinery diminishes the reliability of the system, theoretically. |
| | Presence of Oxidizer | The presence of on-board oxidizer impacts the safety of the system. |
| *Operations* | Throttling capability | The possibility of playing with the thrust module allows to enlarge the ranges of application of this propulsive system. |
| | Re-start capability | The possibility for a propulsion system to be restarted allows to enlarge the operative scenarios. |
| | Maximum Operative Mach number | The maximum operative Mach Number defines the possibility of exploiting a certain propulsive system in each single mission phases. |
| | Thrust Vectoring capability | The possibility of guaranteeing a Thrust Vectoring allows perform vertical/short take-off and landing. |
| *Maintenance* | Number of different propulsion systems | The highest is the number of different propulsion systems, the highest will be the impact on maintenance. More maintenance actions are required. |
| | Wall Temperature | The wall temperature is an indicator of the criticalities that characterize propulsion system structure and material. Indeed, the highest is the wall temperature, the heaviest will be the required maintenance actions. |
| | Presence of rotating machinery | The presence of rotating machinery diminishes the reliability of the system, theoretically. |
| | Presence of Oxidizer | The presence of on-board oxidizer will require more maintenance actions. |

***Table 33 Impact of design parameters on the figures of merit***

Moreover, in the following tables (table 34, table 35, table 36), the requirements that have impacted on the figures of merit are shown in a more schematic way.

| ***Requirement*** | ***Safety*** | ***Operation*** | ***Maintenance*** |
|---|---|---|---|
| *The aircraft shall do suborbital flights.* | | ✓ | |
| *The aircraft shall be a hypersonic aircraft.* | | ✓ | |
| *The aircraft shall allow space flight experiences.* | | ✓ | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | |
| *The aircraft shall allow vertical take-off and vertical landing.* | | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | | ✓ |
| *The rotating machinery shall be reduced.* | ✓ | | ✓ |
| *The number of propulsive system shall be reduced as to increase the safety of the aircraft.* | ✓ | | ✓ |
| *The aircraft shall work in different operative scenarios.* | | ✓ | |
| *The propulsive system shall able to re-start.* | | ✓ | |
| *The propulsive system shall able to throttle.* | | ✓ | |
| *The engine shall provide high thrusts.* | | ✓ | |
| *The engine shall provide a high specific impulse.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach..* | | ✓ | |

***Table 34 Requirements that impact the propulsive strategy, case of suborbital flight***

| ***Requirement*** | ***Safety*** | ***Operation*** | ***Maintenance*** |
|---|---|---|---|
| *The aircraft shall reach a point on the glob in (TDB) time.* | | ✓ | |
| *The aircraft shall be a hypersonic aircraft.* | | ✓ | |
| *The aircraft shall allow the carriage of* | | ✓ | |

| | | | |
|---|---|---|---|
| *passengers.* | | | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | |
| *The aircraft shall allow vertical take-off and vertical landing.* | | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | | ✓ |
| *The rotating machinery shall be reduced.* | ✓ | | ✓ |
| *The number of propulsive system shall be reduced as to increase the safety of the aircraft.* | ✓ | | ✓ |
| *The aircraft shall work in different operative scenarios.* | | ✓ | |
| *The propulsive system shall able to re-start.* | | ✓ | |
| *The propulsive system shall able to throttle.* | | ✓ | |
| *The engine shall provide high thrusts.* | | ✓ | |
| *The engine shall provide a high specific impulse.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach..* | | ✓ | |

***Table 35  Requirements that impact the propulsive strategy, case of point to point mission***

| ***Requirement*** | ***Safety*** | ***Operation*** | ***Maintenance*** |
|---|---|---|---|
| *The aircraft shall reach the space.* | | ✓ | |
| *The aircraft shall be a hypersonic aircraft.* | | ✓ | |
| *The aircraft shall allow the carriage of passengers.* | | ✓ | |
| *The aircraft shall be re-usable.* | | ✓ | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | |
| *The aircraft shall allow vertical take-off and vertical landing.* | | ✓ | |
| *The aircraft shall be able to withstand the thermal* | ✓ | | ✓ |

| | | | |
|---|---|---|---|
| *loads.* | | | |
| *The rotating machinery shall be reduced.* | ✓ | | ✓ |
| *The number of propulsive system shall be reduced as to increase the safety of the aircraft.* | ✓ | | ✓ |
| *The aircraft shall work in different operative scenarios.* | | ✓ | |
| *The propulsive system shall able to re-start.* | | ✓ | |
| *The propulsive system shall able to throttle.* | | ✓ | |
| *The engine shall provide high thrusts.* | | ✓ | |
| *The engine shall provide a high specific impulse.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach.* | | ✓ | |

***Table 36  Requirements that impact the propulsive strategy, case of reusable launcher***

| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|---|
| | | TJ with AB Rocket | TF Rocket Ramjet | TJ with AB Rocket Scramjet | TJ with AB Rocket Scramjet Rocket | TJ with AB Ramjet Rocket | Rocket Ramjet Rocket | Rocket |
| **Safety** | [A1] Number of different propulsion systems | 2 | 3 | 3 | 4 | 3 | 3 | 1 |
| | [A2] Wall temperature | 5 | 10 | 10 | 10 | 5 | 5 | 5 |
| | [A3] Presence of rotating machinery | 0,5 | 0,33333 | 0,3333333 | 0,25 | 0,3333333 | 0 | 0 |
| | [A4] Presende of oxidizer | 0,5 | 0,33333 | 0 | 0,25 | 0,3333333 | 0,666667 | 1 |
| **Operations** | [B1] Re-start capability | 5 | 3 | 5 | 5 | 5 | 3 | 1 |
| | [B2] Throttling capability | 5 | 3 | 5 | 5 | 5 | 3 | 1 |
| | [B3] Maximum Operative Mach number | 6 | 6 | 8 | 25 | 25 | 25 | 25 |
| | [B4] Thrust Vectoring capability | 1 | 0 | 1 | 1 | 1 | 0 | 0 |
| **Maintenance** | [C1] Number of different propulsion systems | 2 | 3 | 3 | 4 | 3 | 3 | 1 |
| | [C2] Wall Temperature | 5 | 10 | 10 | 10 | 5 | 5 | 5 |
| | [C3] Presence of rotating machinery | 0,5 | 0,33333 | 0,3333333 | 0,25 | 0,3333333 | 0 | 0 |
| | [C4] Presence of Oxidiz | 0,5 | 0,33333 | 0 | 0,25 | 0,3333333 | 0,666667 | 1 |

***Figure 30 Figure of Mert of propulsive strategy***

In order to evaluate the best alternative in terms of propulsive strategy, the different Figures of Merit listed in the previous table have been combined as follows:

$$TO = -K_A * \sum (A_i)_n + K_B * \sum (B_i)_n - K_C * \sum (C_i)_n$$

where
$TO$ is the global FoM
$K_A$ is the weighting factor taking into account the impact of safey area of interest on the selection of the propulsive strategy. The minus sign is due to the fact that the characteristics afferent to this area of interest are playing against it.
$K_B$ is the weighting factor taking into account the impact of operations area of interest on the selection of the propulsive strategy.
$K_C$ is the weighting factor taking into account the impact of maintenance area of interest on the selection of the propulsive strategy. The minus sign is due to the fact that the characteristics afferent to this area of interest are playing against it.
$(A_i)_n$ is the normalized estimation obtained as $\frac{A_i}{\max(A_i)}$ .s

$(B_i)_n$ is the normalized estimation obtained as $\frac{B_i}{\max(B_i)}$ .
$(C_i)_n$ is the normalized estimation obtained as $\frac{C_i}{\max(C_i)}$ .
This procedure was taken from the following document [5].

<u>Suborbital flight</u>: here among the three figures of merit, based on the high level requirements that we have found from the Stakeholder analysis, we want the one with the greatest impact to be operation, as we have to face different scenarios, different Mach, we want to take off vertical and also starting from already existing tracks.
Then we choose: S 1/4, O 1/2, M 1/4.

<u>Flight Point to Point</u>: here among the three figures of merit, based on the high level requirements that we have found from the analysis of the Stakeholders, we want the one with the greatest impact to be safety, as we have to transport people.
Then we choose: S 1/2, O 1/4, M 1/4.

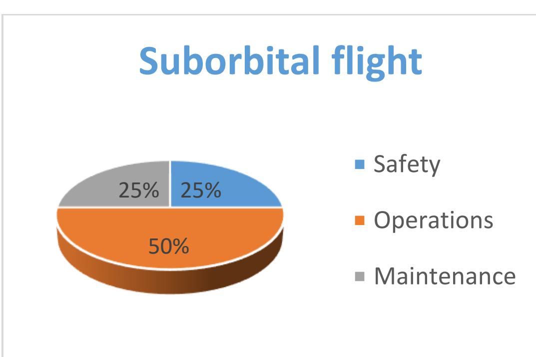
<u>Reusable launcher</u>: here among the three figures of merit, based on the high-level requirements that we found from the Stakeholder analysis, we want the one with the greatest impact to be operation, as we have to face different scenarios, different Mach, we want to take off vertical and also starting from already existing tracks.
Then we choose: W and B 1/4, O 1/2, M 1/4.

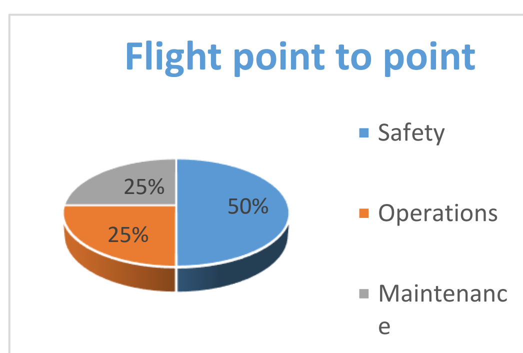
| | Weight | | | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ka | Kb | Kc | TJ with AB Rocket | TF Rocket Ramjet | TJ with AB Rocket Scramjet | TJ with AB Rocket Scramjet Rocket | TJ with AB Ramjet Rocket | Rocket Ramjet Rocket | Rocket |
| Volo Suborbtale | 0,25 | 0,5 | 0,25 | 0,37 | -0,655 | 0,451667 | 0,625 | 0,875 | 0,141667 | -0,175 |
| Volo Punto a Punto | 0,5 | 0,25 | 0,25 | -1,065 | -1,7025 | -0,9825 | -1,0625 | -0,6875 | -0,8875 | -0,9625 |
| Lanciatori Riutilizzabili | 0,25 | 0,5 | 0,25 | 0,37 | -0,655 | 0,451667 | 0,625 | 0,875 | 0,141667 | -0,175 |

***Figure 31 Propulsive strategy trade-off***

The configuration with the highest scoring results is: a Turbojet with the postburner, a ramjet and a rocket technology.

Moreover, it is noted that when the mission varies, the weights obtained for the various figures of merit vary (figure 32).



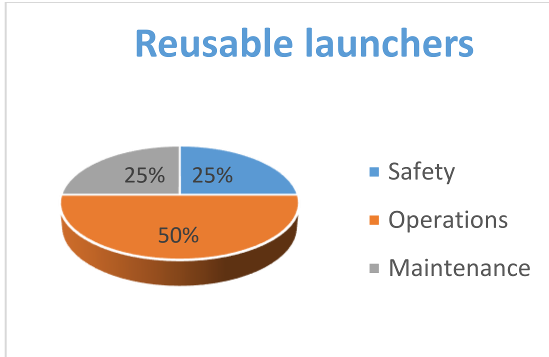



*Figure 32 Different weight for the same Figure of Merit for different mission*

## 3.3 Take-off and Landing strategy

The landing is a phase of the flight in which an airplane makes contact with the ground. There are different types of landing and they varied in bas at the surface that the aircraft makes contact. The take-off is the flight phase in which the aircraft acquires the necessary speed that guarantees the lift of the wing. The way in which it takes place is many and depend on the type of aircraft, the length of the runway, the intensity and direction of the wind and the density of the air.
About the take-off and landing strategy two main options may be available: The traditional horizontal take-off and landing and vertical take-off and landing.
Thus, the choice typically falls between two large classes:
• HOTOL (Horizontal Take Off and Landing)
• VTOL (Vertical Take Off and Landing)
There may be several alternatives to implement a VTOL. They should be analyzed from the beginning of the design process because they have a strong impact on vehicle configuration.

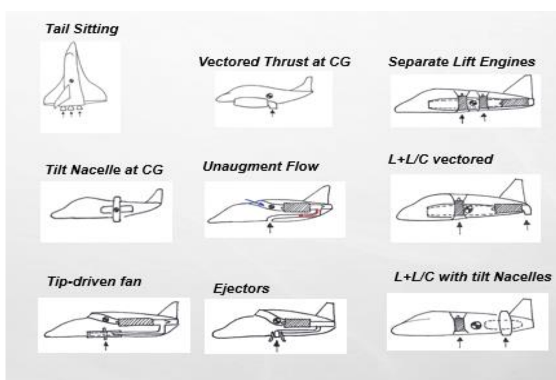



*Figure 33 Take-off and landing strategy*

- Tail Sitting
- Vectored Trust at CG
- Tail Nacelle at GC
- Un-augmented flow

- Tip driiven fan
- Enjectors
- Separate Lift Engines
- L+L/C vectored
- L+L/C tilt nacelles

### 3.3.1 Take-off trade-off Landing strategy trade-off

For the choice of the take-off and landing strategy, proceed as for the choice of the propulsive strategy seen in the previous paragraph.

However, different merit figures are chosen, they are:
- Accommodation area of interest;
- Structure;
- Maintenance.

| | ***Accommodation area of interest*** | ***Structure*** | ***Maintenance*** |
|---|---|---|---|
| ***Tail Sitting*** | 3 | 4 | 2 |
| ***Vectored Trust at CG*** | 5 | 3 | 4 |
| ***Tail Nacelle at CG*** | 5 | 3 | 3 |
| ***Un-augmented flow*** | 4 | 3 | 2 |
| ***Tip driven fan*** | 4 | 3 | 2 |
| ***Ejectors*** | 4 | 3 | 2 |
| ***Separate Lift Engines*** | 5 | 4 | 4 |
| ***L+L/C vectored*** | 5 | 4 | 4 |
| ***L+L/C tilt nacelles*** | 5 | 4 | 4 |

***Table 37 Figure of Merit***

The following tables (table 38, table 39, table 40) show the requirements that have impacted on the figures of merit.

| ***Requirement*** | ***Accomodation area of interest*** | ***Structure*** | ***Maintenance*** |
|---|---|---|---|
| *The aircraft shall allow aerospace testing and demonstration.* | ✓ | | |
| *The aircraft shall allow space flight experiences.* | ✓ | | |
| *The aircraft shall be used for training space personnel.* | ✓ | | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | ✓ |
| *The aircraft shall allow vertical take-off and* | | ✓ | ✓ |

| | | | |
|---|---|---|---|
| *vertical landing.* | | | |
| *The volume available to accommodate passenger/cargo shall be maximized.* | ✓ | | |

**Table 38 Requirements that impact the take-off and landing strategy, case of suborbital flight**

| Requirement | Accomodation area of interest | Structure | Maintenance |
|---|---|---|---|
| *The aircraft shall allow the carriage of cargo.* | ✓ | | |
| *The aircraft shall allow the carriage of passengers.* | ✓ | | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | ✓ |
| *The aircraft shall allow vertical take-off and vertical landing.* | | ✓ | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | ✓ | | |

**Table 39 Requirements that impact the take-off and landing strategy, case of point to point mission**

| Requirement | Accomodation area of interest | Structure | Maintenance |
|---|---|---|---|
| *The aircraft shall allow the carriage of cargo.* | ✓ | | |
| *The aircraft shall allow the carriage of passengers.* | ✓ | | |
| *The aircraft shall allow take-off and land on existing runways.* | | ✓ | ✓ |
| *The aircraft shall allow vertical take-off and vertical landing.* | | ✓ | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | ✓ | | |

**Table 40 Requirements that impact the take-off and landing strategy, case of reusable launcher**

At this point the trade-off is performed in the same way as in the previous paragraph, obtaining the following results:

| | Weight | | Tail Sitting | Vectored Trust at CG | Tilt Nacelle at CG | Un-augmented flow | Tip driven fan | Enjectors | Separate Lift Engines | L+L/C vectored | L+L/C tilt nacelles |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Accomodation area of interest | K1 | 0,5 | 3 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 |
| Structure | K2 | 0,25 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 |
| Maintenance | K3 | 0,25 | 2 | 4 | 3 | 2 | 2 | 2 | 4 | 4 | 4 |
| | | | | | | | | | | | |
| | Score | | 3 | 4,25 | 4 | 3,25 | 3,25 | 3,25 | 4,5 | 4,5 | 4,5 |

***Figure 34 Take-off and Landing strategy trade-off, case of suborbital flight***

| | Weight | | Tail Sitting | Vectored Trust at CG | Tilt Nacelle at CG | Un-augmented flow | Tip driven fan | Enjectors | Separate Lift Engines | L+L/C vectored | L+L/C tilt nacelles |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Accomodation area of interest | K1 | 0,5 | 3 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 |
| Structure | K2 | 0,25 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 |
| Maintenance | K3 | 0,25 | 2 | 4 | 3 | 2 | 2 | 2 | 4 | 4 | 4 |
| | | | | | | | | | | | |
| | Score | | 3 | 4,25 | 4 | 3,25 | 3,25 | 3,25 | 4,5 | 4,5 | 4,5 |

***Figure 35 Take-off and Landing strategy trade-off, case of point to point mission***

| | Weight | | Tail Sitting | Vectored Trust at CG | Tilt Nacelle at CG | Un-augmented flow | Tip driven fan | Enjectors | Separate Lift Engines | L+L/C vectored | L+L/C tilt nacelles |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Accomodation area of interest | K1 | 0,25 | 3 | 5 | 5 | 4 | 4 | 4 | 5 | 5 | 5 |
| Structure | K2 | 0,25 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 |
| Maintenance | K3 | 0,5 | 2 | 4 | 3 | 2 | 2 | 2 | 4 | 4 | 4 |
| | | | | | | | | | | | |
| | Score | | 2,75 | 4 | 3,5 | 2,75 | 2,75 | 2,75 | 4,25 | 4,25 | 4,25 |

***Figure 36 Take-off and Landing strategy trade-off, case of reusable launchers***

Moreover, it is noted that when the mission varies, the weights obtained for the various figures of merit vary (figure 37).

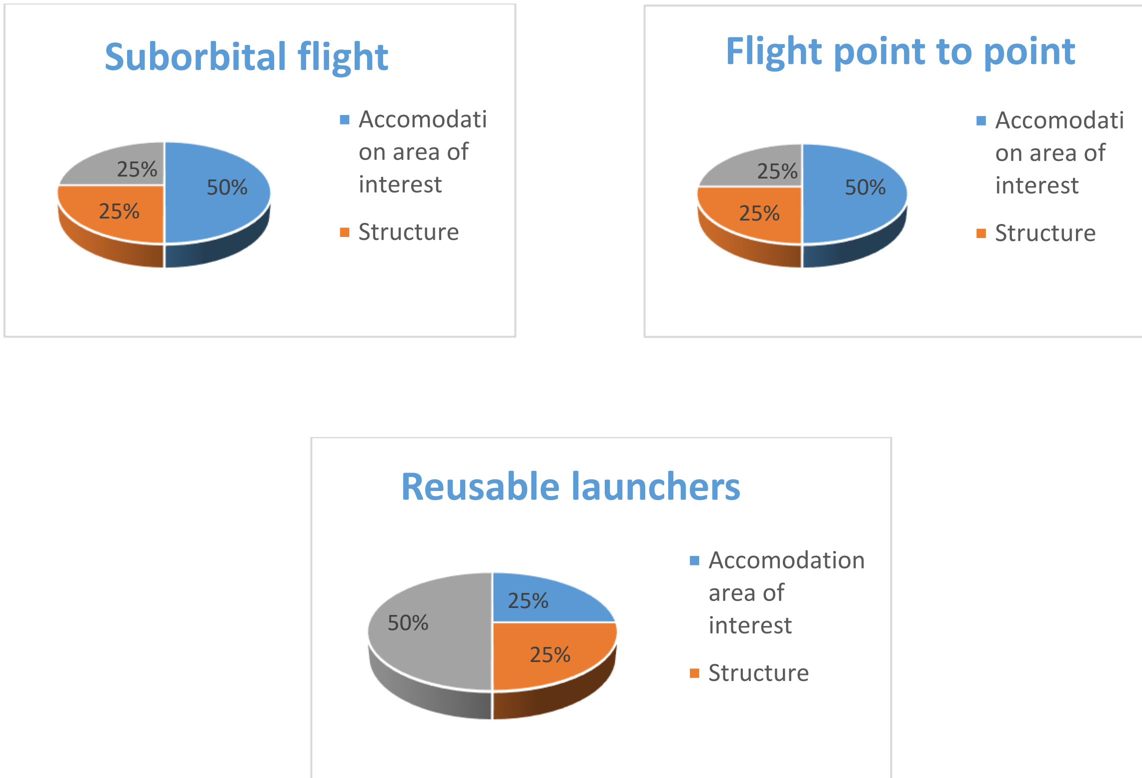



***Figure 37 Different weight for the same Figure of Merit for different mission***

## *3.4 Aerothermodynamic configuration*

When the architecture of the aircraft is defined, qualitative and quantitative choices are made, and the right compromises must be found.
One of the first things that is chosen is the aerothermodynamic configuration.
Basically, two great classes are distinguished:

- Configuration for atmospheric missions:
  - Flying Wing
  - Fuselage+Wing
- Configuration for transatmospheric and space mission:
  - Re-entry vehiclesss
    - ✓ Winged re-entry vehicles
    - ✓ Non winged re-entry vehicles
  - Ascent and re-entry vehicles
    - ✓ Orbital ascent and re-entry vehicles
    - ✓ Suborbital ascent and re-entry vehicles
  - Cruise and acceleration vehicles

Entering more in detail [5]:

<u>Winged Vehicle (Flying Wing)</u>

A winged vehicle is an aircraft consisting exclusively of the wing, and therefore without a fuselage or empennage; winged vehicles are also defined all those aircraft without horizontal empennage and a defined fuselage but are equipped with tail of generally very small dimensions. The fuselage is not clearly distinct. This configuration is characterized by a high lifting surface. An airplane with this configuration can carry all its payload inside the wing, it is preferable in case a high number of passengers should be accommodated.

Winged-Re-entry Vehicle (Fuselage+wing)
This vehicle is the most traditional configuration, where the fuselage and the wing are clearly distinct. In this case, the passenger compartment is housed inside the conical section, while the wing surface is the main responsibility of the aerodynamic generation. This configuration can be a good compromise between different needs of the mission.

No-Winged-Re-entry Vehicle (Lifting Body)
This configuration can be considered optimal as regards the ability to withstand thermal loads during re-entry. On the contrary, it is necessary to provide special navigation and orientation control systems to improve the controllability of this object. Furthermore, it is worth noting that this configuration is more suitable in case a limited amount of payload should be transported.

Spherical Capsule
The spherical capsule is the simplest configuration that can perform a re-entry. Considering the impossibility of including flight control systems within this configuration, the spherical shape is the worst in terms of control and maneuverability. Static stability is ensured by the position of the center of mass, while the dynamic is more problematic. On the contrary, it can provide high volumetric efficiency with an optimal weight distribution. Suitable for small passengers. This type of configuration, as well as all other capsule configurations, is only suitable for re-entry missions.

Blunt Cone Capsule
The conical capsule is the best compromise between aero-thermodynamic efficiency, simplicity and volumetric efficiency. In fact, the shape makes it possible to make a clear division of the available volume: the lower part for the main subsystems and the upper part for passengers could be located.

Conic capsule
The conical capsule can be considered as the most aerodynamic capsule and is mainly due to differences in the radius of the upper and lower part. From the point of view of stability, this configuration has the advantages of an asymmetric shape. Its stability is superior to that of a spherical section.

Bluff Bi-conic Capsule
The bi-conical bluff capsule is a form expected by some German studies, as part of the European project of the crew rescue vehicle.

Slender B-conic Capsule
This capsule has been envisaged by Russians to carry out re-entry missions from the Low Earth Orbits. Furthermore, some concepts of Mars Lander have exploited this form.

Heatshield with Afterbody
This configuration ensures the ability to withstand extreme thermal loads at the non-winged configuration.

At this point it is observed that the type of mission and the environment in which it operates, are indispensable for the choice. So, the mission and the requirements greatly influence the choice.
To do this, an answer is given to the following question:

- How do the mission and the requirements for choosing the most suitable aerothermodynamic configuration affect? example on the basis of the payload (passengers, load, etc.) there will be a certain configuration, characterized by a given volume, etc; depending on the type of mission (point-to-point flight, sub-orbital, reusable launchers, etc.) one will have a configuration rather than another.

After that, a trade-off analysis is performed.

### 3.4.1 Aerothermodynamic confguration trade-off

Among the various possible configurations, the best configuration is chosen, in particular it is chosen on the basis of the mission that the aircraft has to perform, and the expectations of the stakeholders must always be kept in mind.
The Analytic Hierarchy Process (AHP) is a multicriteria-based support technique which allows to compare multiple alternatives in relation to a variety of quantitative or qualitative criteria and to obtain a global assessment for each of them. This manages to order and select the best alternative.
First of all, it’s important to identify a set of evaluation criteria for the decision-making alternatives (i.e. the Figures of Merit) and assign each criterion a normalized weight. Then a score that represents the impact of the criterion on the decision is assigned.
Trade-Off AHP Analysis can be conducted through two main ways: the Direct Analysis or the Indirect Method.
The first one derives from Game Theory, a branch of Statistics, Mathematics, Economics and Logic and it is also called Lottery Equivalent Probability or Direct Probabilistic Dichotomic Method:

- Direct: the values of the alternative choices are asked directly to the main actor of the game (in this case, to the customers, i.e. Stakeholders);
- Probabilistic: the importance of choices is calculated both with players’ opinions (as described before), but also on the base of the risk (failure, complexity, difficulty to be put in practise) affecting the choice;
- Dichotomic: players must choose only between two alternatives and these ones always fork in other two ones.

This mission has not a real feedback coming from game players (Stakeholders) or a direct interaction with them, so the Indirect Method was chosen. This one is based on the Swinging Weights Method which is faster than Indirect Analysis.
This method is based on analyzing individual decisions and opinions and their impact on the mission. This method normalizes all mission priorities coming from different fields in terms of a simple vote weighted through the Figures of Merit.
From the Stakeholders analysis and the quality house, several needs / values have been obtained; which are very important to evaluate the relative weights of the merit figures.
The figures of merit are determined separately for each analysis and the relative weights have been calculated starting from the Needs previously found. To each of them was assigned a score that came out of the house of quality, starting from these have divided the Need in the figures of merit identified, and then divided the values obtained for the total score (as required by AHP).
After, votes were assigned from 0 to 5, and each of these votes were multiplied by the corresponding weights; from these a total sum was calculated by column, where the highest value corresponds to the winning design solution. [4], [7]
In this case the figures of merit that have been taken into consideration are:

- Safety;

- Cost;
- Operation.

Suborbital flight

First, we try to understand how the mission and the requirements go to influence the choice of the aerothermodynamic configuration.

"How do the mission and requirements affect the choice of the most suitable aerothermodynamic configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| *Mission and requirements* | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates;<br>Confort. |
| | Mission profile | Suborbital flight. | Mission profile influences:<br>Structural loads;<br>Thermical loads;<br>L/D, |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis, the Needs are divided into the various figures of merit:

- Safety:
  - Maintain a high level of safety, ensuring that the various standards are respected.
  - Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies.
- Cost:
  - Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity.
  - Promote and present hypersonic aircraft.
  - Investing on new products, new technologies.
  - Work, economic agreements.
  - Participate in the design, development and implementation.
  - Being involved, receiving information about new technologies.
- Operation:

  Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing.

After the weights of the various figures of merit are evaluated, as explained above in figure 38:

**EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS**

**Suborbital flight**

| Needs | Score | Ranking |
|---|---|---|
| Human spaceflight experiences for tourism or for training, tests and demonstrations of aerospace technologies. | 685 | 1 |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | 479 | 4 |
| Promote and present hypersonic aircraft. | 278 | 8 |
| Being involved, receiving information about new technologies. | 127 | 9 |
| Human spaceflight experiences for tourism or training, basic and applied research in space and microgravity, tests and demonstrations of aerospace technologies, remote sensing. | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected. | 677 | 2 |
| Investing on new products, new technologies. | 505 | 3 |
| Work, economic agreements. | 351 | 7 |
| Participate in the design, development and implementation. | 367 | 6 |
| TOTAL | 3928 | |

| Figures of Merit | | | |
|---|---|---|---|
| **Safety** | **Cost** | **Operation** | TOT |
| 1362 | 2107 | 459 | **3928** |
| 0,346741 | 0,536405 | 0,11685336 | **Weights** |

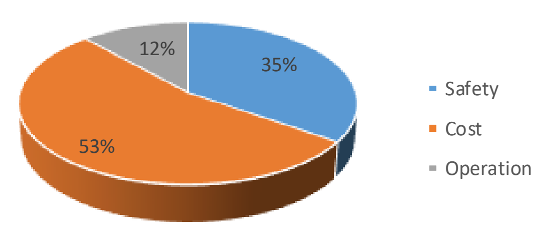



***Figure 38 Aerothermodynamic configuration, evalutation of weights, case of suborbital flight***

After which they were given grades from 0 to 5, and each of these votes were multiplied by the corresponding weights; to which a total sum has been calculated per column, where the highest value corresponds to the winning design solution.
The scale that has been used is the following:

- Security: 0 (not very safe), 5 (very safe);
- Cost (in terms of both money and time, the costs related to research and development, production, operations) are taken into consideration: 0 (very expensive), 5 (inexpensive);
- Operations: 0 (difficulty in carrying out operations), 5 (operations performed more easily).

For each figure of merit identified, an impact analysis can be carried out trying to understand the impact of the design parameters on them (for example: the cost on what can impact? Wing, yes or no? Etc. etc).

| *Possible aero-thermodynamic* | *Safety* | *Cost* | *Operation* |
|---|---|---|---|
| ***Winged Vehicle (Flying Wing)*** | High security level, it is a widely used configuration. Furthermore, this configuration can be a good compromise between different needs of the mission. It is very good for take-off, cruising, re-entry, landing. | Very expensive. He is able to complete the whole mission. | This configuration can be a good compromise between different needs of the mission. All right for take-off, cruising, re-entry, landing. It's good when many passengers are expected. |
| ***Winged-Re-entry Vehicle (Fuselage+wing)*** | High security level, it is a widely used configuration. Furthermore, this configuration can be a good compromise between different needs of the mission. It is very good for take-off, cruising, re-entry, landing. | Very expensive. He is able to complete the whole mission. | More traditional configuration. This configuration can be a good compromise between different needs of the mission. All right for take-off, cruising, re-entry, landing. |
| ***No-Winged-Re-entry Vehicle (Lifting Body)*** | Safety level quite high, withstands heat loads very well during re-entry; but it is necessary to provide special navigation and orientation control systems to improve the controllability of this object. | Very expensive. It is able to accomplish the whole mission, although, difficultly, this configuration can be exploited to perform an autonomous ascent or cruise phase. | Configuration considered optimal as regards the ability to withstand thermal loads during re-entry. Limited amount of payload. This configuration can hardly be exploited to perform an autonomous ascent or cruising phase. |
| ***Spherical Capsule*** | Not very high security level, it is one of the worst configurations in terms of control and maneuverability. Static stability is ensured by the position of the center of mass, while the dynamic one is more problematic. It is only suitable for re-entry missions. | Very expensive. It's okay just for the return missions. It must be combined with another system. | This configuration is only suitable for small passengers and return missions. |
| ***Blunt Cone Capsule*** | Safety level quite good. The conical capsule is the best compromise between aero-thermodynamic efficiency, simplicity and volumetric efficiency. It is only suitable for return missions. | Very expensive. It's okay just for the return missions. It must be combined with another system. | The shape of this configuration makes it possible to make a clear division of the available volume: the lower part, where the main subsystems could be located and the upper part for passengers. It is only suitable for return missions. |
| ***Conic Capsule*** | Its stability is superior to that of a spherical section, a fairly high level of security. | Very expensive. It's okay just for the return missions. It must be combined with another system. | This configuration is considered the most aerodynamic capsule and is mainly due to differences in the radius of the upper and lower part. It is only suitable for return missions. |

| | | | |
|---|---|---|---|
| ***Bluff Bi-conic Capsule*** | Its stability is superior to that of a spherical section, a fairly high level of security. | Very expensive. It's okay just for the return missions. It must be combined with another system. | It is a configuration expected by some German studies. Being a capsule should only be suitable for re-entry missions. |
| ***Slender B-conic Capsule*** | Its stability is superior to that of a spherical section, a fairly high level of security. | Very expensive. It's okay just for the return missions. It must be combined with another system. | This configuration is suitable for re-entry missions from low terrestrial orbit. |
| ***Heatshield with Afterbody*** | Safety level quite high. It is able to withstand extreme thermal loads. It is also possible to envisage the use of a detachable heat shield in certain mission phases. | Very expensive. It's okay just for the return missions. It must be combined with another system. | This configuration is able to withstand extreme thermal loads. |

***Table 41 Impact analysis***

The requirements that have impacted on the choice are the following:

| ***Requirement*** | ***Safety*** | ***Cost*** | ***Operation*** |
|---|---|---|---|
| *The aircraft shall do suborbital flights.* | | | ✓ |
| *The aircraft shall be a hypersonic aircraft.* | | | ✓ |
| *The aircraft shall allow aerospace testing and demonstration.* | | ✓ | ✓ |
| *The aircraft shall allow space flight experiences.* | ✓ | ✓ | ✓ |
| *The aircraft shall be used for training space personnel.* | ✓ | ✓ | ✓ |
| *The aircraft shall allow research, in spatial environment and in microgravity, in different fields.* | | ✓ | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | |
| *The aircraft shall have a high L/D.* | | | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | ✓ | | ✓ |

| | | |
|---|---|---|
| *The aircraft shall be maneuverable.* | ✓ | ✓ |
| *The aircraft shall be controllable.* | ✓ | ✓ |

***Table 42  Requirements that impact the choice of the aerothermodynamic configuration, case of suborbital flight***

The figure shows which of the proposed configurations is the best for the mission.

| | Weights | **Flying Wing** | **Fuselage+ wing** | **Lifting Body** | **Spherical Capsule** | **Blunt Cone Capsule** | **Conic Capsule** | **Bluff Bi-conic Capsule** | **Slender B-conic Capsule** | **Heatshield with Afterbody** |
|---|---|---|---|---|---|---|---|---|---|---|
| Safety | 0,34674134 | 5 | 5 | 4 | 2 | 3 | 3 | 3 | 3 | 3 |
| Cost | 0,5364053 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Operation | 0,11685336 | 5 | 5 | 4 | 2 | 2 | 2 | 2 | 3 | 2 |
| Score | | **3,927189409** | **3,927189409** | **3,463594705** | **2** | **2,346741344** | **2,346741344** | **2,346741344** | **2,463594705** | **2,346741344** |

***Figure 39 Aerothermodynamic configuration trade-off, case of suborbital flight***

From the analysis just carried out, a more traditional configuration is more suitable for the mission.

Flight point to point

First, we try to understand how the mission and the requirements go to influence the choice of the aerothermodynamic configuration.

"How do the mission and requirements affect the choice of the most suitable aerothermodynamic configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| ***Mission and requirements*** | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates ;<br>Comfort. |
| | Mission profile | Flight point to point. | Mission profile influences:<br>Structural loads;<br>Thermal loads;<br>L/D. |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis the Needs are divided into the various figures of merit:

- Safety:
  - Maintain a high level of safety, ensuring that the various standards are respected.
  - Reach distant points on the globe in a short time, security.
- Cost:
  - Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity.
  - Promote and present hypersonic aircraft.
  - Investing on new products, new technologies.
  - Work, economic agreements.
  - Participate in the design, development and implementation.
  - Being involved, receiving information about new technologies.
- Operation:
  - Reach distant points on the globe in a short time.
  - Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time.

After the weights of the various figures of merit are evaluated, as explained above in figure 40:

**EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS**

**Flight point to point**

| Needs | Score | Ranking |
|---|---|---|
| Reach distant points on the globe in a short time. | 705 | 1 |
| Being involved in the study, in the project of new technologies; research in different fields, exploiting the unique properties of the space environment and microgravity. | 477 | 4 |
| Promote and present hypersonic aircraft. | 288 | 8 |
| Being involved, receiving information about new technologies. | 129 | 9 |
| Reach distant points on the globe in a short time, security. | 459 | 5 |
| Reach distant points on the globe in a short time, so as to penetrate any air space in the planet in a short time. | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected. | 697 | 2 |
| Investing on new products, new technologies. | 525 | 3 |
| Work, economic agreements. | 353 | 7 |
| Participate in the design, development and implementation. | 369 | 6 |

| Figures of Merit | | | |
|---|---|---|---|
| **Safety** | **Cost** | **Operation** | TOT |
| 1156 | 2141 | 1164 | **4461** |
| 0,259135 | 0,479937 | 0,260928 | **Weights** |

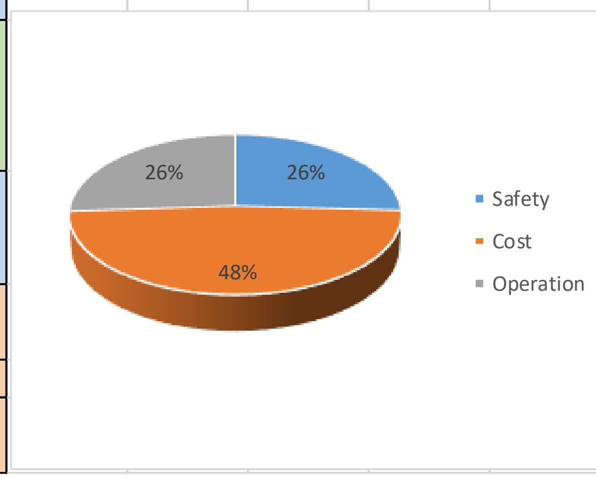



***Figure 40 Aerothermodynamic configuration, evalutation of weights, case of point to point mission***

After which they were given grades from 0 to 5, and each of these votes were multiplied by the corresponding weights; to which a total sum has been calculated per column, where the highest value corresponds to the winning design solution.
Furthermore, for each figure of merit identified, an impact analysis can be carried out trying to understand the impact of the design parameters on them. (See Table 41)

The requirements that have impacted on the choice are the following:

| *Requirement* | *Safety* | *Cost* | *Operation* |
|---|---|---|---|
| *The aircraft shall reach a point on the glob in (TDB) time.* | | | ✓ |
| *The aircraft shall be a hypersonic aircraft.* | | | ✓ |
| *The aircraft shall allow the carriage of cargo.* | | ✓ | ✓ |
| *The aircraft shall allow the carriage of passengers.* | ✓ | ✓ | ✓ |
| *The aircraft shall allow research, in spatial environment and in microgravity, in different fields.* | | ✓ | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | |
| *The aircraft shall have a high L/D.* | | | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | ✓ | | ✓ |
| *The aircraft shall be maneuverable.* | ✓ | | ✓ |
| *The aircraft shall be controllable.* | ✓ | | ✓ |

***Table 43 Requirements that impact the choice of the aerothermodynamic configuration, case of point to point mission***

The figure shows which of the proposed configurations is the best for the mission.

| | Weights | Flying Wing | Fuselage+wing | Lifting Body | Spherical Capsule | Blunt Cone Capsule | Conic Capsule | Bluff Bi-conic Capsule | Slender B-conic Capsule | Heatshield with Afterbody |
|---|---|---|---|---|---|---|---|---|---|---|
| Safety | 0,259135 | 5 | 5 | 4 | 2 | 3 | 3 | 3 | 3 | 3 |
| Cost | 0,479937 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Operation | 0,260928 | 5 | 5 | 4 | 2 | 2 | 2 | 2 | 3 | 2 |
| Score | | 4,040126 | 4,040126 | 3,520063 | 2 | 2,259135 | 2,2591347 | 2,2591347 | 2,52006277 | 2,2591347 |

***Figure 41 Aerothermodynamic configuration trade-off, case of point to point mission***

From the analysis just carried out, a more traditional configuration is more suitable for the mission.

Reusable launchers

First, we try to understand how the mission and the requirements go to influence the choice of the aerothermodynamic configuration.

"How do the mission and requirements affect the choice of the most suitable aerothermodynamic configuration?”

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| *Mission and requirements* | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates;<br>Comfort. |
| | Mission profile | Reusable launchers. | Mission profile influences:<br>Structural loads;<br>Thermal loads;<br>L/D. |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis the Needs are divided into the various figures of merit:

- Safety:
  - Maintain a high level of safety, ensuring that the various standards are respected.
- Cost:
  - Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches.
  - Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity.
  - Promote and present hypersonic aircraft.
  - Being involved, receiving information about new technologies.
  - Investing on new products, new technologies.
  - Work, economic agreements.
  - Participate in the design, development and implementation.
- Operation:
  - Perform space missions, send satellites in orbit.

After the weights of the various figures of merit are evaluated, as explained above in figure 42:

| EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS | | |
|---|---|---|
| **Reusable launchers** | | |
| Needs | Score | Ranking |
| Perform space missions, send satellites in orbit using reusable launchers to reduce the cost of launches. | 685 | 1 |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | 475 | 4 |
| Promote and present hypersonic aircraft. | 278 | 8 |
| Being involved, receiving information about new technologies. | 127 | 9 |
| Perform space missions, send satellites in orbit. | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected. | 677 | 2 |
| Investing on new products, new technologies. | 505 | 3 |
| Work, economic agreements. | 351 | 7 |
| Participate in the design, development and implementation. | 367 | 6 |

| Figures of Merit | | | |
|---|---|---|---|
| **Safety** | **Cost** | **Operation** | TOT |
| 677 | 2788 | 459 | **3924** |
| 0,172528 | 0,710499 | 0,116972 | **Weights** |

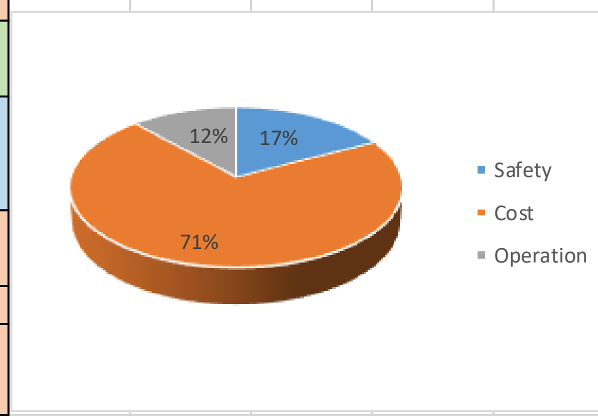



***Figure 42 Aerothermodynamic configuration, evalutation of weights, case of reusable launcher***

After which they were given grades from 0 to 5, and each of these votes were multiplied by the corresponding weights; to which a total sum has been calculated per column, where the highest value corresponds to the winning design solution.

Furthermore, for each figure of merit identified, an impact analysis can be carried out trying to understand the impact of the design parameters on them. (See Table 41)

The requirements that have impacted on the choice are the following:

| ***Requirement*** | ***Safety*** | ***Cost*** | ***Operation*** |
|---|---|---|---|
| *The aircraft shall reach the space.* | | | ✓ |

| | | | |
|---|---|---|---|
| *The aircraft shall be a hypersonic aircraft.* | | | ✓ |
| *The aircraft shall allow the carriage of satellites.* | | ✓ | ✓ |
| *The aircraft shall allow the carriage of passengers.* | ✓ | ✓ | ✓ |
| *The aircraft shall be re-usable.* | | ✓ | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | |
| *The aircraft shall have a high L/D.* | | | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | ✓ | | ✓ |
| *The aircraft shall be maneuverable.* | ✓ | | ✓ |
| *The aircraft shall be controllable.* | ✓ | | ✓ |

***Table 44 Requirements that impact the choice of the aerothermodynamic configuration, case of reusable launcher***

The figure shows which of the proposed configurations is the best for the mission.

| | Weights | Flying Wing | Fuselage+wing | Lifting Body | Spherical Capsule | Blunt Cone Capsule | Conic Capsule | Bluff Bi-conic Capsule | Slender B-conic Capsule | Heatshield with Afterbody |
|---|---|---|---|---|---|---|---|---|---|---|
| Safety | 0,172528033 | 5 | 5 | 4 | 2 | 3 | 3 | 3 | 3 | 3 |
| Cost | 0,71049949 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| Operation | 0,116972477 | 5 | 5 | 4 | 2 | 2 | 2 | 2 | 3 | 2 |
| Score | | 3,579001 | 3,579 | 3,2895 | 2 | 2,172528 | 2,17253 | 2,172528 | 2,2895 | 2,172528 |

***Figure 43 Aerothermodynamic configuration, case of reusable launcher***

From the analysis just carried out, a more traditional configuration is more suitable for the mission.

Re-entry aircraft

This mission is considered only as an example to understand how effectively the mission determines the choice of configuration.

First, we try to understand how the mission and the requirements go to influence the choice of the aerothermodynamic configuration.

"How do the mission and requirements affect the choice of the most suitable aerothermodynamic configuration?"

To find an answer to this question more easily, the following table is provided:

| | | | |
|---|---|---|---|
| ***Mission and requirements*** | Payload | Passengers;<br>Cargo. | Payload influences:<br>Available volume;<br>Max acceleration rates ;<br>Comfort. |
| | Mission profile | Re-entry. | Mission profile influences:<br>Structural loads;<br>Thermal loads;<br>L/D. |
| | Subsystems | Propellant;<br>Propulsion;<br>Thermal protection;<br>Landing gear;<br>Flight control. | Subsystems influence:<br>Structure / configuration of the aircraft. |

Starting from the Stakeholders analysis the Needs are divided into the various figures of merit:

- Safety:
    - Maintain a high level of safety, ensuring that the various standards are respected.
    - Return people, cargo from space.

- Cost:
    - Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity.
    - Promote and present this technology.
    - Being involved, receiving information about these technologies.
    - Investing on new products, new technologies.
    - Work, economic agreements.

- Participate in the design, development and implementation.

- Operation:
    - Return from space.

After the weights of the various figures of merit are evaluated, as explained above in figure 44:

| EVALUATION OF WEIGHTS FOR MAIN TRADE-OFF ANALYSIS | | |
|---|---|---|
| **Re-entry** | | |
| Needs | Score | Ranking |
| Return people, cargo from space. | 685 | 1 |
| Being involved in the study, in the project of new technologies. Furthermore, research in different fields, exploiting the unique properties of the space environment and microgravity. | 479 | 4 |
| Promote and present this technology. | 278 | 8 |
| Being involved, receiving information about these technologies. | 127 | 9 |
| Return from space. | 459 | 5 |
| Maintain a high level of safety, ensuring that the various standards are respected. | 677 | 2 |
| Investing on new products, new technologies. | 505 | 3 |
| Work, economic agreements. | 351 | 7 |
| Participate in the design, development and implementation. | 367 | 6 |
| TOTAL | 3928 | |

| Figures of Merit | | | |
|---|---|---|---|
| **Safety** | **Cost** | **Operation** | TOT |
| 1362 | 2107 | 459 | **3928** |
| 0,346741 | 0,536405 | 0,116853 | **Weights** |

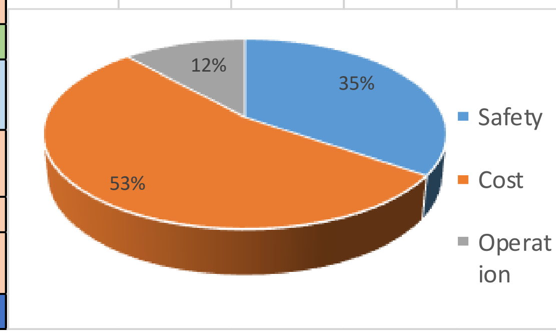



***Figure 44 Aerothermodynamic configuration, evalutation of weights, case of re-entry***

After which they were given grades from 0 to 5, and each of these votes were multiplied by the corresponding weights; to which a total sum has been calculated per column, where the highest value corresponds to the winning design solution.

Furthermore, for each figure of merit identified, an impact analysis can be carried out trying to understand the impact of the design parameters on them. (See Table 41)

The requirements that have impacted on the choice are the following:

| ***Requirement*** | ***Safety*** | ***Cost*** | ***Operation*** |
|---|---|---|---|
| *The aircraft shall re-entry from the space.* | | | ✓ |
| *The aircraft shall allow the carriage of cargo.* | | ✓ | ✓ |
| *The aircraft shall allow the carriage of passengers.* | ✓ | ✓ | ✓ |

| | | | |
|---|---|---|---|
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | |
| *The aircraft shall have a high L/D.* | | | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |

***Table 45 Requirements that impact the choice of the aerothermodynamic configuration, case of re-entry***

The figure shows which of the proposed configurations is the best for the mission.

| | Weights | Flying Wing | Fuselage+wing | Lifting Body | Spherical Capsule | Blunt Cone Capsule | Conic Capsule | Bluff Bi-conic Capsule | Slender B-conic Capsule | Heatshield with Afterbody |
|---|---|---|---|---|---|---|---|---|---|---|
| Safety | 0,346741 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Cost | 0,536405 | 2 | 2 | 2 | 4 | 4 | 4 | 3 | 3 | 3 |
| Operation | 0,116853 | 2 | 2 | 2 | 5 | 5 | 5 | 5 | 5 | 5 |
| Score | | 3,04022 | 3,040224 | 3,04022403 | 4,4635947 | 4,4635947 | 4,46359 | 3,927189 | 3,9271894 | 3,9271894 |

***Figure 45 Aerothermodynamic configuration, case of re-entry***

From the analysis just carried out, a capsule configuration is more suitable for this mission.

### 3.4.2 Aerothermodynamic confguratin: Blunt or Sharp?

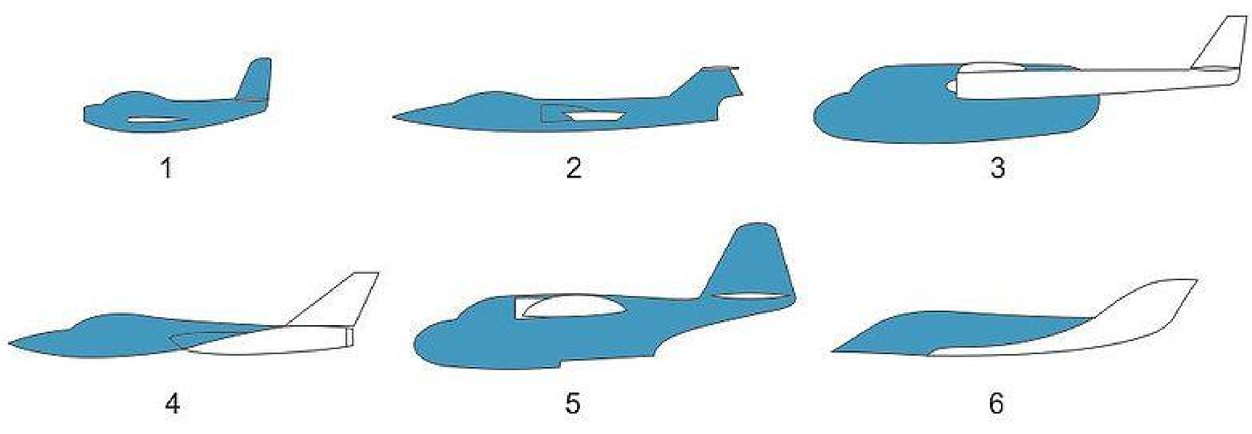
To understand which geometry is best between Blunt and Sharp for the analyzed missions, it is necessary to observe the characteristics that present both geometries.
In a Blunt geometry during its crossing of the atmosphere a strong shock wave will form in front of it (the shock wave is a surface of discontinuity through which the dynamic and thermodynamic parameters of the fluid vary suddenly, in particular the speed, which undergoes a abrupt decrease, with a consequent increase in temperature), which on the one hand reduces the thermal flow on the surface of the aircraft and on the other, increases the aerodynamic drag.
This allows to obtain more efficient decelerations during the crossing of the upper layers of the atmosphere (where the density is lower), thus ensuring a reduction of the maximum thermal flows along the trajectory. A geometry of this type, however, has low aerodynamic efficiencies $\frac{L}{D}$, with L Lift and D Drag, and this makes sure that there is no maneuverability. More $\frac{L}{D}$ increases, greater the aerodynamic efficiency.
Whereas, a Sharp geometry is characterized by a stagnation point very close to the surface of the body, so in this case there would be stagnation temperatures between 4000 and 5000K, so it would not be good to get into orbit due to the technological limitation related to the materials available. However, this configuration ensures greater efficiency.

In summary: sharp is fine for flights with Supersonic Speed and Low Hypersonic (very important aerodynamic efficiency); blunt is fine for High Hypersonic (deceleration, important to reduce thermal flows).
A blunt profile causes a much greater variation in fluid velocity than a sharp profile, which corresponds to a greater pressure drag. So, the aerodynamic drag of a blunt profile is greater, and the aerodynamic efficiency is lower. This means less maneuverability, greater propulsive expenditure and a greater overall increase in fluid temperature (even in areas further away from the body). Furthermore, a sharp leading edge maintains the aerodynamic configuration unchanged in a wider range of angles of attack. In conclusion, a sharp configuration presents great advantages in terms of flexibility and maneuverability of the vehicle, but at the same time generates a shock wave ideally attached to the body, which entails high concentrated thermal flows and, therefore, high temperatures. [9]
Based on what has just been said, it is deduced:
• Flight point to point → Sharp,
• Suborbital flight → Sharp,
• Reusable launcher → Blunt.

## *3.5 Fuselage*

The fuselage is the main part of an aircraft that contains passengers and / or cargo. The fuselage also serves to position control and stabilization surfaces in specific relationships to lifting surfaces, which is required for aircraft stability and maneuverability.
Shape and dimensions of the fuselage vary depending on the category of the aircraft, as well as the required performance.
The design of the fuselage is very important as it influences the other design phases. It starts from the project specifications, and on the basis of the mission requirements it tries to define the diameter length, etc.

There are different types of fuselages:




1. Subsonic aircraft;
2. Supersonic aircraft;
3. High-capacity and subsonic aircraft;
4. Highly maneuvered supersonic aircraf;

5. Seaplane;
6. Hypersonic aircraft.

In profile, therefore, the fuselages can take the following forms [10]:

- Spindle shape, suitable for very fast aircraft;
- Spindle shape with curvilinear axis;
- Shape with circular lobes, in which the presence of the two lobes is clearly noted;
- 'Caribou' type shape, used in the past;
- Shape with high penetration extremity and with a long section with a constant cylindrical section, the most used in every field.

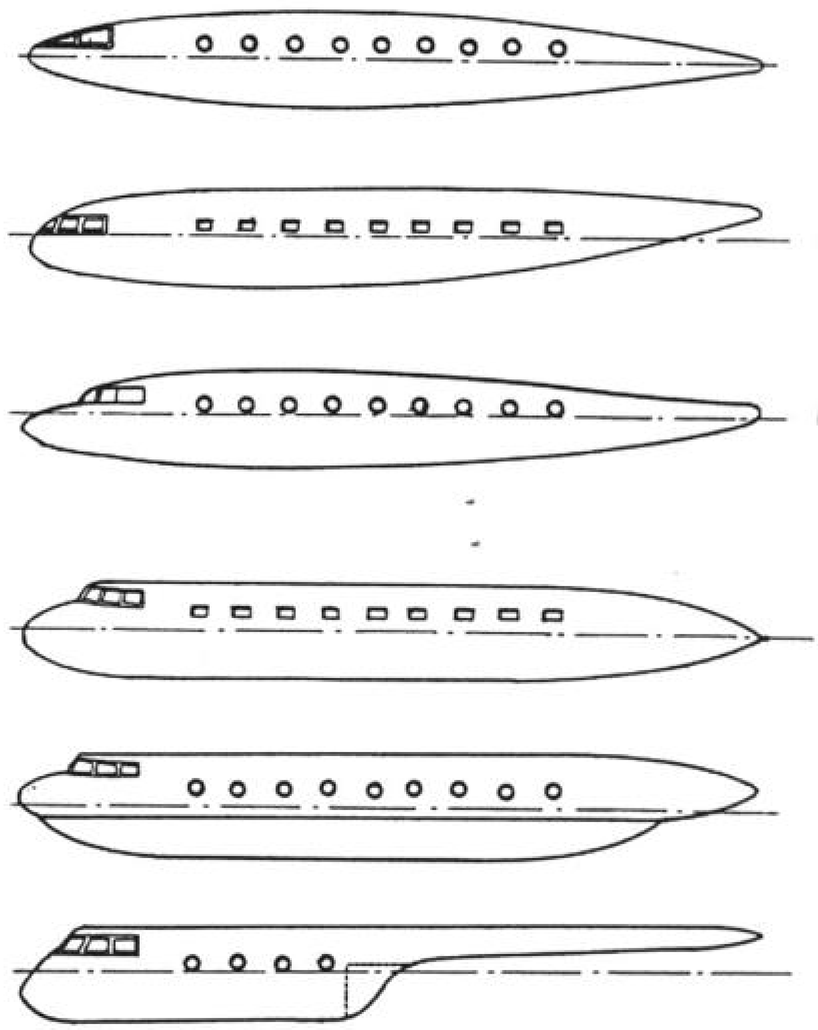


***Figure 46 Forms of fuselage***[10]

Furthermore, fuselages also differ for the cross section. The most used cross sections in civil aircraft are as follows:

- Rectangular or rectangular section with cap shell, now in disuse;

- Oval section, used for small people transport aircraft;
- Circular lobe section, used in transport aircraft;
- Circular section, excellent in every aspect, it is the most common;

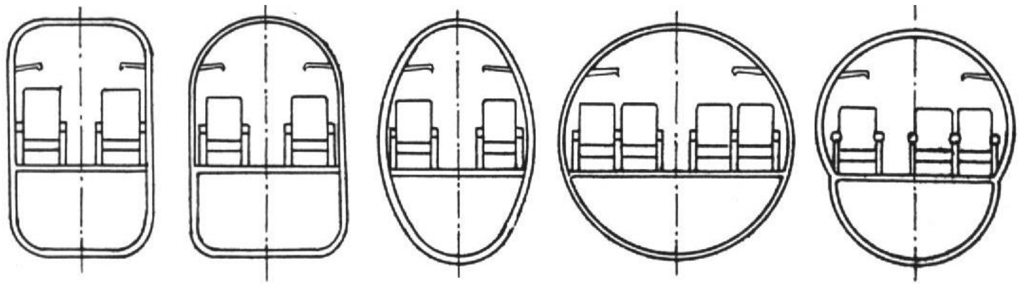


***Figure 47 Cross section of fuselage*** [10]

Sometimes it is possible to notice fuselages with a triangular section (with rounded edges), suitable for low-wing aircraft. More rarely there are fuselages with a section with edges: their use is confined to gliders and military aircraft. In any case, between the various fuselage configurations, the fuselages tend to be circular, since they are better able to withstand pressurization; it gives less resistance from the aerodynamic point of view. In particular, by eliminating the angles the flow will not separate.
Sometimes large amounts of space would be wasted with a circular fuselage, in particular when specific arrangements for passenger seats and cargo containers need to be arranged.
In these cases, an elliptical or double bubble arrangement can be used.
After this brief introduction it is clear how, in the context of a classical design approach, the cross section and the longitudinal geometry require a careful study based on the individual needs of the project.
In the study of the fuselage the fineness ratio $\frac{L}{D}$ is very important, (it is the ratio between length and diameter of the fuselage), so as to obtain low values of the friction coefficient of the fuselage and of the drag coefficient. As the fineness ratio increases, the aircraft's drag decreases, but this leads to very high deformations. This ratio is generally chosen by choosing a value not too different from the existing one with similar requirements, for which a detailed study was presumably made. In the absence of this orientation, an initial layout is selected that meets the payload requirements. [10], [11]
Typically, the values of $\frac{L}{D}$ are:

- Low $\frac{L}{D}$ (3-5), this means large diameter, low friction drag, high shape drag.
- High $\frac{L}{D}$ (6-9), this means low shape drag.

After making these observations, the study of the fuselage is treated for each of the three missions dealt with.

<u>Suborbital flight</u>
From the analysis of the Stakeholders it was found that the aircraft must be able to perform testing and demonstration of aerospace technologies. Furthermore, it shall make human spaceflight experiences for tourism or training. The spacecraft shall perform take-off and landing from existing runways, and can also perform vertical take-off and landing.
The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote

sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications).

The requirements that will impact the fuselage are as follows:

| ***Requirement*** | ***Cost*** | ***Safety*** | ***Complexity*** |
|---|---|---|---|
| *The aircraft shall do suborbital flights.* | ✓ | | ✓ |
| *The aircraft shall be a hypersonic aircraft.* | ✓ | | ✓ |
| *The aircraft shall allow aerospace testing and demonstration.* | | | ✓ |
| *The aircraft shall allow space flight experiences.* | | ✓ | ✓ |
| *The aircraft shall be used for training space personnel.* | | ✓ | ✓ |
| *The aircraft shall be used for remote sensing.* | | | ✓ |
| *The aircraft shall allow research, in spatial environment and in microgravity, in different fields.* | | | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | ✓ |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | | ✓ | |
| *The aircraft shall be maneuverable.* | | ✓ | |
| *The aircraft shall be controllable.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach.* | | ✓ | ✓ |
| *The fuselage weight shall be minimized.* | ✓ | | |
| *The configuration of aircraft shall facilitate the operations.* | | | ✓ |
| *The configuration shall minimize the drag.* | | ✓ | |
| *The configuration of aircraft shall guarantee a* | | ✓ | |

| | | |
|---|---|---|
| *proper pilot visibility.* | | |
| *The aircraft shall be easy to maintain.* | ✓ | ✓ |

***Table 46 Requirements that impact the fuselage, case of suborbital flight***

Furthermore, for this mission, a limited number of passengers is chosen, 6.
Various interior configurations of the cockpit are considered, and for each of them the fuselage will be sized. This is done in order to choose the best configuration based on the $\frac{L}{D}$ ratio.

The cases that will be treated are the following:

| Number of rows | Seats abreast | Aisle |
|---|---|---|
| 6 | 1 | 1 |
| 3 | 2(1+1) | 1 |
| 2 | 3(2+1) | 1 |

***Table 47 Cases of study, case of suborbital flight***

**CASE 1:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

***Table 48 Seat width***

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 25in (635mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 25 + 24 = 49in = 1.3m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.3 m in the widest part and high 2m in the passenger part.

While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 1.352m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.

For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

***Table 49 Seat pitch***

Seat pitch refers to the distance shown in the following figure:

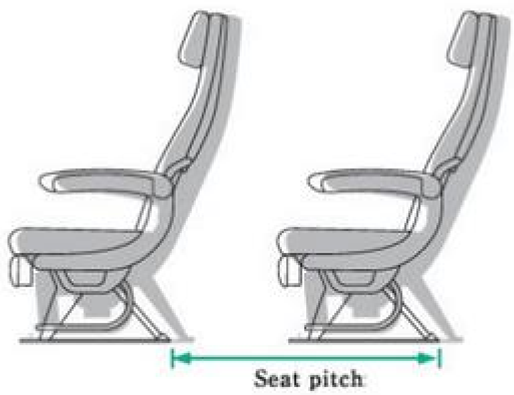



***Figure 48 Seat pitch***

Based on this, the following length is obtained:

$$6 \cdot 40 = 240in = 6.096m$$

As already mentioned, a galley and a toilet are also considered.
As for this aircraft, it was decided to use a galley and a toilet, which were placed at the front of the aircraft.
Regarding the geometry of these two components, the following were considerate:

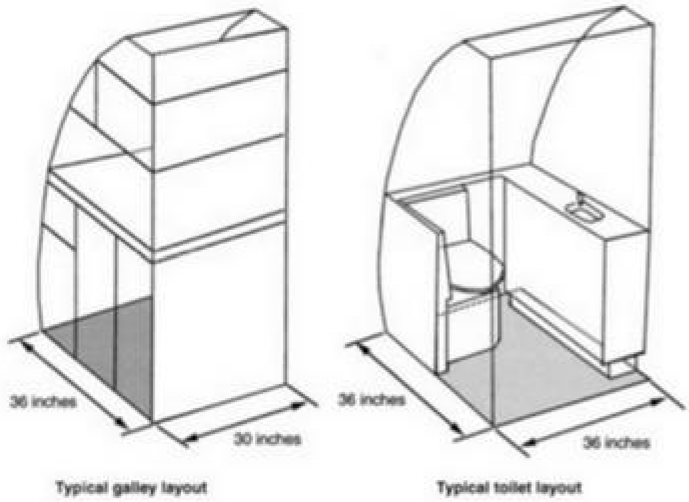



*Figure 49 Galley and toilet geometry*

Thus obtaining: *66in=1.7m*

Furthermore, an emergency exit must be considered, which is placed at the front of the aircraft:

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

*Table 50 Emergency exit*

A type IV door (width 483mm) is chosen by law.

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\, {}^{lb}/_{ft^3}$ and luggage $12.5\, {}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 0.80$m$ in height, about 1$m$ in base and about 7.3$m$ of width. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

*L=31+31+24=86in=2.18m*

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 49in = 1.25m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=5, and considering $d_{cockpitMax} = 1.1m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 11.54°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 5.44m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 1.1m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 2.43m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 6.1m + 1.7\text{m} + 0.483\text{m} + 2.18m + 5.44m + 2.43\text{m} = 19\text{m}$$

**CASE 2:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.

A seat width of 21in (533mm) and a corridor of 21in (533mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 2 \cdot 21 + 21 = 63in = 1.6m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.6 m in the widest part and high 2m in the passenger part.

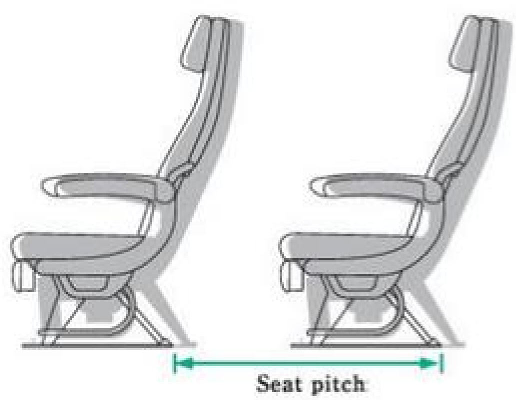
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 1.7m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

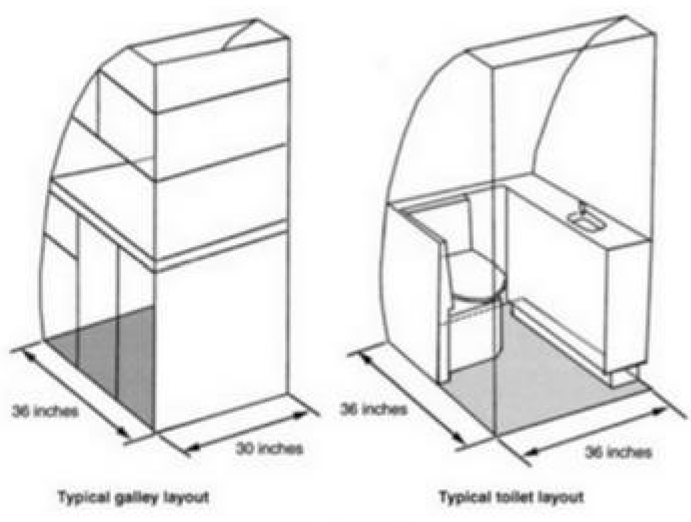
Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$3 \cdot 40 = 120in = 3.048m$$

As already mentioned, a galley and a toilet are also considered.
As for this aircraft, it was decided to use a galley and a toilet, which were placed at the front of the aircraft.
Regarding the geometry of these two components, the following were considerate:




Thus obtaining: *66in=1.7m*

Furthermore, an emergency exit must be considered, which is placed at the front of the aircraft:

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

A type IV door (width 483mm) is chosen by law.

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 0.60$m$ in height, about 1$m$ in base and about 4.5$m$ of width. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

$$L=31+24=55in=1.4m$$

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;

$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 60in = 1.5m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=5, considering $d_{cockpitMax} = 1.4m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 11.54°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add} = 6.9m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 1.4m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 3.06m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 3.048m + 1.7\text{m} + 0.483\text{m} + 1.4m + 6.9m + 3.06\text{m} + 3\text{m} = 19.6\text{m}$$

**CASE 3:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 25in (635mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 3 \cdot 25 + 24 = 99in = 2.5m$$

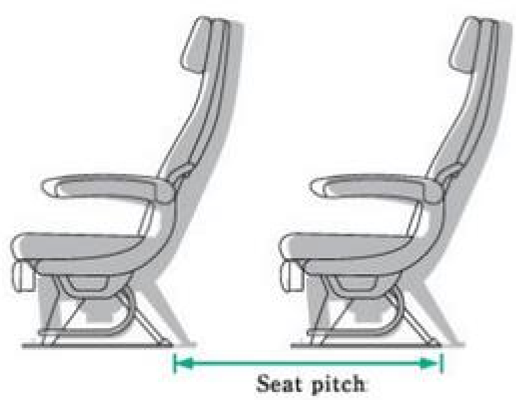
In this case a circular fuselage is made.
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 2.6m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

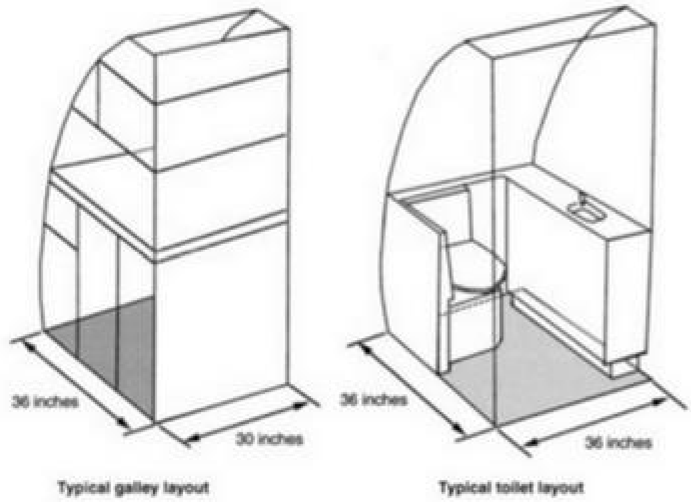
Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$2 \cdot 40 = 80in = 2.032m$$

As already mentioned, a galley and a toilet are also considered.
As for this aircraft, it was decided to use a galley and a toilet, which were placed at the front of the aircraft.
Regarding the geometry of these two components, the following were considerate:




Thus obtaining: *66in=1.7m*

Furthermore, an emergency exit must be considered, which is placed at the front of the aircraft:

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

A type IV door (width 483mm) is chosen by law.

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\, {}^{lb}/_{ft^3}$ and luggage $12.5\, {}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 0.5$m$ in height and about 2$m$ in base. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

$$L=31+24=55in=1.4m$$

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;

$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 76in = 1.93m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=5, considering $d_{cockpitMax} = 1.7m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 11.54°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add} = 8.4m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 1.7m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 3.56m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 2.032m + 1.7\text{m} + 0.483\text{m} + 1.4m + 8.4m + 3.56\text{m} = 17.6\text{m}$$

<u>Point to point mission</u>
From the analysis of the Stakeholders it was found that the aircraft must be able to reach distant points on the globe in a short. Furthermore, it can be used for the transportation of cargo or human, military use, surveillance. The spacecraft shall perform take-off and landing from existing runways and can also perform vertical take-off and landing.
The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications).

The requirements that will impact the fuselage are as follows:

| ***Requirement*** | ***Cost*** | ***Safety*** | ***Complexity*** |
|---|---|---|---|
| *The aircraft shall reach a point on the glob in (TDB) time.* | ✓ | | ✓ |
| *The aircraft shall be a hypersonic aircraft.* | ✓ | | ✓ |

| | | | |
|---|---|---|---|
| *The aircraft shall allow the carriage of cargo.* | | | ✓ |
| *The aircraft shall allow the carriage of passengers.* | | ✓ | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | ✓ |
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | | ✓ | |
| *The aircraft shall be maneuverable.* | | ✓ | |
| *The aircraft shall be controllable.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach.* | | ✓ | ✓ |
| *The fuselage weight shall be minimized.* | ✓ | | |
| *The configuration of aircraft shall facilitate the operations.* | | | ✓ |
| *The configuration shall minimize the drag.* | | ✓ | |
| *The configuration of aircraft shall guarantee a proper pilot visibility.* | | ✓ | |
| *The aircraft shall be easy to maintain.* | ✓ | | ✓ |

***Table 51  Requirements that impact the fuselage, case of point to point mission***

Furthermore, for this mission, a high number of passengers is chosen, 160.
Various interior configurations of the cockpit are considered, and for each of them the fuselage will be sized. This is done in order to choose the best configuration based on the L / D ratio.

The cases that will be treated are the following:

| Number of rows | Seats abreast | Aisle |
|---|---|---|
| 160 | 1 | 1 |
| 80 | 2(1+1) | 1 |
| 54 | 3(2+1) | 1 |
| 40 | 4(2+2) | 1 |
| 32 | 5(3+2) | 1 |
| 27 | 6(3+3) | 1 |
| 27 | 6(2+2+2) | 2 |

**CASE 1:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 23in (584mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 21 + 24 = 45in = 1.14m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.1 m in the widest part and high 2m in the passenger part.

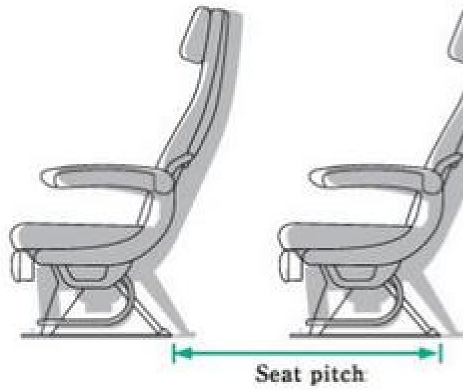
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 1.19m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$160 \cdot 34 = 5440in = 138.2m$$

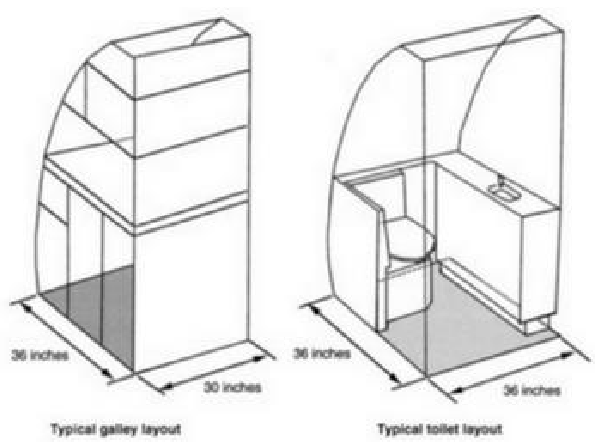
The number of flight attendants must also be considered. The legislation provides:

| Class | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:



Thus obtaining: *36·2+30·2=132in=3.35m*

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | **Type I** | **Type II** | **Type III** | **Type IV** |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

***Table 52 Emergency exits for each side of the fuselage***

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

*L=1.220m*

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 0.8$m$ in height and about 1$m$ in base. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

*L=31+24=55in=1.4m*

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;

$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 43in = 1.09m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 0.8m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$
$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 4.77m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 0.8m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 2.14m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 138.2m + 1.22\text{m} + 3.35\text{m} + 1.4m + 4.77m + 2.14\text{m} + 3.5\text{m} = 154.6\text{m}$$

**CASE 2:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 21in (533mm) and a corridor of 24in (610mm) are considered.

At this point the diameter was evaluated:

$$D_{internal} = 2 \cdot 21 + 24 = 66in = 1.7m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.7 m in the widest part and high 2.5m in the passenger part.

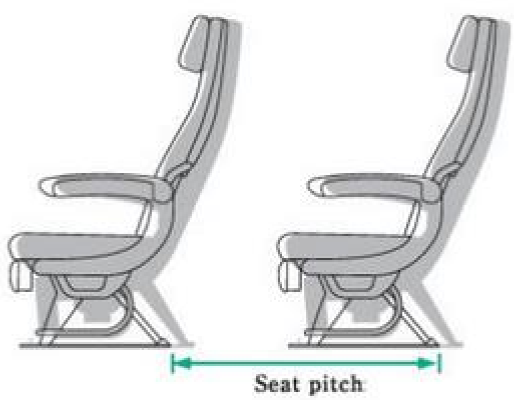
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal} \frac{4}{100}\right) = 1.78m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$80 \cdot 34 = 2720in = 70m$$

The number of flight attendants must also be considered. The legislation provides:

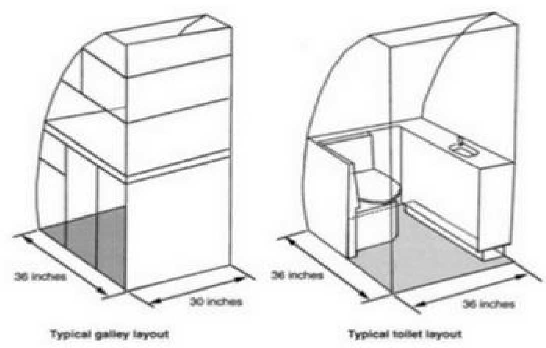
| Class | Numerber of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.

So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining: $36 \cdot 2+30 \cdot 2=132in=3.35m$

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | Type I | Type II | Type III | Type IV |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\ {}^{lb}/_{ft^3}$ and luggage $12.5\ {}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 1.5$m$ in height and about 1.5$m$ in base. Therefore, containers with these characteristics are chosen.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

$$L=31+24=55in=1.4m$$

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 63.4in = 1.6m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 1.4m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 8.34m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 1.4m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 3.2m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 70m + 1.22\text{m} + 3.35\text{m} + 1.4m + 8.34m + 3.2\text{m} + 3.5\text{m} = 91\text{m}$$

**CASE 3:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 21in (533mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 3 \cdot 21 + 24 = 87in = 2.2m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 2.2 m in the widest part and high 2.5m in the passenger part.

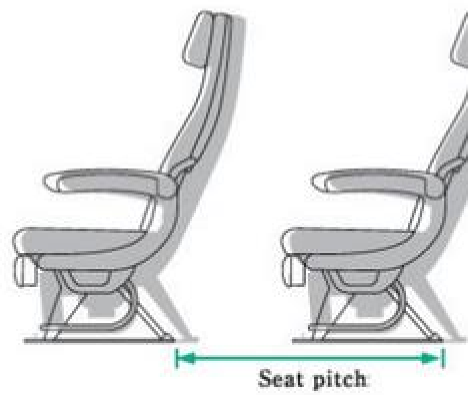
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 2.29m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$54 \cdot 35 = 1836in = 46.6m$$

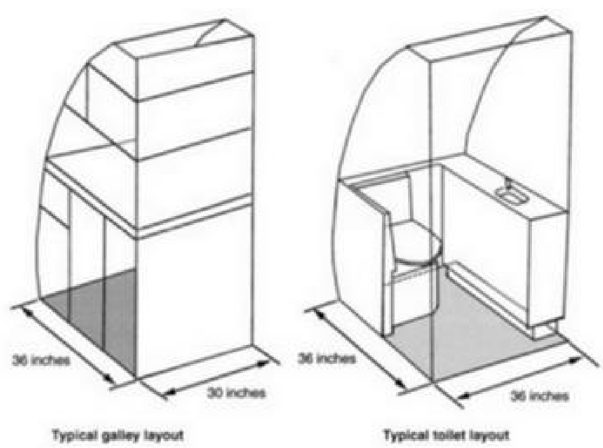
The number of flight attendants must also be considered. The legislation provides:

| Classe | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining: *36·2+30·2=132in=3.35m*

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | **Type I** | **Type II** | **Type III** | **Type IV** |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 1.5$m$ in height and about 1.8$m$ in base. Therefore, containers with these characteristics are chosen.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

L=31+24=55in=1.4m

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;

$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 70in = 2m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 1.8m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 10.72m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 1.8m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 4.1m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 46.6m + 1.22\text{m} + 3.35\text{m} + 1.4m + 10.72m + 4.1\text{m} + 3.5\text{m} = 70.9\text{m}$$

**CASE 4:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 19in (483mm) and a corridor of 19in (483mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 4 \cdot 19 + 19 = 95in = 2.4m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 2.64 m in the widest part and high 2m in the passenger part.

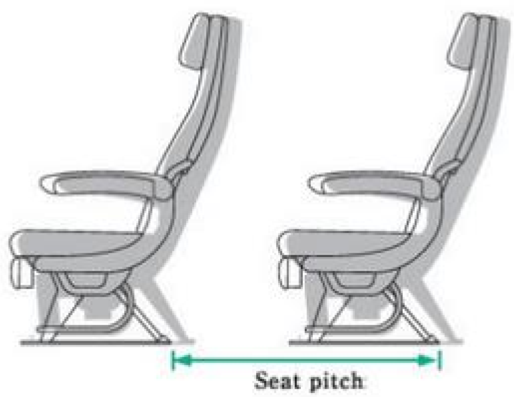
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 2.5m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$40 \cdot 34 = 1360in = 34.5m$$

The number of flight attendants must also be considered. The legislation provides:

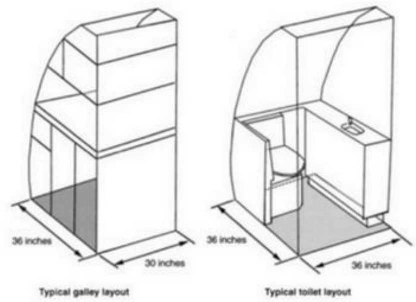
| Class | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.

From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining*: 36·2+30·2=132in=3.35m*

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | Type I | Type II | Type III | Type IV |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about $1.5m$ in height and about $2m$ in base. Therefore, containers with these characteristics are chosen.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

$$L=31+24=55in=3.8m$$

Regarding the nose:

$$L_{nose} = 1.5 \cdot D_{ext} = 3.75m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 4.9m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 34.5m + 1.22\text{m} + 3.35\text{m} + 1.4m + 3.75m + 4.9\text{m} = 49.12\text{m}$$

**CASE 5:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 21in (533mm) and a corridor of 20in (508mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 5 \cdot 21 + 20 = 125in = 3.2m$$

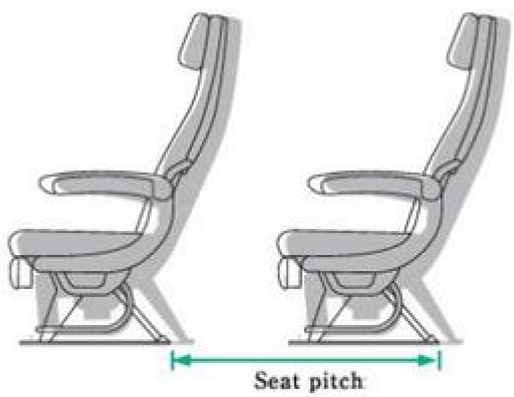
In this case a circular fuselage is made.
While the external diameter is equal to:

$$D_{esternal} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 3.3m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$32 \cdot 34 = 1088in = 27.6m$$

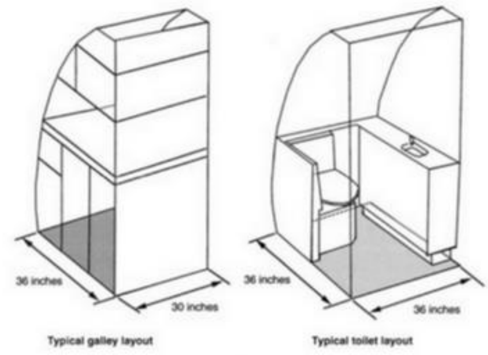
The number of flight attendants must also be considered. The legislation provides:

| Class | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining*: 36·2+30·2=132in=3.35m*

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | Type I | Type II | Type III | Type IV |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 *lb* for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 1.2*m* in height and about 2.8*m* in base. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

L=31+25=56in=1.4m

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 105in = 2.7m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 2.5m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$
$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 15m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 2.5m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 5.94m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 27.6m + 1.22\text{m} + 3.35\text{m} + 1.4m + 15m + 5.94\text{m} + 3.5\text{m} = 58\text{m}$$

**CASE 6:**
The first thing is to evaluate the diameter of the fuselage.

To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 19in (483mm) and a corridor of 18in (457mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 6 \cdot 19 + 18 = 132in = 3.4m$$

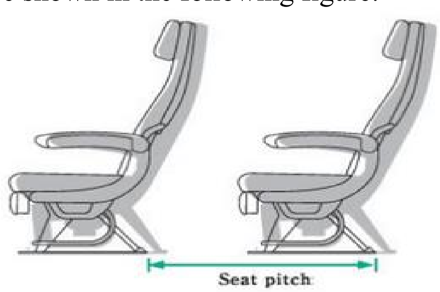
In this case a circular fuselage is made.
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 3.5m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$27 \cdot 34 = 918n = 24m$$

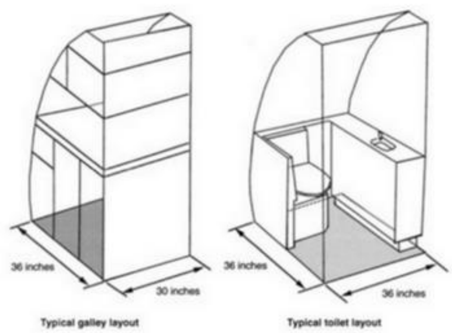
The number of flight attendants must also be considered. The legislation provides:

| Class | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining*: 36·2+30·2=132in=3.35m*

Furthermore, an emergency exit must be considered.

| **Passenger seating configuration (crew mwmber seats not included)** | **Emergency exits for each side of the fuselage** | | | |
|---|---|---|---|---|
| | **Type I** | **Type II** | **Type III** | **Type IV** |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| **Type** | **Dimensions** |
|---|---|

| | |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about $1.2m$ in height and about $3m$ in base. Standard containers cannot be used as they all have a height greater (or equal) than 1.5m. The lower space can be used, the same, for transport.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

*L=31+26=57in=1.5m*

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 126in = 3.2m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 3m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1 + k_{nose})} + k_{nose\ add} = 17.9m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 3m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 4.9m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 23m + 1.22\text{m} + 3.35\text{m} + 1.5m + 17.9m + 6.5\text{m} + 3.5\text{m} = 57\text{m}$$

**CASE 7:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 19in (483mm) and a corridor of 18in (457mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 6 \cdot 19 + 2 \cdot 18 = 150in = 3.8m$$

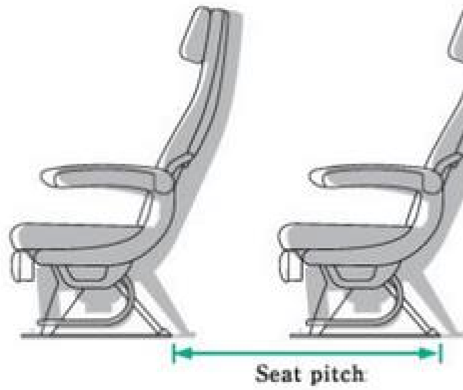
In this case a circular fuselage is made.
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 3.9m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail, the emergency exits, the toilettes and the galleys.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$27 \cdot 34 = 918n = 24m$$

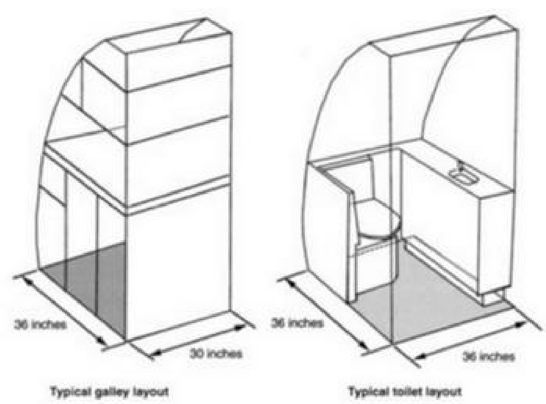
The number of flight attendants must also be considered. The legislation provides:

| Class | Number of passengers | Flight attendants |
|---|---|---|
| **Business** | 20-25 | 1 |
| **Economy** | 30-40 | 1 |

In this case you have 4 flight attendants.
So, 160 passengers, 4 flight attendants and 2 pilots; 166 people on board.

As already mentioned, a galley and a toilet are also considered.
From legislation:
10-60 passengers for each galley
15-40 passengers for each toilet
As for this aircraft, it was decided to use 3 galleys and 4 toilettes. The two galleys are placed in the posterior part of the aircraft and one in front, while the toilettes are placed at the front of the aircraft and two at the posterior part.

Regarding the geometry of these two components, the following were considerate:




Thus obtaining: $36 \cdot 2 + 30 \cdot 2 = 132in = 3.35m$

Furthermore, an emergency exit must be considered.

| Passenger seating configuration (crew mwmber seats not included) | Emergency exits for each side of the fuselage | | | |
|---|---|---|---|---|
| | Type I | Type II | Type III | Type IV |
| 1 to 9 | | | | 1 |
| 10 to 19 | | | 1 | |
| 20 to 39 | | 1 | 1 | |
| 40 to 79 | 1 | | 1 | |
| 80 to 109 | 1 | | 2 | |
| 110 to 139 | 2 | | 1 | |
| 140 to 179 | 2 | | 2 | |

In this case there are 160 passengers, so you need two types I (one front and one behind) and two types III (on the wings).

| Type | Dimensions |
|---|---|
| Tipo I | 610 x 1219 mm |
| Tipo II | 508 x 1118 mm |
| Tipo III | 508 x 914 mm |
| Tipo IV | 483 x 660 mm |
| Tipo A | 1067 x 1829 mm |

L=1.220m

Moreover, the space available for the cargo must be dimensioned. Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$ and luggage $12.5\,{}^{lb}/_{ft^3}$. Passengers are generally allocated from 35 to 40 $lb$ for bags. This means about $4ft^3$ per passenger per baggage.
The preferred approach is to accommodate standard-sized containers. In this case, the available space is about 1.5$m$ in height and about 3.5$m$ in base. Therefore, containers with these characteristics are chosen.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

L=31+26=57in=1.5m

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;

$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 143in = 3.6m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance, minimize heat loads and guarantee correct visibility to the pilot.

Assuming M=6, considering $d_{cockpitMax} = 3.4m$, $k_{nose}$=0 (since a shape configuration was chosen), $k_{nose\ add}$=0

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add}$$

$$\mu = \sin^{-1}\frac{1}{M} = 9.594°$$

$$L_{nose} = \frac{d_{cockpit}}{2\tan\frac{\mu}{2}} \cdot \frac{1}{(1+k_{nose})} + k_{nose\ add} = 20.3m$$

$$D_{nose} = 2 \cdot L_{nose} \cdot \tan\frac{\mu}{2} = 3.4m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 7m$$

Furthermore, a possible space for tanks, etc. is considered.
Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 24m + 1.22\text{m} + 3.35\text{m} + 1.5m + 20.3m + 7\text{m} + 3.5\text{m} = 61\text{m}$$

<u>Reusable launcher</u>
From the analysis of the Stakeholders it was found that the aircraft must be able to reach the space. The spacecraft shall perform take-off and landing from existing runways and can also perform vertical take-off and landing.
The aircraft can be used for other applications: basic and applied research in space environment and microgravity (biological and physical research, space science, earth science, human research), remote sensing (acquisition of imagery of the Earth and Earth systems for commercial, civil government or military applications).

The requirements that will impact the fuselage are as follows:

| ***Requirement*** | ***Cost*** | ***Safety*** | ***Complexity*** |
|---|---|---|---|
| *The aircraft shall reach the space.* | ✓ | | ✓ |
| *The aircraft shall be a hypersonic aircraft.* | ✓ | | ✓ |
| *The aircraft shall allow the carriage of satellites.* | | | ✓ |
| *The aircraft shall allow the carriage of passengers.* | | ✓ | ✓ |
| *The aircraft shall be re-usable.* | ✓ | ✓ | ✓ |
| *The aircraft shall be able to withstand the structural loads.* | ✓ | ✓ | ✓ |

| | | | |
|---|---|---|---|
| *The aircraft shall be able to withstand the thermal loads.* | ✓ | ✓ | ✓ |
| *The volume available to accommodate passenger/cargo shall be maximized.* | | | ✓ |
| *The aircraft shall be stable.* | | ✓ | |
| *The aircraft shall be maneuverable.* | | ✓ | |
| *The aircraft shall be controllable.* | | ✓ | |
| *The aircraft shall be able to reach the desired Mach.* | | ✓ | ✓ |
| *The fuselage weight shall be minimized.* | ✓ | | ✓ |
| *The configuration of aircraft shall facilitate the operations.* | | | ✓ |
| *The configuration shall minimize the drag.* | | ✓ | |
| *The configuration of aircraft shall guarantee a proper pilot visibility.* | | ✓ | |
| *The aircraft shall be easy to maintain.* | ✓ | | ✓ |

***Table 53 Requirements that impact the fuselage, case of reusable launcher***

For this mission, two cases will be dealt with, the case for which passengers must be transported (astronauts to the space station) and the case for which goods must be transported (cargo for the space station or satellites to be left in orbit).

<u>Transport people</u>
Furthermore, for this mission, a limited number of passengers is chosen, 4
Various interior configurations of the cockpit are considered, and for each of them the fuselage will be sized. This is done in order to choose the best configuration based on the $\frac{L}{D}$ ratio.

**CASE 1:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 24in (610mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 2 \cdot 24 + 24 = 72in = 1.9m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.9 m in the widest part and high 2m in the passenger part.

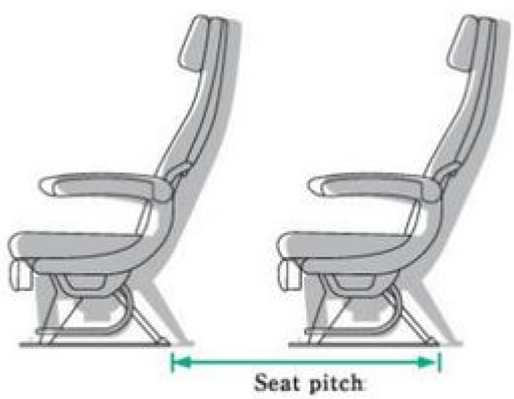
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal} \frac{4}{100}\right) = 2m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail and the space for cargo.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$2 \cdot 37 = 74in = 1.9m$$

Moreover, the space available for the cargo must be dimensioned. The preferred approach is to accommodate standard-sized containers. In this case, the available space is about $2m$ in height and about $1.9m$ in base. Then, a part of the fuselage is used to accommodate the cargo. Typically, the cargo weighs $10\, {}^{lb}/_{ft^3}$. An additional space of 5m in length is considered. Then, there are about 16 m ^ 3 of available volume; knowing that typically the cargo weighs $10\,{}^{lb}/_{ft^3}$, about 3000kg of cargo can be transported.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

*L=31+26=57in=1.5m*

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 69in = 1.7m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance and minimize heat load.

$$L_{nose} = 1.5 \cdot D_{ext} = 3m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 3.6m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 5m + 1.5m + 1.9m + 3\text{m} + 3.6\text{m} = 15\text{m}$$

**CASE 2:**
The first thing is to evaluate the diameter of the fuselage.
To calculate the total diameter of the fuselage, the sum between the corridor distances and the seat width is added. Furthermore, to derive the external diameter, a factor of 4% is added to the internal diameter.
To proceed with the calculations the following regulations must be considered, which give the values of the width of the seats according to the class they belong to:

| Class | Seat width [in] | Seat width [mm] |
|---|---|---|
| **Economy** | 19-21 | 483-533 |
| **Business** | 23-25 | 584-635 |
| **First** | 25-28 | 635-711 |

Furthermore FAR 25.815 requires that the width of the corridor is less than 25 in.
A seat width of 24in (610mm) and a corridor of 24in (610mm) are considered.
At this point the diameter was evaluated:

$$D_{internal} = 24 + 24 = 48in = 1.2m$$

It is thought to realize an ovalized fuselage, since a circular fuselage with this diameter would not be comfortable, as far as height, for passengers. So, it is thought to make a fuselage of 1.2 m in the widest part and high 2m in the passenger part.

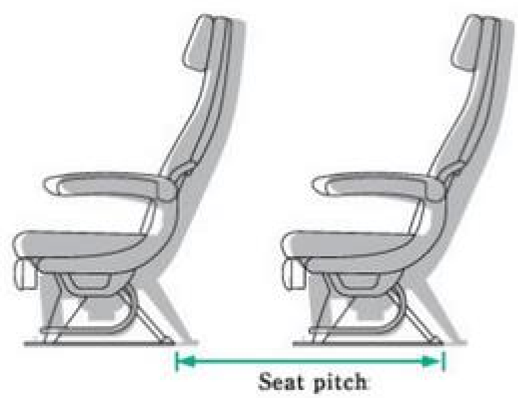
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 1.25m$$

At this point it is possible to proceed with the calculation of the total length of the fuselage.
For the calculation of the total length of the fuselage, the distances between the rows and the dimensions of the seats must be added. In this way the length takes into consideration only the seats; therefore, to this result it is added the length relative to the cockpit, the tail and the space for cargo.
The seats and the internal environment are sized considering the following legislation:

| Class | Seat pitch [in] | Seat pitch [mm] |
|---|---|---|
| **Economy** | 31-34 | 787-864 |
| **Business** | 36-38 | 914-965 |
| **First** | 38-42+ | 965-1067+ |

Seat pitch refers to the distance shown in the following figure:




Based on this, the following length is obtained:

$$4 \cdot 37 = 148in = 3.8m$$

Moreover, the space available for the cargo must be dimensioned. The preferred approach is to accommodate standard-sized containers. In this case, the available space is about $2m$ in height and about $1.2m$ in base. Then, a part of the fuselage is used to accommodate the cargo. Typically, the cargo weighs $10\, {}^{lb}/_{ft^3}$. An additional space of 5m in length is considered. Then, there are about 12 m ^ 3 of available volume; knowing that typically the cargo weighs $10\, {}^{lb}/_{ft^3}$, about 2000kg of cargo can be transported.

At this point it is necessary to evaluate the dimensions of the crew compartment:

$$L = L_{seat\ pitch} + L_{empty\ space}$$

L=31+26=57in=1.5m

$$(D_{crew\ compartment})_{Max} = n_{pilot} \cdot w_{pilot\ seat} + (1 + k_{crew}) \cdot (b_{seat} - w_{pilot\ seat}) \cdot k_s$$

Where:
$n_{pilot}$ is the number of pilots;
$w_{pilot\ seat}$ is the pilot's seat width;
$b_{seat}$ is the distance between two pilot's seats measured from/to seat CGs;
$k_{crew}$ is a parameter that allows estimating the additional space that should be considered;
$k_s$ is a safety factor that allows to take into account an enlargement of the fuselage diameter.

$$(D_{crew\ compartment})_{Max} = 69in = 1.7m$$

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance and minimize heat load.

$$L_{nose} = 1.5 \cdot D_{ext} = 3m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 3.6m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 6m + 3.8m + 1.9m + 3\text{m} + 3.6\text{m} = 18.3\text{m}$$

<u>Transport goods</u>
The same applies to the previous cases. It is supposed to have a payload of 6000kg.
The first thing is to evaluate the diameter of the fuselage. In this case it is evaluated based on existing containers.
Consider, for example, base 3.20m, height 2, length 7m.
The diameter is:

$$D_{internal} = 3.5m$$

In this case a circular fuselage is made.
While the external diameter is equal to:

$$D_{external} = D_{internal} + \left(D_{internal}\frac{4}{100}\right) = 3.64m$$

Typically, the cargo weighs $10\,{}^{lb}/_{ft^3}$. An additional space of 7m in length is considered. Then, there are about 40 m ^ 3 of available volume; knowing that typically the cargo weighs $10\,{}^{lb}/_{ft^3}$, about 6000kg of cargo can be transported.

At this point the dimensions of the nose are evaluated. As already mentioned, the nose is chosen in such a way as to minimize resistance and minimize heat load.

$$L_{nose} = 1.5 \cdot D_{ext} = 5.46m$$

Regarding the tail:

$$L_{tail} = 1.8 \cdot D_{ext} = 6.5m$$

Going to sum all the lengths found, we find the overall length:

$$L_{tot} = 7m + 5.46\text{m} + 6.5\text{m} = 19\text{m}$$

At this point the optimal $L/_D$ is evaluated for each mission, on the basis of the characteristic to be optimized for that mission.

($L/_D$) must:

- Allow the lowest zero---lift drag (CD0 parasitic drag): high ($L/_D$)
- Guarantee the lowest wetted area: low ($L/_D$)
- Minimize the fuselage weight (proportional to wetted area): low ($L/_D$)
- Guarantee to maximize the fuselage internal volume: low ($L/_D$)
- Guarantee the lowest mass moment of inertia: low ($L/_D$)
- Enhance the aircraft stability (higher tail arm for maneuverability): high ($L/_D$)
- Minimize production costs

The first and second objectives concern the performance requirements of the aircraft. The third objective points to the weight requirements and the fourth meets the operational requirements. The fifth objective is the controllability requirements, while the sixth meets the stability requirements. Finally, the last goal aims at the lowest cost of fuselage production. Depending on the aircraft's mission and design priorities, one of these goals becomes the most significant.

Optimum Slenderness Ratio for Lowest $f_{LD}$

The drag of the fuselage is proportional to the slenderness ratio of the fuselage, since the coefficient of the zero lift drag of the fuselage is given by the following expression:

$$C_{D_{0f}} = C_f f_{LD} f_M \frac{S_{wet_f}}{S_{ref}}$$

Where $C_f$ is the skin friction coefficient, $f_M$ is a function of aircraft speed, $S_{ref}$ is the wing reference area, and $S_{wet_f}$ is the fuselage wetted area.

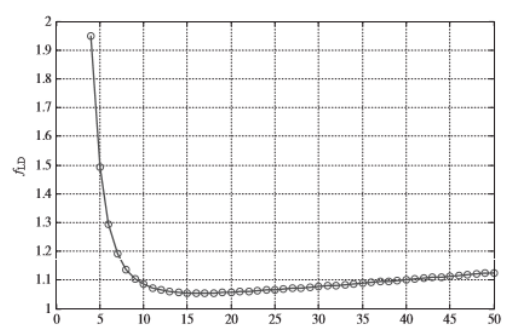



***Figure 50*** $f_{ld} - L/_D$

The second parameter $f_{LD}$ is a function of the fuselage length-to-diameter ratio. It is defined as:

$$f_{LD} = 1 + \frac{60}{(L/D)^3} + 0.0025\left(\frac{L}{D}\right)$$

Where L is the fuselage length and D is its maximum diameter. The variation of $f_{LD}$ with respect to length-to-diameter ratio is sketched in Figure 47. To determine the lowest value for this function, proceed as follows:

$$\frac{d_{fLD}}{d(L/D)} = 0 \rightarrow \frac{-180}{(L/D)^4} + 0.0025 = 0 \rightarrow (L/D)^4 = 72000$$

The solution of this equation provides as optimal value of this ratio, 16.3. [12]

<u>Suborbital flight</u>
In this case the performance requirements of the aircraft are very important. So it would be appropriate to have a $L/D$ neither too high nor too low. This is because if $L/D$becomes too high, we can have zero lift drag lower, but at the same time we will have a higher wetted area. On the other hand, if we choose an L / too low.
As seen before, you go to choose:

| Number of rows | Seats abreast | Aisle | $D_f$ (m) | $L_f$ (m) | $L_f/D_f$ |
|---|---|---|---|---|---|
| 6 | 1 | 1 | 1.3 | 8.3 | 6.4 |
| 3 | 2(1+1) | 1 | 1.6 | 5.3 | 3.3 |
| 2 | 3(2+1) | 1 | 2.5 | 4.2 | 1.7 |

***Table 54 Optimum slenderness ratio, case of suborbital flight***

<u>Point to point mission</u>
In this case the performance requirements of the aircraft are very important. So it would be appropriate to have a L / D neither too high nor too low. This is because if L / D becomes too high, we can have zero lift drag lower, but at the same time we will have a higher wetted area. On the other hand, if we choose an L / too low.
As seen before, you go to choose:

| Number of rows | Seats abreast | Aisle | $D_f$ (m) | $L_f$ (m) | $L_f/D_f$ |
|---|---|---|---|---|---|
| 160 | 1 | 1 | 1.14 | 142.77 | 125.24 |
| 80 | 2(1+1) | 1 | 1.7 | 74.57 | 43.86 |
| 54 | 3(2+1) | 1 | 2.2 | 51.17 | 23.25 |
| 40 | 4(2+2) | 1 | 2.4 | 39.1 | 16.3 |
| 32 | 5(3+2) | 1 | 3.2 | 32.17 | 10.50 |
| 27 | 6(3+3) | 1 | 3.4 | 28.57 | 8.40 |
| 27 | 6(2+2+2) | 2 | 3.8 | 28.57 | 7.52 |

***Table 55 Optimum slenderness ratio, case of point to point mission***

<u>Reusable launcher</u>
In this case, maximize the internal volume of the aircraft is very important, as a large number of payloads can be transport. In this case, therefore, it would be advisable to maximize the internal volume.

The configuration with low L / D is chosen.

| Number of rows | Seats abreast | Aisle | $D_f$ (m) | $L_f$ (m) | $L_f/D_f$ |
|---|---|---|---|---|---|
| 2 | 2(1+1) | 1 | 1.9 | 6.9 | 3.6 |
| 4 | 1 | 1 | 1.2 | 9.8 | 8.2 |

***Table 56 Optimum slenderness ratio, case of reusable launcher***

## 3.6 Wing definition

The term Wing in aerodynamics refers to a surface generally disposed according to a determined order, respect to the fluid current that invests it (and not necessarily in a horizontal position) and capable of generating a series of fluid-dynamic actions (resulting in forces and moments) caused by complex physical mechanisms linked to local variations in velocity, pressure and viscous actions acting on its surface.

Usually the resultant of the aerodynamic forces is 'split' into three components, divided as follows:

1. A lift action (lift, L) arranged orthogonally to the asymptotic velocity vector of the air which invests it;
2. A drag action (drag, D) arranged parallel to the asymptotic velocity vector of the air which invests it and equals it;
3. A slip action (slip, S) arranged orthogonally to the asymptotic velocity vector of the air.

There are different types of wing geometries.
This term indicates the shape of the contour, according to a plan view; the main families can be subdivided as follows: rectangular, trapezoidal, elliptic (symmetric and non), sweep wing (positive and negative), delta (and double delta), delta ogival and oblique. [13]

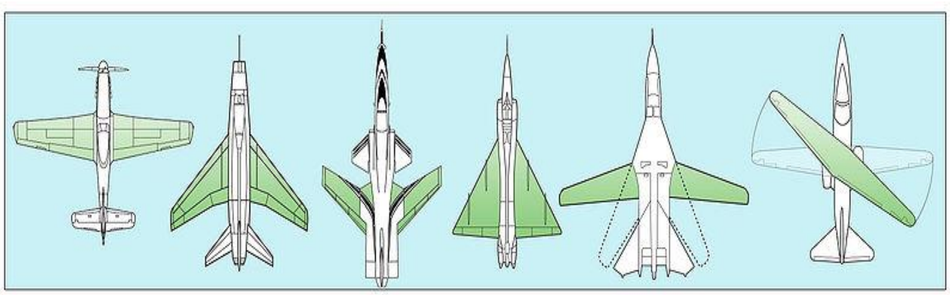


***Figure 51 Different types of wing geometries***

In addition, the wing, depending on its position with respect to the fuselage, can be:

• High: placed above the fuselage;
• Mid: placed near the fuselage median;
• Low: placed below the fuselage.

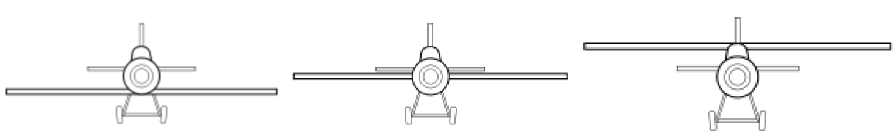



***Figure 52 Wing position respect the fuselage***

The position of the wing is an important factor of stability. A high wing makes the aircraft more stable, its center of gravity is lower than the lift application point, so the aircraft tends to come back alone in a stable position.
The lower wing instead, with the center of gravity located above the point of application of the lift, makes the aircraft more unstable but at the same time gives it greater maneuverability.
The mid wing requires a slightly more complex structure, but slightly improves the performance of the aircraft by reducing shape drag. For this reason, it is often used in modern aircraft and in sailplanes. [13]

### 3.6.1 Wing Vertical Position

When a wing is designed, first of all, it establishes its physical position.
The position of the wing is influenced by the operating environment of the aircraft (lower atmosphere, upper atmosphere, space), the role (civil, military transport, monitoring) and the speed regime of the aircraft.
The tables below describe the impact areas for each of the existing configurations shown above.

<u>High Wing</u>

| Areas of Impact | Comments |
|---|---|
| Aerodynamics | • Higher aerodynamic drag.<br>• For an aircraft designed with short take-off and landing requirements, the high position of the wing allows room for the very large wing flaps needed for a high lift coefficient. |
| Stability and Control | • Less stability during taxiing. |
| Safety and Operation | • Limited pilot’s visibility in case of small aircraft.<br>• Possibility of performing take-off from un-prepared fields. |
| Maintenance | • Easy loading and unloading especially of cargo, because of the closest location of the fuselage to the ground.<br>• Ground support infrastructure required to do the refueling. |
| Structure | • Lighter fuselage due to the lower number of cuts and relative stiffened.<br>• No excessive length of the landing gear (generally retracted inside the fuselage). As a result, the weight of the landing gear is generally reduced for a high wing aircraft. |
| Payload Accommodation | • Enhanced volume for payload; both cargo and passengers would be easily accommodated. |

***Table 57  Areas of impact, high wing configuration***

<u>Mid Wing</u>

| Areas of Impact | Comments |
|---|---|
| Aerodynamics | • Improves aircraft performance by reducing shape resistance. |

| | |
|---|---|
| | • This is the configuration with the cleaner aerodynamic configuration because there is no evident need of external fairings. |
| Stability and Control | • Greater stability during taxiing than in the previous case.<br>• Higher maneuverability, also at high speed and enhanced aerobatic performance. |
| Safety and Operation | • More facilitated inspections and tank controls.<br>• Better pilot's visibility in case of small aircraft. |
| Maintenance | • Simpler maintenance operations compared to the previous case.<br>• Depending on the overall aircraft size (distance from ground), mid wing configuration may require special support tools and infrastructures. |
| Structure | • Requires a slightly more complex structure. Heavier fuselage. |
| Payload Accommodation | • Less volume available for cargo and passengers. |

***Table 58  Areas of impact, mid wing configuration***

<u>Low Wing</u>

| Areas of Impact | Comments |
|---|---|
| Aerodynamics | • Less aerodynamic resistance |
| Stability and Control | • Greater stability during taxiing than in the previous case.<br>• Better qualities in supporting the winds at the cross. |
| Safety and Operation | • More facilitated inspections and tank controls. |
| Maintenance | • Simpler maintenance work.<br>• Requires special ground equipment for loading and unloading. |
| Structure | • Heaver fuselage due to the higher number of cuts and relative stiffened.<br>• The major advantage of the low-wing approach comes in landing gear stowage.<br>• The fuselage must be positioned higher from the ground than a high wing aircraft. |
| Payload Accommodation | • More volume available for payload and passengers compared to the previous case. |

***Table 59  Areas of impact, low wing configuration***

At this point the trade-off is carried out. In particular, it is necessary to evaluate the impact of the technical and operational characteristics on the vertical position of the wing. Scores ranging from 1 to 10 have been assigned.

In addition, appropriate mathematical formulas were used to evaluate the weight to be assigned to each technical characteristic. These are closely related to the type of aircraft and mission.

| Technical Feature | Mathematical formulation | Comments |
|---|---|---|
| **Volume available for payload** | $w_1 = \frac{V_{payload}}{L_{fus}\, A_{fus}}$ | where<br>$V_{payload}$ is the volume available for passengers and cargo [$m^3$].<br>$L_{fus}$ is the length of the fuselage [m].<br>$A_{fus}$ is the fuselage section area [$m^2$]<br>This formula allows to estimate the available the volume efficiency for the different aircraft. |
| **Wing weight and complexity** | $w_2 = \frac{m_{wing}}{MTOM}$ | $m_{wing}$ is the wing mass estimation [kg].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>This formula allows estimating the relevance in terms of mass and complexity of the wing on the overall vehicle architecture. |
| **Fuselage weight and complexity** | $w_3 = \frac{m_{fus}}{MTOM}$ | $m_{fus}$ is the fuselage mass estimation [kg].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>This formula allows estimating the relevance in terms of mass and complexity of the fuselage on the overall vehicle architecture. |
| **Landing gear weight and complexity** | $w_4 = \frac{m_{lg}}{MTOM}$ | $m_{lg}$ is the landing gear mass estimation [kg].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>This formula allows estimating the relevance in terms of mass and complexity of the landing gear on the overall vehicle architecture. |
| **Passengers Loading and Unloading** | $w_5 = \frac{m_{pax} \cdot t_{load}}{MTOM \cdot TAT}$ | $m_{pax}$is the passengers mass [kg].<br>$t_{load}$ is the time estimated to perform the boarding/unboarding of passengers [s].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>$TAT$ is the Turn Around Time [s]<br>This formula allows estimating the impact of passengers loading and un-loading operations on the overall mission. |
| **Cargo Loading and Unloading** | $w_6 = \frac{m_{cargo} \cdot t_{load}}{MTOM \cdot TAT}$ | $m_{cargo}$is the payload mass [kg].<br>$t_{load}$ is the time estimated to perform the boarding/unboarding of cargo [s].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>$TAT$ is the Turn Around Time [s]<br>This formula allows estimating the impact of cargo loading and un-loading operations on the overall mission. |
| **System accessibility** | $w_7 = \frac{m_{sys} \cdot MTTR}{MTOM \cdot TAT}$ | $m_{sys}$is the on-board systems mass [kg].<br>$MTTR$ is the time estimated to perform the maintenance actions after each single mission[s].<br>$MTOM$ is the Maximum Take-Off Mass [kg]<br>$TAT$ is the Turn Around Time [s]<br>This formula allows estimating the impact of systems on the overall accessibility and maintenance characteristics of the aircraft. |
| **Handling qualities in take-off** | $w_8 = \frac{t_{TO} \cdot T_{TO}}{t_{mission} \cdot T_{max}}$ | $t_{TO}$is the duration of the take-off maneuver [s]<br>$T_{TO}$ is the thrust required to perform the take-off [N].. |

| | | |
|---|---|---|
| | | $t_{mission}$ is the overall mission duration [s]<br>$T_{max}$ is the maximum available thrust [N].<br>This formula allows estimating the importance of take-off phase on the overall mission. |
| **Handling qualities in climb** | $w_9 = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$ | $t_{climb}$ is the duration of the climb maneuver [s]<br>$T_{climb}$ is the thrust required to perform the climb phase [N]..<br>$t_{mission}$ is the overall mission duration [s]<br>$T_{max}$ is the maximum available thrust [N].<br>It has to be noticed that in case of multi staged climb, performed with different propulsion systems, the overall FoM values should be evaluated as a $\sum_i w_{9_i}$.<br>This formula allows estimating the importance of climb phase on the overall mission. |
| **Handling qualities in cruise** | $w_{10} = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$ | $t_{climb}$ is the duration of the cruise maneuver [s]<br>$T_{climb}$ is the thrust required to perform the cruise phase [N]..<br>$t_{mission}$ is the overall mission duration [s]<br>$T_{max}$ is the maximum available thrust [N].<br>This formula allows estimating the importance of cruise phase on the overall mission. |
| **Handling qualities in re-entry** | $w_{11} = \frac{t_{re} \cdot T_{re}}{t_{mission} \cdot T_{max}}$ | $t_{climb}$ is the duration of the re-entry maneuver [s]<br>$T_{climb}$ is the thrust required to perform the re-entry phase [N]..<br>$t_{mission}$ is the overall mission duration [s]<br>$T_{max}$ is the maximum available thrust [N].<br>This formula allows estimating the importance of re-entry phase on the overall mission. |
| **Handling qualities in landing** | $w_{12} = \frac{t_{land} \cdot T_{land}}{t_{mission} \cdot T_{max}}$ | $t_{climb}$ is the duration of the land maneuver [s]<br>$T_{climb}$ is the thrust required to perform the land phase [N]..<br>$t_{mission}$ is the overall mission duration [s]<br>$T_{max}$ is the maximum available thrust [N].<br>This formula allows estimating the importance of re-entry phase on the overall mission. |

***Table 60 Technical Feature and mathematical formulation***[14]

At the end of the trade-off analysis it can be noted that the alternative with the highest score is the one that offers the best compromise considering all the expectations of the Stakeholders.
The results obtained for each of the three missions analyzed are shown below.

<u>Suborbital flight</u>
In the case of sub-orbital flights, persons and / or payloads must be able to be transported. Furthermore, systems accessibility is required in terms of maintenance; you want the aircraft to be stable in all flight phases.

| Technical Feature | Level of importance for a Low Wing | Level of importance for a Mid Wing | Level of importance for a High Wing |
|---|---|---|---|
| **Volume available for payload** | 10 | 9 | 10 |
| **Wing weight and complexity** | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 8 | 9 | 10 |
| **System accessibility** | 10 | 9 | 8 |
| **Handling qualities in take-off** | 9 | 8 | 7 |
| **Handling qualities in climb** | 7 | 6 | 4 |
| **Handling qualities in cruise** | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 7 | 6 | 5 |
| **Handling qualities in landing** | 8 | 9 | 10 |

***Table 61 Technical Feature, case of suborbital flight***

The requirements that have impacted on the choice are the following:

| **Requirements** |
|---|
| The confguration shall minmize the drag. |
| The frontal section of aircraft shall be minmize. |
| The configuration of aircraft shall facilitate the operations. |
| The configuration of aircraft shall guarantee a proper pilot visibility. |
| The wing weght shall be minimized. |
| The fuselage weight shall be minimized. |
| The aircraft to be easy to be maintained. |
| The volume available to accommodate passenger/cargo shall be maximized. |

***Table 62 Requirements that impact the wing vertical position, case of suborbital flight***

The weights assigned to each technical feature are as follows:

| | |
|---|---|
| **Volume available for payload**<br>$L_{fus} = 19.6m$<br>$A_{fus} = \pi r^2 = 6m^2$<br>$V_{payload} = 18m^3$ | $w_1 = \frac{V_{payload}}{L_{fus}\, A_{fus}}$<br>$w_1 = 0.153$ |
| **Wing weight and complexity**<br>$m_{wing} = 2000kg$<br>$MTOM = 24071kg$ | $w_2 = \frac{m_{wing}}{MTOM}$<br>$w_2$ =0.083 |
| **Fuselage weight and complexity**<br>$MTOM = 24071kg$ | $w_3 = \frac{m_{fus}}{MTOM}$ |

| | |
|---|---|
| $m_{fus}$ =3600Kg | $w_3 = 0.150$ |
| **Landing gear weight and complexity** $MTOM = 24071kg$ $m_{lg} = 800kg$ | $w_4 = \frac{m_{lg}}{MTOM}$ $w_4 = 0.03$ |
| **Cargo Loading and Unloading** $m_{cargo} = 1280kg$ $t_{load} = 900s$ $MTOM = 24071kg$ $TAT = 900s$ | $w_6 = \frac{m_{cargo} \cdot t_{load}}{MTOM \cdot TAT}$ $w_6 = 0.05$ |
| **Passengers Loading and Unloading** $m_{pax} = 630kg$ $t_{load} = 600s$ $MTOM = 24071kg$ $TAT = 900s$ | $w_5 = \frac{m_{pax} \cdot t_{load}}{MTOM \cdot TAT}$ $w_5 = 0.017$ |
| **System accessibility** $m_{sys} = 300kg$ $MTTR$ =3600s $MTOM = 24071kg$ $TAT = 900s$ | $w_7 = \frac{m_{sys} \cdot MTTR}{MTOM \cdot TAT}$ $w_7 = 0.050$ |
| **Handling qualities in take-off** $t_{TO} = 20s$ $T_{TO} = 290kN$ $t_{mission} = 3600s$ $T_{max} = 300kN$ | $w_8 = \frac{t_{TO} \cdot T_{TO}}{t_{mission} \cdot T_{max}}$ $w_8 = 0.0054$ |
| **Handling qualities in climb** $t_{climb} = 600s$ $T_{climb} = 280kN$ $t_{mission} = 3600s$ $T_{max} = 300kN$ | $w_9 = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$ $w_9 = 0.16$ |
| **Handling qualities in cruise** $\boldsymbol{t_{cruise}} = 600s$ $\boldsymbol{T_{cruise}} = 210kN$ $\boldsymbol{t_{mission}} = 3600s$ $\boldsymbol{T_{max}} = 300kN$ | $w_{10} = \frac{t_{cruise} \cdot T_{cruise}}{t_{mission} \cdot T_{max}}$ $w_{10} = 0.12$ |
| **Handling qualities in re-entry** $t_{re} = 600s$ $T_{re} = 280kN$ $t_{mission} = 3600s$ $T_{max} = 300kN$ | $w_{11} = \frac{t_{re} \cdot T_{re}}{t_{mission} \cdot T_{max}}$ $w_{11} = 0.16$ |
| **Handling qualities in landing** $t_{land} = 20s$ $T_{land} = 290kN$ $t_{mission} = 3600s$ $T_{max} = 300kN$ | $w_{12} = \frac{t_{land} \cdot T_{land}}{t_{mission} \cdot T_{max}}$ $w_{12} = 0.0054$ |

***Table 63 Technical Feature and mathematical formulation, case of suborbital flight***

For the calculation of weights, values obtained from statistical analysis were used.

At this point the trade-off is carried out (figure 53).

| Technical feature | Weight | Low wing | Mid wing | High wing |
|---|---|---|---|---|
| **Volume available for payload** | 0,153 | 10 | 9 | 10 |
| **Wing weight and complexity** | 0,083 | 9 | 9 | 10 |

| | | | | |
|---|---|---|---|---|
| **Fuselage weight and complexity** | 0,15 | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 0,03 | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 0,017 | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 0,05 | 8 | 9 | 10 |
| **System accessibility** | 0,043 | 10 | 9 | 8 |
| **Handling qualities in take-off** | 0,0054 | 9 | 8 | 7 |
| **Handling qualities in climb** | 0,16 | 7 | 6 | 4 |
| **Handling qualities in cruise** | 0,12 | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 0,16 | 7 | 6 | 5 |
| **Handling qualities in landing** | 0,0054 | 8 | 9 | 10 |
| **Score** | | **8,1678** | **7,2518** | **6,5648** |

***Figure 53 Wing vertical position trade-off, case of suborbtal flight***

It turns out that the best configuration for this mission is the low-wing configuration.

Point to point mission

In the case of point to point mission, persons and / or payloads must be able to be transported. Furthermore, systems accessibility is required in terms of maintenance; you want the aircraft to be stable in all flight phases.

| Technical Feature | Level of importance for a Low Wing | Level of importance for a Mid Wing | Level of importance for a High Wing |
|---|---|---|---|
| **Volume available for payload** | 10 | 9 | 10 |
| **Wing weight and complexity** | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 8 | 9 | 10 |
| **System accessibility** | 10 | 9 | 8 |
| **Handling qualities in take-off** | 9 | 8 | 7 |
| **Handling qualities in climb** | 7 | 6 | 4 |

| | | | |
|---|---|---|---|
| **Handling qualities in cruise** | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 7 | 6 | 5 |
| **Handling qualities in landing** | 8 | 9 | 10 |

***Table 64 Technical Feature, case of point to point mission***

The requirements that have impacted on the choice are the following:

| **Requirements** |
|---|
| The confguration shall minmize the drag. |
| The frontal section of aircraft shall be minmize. |
| The configuration of aircraft shall facilitate the operations. |
| The configuration of aircraft shall guarantee a proper pilot visibility. |
| The wing weght shall be minimized. |
| The fuselage weight shall be minimized. |
| The aircraft to be easy to be maintained. |
| The volume available to accommodate passenger/cargo shall be maximized. |

***Table 65 Requirements that impact the wing vertical position, case of point to point mission***

The weights assigned to each technical feature are as follows:

| | |
|---|---|
| **Volume available for payload**<br>$L_{fus} = 49.12m$<br>$A_{fus} = \pi r^2 = 8.3m^2$<br>$V_{payload} = 290m^3$ | $w_1 = \frac{V_{payload}}{L_{fus}\, A_{fus}}$<br>$w_1 = 0.711$ |
| **Wing weight and complexity**<br>$m_{wing} = 5000kg$<br>$MTOM = 66126kg$ | $w_2 = \frac{m_{wing}}{MTOM}$<br>$w_2$ =0.076 |
| **Fuselage weight and complexity**<br>$MTOM = 66126kg$<br>$m_{fus} = 9945$Kg | $w_3 = \frac{m_{fus}}{MTOM}$<br>$w_3 = 0.15$ |
| **Landing gear weight and complexity**<br>$MTOM = 66126kg$<br>$m_{lg} = 1000kg$ | $w_4 = \frac{m_{lg}}{MTOM}$<br>$w_4 = 0.015$ |
| **Passengers Loading and Unloading**<br>$m_{pax} = 11200kg$<br>$t_{load} = 900s$<br>$MTOM = 66126kg$<br>$TAT = 1800s$ | $w_5 = \frac{m_{pax} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_5 = 0.08$ |
| **Cargo Loading and Unloading**<br>$m_{cargo} = 7000kg$<br>$t_{load} = 1200s$<br>$MTOM = 66126kg$<br>$TAT = 1800s$ | $w_6 = \frac{m_{cargo} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_6 = 0.07$ |
| **System accessibility**<br>$m_{sys} = 400kg$<br>$MTTR$ =3600s<br>$MTOM = 66126kg$<br>$TAT = 1800s$ | $w_7 = \frac{m_{sys} \cdot MTTR}{MTOM \cdot TAT}$<br>$w_7 = 0.01$ |
| **Handling qualities in take-off**<br>$t_{TO} = 20s$<br>$T_{TO} = 900kN$<br>$t_{mission} = 14400s$ | $w_8 = \frac{t_{TO} \cdot T_{TO}}{t_{mission} \cdot T_{max}}$<br>$w_8 = 0.002$ |

| | |
|---|---|
| $T_{max} = 910kN$ | |
| **Handling qualities in climb**<br>$t_{climb} = 600s$<br>$T_{climb} = 890kN$<br>$t_{mission} = 14400s$<br>$T_{max} = 910kN$ | $w_9 = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$<br>$w_9 = 0.04$ |
| **Handling qualities in cruise**<br>$t_{cruise} = 13000s$<br>$T_{cruise} = 670kN$<br>$\boldsymbol{t_{mission}} = 14400s$<br>$\boldsymbol{T_{max}} = 910kN$ | $\boldsymbol{w_{10}} = \frac{\boldsymbol{t_{cruise} \cdot T_{cruise}}}{\boldsymbol{t_{mission} \cdot T_{max}}}$<br>$\boldsymbol{w_{10}} = 0.7$ |
| **Handling qualities in re-entry**<br>$t_{re} = 600s$<br>$T_{re} = 890kN$<br>$t_{mission} = 14400s$<br>$T_{max} = 910kN$ | $w_{11} = \frac{t_{re} \cdot T_{re}}{t_{mission} \cdot T_{max}}$<br>$w_{11} = 0.04$ |
| **Handling qualities in landing**<br>$t_{land} = 20s$<br>$T_{land} = 900kN$<br>$t_{mission} = 14400s$<br>$T_{max} = 910kN$ | $w_{12} = \frac{t_{land} \cdot T_{land}}{t_{mission} \cdot T_{max}}$<br>$w_{12} = 0.002$ |

***Table 66 Technical Feature and mathematical formulation, case of point to point mission***

For the calculation of weights, values obtained from statistical analysis were used.

At this point the trade-off is carried out (figure 54).

| Technical feature | Weight | Low wing | Mid wing | High wing |
|---|---|---|---|---|
| **Volume available for payload** | 0,711 | 10 | 9 | 10 |
| **Wing weight and complexity** | 0,076 | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 0,15 | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 0,015 | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 0,08 | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 0,07 | 8 | 9 | 10 |
| **System accessibility** | 0,01 | 10 | 9 | 8 |
| **Handling qualities in take-off** | 0,002 | 9 | 8 | 7 |
| **Handling qualities in climb** | 0,04 | 7 | 6 | 4 |
| **Handling qualities in cruise** | 0,7 | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 0,04 | 7 | 6 | 5 |

| | | | | |
|---|---|---|---|---|
| **Handling qualities in landing** | 0,002 | 8 | 9 | 10 |
| **Score** | | 16,143 | 14,397 | 14,109 |

***Figure 54 Wing vertical position trade-off, case of point to point mission***

It turns out that the best configuration for this mission is the low-wing configuration.

Reusable launcher
Here the two cases will be treated separately: people + cargo, only cargo.
**People + cargo**

| Technical Feature | Level of importance for a Low Wing | Level of importance for a Mid Wing | Level of importance for a High Wing |
|---|---|---|---|
| **Volume available for payload** | 10 | 9 | 10 |
| **Wing weight and complexity** | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 8 | 9 | 10 |
| **System accessibility** | 10 | 9 | 8 |
| **Handling qualities in take-off** | 9 | 8 | 7 |
| **Handling qualities in climb** | 7 | 6 | 4 |
| **Handling qualities in cruise** | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 7 | 6 | 5 |
| **Handling qualities in landing** | 8 | 9 | 10 |

***Table 67 Technical Feature, case of reusable launcher people + cargo***

The requirements that have impacted on the choice are the following:

| Requirements |
|---|
| The confguration shall minmize the drag. |
| The frontal section of aircraft shall be minmize. |
| The configuration of aircraft shall facilitate the operations. |
| The configuration of aircraft shall guarantee a proper pilot visibility. |
| The wing weght shall be minimized. |
| The fuselage weight shall be minimized. |
| The aircraft to be easy to be maintained. |

The volume available to accommodate passenger/cargo shall be maximized.

***Table 68 Requirements that impact the wing vertical position, case of reusable launcher people + cargo***

The weights assigned to each technical feature are as follows:

| | |
|---|---|
| **Volume available for payload**<br>$L_{fus} = 15m$<br>$A_{fus} = \pi r^2 = 4.8m^2$<br>$V_{payload} = 33.12m^3$ | $w_1 = \frac{V_{payload}}{L_{fus}\, A_{fus}}$<br>$w_1 = 0.46$ |
| **Wing weight and complexity**<br>$m_{wing} = 1500kg$<br>$MTOM = 13000kg$ | $w_2 = \frac{m_{wing}}{MTOM}$<br>$w_2$ =0.12 |
| **Fuselage weight and complexity**<br>$MTOM = 13000kg$<br>$m_{fus} = 2410$Kg | $w_3 = \frac{m_{fus}}{MTOM}$<br>$w_3 = 0.18$ |
| **Landing gear weight and complexity**<br>$MTOM = 13000kg$<br>$m_{lg} = 800kg$ | $w_4 = \frac{m_{lg}}{MTOM}$<br>$w_4 = 0.06$ |
| **Passengers Loading and Unloading**<br>$m_{pax} = 280kg$<br>$t_{load} = 900s$<br>$MTOM = 13000kg$<br>$TAT = 1800s$ | $w_5 = \frac{m_{pax} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_5 = 0.01$ |
| **Cargo Loading and Unloading**<br>$m_{cargo} = 3000kg$<br>$t_{load} = 1200s$<br>$MTOM = 13000kg$<br>$TAT = 1800s$ | $w_6 = \frac{m_{cargo} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_6 = 0.15$ |
| **System accessibility**<br>$m_{sys} = 400kg$<br>$MTTR$ =3600s<br>$MTOM = 13000kg$<br>$TAT = 1800s$ | $w_7 = \frac{m_{sys} \cdot MTTR}{MTOM \cdot TAT}$<br>$w_7 = 0.06$ |
| **Handling qualities in take-off**<br>$t_{TO} = 20s$<br>$T_{TO} = 140kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 150kN$ | $w_8 = \frac{t_{TO} \cdot T_{TO}}{t_{mission} \cdot T_{max}}$<br>$w_8 = 0.001$ |
| **Handling qualities in climb**<br>$t_{climb} = 600s$<br>$T_{climb} = 130kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 150kN$ | $w_9 = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$<br>$w_9 = 0.03$ |
| **Handling qualities in cruise**<br>$\boldsymbol{t_{cruise}} = 16400s$<br>$\boldsymbol{T_{cruise}} = 100kN$<br>$\boldsymbol{t_{mission}} = 18000s$<br>$T_{max}$ =150kN | $w_{10} = \frac{t_{cruise} \cdot T_{cruise}}{t_{mission} \cdot T_{max}}$<br>$w_{10} = 0.6$ |
| **Handling qualities in re-entry**<br>$t_{re} = 900s$<br>$T_{re} = 130kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 150kN$ | $w_{11} = \frac{t_{re} \cdot T_{re}}{t_{mission} \cdot T_{max}}$<br>$w_{11} = 0.043$ |
| **Handling qualities in landing**<br>$t_{land} = 20s$<br>$T_{land} = 140kN$ | $w_{12} = \frac{t_{land} \cdot T_{land}}{t_{mission} \cdot T_{max}}$ |

| | |
|---|---|
| $t_{mission} = 18000s$ <br> $T_{max} = 150kN$ | $w_{12} = 0.001$ |

***Table 69  Technical Feature and mathematical formulation, case of reusable launcher people+cargo***

For the calculation of weights, values obtained from statistical analysis were used.

At this point the trade-off is carried out (figure 55).

| Technical feature | Weight | Low wing | Mid wing | High wing |
|---|---|---|---|---|
| **Volume available for payload** | 0,46 | 10 | 9 | 10 |
| **Wing weight and complexity** | 0,12 | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 0,18 | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 0,06 | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 0,01 | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 0,15 | 8 | 9 | 10 |
| **System accessibility** | 0,06 | 10 | 9 | 8 |
| **Handling qualities in take-off** | 0,001 | 9 | 8 | 7 |
| **Handling qualities in climb** | 0,03 | 7 | 6 | 4 |
| **Handling qualities in cruise** | 0,6 | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 0,043 | 7 | 6 | 5 |
| **Handling qualities in landing** | 0,001 | 8 | 9 | 10 |
| **Score** | | **14,618** | **13,155** | **12,702** |

***Figure 55 Wing vertical position trade-off, case of reusable launcher***

It turns out that the best configuration for this mission is the low-wing configuration.

### Only cargo

| Technical Feature | Level of importance for a Low Wing | Level of importance for a Mid Wing | Level of importance for a High Wing |
|---|---|---|---|
| **Volume available for payload** | 10 | 9 | 10 |
| **Wing weight and complexity** | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 10 | 8 | 6 |
| **Landing gear weight** | 9 | 8 | 7 |

| | | | |
|---|---|---|---|
| **and complexity** | | | |
| **Passengers Loading and Unloading** | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 8 | 9 | 10 |
| **System accessibility** | 10 | 9 | 8 |
| **Handling qualities in take-off** | 9 | 8 | 7 |
| **Handling qualities in climb** | 7 | 6 | 4 |
| **Handling qualities in cruise** | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 7 | 6 | 5 |
| **Handling qualities in landing** | 8 | 9 | 10 |

***Table 70 Technical Feature, case of reusable launcher only cargo***

The requirements that have impacted on the choice are the following:

| **Requirements** |
|---|
| The confguration shall minmize the drag. |
| The frontal section of aircraft shall be minmize. |
| The configuration of aircraft shall facilitate the operations. |
| The configuration of aircraft shall guarantee a proper pilot visibility. |
| The wing weght shall be minimized. |
| The fuselage weight shall be minimized. |
| The aircraft to be easy to be maintained. |
| The volume available to accommodate passenger/cargo shall be maximized. |

***Table 71 Requirements that impact the wing vertical position, case of only cargo***

The weights assigned to each technical feature are as follows:

| | |
|---|---|
| **Volume available for payload**<br>$L_{fus} = 19m$<br>$A_{fus} = \pi r^2 = 9.6m^2$<br>$V_{payload} = 67m^3$ | $w_1 = \frac{V_{payload}}{L_{fus}\, A_{fus}}$<br>$w_1 = 0.37$ |
| **Wing weight and complexity**<br>$m_{wing} = 1600kg$<br>$MTOM = 22627kg$ | $w_2 = \frac{m_{wing}}{MTOM}$<br>$w_2 = 0.07$ |
| **Fuselage weight and complexity**<br>$MTOM = 22627kg$<br>$m_{fus} = 3053\text{Kg}$ | $w_3 = \frac{m_{fus}}{MTOM}$<br>$w_3 = 0.14$ |
| **Landing gear weight and complexity**<br>$MTOM = 22627kg$<br>$m_{lg} = 800kg$ | $w_4 = \frac{m_{lg}}{MTOM}$<br>$w_4 = 0.035$ |
| **Passengers Loading and Unloading**<br>$m_{pax} = 0kg$<br>$t_{load} = 900s$<br>$MTOM = 22627kg$<br>$TAT = 1800s$ | $w_5 = \frac{m_{pax} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_5 = 0$ |

| | |
|---|---|
| **Cargo Loading and Unloading**<br>$m_{cargo} = 6000kg$<br>$t_{load} = 1200s$<br>$MTOM = 22627kg$<br>$TAT = 1800s$ | $w_6 = \frac{m_{cargo} \cdot t_{load}}{MTOM \cdot TAT}$<br>$w_6 = 0.18$ |
| **System accessibility**<br>$m_{sys} = 400kg$<br>$MTTR$ =3600s<br>$MTOM = 22627kg$<br>$TAT = 1800s$ | $w_7 = \frac{m_{sys} \cdot MTTR}{MTOM \cdot TAT}$<br>$w_7 = 0.04$ |
| **Handling qualities in take-off**<br>$t_{TO} = 20s$<br>$T_{TO} = 240kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 260kN$ | $w_8 = \frac{t_{TO} \cdot T_{TO}}{t_{mission} \cdot T_{max}}$<br>$w_8 = 0.001$ |
| **Handling qualities in climb**<br>$t_{climb} = 600s$<br>$T_{climb} = 230kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 260kN$ | $w_9 = \frac{t_{climb} \cdot T_{climb}}{t_{mission} \cdot T_{max}}$<br>$w_9 = 0.03$ |
| **Handling qualities in cruise**<br>$\boldsymbol{t_{cruise}} = 16400s$<br>$T_{cruise} = 180kN$<br>$\boldsymbol{t_{mission}} = 18000s$<br>$\boldsymbol{T_{max}} = 260kN$ | $\boldsymbol{w_{10}} = \frac{\boldsymbol{t_{cruise} \cdot T_{cruise}}}{\boldsymbol{t_{mission} \cdot T_{max}}}$<br>$\boldsymbol{w_{10}} = 0.63$ |
| **Handling qualities in re-entry**<br>$t_{re} = 900s$<br>$T_{re} = 230kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 260kN$ | $w_{11} = \frac{t_{re} \cdot T_{re}}{t_{mission} \cdot T_{max}}$<br>$w_{11} = 0.044$ |
| **Handling qualities in landing**<br>$t_{land} = 20s$<br>$T_{land} = 240kN$<br>$t_{mission} = 18000s$<br>$T_{max} = 260kN$ | $w_{12} = \frac{t_{land} \cdot T_{land}}{t_{mission} \cdot T_{max}}$<br>$w_{12} = 0.001$ |

***Table 72 Technical Feature and mathematical formulation, case of reusable launcher only cargo***

For the calculation of weights, values obtained from statistical analysis were used.

At this point the trade-off is carried out (figure 56).

| Technical feature | Weight | Low wing | Mid wing | High wing |
|---|---|---|---|---|
| **Volume available for payload** | 0,37 | 10 | 9 | 10 |
| **Wing weight and complexity** | 0,07 | 9 | 9 | 10 |
| **Fuselage weight and complexity** | 0,14 | 10 | 8 | 6 |
| **Landing gear weight and complexity** | 0,035 | 9 | 8 | 7 |
| **Passengers Loading and Unloading** | 0 | 7 | 7 | 7 |
| **Cargo Loading and Unloading** | 0,18 | 8 | 9 | 10 |

| | | | | |
|---|---|---|---|---|
| **System accessibility** | 0,04 | 10 | 9 | 8 |
| **Handling qualities in take-off** | 0,001 | 9 | 8 | 7 |
| **Handling qualities in climb** | 0,03 | 7 | 6 | 4 |
| **Handling qualities in cruise** | 0,63 | 7 | 6 | 5 |
| **Handling qualities in re-entry** | 0,044 | 7 | 6 | 5 |
| **Handling qualities in landing** | 0,001 | 8 | 9 | 10 |
| **Score** | | **12,83** | **11,581** | **11,112** |

***Figure 56 Wing vertical position trade-off, case of reusable launcher***

It turns out that the best configuration for this mission is the low-wing configuration.

### 3.6.2 Airfoil design/selection

Once the vertical position of the wing has been defined, it is continued with the definition of the wing profile. It is important to define the 2D wing section profile.
Two different approaches may be envisaged at this high level of design: from one side, a new airfoil can be design from scratch, investigating the main design parameters, such as the Leading-Edge Radius, the camber and so on and then, the new airfoil aerodynamics characteristics should be investigated in order to verify the compliance with the requirements. On the opposite, another approach, starting from requirements and leading to the selection of an existing airfoil for which the main aerodynamic performances are known. [14]
Infact, the design of the airfoil is a complex and time-consuming process and needs expertise in the fundamentals of aerodynamics at graduate level. Since the airfoil needs to be verified by testing it in a wind tunnel, it is expensive too. Large aircraft production companies aerodynamicists and sufficient budget to design their own airfoil for every aircraft, but, for example small aircraft companies, and home-built manufacturers cannot afford to design their own airfoils. Instead, they select the best airfoils among the currently available airfoils found in several books or websites. [12]
In this thesis it was decided to follow the second path.
To proceed with the selection, appropriate mathematical formulations were used.

| Step | Formulas | Comments |
|---|---|---|
| **Calculate the aircraft ideal cruise lift coefficient** | $$C_{L_C} = \frac{2W_{mean}}{\rho V_C^2 S}$$ *Where:* $C_{L_C}$ is the aircraft ideal cruise lift coefficient; $\rho$ is the air density (at cruise altitude) [kg/m$^3$]; $S$is wing surface [m$^2$]. | This first step allows estimating a first value for the requirements of the overall aircraft in an intermediate point of the cruise. |
| **Calculate the wing lift coefficient** | $$C_{L_{C_W}} = \frac{C_{L_C}}{k_w}$$ Where: $C_{L_{C_W}}$ is the wing cruise lift | This step allows the designer to move from aircraft-level to the wing-level. Considering that the wing is usually the solely responsible for the generation of |

| | | |
|---|---|---|
| | coefficient;<br>$k_w$ is the wing contribution percentage to the overall aircraft lifting characteristics. | the lift, $k_w$ can be set at 0.95 for traditional configuration [REF SE].<br>It is clear that in case of configuration on which tail/canard surfaces or the fuselage are more strongly contributing to the overall aircraft lifting capacity, this value should be properly reduced. |
| **Calculate the wing airfoil ideal lift coefficient** | $C_{L_i} = \frac{C_{L_{C_W}}}{k_a}$<br>$C_{L_i}$ is the wing cruise lift coefficient;<br>$k_a$ is the wing airfoil lifting contribution to the wing lifting coefficient. | This step allows moving from a 3D problem at wing level, to a 2D investigation, focusing on the airfoil.<br>The parametric coefficient $k_a$ present in this equation can be set at 0.9 in conceptual and preliminary design evaluation. This allows considering the fact that the wing span is limited, and the possible presence of sweep angle and non-constant chord. |
| **Calculate the aircraft maximum lift coefficient** | $C_{L_{max}} = \frac{2W_{TO}}{\rho_0 V_S^2 S}$<br>*Where:*<br>$C_{L_{max}}$ is the aircraft maximum lift coefficient;<br>$\rho_0$ is the air density (at sea level) [kg/m$^3$];<br>$S$ is wing surface [m$^2$].<br>$W_{TO}$ is the maximum take-off weight;<br>$V_S$ is the stall speed [m/s] | This step is absolutely similar to the very first one, but allows deriving the maximum aircraft lift coefficient. Following the same top-down approach it will be possible to estimate the wing airfoil maximum lift coefficient. |
| **Calculate the wing maximum lift coefficient** | $C_{L_{maxW}} = \frac{C_{L_{max}}}{k_w}$<br>Where:<br>$C_{L_{maxW}}$ is the maximum wing lift coefficient;<br>$k_w$ is the wing contribution percentage to the overall aircraft lifting characteristics. | |
| **Calculate the wing airfoil gross maximum lift coefficient** | $C_{l_{max-gross}} = \frac{C_{L_{maxW}}}{k_a}$<br>$C_{L_{max-gross}}$ is the wing airfoil gross maximum lift coefficient ;<br>$k_a$ is the wing airfoil lifting contribution to the wing lifting coefficient. | The effect of High Lift Devices (HLD) is included |
| **Calculate the wing airfoil net maximum lift** | $c_{l_{max}} = C_{l_{max-gross}} - \Delta C_{l_{HLD}}$ | Where the contribution to the to the wing maximum lift coefficient depends on the |

| | |
|---|---|
| **coefficient** | geometry, type and maximum deflection of the selected HLD. |

***Table 73 Mathematical formulation for airfoil selection***

For the calculation of the coefficients, values obtained from statistical analysis were used (See figure 57, figure 58, figure 59, figure 60, figure 61).

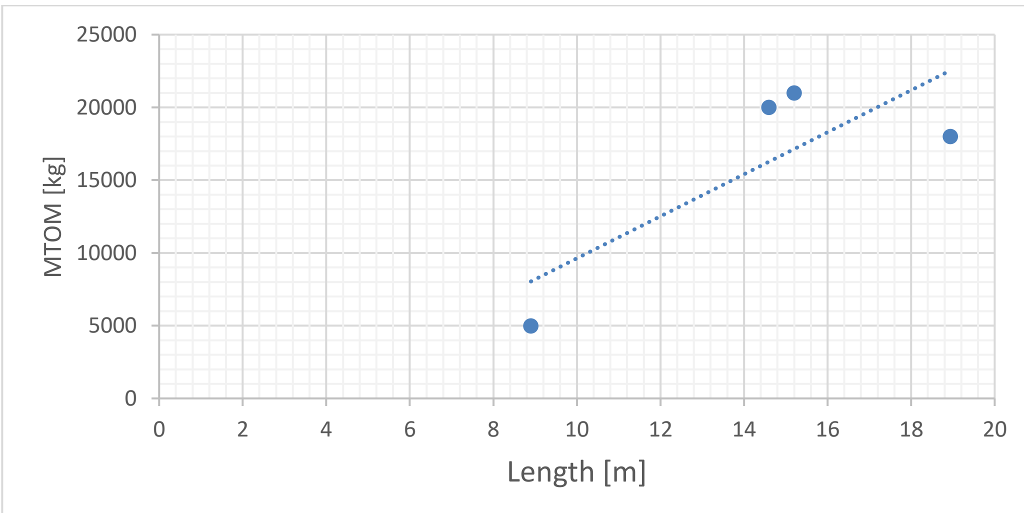



***Figure 57 Length-MTOT***

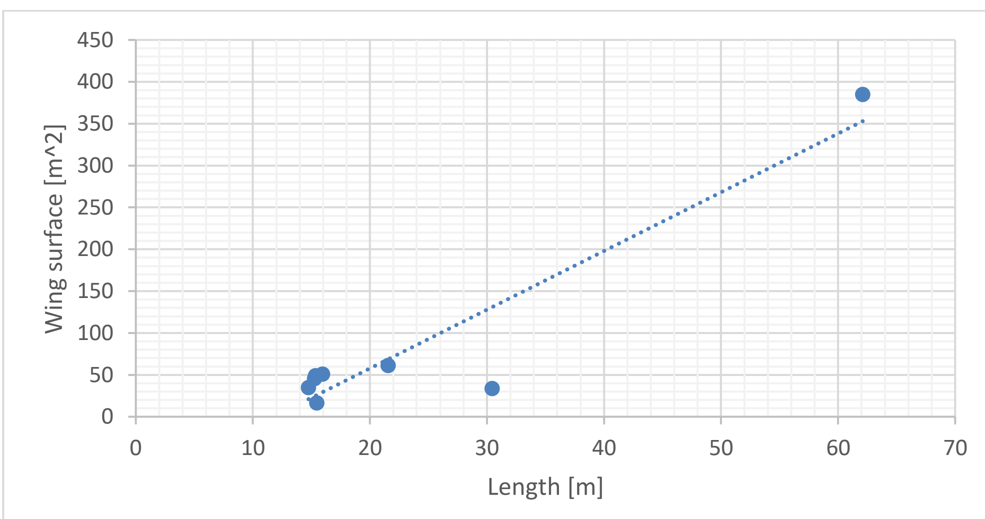



***Figure 58 Length-Wing surface***

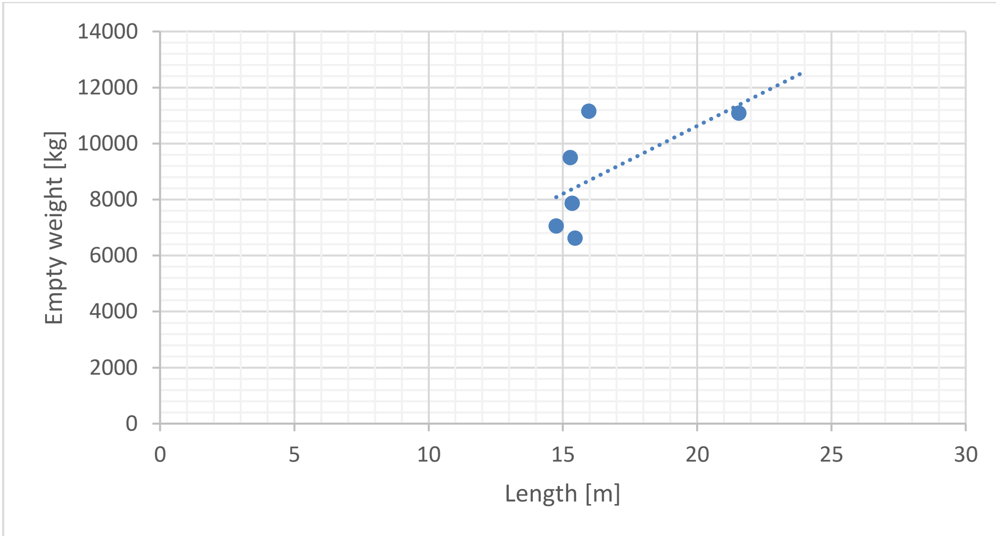



***Figure 59 Length-Empty weight***

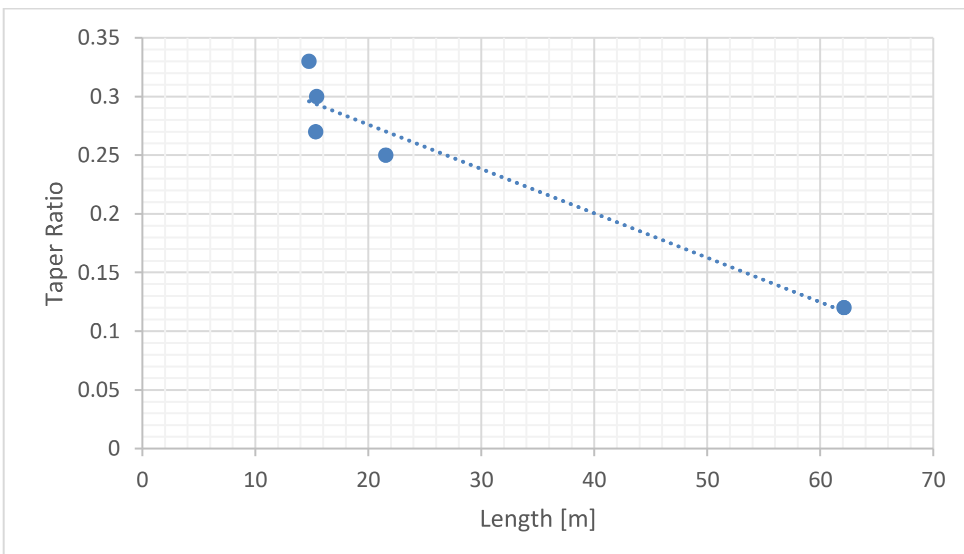



***Figure 60 Length-Taper Ratio***

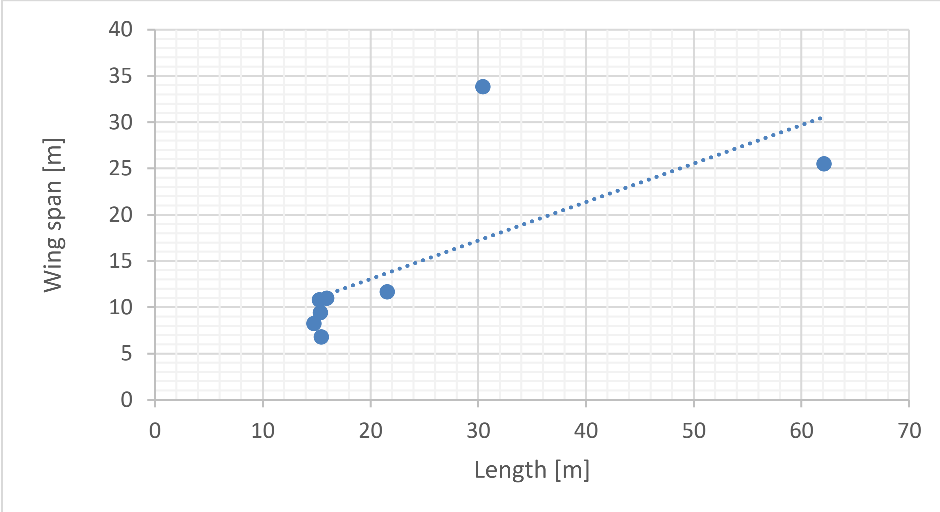



***Figure 61 Length-Wiing span***

Some of these values do not appear directly in the aerodynamic coefficient formulas but are used to evaluate the mass of the fuel.
There are several expressions to go to evaluate the mass of the fuel, one of these is the Breguet equation:

$$\frac{MF}{MTOW} = 1 - e^{\left[-SFC\cdot\left(\frac{D}{L}\right)\cdot\left(\frac{ESAR}{V}\right)\right]}$$

$L/_D$ ratio or Lift-to-drag is a measure of the overall aerodynamic efficiency of the project. $L/_D$ depends heavily on the configuration layout.
The aspect ratio could be used to estimate $L/_D$.
$L/_D$ depends first of all on the wingspan and on the wet surface. This suggests a new parameter "Wetted Aspect Ratio", which is referred to as the wing span square by fracturing the total wet surface.

The designer selects the aspect ratio and determines the configuration layout, which in turn determines the watted-area ratio $\left({S_{wer}}/{S_{ref}}\right)$.
The wetted area ratio can be estimated using the image below. [15]

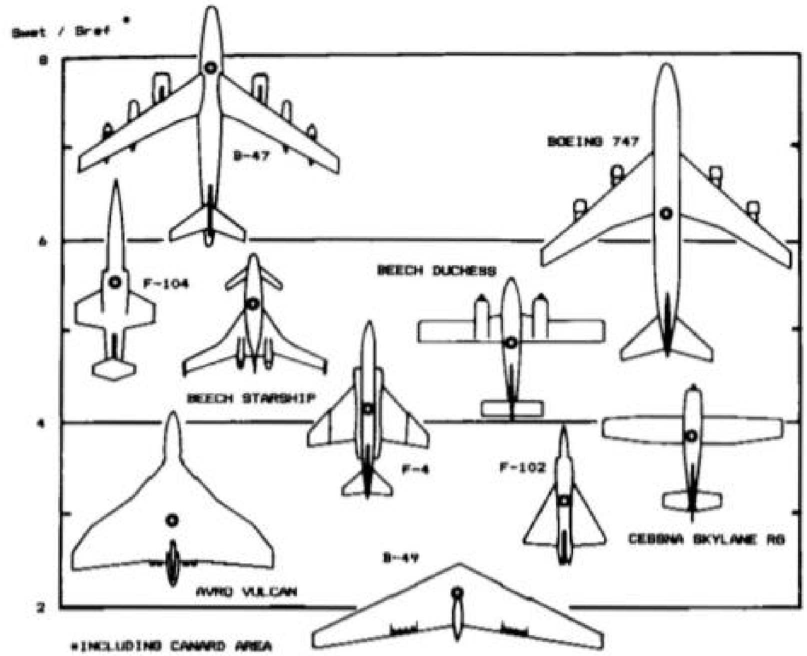



*Figure 62 Watted area ratios*

The wetted aspect ratio can then be calculated as the wing aspect ratio divided by the wetted-area ratio.
At this point using the figure below you can evaluate the Maximum $L/_D$.

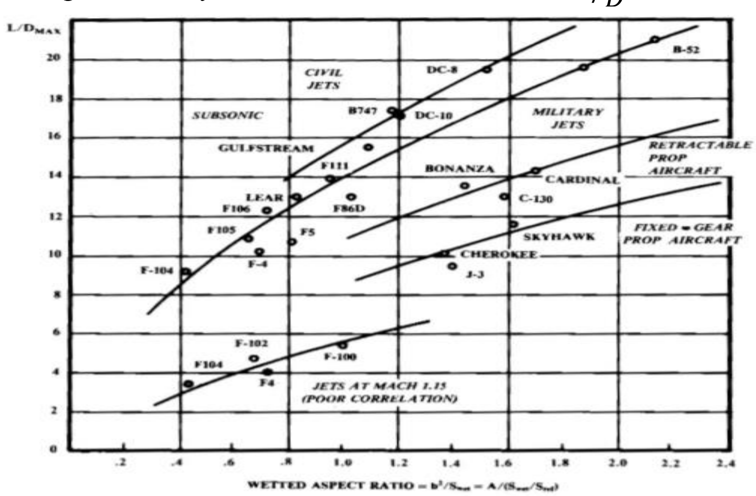



*Figure 63 Maximum lift to drag rato trends*

At this point you have everything you need to be able to evaluate the various coefficients.
Once you have evaluated $C_{li}$ and $C_{Lmax}$, you can find the appropriate aerodynamic profile for that particular mission using the following graph.

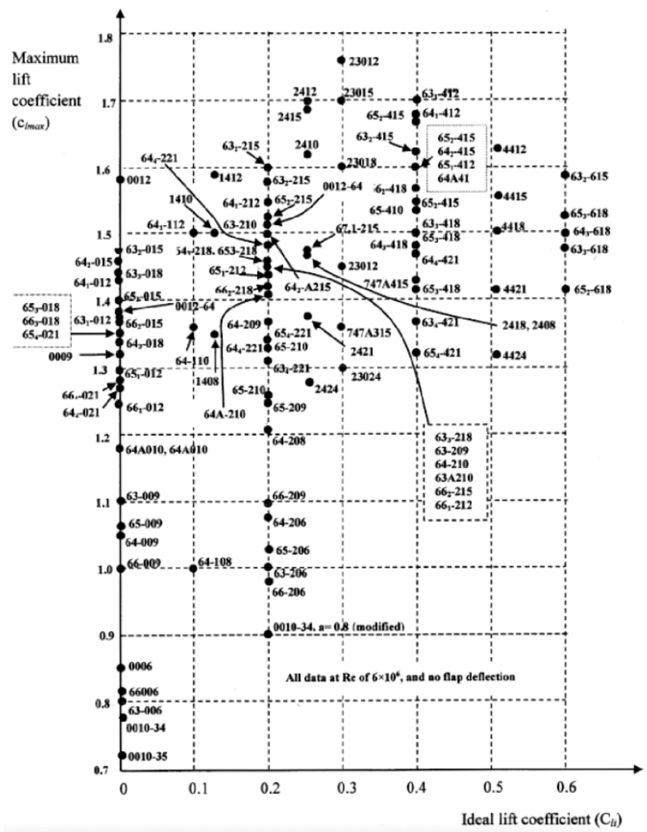



***Figure 64 Maximum lift coefficient versus ideal lift coefficient for several NACA airfoil section***

<u>Suborbital flight</u>

As mentioned before, in order to choose the most suitable 2D geometry for the mission, the aerodynamic coefficients, whose formulas are listed above, are evaluated.

For this case of study are obtained:

**1) Calculate the aircraft ideal cruise lift coefficient**

$$C_{L_C} = \frac{2W_{mean}}{\rho V_C^2 S} = \frac{2 \cdot 196548}{0.01 \cdot 1715^2 \cdot 74.5} = 0.18$$

**2) Calculate the wing lift coefficient**

$$C_{L_{CW}} = \frac{C_{L_C}}{k_w} = \frac{0.18}{0.95} = 0.19$$

**3) Calculate the wing airfoil ideal lift coefficient**

$$C_{L_i} = \frac{C_{L_{CW}}}{k_a} = \frac{0.19}{0.9} = 0.21$$

**4) Calculate the aircraft maximum lift coefficient**

$$C_{L_{max}} = \frac{2W_{TO}}{\rho_0 V_S^2 S} = \frac{2 \cdot 236137}{1.225 \cdot 83^2 \cdot 74.5} = 0.75$$

**5) Calculate the wing maximum lift coefficient**

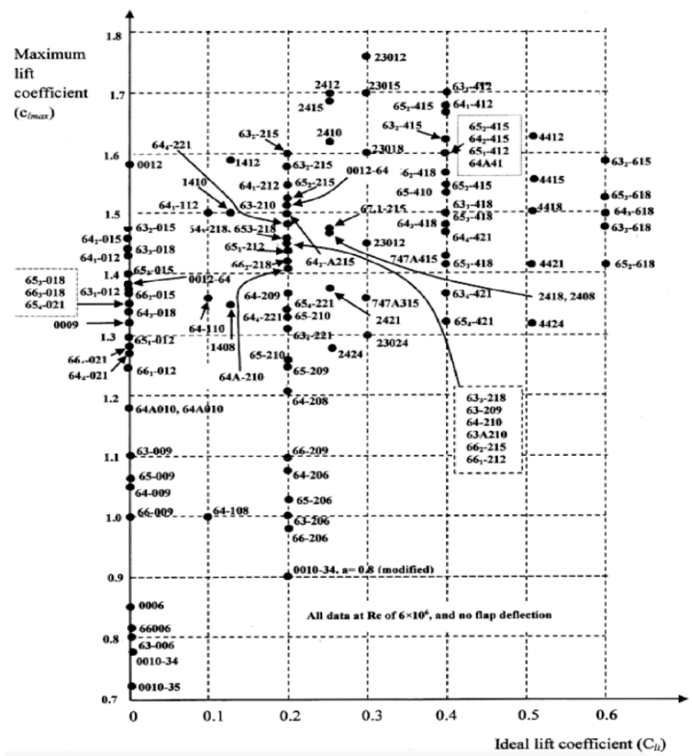
$$C_{L_{maxW}} = \frac{C_{L_{max}}}{k_w} = \frac{0.75}{0.95} = 0.8$$

**6) Calculate the wing airfoil gross maximum lift coefficient**

$$C_{l_{max-gross}} = \frac{C_{L_{maxW}}}{k_a} = \frac{0.8}{0.9} = 1$$

**7) Calculate the wing airfoil net maximum lift coefficient**

$$c_{l_{max}} = C_{l_{max-gross}} - \Delta C_{l_{HLD}} = 0.9$$




0010-34. a=0.8 (modified)

<u>Point to point mission</u>

As mentioned before, in order to choose the most suitable 2D geometry for the mission, the aerodynamic coefficients, whose formulas are listed above, are evaluated.
For this case of study are obtained:

**1) Calculate the aircraft ideal cruise lift coefficient**

$$C_{L_C} = \frac{2W_{mean}}{\rho V_C^2 S} = \frac{2 \cdot 432258}{0.01 \cdot 1715^2 \cdot 262} = 0.11$$

2) **Calculate the wing lift coefficient**

$$C_{L_{C_W}} = \frac{C_{L_C}}{k_w} = \frac{0.11}{0.95} = 0.116$$

3) **Calculate the wing airfoil ideal lift coefficient**

$$C_{L_i} = \frac{C_{L_{C_W}}}{k_a} = \frac{0.116}{0.9} = 0.13$$

4) **Calculate the aircraft maximum lift coefficient**

$$C_{L_{max}} = \frac{2W_{TO}}{\rho_0 V_S^2 S} = \frac{2 \cdot 648696}{1.225 \cdot 80^2 \cdot 262} = 0.63$$

5) **Calculate the wing maximum lift coefficient**

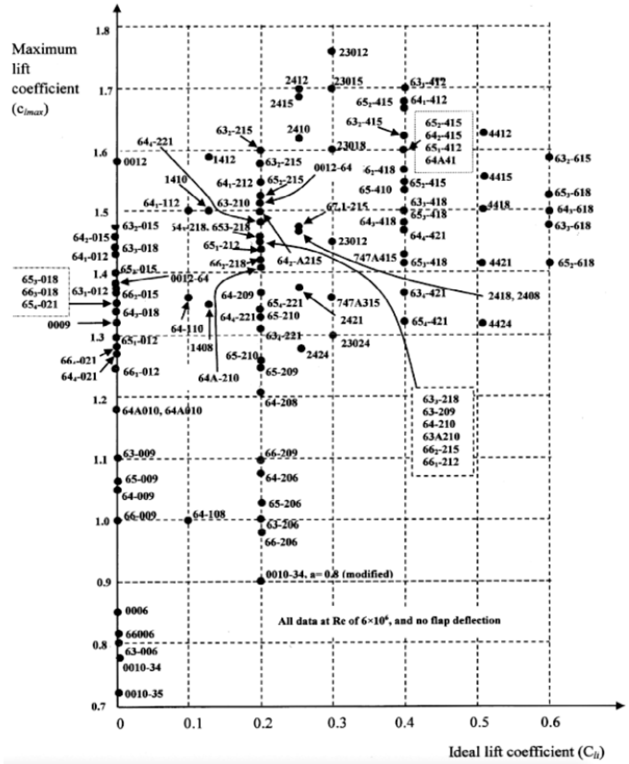
$$C_{L_{max_W}} = \frac{C_{L_{max}}}{k_w} = \frac{0.63}{0.95} = 0.66$$

6) **Calculate the wing airfoil gross maximum lift coefficient**

$$C_{l_{max-gross}} = \frac{C_{L_{max_W}}}{k_a} = \frac{0.66}{0.9} = 0.7$$

7) **Calculate the wing airfoil net maximum lift coefficient**

$$c_{l_{max}} = C_{l_{max-gross}} - \Delta C_{l_{HLD}} = 0.7$$




0010-35

Reusable launcher

**People + cargo**

As mentioned before, in order to choose the most suitable 2D geometry for the mission, the aerodynamic coefficients, whose formulas are listed above, are evaluated.
For this case of study are obtained:

1) **Calculate the aircraft ideal cruise lift coefficient**

$$C_{L_C} = \frac{2W_{mean}}{\rho V_C^2 S} = \frac{2 \cdot 97769.4}{0.01 \cdot 2400^2 \cdot 23} = 0.15$$

2) **Calculate the wing lift coefficient**

$$C_{L_{CW}} = \frac{C_{L_C}}{k_w} = \frac{0.15}{0.95} = 0.16$$

3) **Calculate the wing airfoil ideal lift coefficient**

$$C_{L_i} = \frac{C_{L_{CW}}}{k_a} = \frac{0.16}{0.9} = 0.18$$

4) **Calculate the aircraft maximum lift coefficient**

$$C_{L_{max}} = \frac{2W_{TO}}{\rho_0 V_S^2 S} = \frac{2 \cdot 127530}{1.225 \cdot 90^2 \cdot 23} = 1.1$$

5) **Calculate the wing maximum lift coefficient**

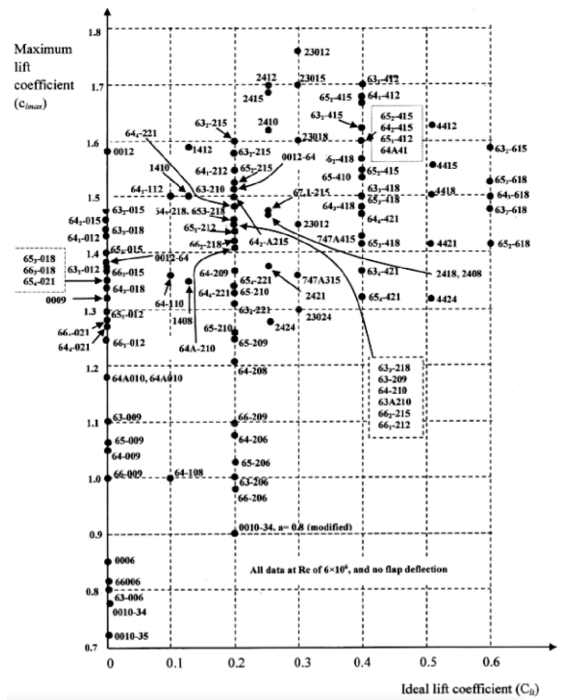
$$C_{L_{maxW}} = \frac{C_{L_{max}}}{k_w} = \frac{1.1}{0.95} = 1.16$$

6) **Calculate the wing airfoil gross maximum lift coefficient**

$$C_{l_{max-gross}} = \frac{C_{L_{maxW}}}{k_a} = \frac{0.16}{0.95} = 1.22$$

7) **Calculate the wing airfoil net maximum lift coefficient**

$$c_{l_{max}} = C_{l_{max-gross}} - \Delta C_{l_{HLD}} = 1$$




0010-34. a=0.8 (modfied)

<u>Reusable launcher</u>

**Only cargo**

As mentioned before, in order to choose the most suitable 2D geometry for the mission, the aerodynamic coefficients, whose formulas are listed above, are evaluated.
For this case of study are obtained:

1) **Calculate the aircraft ideal cruise lift coefficient**

$$C_{L_C} = \frac{2W_{mean}}{\rho V_C^2 S} = \frac{2 \cdot 168742}{0.01 \cdot 2400^2 \cdot 50.7} = 0.12$$

2) **Calculate the wing lift coefficient**

$$C_{L_{CW}} = \frac{C_{L_C}}{k_w} = \frac{0.12}{0.95} = 0.13$$

3) **Calculate the wing airfoil ideal lift coefficient**

$$C_{L_i} = \frac{C_{L_{CW}}}{k_a} = \frac{0.13}{0.9} = 0.14$$

4) **Calculate the aircraft maximum lift coefficient**

$$C_{L_{max}} = \frac{2W_{TO}}{\rho_0 V_S^2 S} = \frac{2 \cdot 221971}{1.225 \cdot 90^2 \cdot 50.7} = 0.88$$

5) **Calculate the wing maximum lift coefficient**

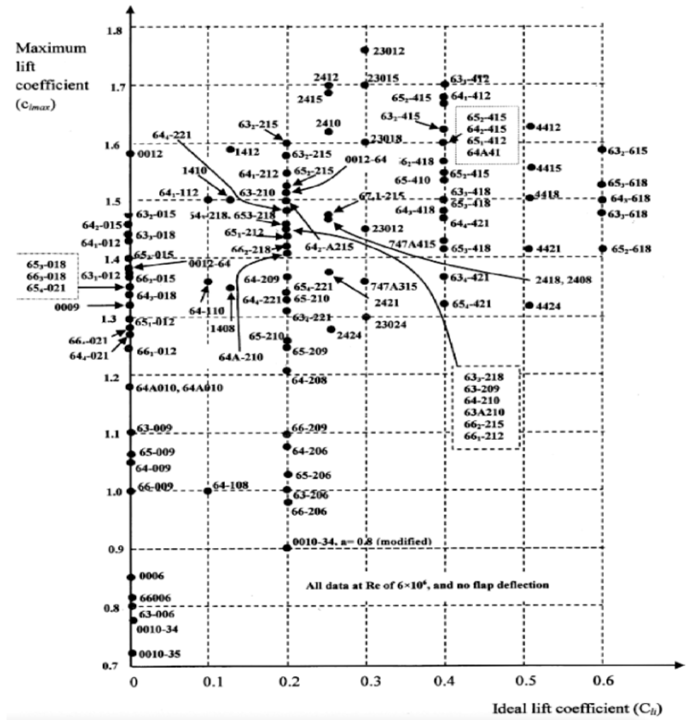
$$C_{L_{maxW}} = \frac{C_{L_{max}}}{k_w} = \frac{0.88}{0.95} = 0.93$$

6) **Calculate the wing airfoil gross maximum lift coefficient**

$$C_{l_{max-gross}} = \frac{C_{L_{maxW}}}{k_a} = \frac{0.93}{0.9} = 1.1$$

7) **Calculate the wing airfoil net maximum lift coefficient**

$$c_{l_{max}} = C_{l_{max-gross}} - \Delta C_{l_{HLD}} = 1$$




64-108

### 3.6.3 Wing geometry definition

In this paragraph the main geometric parameters are defined.

1. Angle of incidence (α)
   The angle of incidence is fundamental in the development of the dynamic forces of lift and drag, since the respective coefficients depend only on the shape and angle of incidence of the object invested by the current.In general it can be said that the developed lift increases with the increase in the incidence angle (which, below a certain value, depending on the shape of the wing profile, can generate a downforce), up to a maximum value corresponding to an angle said stall angle. Once this angle has been exceeded, there is a sudden drop in the lift values and an increase in drag values. For most of the initial design work, it can be assumed that general aviation and homebuilt aircraft will have an incidence of around 2 degrees, transport aircraft of around 1 degree and military aircraft approximately zero.
   Regarding this parameter, there are mainly two alternatives: variable incidence of the wing and the fixed one. There are pros and cons for both configurations. However, the best option

to reduce weight and to avoid possible safety and operating constraints is the wing with a fixed incidence. This applies especially in the case of hypersonic aircraft (the possibility of changing the incidence of very large surfaces at very high speeds would require large amounts of power but at the same time limited stability). [12], [14]
However, once it is decided whether "fixed incidence wing" or "variable incidence wing", the best value of α is chosen. To understand how to choose the best value of α, it is important to list which high-level requirements can have a deeper impact on this parameter:

| Requirements |
|---|
| The wing shall maximize the lift generation. |
| The wing contribution to the overall drag shall be minimized during the cruise phase. |
| The wing lifting performances shall be maximized during the cruise phase. |
| The excursion of angle of attack during take-off shall be maximized. |

***Table 74 Requirements that impact the wing incidence***

| *Aircraft Type* | *Wing Incidence* |
|---|---|
| ***Supersonic fighters*** | 0 – 1 deg |
| ***Hypersonic Transportation Systems*** | 0 – 1 deg |
| ***General Aviation*** | 2 – 4 deg |
| ***Jet transportation*** | 3 – 5 deg |

***Table 75 Typical values of wing incidence***

2. Aspect Ratio (AR)
The Aspect Ratio is defined as the ratio between the wingspan (characteristic length in the transverse direction) and the geometric mean cord (characteristic length in the longitudinal direction) or between the square of the wingspan and the wing surface. Being the ratio between two measures of length or surface it is a dimensionless number. The wing aspect ratio characteristic of the currently active aircraft are: 2-3 for combat supersonic, about 7 for commercial transport, up to 20-30 for gliders, where it is essential to keep the overall resistance of the configuration to a minimum. It is clear that if a supersonic aircraft is to be designed, when flying at high speed to Mach> 1, the lift coefficient will certainly be reduced and the angle of attack will be low, so the drag induced in those flight conditions and of design is certainly not a problem: it will therefore be better to take all the advantages (for example of a structural type) of a wing with a low aspect ratio; if instead you have to design a glider, it is very important that the overall drag is low and therefore a wing with a high aspect ratio is taken. For hypersonic aircraft, there are not many aircraft and projects, the value was chosen on the basis of similar aircraft. [15]

| *Type of aircraft* | *Aspect Ratio estimation* | *Suggestion* |
|---|---|---|
| ***Sailplane*** | $0.19\left(best\,\frac{L}{D}\right)^{\frac{1}{3}}$ | 20 – 40 |
| ***Jet trainer*** | $4.737\,(M_{max})^{-0.979}$ | 4 - 8 |
| ***Jet fighter*** | $4.110\,(M_{max})^{-0.0622}$ | 2 - 4 |

| | | |
|---|---|---|
| ***Military Cargo*** | $5.570\ (M_{max})^{-1.075}$ | 6 – 12 |
| ***Low subsonic Transport*** | | 6 - 9 |
| ***High subsonic Transport*** | | 8 – 12 |
| ***Supersonic transport*** | | 2 - 4 |
| ***Hypersonic transport*** | | 1 - 3 |

***Table 76 Aspect Ratio***[14]

Suborbital aircraft: 2.3
Point to point mission: 2.3
Reusable launcher: 2

The requirements that impact on the Aspect Ratio are:

| **Requirements** |
|---|
| The wing shall prevent the stall. |
| The wing shall be able to maximize L/D. |
| The wing shall maximized the lift generation. |
| The wing geometry shall minimize the 3D effect due to wing tip vortex. |
| The wing geometry shall maximize the effectiveness off wing control. |
| The wing stall shall be anticipated with respect to the tail stall. |

***Table 77 Requirements that impact the Aspect Ratio***

3. Wing sweep angle
   In aeronautics the wing sweep angle is the angle between a point of the wing profile of a wing or an empennage and the transverse plane of the aircraft. The leading edge is usually used as a reference point. The wing sweep can be either positive, when the wings are facing the tail or negative, when they are on the muzzle. In airplanes that fly in subsonic regime (in particular no more than M = 0.7) the optimal sweep angle can vary from 0 ° to 5 °. In transonic airplanes it varies in general from 25 ° to 35 °, while in those destined to travel in supersonic regime from 35 ° to 45 °. However, other configurations are possible. As said before the sweep angle can be positive or negative. The negative one is used on some types of aircraft, both civil (like HFB 320 Hansa Jet) and military (like Junkers Ju 287, Grumman X-29 or Sukhoi Su-47). This type of wing is used above all for aerodynamic reasons on some aircraft equipped with canard or experimental fins. Some aircraft models called variable geometry, such as the F-14 Tomcat, the MiG-23, the Tornado or the Mirage G have the possibility to vary their wingspan during the flight, extending or retracting the two wings. The resulting advantage is enormous, as the aircraft can keep the wings spread out at low speed, with a very small sweep angle, and retract them towards the fuselage at transonic and supersonic regimes, increasing the width of the angle.

The oblique wing is a particular type of wing with variable sweep angle. An airplane with an oblique wing has a mechanism that can rotate the entire wing around a point in the fuselage, so that one of the two wings has a positive sweep angle and the other has a negative sweep angle. By varying the sweep angle in this way, it is possible to decrease the drag induced in flight at high speeds, using a high angle of rotation without sacrificing performance at low speed and using an angle equal to or near zero for subsonic flight. On an aircraft of this type a wing only rotates in one direction, that is to say that the two axles can change their sweep angle only from zero to a certain value and from that value back to zero. The use of sweep wings is aimed at reducing the fluid dynamic drag during the flight of aircraft at speeds that are around the sound. The presence of positive sweep wings also increases the number of critical Mach. For airplanes that fly at lower speeds (longer than the sound), straight wings are more suitable. Initially, the wings with sweep angle were used in military fighter jets, today they are the most widespread wings even in civilian transport, with the exception of less fast aircraft, especially in airliners. As already mentioned, there are two particular variants: the wing with negative-sweep angle, in which the two wingtips are facing the nose of the aircraft, the wing with positive-sweep angle and the variable-geometry wing, able to vary its sweep angle in the course of the flight by moving the two wing seeds. The negative sweep wing is an efficient configuration, but the advantages obtained are not sufficient to compensate for the structural problems encountered, however it is a widespread wing configuration. They are dynamically unstable planes, therefore very maneuverable. The sweep wing, whether positive or negative, offers the important advantage of reducing the wave drag at transonic or supersonic speeds, reducing the Mach number of the air flowing on the wing. Since the effects of the sweep angle vary proportionally to the cosine of the angle itself, there should be no difference between a wing with a positive sweep and a wing with a negative sweep. However, it is necessary to make some additional considerations.

**Stall**

One of the advantages of using a wing with negative sweep angle is the best control at high angles of attack, due to the lower vulnerability to power stall. In a wing with positive sweep angle, the flow of air flowing on the wing goes from the inside out, and the fluid threads become turbulent at the wing ends before the center. This means that the stall starts at the wing ends, where the control surfaces are mounted. In a negative arrow wing instead, the air flow goes from the outside to the inside. This means that at high speeds the stall starts from the center of the wing, ensuring better control of the ailerons at high angles of attack.

**Structure**

An inverse sweep wing is mounted further downstream of the fuselage than a positive sweep wing, because its weight tends to weigh towards the nose of the aircraft instead of towards the tail. This allows a greater useful space in the fuselage to be used as a load compartment, because the same is not obstructed by the necessary support structures of the wing. The use of a reverse sweep wing often involves the use of canard fins. Since the canard wing and the main wing are one upstream and one downstream of the plane's gravity, they can both be lifting without destabilizing and making the aircraft dynamically unstable.

On the other hand, the flow of air that invests the wing at high speeds tends to twist them with a twisting moment proportional to the speed of the flow itself. It can be avoided that this phenomenon (called aeroelastic dynamic divergence) is dangerous by dimensioning the wing in order to operate at a higher speed than the aircraft can reach, but this means that an inverse sweep wing must be more robust than a similar wing with positive sweep, and therefore more expensive. In order to avoid having to strengthen the wing making it much heavier it is necessary to use composite materials, of greater cost.

**Stabilty**

An aircraft with a wing with a negative sweep angle is less stable than an aircraft with a conventional wing.

Longitudinal stability: when an aircraft with a reverse-sweep wing performs a maneuver along the pitch axis, the wing tends to accentuate the maneuver: the drag of form increases, but since the center of rotation of the wing it is behind the center of application of the force, this generates a moment that tends to increase the angle of rotation again. Vice versa, in a positive sweep wing, the variations in the angle of incidence tend to counteract the rotation itself.

Stability at the turn: when an aircraft with a reverse-sweep wing makes a turn, the outer wing generates less drag than the internal one, accentuating the maneuver. Vice versa, in a positive sweep wing, the outer wing generates a greater drag, damping the maneuver. In particular, the lowering wing increases its angle of attack, this causes an increase in lift that tends to oppose the maneuver, but also creates an increase in drag that tends to retreat the wing. The "dutch roll" is created, this name deriving from a skating maneuver that explains the close link between the transverse and directional stability, or better still, a yaw movement is always correlated with each rolling movement.

In aeronautics the greatest instability is on the one hand a desired parameter, because it translates into better agility and maneuvering capacity, but on the other makes the control of the aircraft more difficult and therefore increases the need for the flight to be servo-assisted. [12], [16]

Furthermore, two different architectural alternatives must be evaluated:

- fixed wing sweep angle;
- variable wing sweep angle.

Pros and cons of the two options were analyzed in depth. In particular, it should be noted that the variable geometry was deeply studied at the end of the 80s, above all because it offers the best compromise between very different mission phases. However, the high level of complexity, risk and cost associated with this innovative and technologically advanced solution has forced engineers to focus on different design architectures.

Furthermore, as regards the wing configuration, it is possible to classify alternatives as a single angle or double sweep angle.

Considering these alternatives, a double wing can be used to compensate for aerodynamic variations in low and high-speed regimes and would be very useful for single stage hypersonic vehicles that would have to cope with flight phases with a wide range of speeds and altitudes.

The requirements that impact on the wing sweep angle are:

| Requirements |
|---|
| The wing shall maximized the lift generation. |
| The wing area shall be included within the Mach cone to withstand the heating and structural loods. |
| The stall speed shall be increased. |
| The aircraft maneuverability shall be guaranteed. |
| The aircraft stability shall be guaranteed. |

***Table 78 Requirements that impact the sweep angle***

Considering the case of hypersonic vehicles, the maximum number of Mach and the related requirements are the most interesting parameters for selecting the most suitable sweep angle. In particular, from the theoretical point of view, the semi-opening of the Mach cone (μ) can be defined as:

$$\mu = \sin^{-1}\left(\frac{1}{M}\right)$$

And the relative sweep angle can be defined as:

$$\Lambda = k_{\Lambda}(90 - \mu)$$

where $k_{\Lambda}$ is a factor that will be used to decrease wave drag in supersonic and hypersonic speed. Considering some results provided by the literature, a factor of 1.2 will guarantee the lowest loss of the wave, avoiding that the shock wave is very closed at the leading edge of the wing, generating a high temperature due to a serious increase in aerodynamic heating.

Suborbital flight: 78°
Point to point mission:78°
Reusable launcher: 80°

4. Dihedral Angle
   An angle of positive dihedral provides aerodynamic stability to roll, intended in the sense of tendency to maintain leveled wings.
   Following a perturbation that induces a roll, the aircraft will begin to slide from the part of the half-wing that lowers, since the weight force is no longer perfectly balanced by lift. This sliding movement induces a flow of air transverse to the aircraft that will be composed with the flow due to the advancement of the aircraft. Because of the different geometry of the axials due to the dihedral angle, the resulting current that hits the half-wing that has lowered will have a greater angle of attack than that of the opposite half-wing. Consequently, the lift developed by the lowered half-wing will be greater than that developed by the other, causing a moment along the longitudinal axis that tends to bring the aircraft with leveled wings. In reality the effect of the dihedral angle on the stability is much more complex, because it results from the coupling of the two rolling and yaw motions. An angle of negative dihedral has the opposite effect and is used to increase the agility to roll the airplane, making it unstable.
   The dihedral angle is strongly linked to the vertical position of the wing. In particular, it can be observed that if the wing is high, there is a negative dihedral angle; on the contrary, the presence of a positive dihedral angle is associated with a low-wing configuration. Furthermore, in the case of a forward wing a negative dihedral angle will be necessary. Then a first estimate of the value of this angle is made based on the vertical position of the wing and the sweep angle.

| | ***Low Wing*** | ***Mid Wing*** | ***High Wing*** |
|---|---|---|---|
| ***Un-swept*** | 5 to 10 deg | 3 to 6 deg | -4 to -10 deg |
| ***Low-subsonic swept*** | 2 to 5 deg | -3 to 3 deg | -3 to -6 deg |
| ***High subsonic swept*** | 3 to 8 deg | -4 to 2 deg | -5 to -10 deg |
| ***Supersonic swept*** | 0 to -3 deg | 1 to -4 deg | 0 to -5 deg |

| | | | |
|---|---|---|---|
| ***Hypersonic swept*** | 1 to 0 deg | 0 to -1 deg | -1 to -2 deg |

***Table 79 Dihedral angle***

The requirements that impact on the dihedral angle are:

| **Requirements** |
|---|
| The wing shall maximized the lift generation. |
| The aircraft stability shall be guaranteed. |

***Table 80 Requirements that impact the dihedral angle***

5. Taper ratio

   Taper ratio is defned as the rato between the tiip chord to the root chord.

$$\lambda = \frac{C_t}{C_r}$$

   In general ths parameter varies between zero and one.

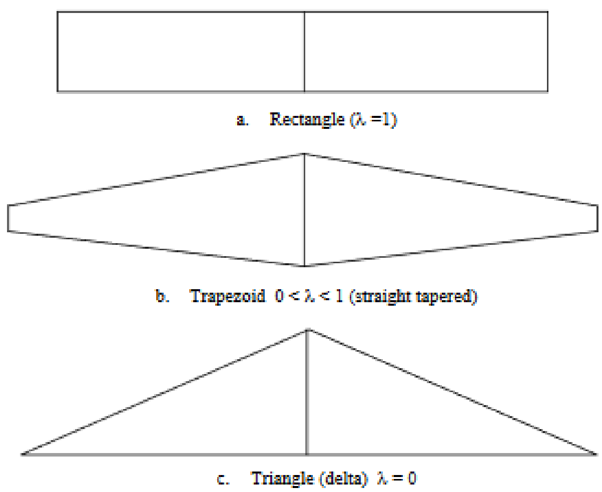



***Figure 65 Wing with various taper ratio*** [12]

The effect of wing taper can be summarzed as follows:

- It will change the wing lift distribution.
- It will increase the cost of the wing manufacture, since the wing ribs have different shapes.
- It will influence the aircraft static lateral stability.

A system engineering technique by using a weighted parametric table must be employed to determine the exact value of the taper ratio. [12]

The typical effect of taper ratio on the lift distribution is sketched in the following figure.

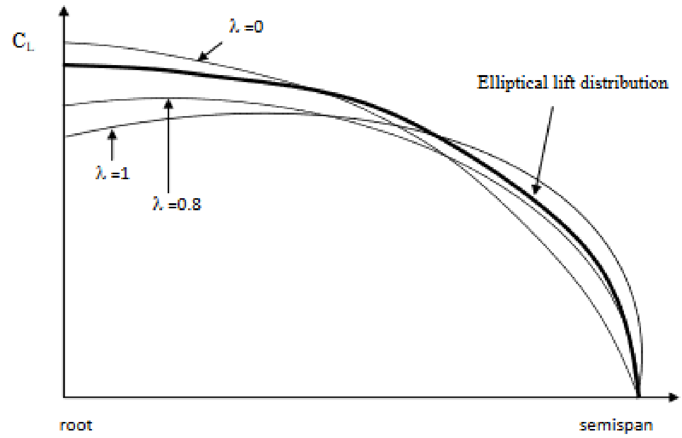



***Figure 66 The typical effect of taper ratio on the lift distribution*** [12]

The requirements that impact on the Taper Ratio are:

| Requirements |
| --- |
| The wing shall maximized the lift generation. |
| The wing weght shall be minimized. |
| The aircraft controllability shall be guaranteed. |
| The aircraft stability shall be guaranteed. |

***Table 81 Requirements that impact the Taper ratio***

To select a suitable plan shape and therefore to hypothesize a correct value of the taper ratio, the most useful and simple approach, applicable during the conceptual design phase, is to evaluate the variations in terms of lifting capacity of a family of wing geometries having the same aerodynamic profile and identical geometric characteristics, except for the tapered ratio of the wing. [14]

For the selected missions, the results obtained are shown below (See figure67):

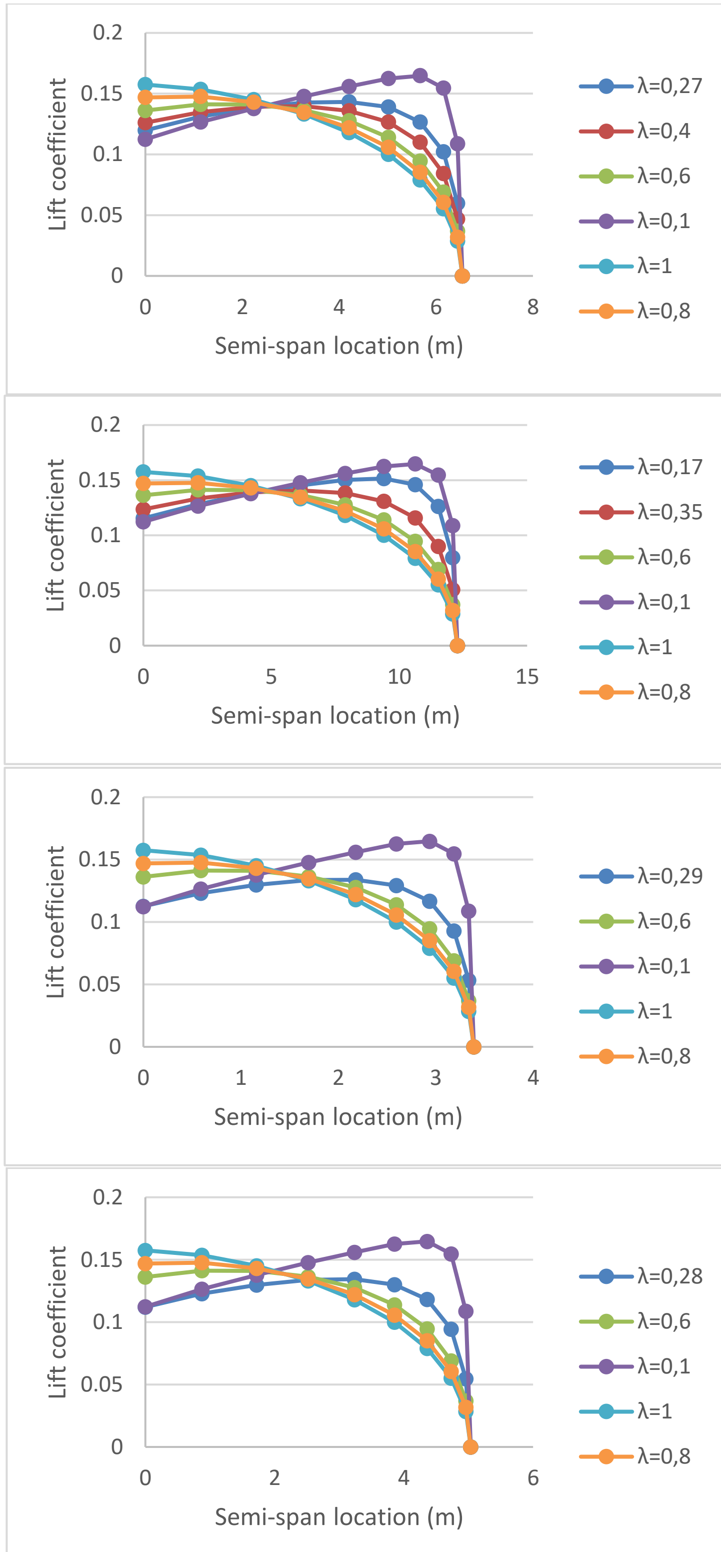



***Figure 67 Effect of taper ratio on the lift distribution***

Suborbital flight: λ=0.27
Point to point mission: λ=0.17
Reusable launcher: people+cargo λ=0.29; Only cargo λ=0.28

## 3.7 *Fuselage, Wing and main subsystems integration*

At this point integration is performed. To do this, we start from the preliminary sketch, wing + fuselage, of the external layout. Reference is made to an upper and lateral view.
In this way, it is possible to hypothesize the position of the main structural elements, both of the wing and of the fuselage.
Very important is a first definition of the main ribs, in particular those connected to the spars.
The main concern in the development of a good structural arrangement is to provide efficient load paths. The weights of the structural elements will be reduced to a minimum by identifying the shortest and smoothest load path possible.
Large concentrated loads, such as wing attachments and landing gear, must be transported by a robust structural element such as bulkhead fuselage majors. The number of these bulkheads can be reduced to a minimum, making sure that each has a certain number of concentrated loads rather than just one.
On the main ribs, if possible, go to attack the main landing gear and if possible, the engine, if inside the fuselage.
Main subsystems, such as engines, tanks and cart must be inserted into the sketch.
Once this is done, an estimate of the weights is carried out, which is very important above all for positioning the center of gravity of the aircraft and then checking its stability. In this phase the weights of each single part of the aircraft are estimated through specific methods in which there are formulas of a statistical nature.
For this weight estimate, the Torenbeek method was used. [17]

**Wing mass**

To obtain the mass of the wing, the Torenbeek method uses two formulas, one for airplanes with a maximum take-off weight of less than 5670 kg and one for airplanes with a maximum take-off weight of more than 5670 kg. In the cases that will be treated the mass is greater than 5670 kg, so the formula used by Torenbeek is the following:

$$M_w = 0.00667 M_{MZF}\left(b/\cos(\Lambda_{1/2})\right)^{0.75}\left(1+\left(1.905\cos(\Lambda_{1/2})/b\right)^{0.5}\right)(n_{ult})^{0.55}\left(\frac{b/\cos\Lambda_{1/2}/t_r}{M_{MZFW}/S}\right)^{0.30}$$

With:

- $M_W$= wing mass in kg;
- $M_{ZFM}$= maximum take-off weight at "zero fuel" obtained from the difference between the maximum take-off weight and the weight of the fuel
  :
  $$M_{ZFM} = M_{MTOW} - M_F$$
- $\Lambda_{1/2}$=sweep angle valued at 50% of the chord;
- $b$= wingspan;
- $n_{ult}$= load factor to robustness;
- $t_r$= maximum thickness of the root chord;
- $S$= wing surface.

**Mass of the tail plans**

The mass of the tail plans is given by the sum of the mass of the horizontal empennage plus the mass of the vertical empennage.

$$M_{TAIL} = M_H - M_V$$

Usually the mass of the tail planes is 2-4% of the take-off mass but has a significant effect on the barycenter.

**Mass of horizontal empennage**
The Torenbeek formula used to calculate the mass of the horizontal empennage is as follows:

$$M_H = K_H S_H \left(0.05836 \left(\frac{S_H^{0.2} V_D}{(\cos \Lambda_H)^{0.5}}\right) - 1.41\right)$$

With:

- $M_H$= horizontal tail plane mass in kg;
- $S_H$= surface of the horizontal tail plane;
- $\Lambda_H$=sweep angle of the horizontal tail plane valued at 50ù5 of the chord;
- $V_D$= it is the EAS, measured in m/s which according to the standard results to be equal to the cruising speed multiplied by 1.4
$$V_D = 1.4 * V$$
- $K_H$= corrective factor that takes into account mounted stabilizers. This value will be equal to 1 in the case where fixed stabilizers are used and 1.1 if mobile stabilizers are used.

**Mass of vertical empennage**
For the calculation of the mass of the vertical empennage, the same formula used for the horizontal empennage is used:

$$M_H = K_V S_V \left(0.05836 \left(\frac{S_V^{0.2} V_D}{(\cos \Lambda_V)^{0.5}}\right) - 1.41\right)$$

with:

- $M_V$= vertical tail plane mass in kg in kg;
- $S_V$= surface of the vertical tail plane;
- $\Lambda_V$= sweep angle of the vertical tail plane valued at 50ù5 of the chord;
- $V_D$= it is the EAS, measured in m/s which according to the standard results to be equal to the cruising speed multiplied by 1.4
$$V_D = 1.4 * V$$
- $K_V$ corrective factor that takes into account mounted stabilizers.

$$K_V = 1 + 0.15 \frac{S_H h_H}{S_V b_V}$$

Where:

- $b_V$ is the span of the vertical tail plane;
- $h_H$ is the distance of the horizontal tail plane from the toot chord of the vertical tail plane.

**Mass of the fuselage**
The estimate of the mass of the fuselage is more complicated than the estimate of the mass of the wing due to the presence of windows, doors, furnishings, etc.
An estimate offered by Torenbeek is as follows:

$$M_F = K_{MF}\left(V_D\frac{l_T}{b_F+h_F}\right)^{0.5} S_G^{1.2}$$

With:

- $M_F$= mass of fuselage in kg;
- $V_D$ = it is the EAS, measured in m/s which according to the standard results to be equal to the cruising speed multiplied by 1.4
$$V_D = 1.4 * V$$
- $l_T$= distance between 25% of the centerline of the wing and 25% of the horizontal tail plane in m;
- $b_F$= maximum width of the fuselage;
- $h_F$= maximum height of the fuselage;
- $K_{MF}$= correttive factor;
- $S_G$ = external surface of the fuselage calculated as

$$S_G = \pi D_F l_F (1 - 2/\lambda_F)^{2/3}(1 + 1/\lambda_F^2)$$

With:

- $l_F$= fuselage length;
- $D_F$= outer diameter of the fuselage in the central trunk;
- $\lambda_F$= ratio between the length of the fuselage and the outer diameter of the fuselage in the central trunk.

**Mass of landing gear**

The formulation used to calculate the mass of the landing gear is always the same, regardless of the type of landing gear used, both for fixed and retractable ones, the only thing that varies are the constant coefficients A, B, C, D that are found within the formula.

$$W_{UC} = K_{UC}\left(A + BW_{TO}^{0.75} + CW_{TO} + DW_{TO}^{1.5}\right)$$

With:

- $W_{UC}$=mass of landing gear;
- $K_{UC}$= corrective factor depending on the type of aircraft studied. For high-wing aircraft (due to the presence of propellers) this factor is equal to 1.08. For low-wing aircraft this factor is equal to 1.
- $W_{TO}$= maximum takeoff weight in kg.

The values of A,B,C,D can be obtained from the following table:

| Aircraft | Landing gear | | A | B | C | D |
|---|---|---|---|---|---|---|
| Jet aircraft: trainers, executive | Retractile | Principal | 15.0 | 0.033 | 0.021 | 0 |
| | | Anterior | 5.4 | 0.049 | 0 | 0 |
| All other civil aircraft | Fixed | Princiipal | 9.1 | 0.082 | 0.019 | |
| | | Anterior | 11.3 | | 0.0024 | |
| | | Tail wheel | 4.1 | | 0.0024 | |
| | Retractile | Principal | 18.1 | 0.131 | 0.019 | 2.2310-5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Anterior | 9.1 | 0.082 | | 2.9710-6 |
| | | Tail wheel | 2.3 | | 0.0031 | |

*Table 82 A,B,C,D values for the valutation of the mass of landing gear*

**Mass of the engine nacelles**

Depending on the type of aircraft that is being studied, different expressions can be made for the estimation of the weight of the engine gondolas, based above all on the type of engine that is used.
In this case you will have:

$$M_N = 6.8 \cdot T_{TO}$$

With:

- $M_N$= mass of the engine nacelles;
- $T_{TO}$= maximum take-off thrust for the single engine.

**Mass of the propulsion system**

The formula used by Torenbeek allows to obtain the mass of the engine for its estimation the hypothesis is made that the mass of the dry motor is known.

$$M_{PROP} = K_{PG} K_{THR} M_E$$

With:

- $M_E$= mass of engine;
- $K_{PG}$= corrective factor;
- $K_{THR}$=corrective factor.

**Mass of installed systems**

At this point, an approximate calculation of the mass of the installed systems is made. This calculation considers all the systems present on the aircraft, ie hydraulic system, pneumatic system, electrical system, air conditioning system, anti-icing system, on-board instruments, avionics and furniture.
This estimate results to be quite difficult and in first approximation the mass of these installations can be obtained as a percentage on the maximum takeoff weight of the aircraft, with percentage fixed by a table proposed by Torenbeek:

| | |
|---|---|
| **Single-engined** | 8% Mto |
| **Twin-engined** | 11% Mto |
| **Short range transport aircraft** | 14% Mto |
| **Medium range transport aircraft** | 11% Mto |
| **Long range transport aircraft** | 8% Mto |

*Table 83 Estimation of installed systems*

**Mass of payload**

In order to estimate the mass of the payload, reference is made to the legislation in particular to the JAR-25.
The legislation requires to consider for each passenger a mass between 75-85 kg to which a weight is added for the baggage that goes between 20 and 30 kg.

**Mass of crew member**
The estimate of the mass of the crew is made in the same way as the mass estimate of the payload. Reference is always made to the JAR-25 standard according to which a mass of 93 kg per pilot and copilot and a mass of 63 kg for hostesses can be considered.

**Operating mass**
For the calculation of the operating mass it is necessary to determine the unutilizable fuel mass, liquids and oils present on the aircraft. To do this, Torenbeek considers these weights as a small percentage of the maximum take-off weight.

**Mass of control surfaces**
Also calculating the mass of the control surfaces is difficult but Torenbeek always provides an approximate formulation that considers these weights as a small percentage of the maximum takeoff weight, ie:

$$M_{CS} = 0.4 M_{TO}^{0.684} M_{TO}$$

At this point you have everything you need to move to estimate the position of the center of gravity of the aircraft.
To calculate the center of gravity of the entire aircraft, it is necessary first to estimate the center of gravity of the individual elements of the aircraft.

As a first thing, the reference system is defined: in this case the origin of the reference system is the nose of the aircraft, with x-axis facing from the nose to the tail in the middle of the aircraft, z-axis directed from bottom to top and y-axis facing in such a way that the backhoe turns out to be right-handed.
Then the center of gravity of the individual in components is calculated in such a way as to be able to estimate the overall center of gravity of the aircraft.
the center of gravity of the various components is tested using the Jenkinson formulation:

| Component | Position of the center of gravity |
|---|---|
| Straight wing | At 38-42% of the chord placed at 40% of the semi-span |
| Wing with sweep angle | At 70% of the distance between the front and rear spar to 35% of the semi-span |
| Horizontal tail | At 42% of the chord placed at 38% of the semi-span |
| Vertical tail | At 42% of the chord placed at 38% of the span |
| Vertical T-tail | At 42% of the chord placed at 55% of the span |
| Fuselage (depending on the length) | Single-engined: at 32-35% |
| | Helical multii-engine: at 45-48% |
| | Jet transport (with engines in the wing) |
| | Jet transport (with engines in the tai): at 47-50% |
| Engine nacelles | At 40% of the length of the necelle |
| Landing gear | At the position of the landng gear |
| Engine | From the engine data |
| Installations | Depending on the distribution of the systems: the on-board and avionic instruments in the |

| | |
|---|---|
| | area of the cockpit, the furniture in the passenger area, for the other plants partly destroyed in the position where they are installed. |
| Fuel | At the center of gravity of the tanks |

***Table 84 Jenkinson formulation for the center of gravity of the various components***

Following are the results for the three missions dealt with.

### 3.7.1 Fuselage, Wing and main subsystems integration results

<u>Suborbital flight</u>
For the integration of the components, proceed as indicated in the previous paragraph.
The results are shown below.

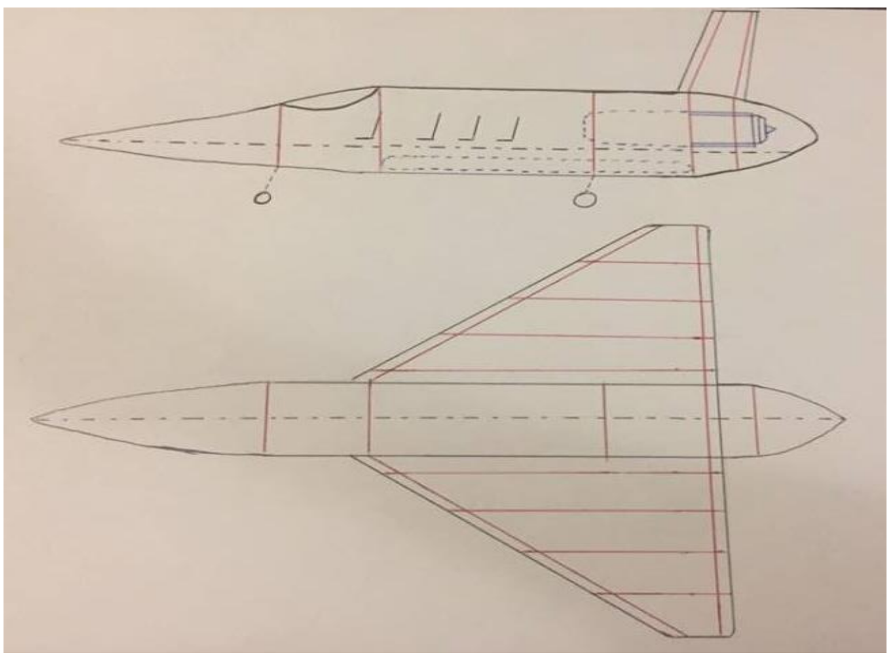


***Figure 68 Fuselage, Wing and main subsystems integration, case of suborbital flight***

Regarding the estimation of the weights and the positioning of the barycenter, the results obtained are as follows.

| **OUTPUT WEIGHTS** | |
|---|---|
| Wing mass | 4297,79353 |
| Mass of vertical empennage | 12,9944858 |
| Mass of the fuselage | 5893,9834 |
| Mass of principal landing gear | 940,229372 |
| Mass of anterior landing gear | 200,865887 |

| | |
|---|---|
| Tail wheel mass | 89,301312 |
| Mass of the engine nacelles | 2040 |
| Mass of the propulsion system | 2714 |
| Mass of installed systems | 3000 |
| Mass of passenger | 540 |
| Mass of crew member | 186 |
| Operating mass | 157,230994 |
| Mass of fuel | 7546,06705 |
| Mass control surfaces | 441,168242 |

***Table 85 Estimation of the weights, case of suborbital flight***

For a better understanding of weight distribution, both pie and histogram charts have been developed.

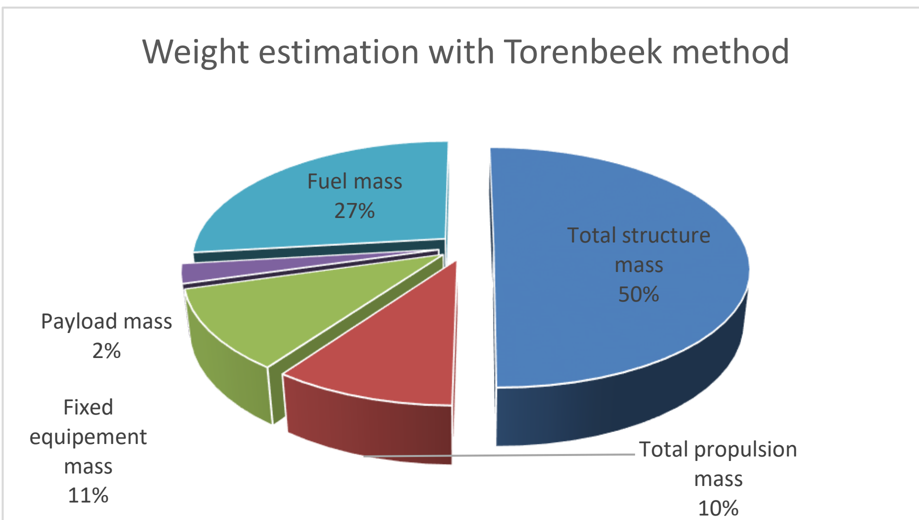



***Figure 69 Pei chart weight estimation with Torenbeek method, case of suborbital flight***

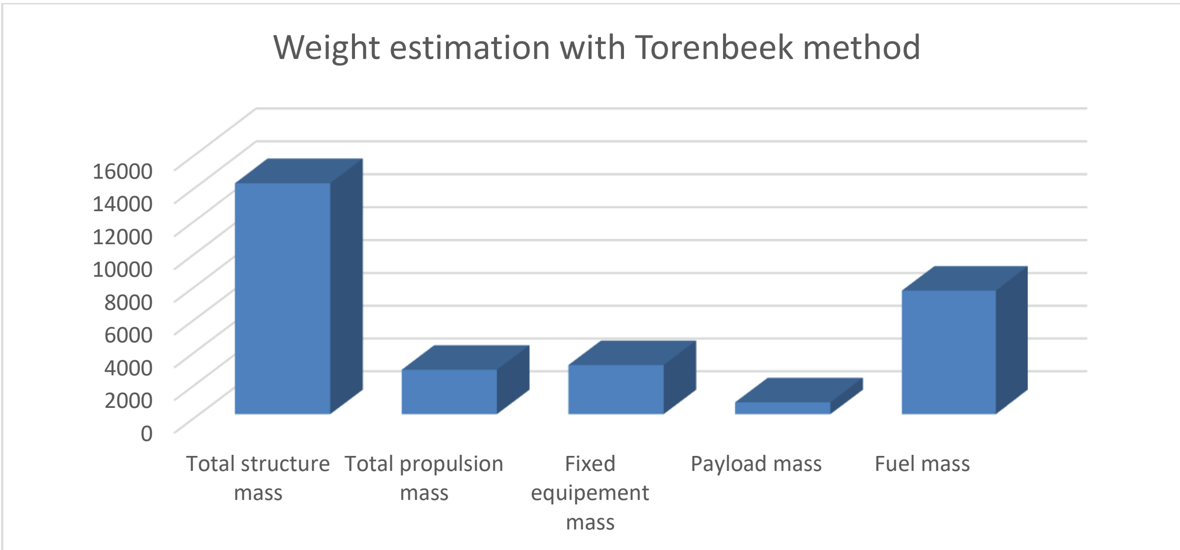



***Figure 70 Weight estimation with Torenbeek method, case of suborbital flight***

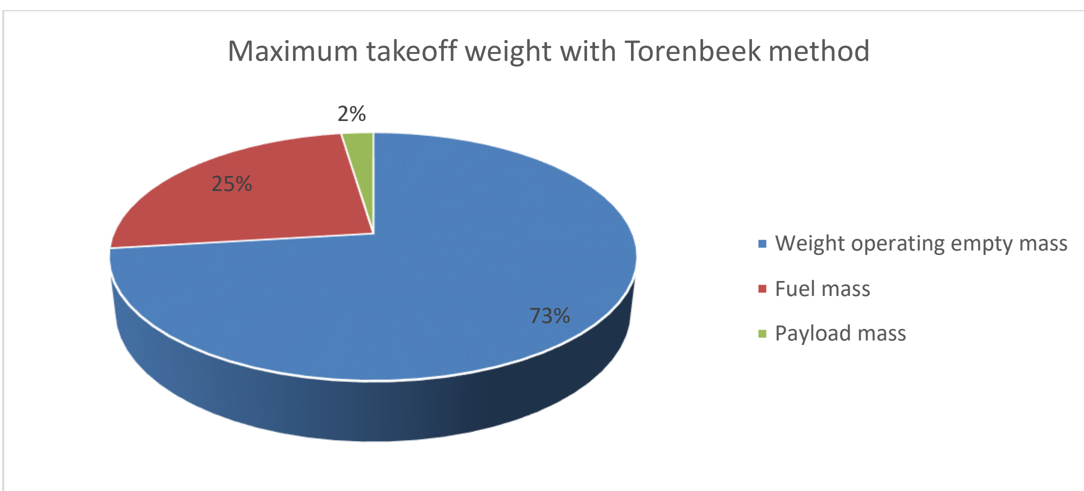



***Figure 71 Pei chart maximum takeoff weight with Torenbeek method, case of suborbital flight***

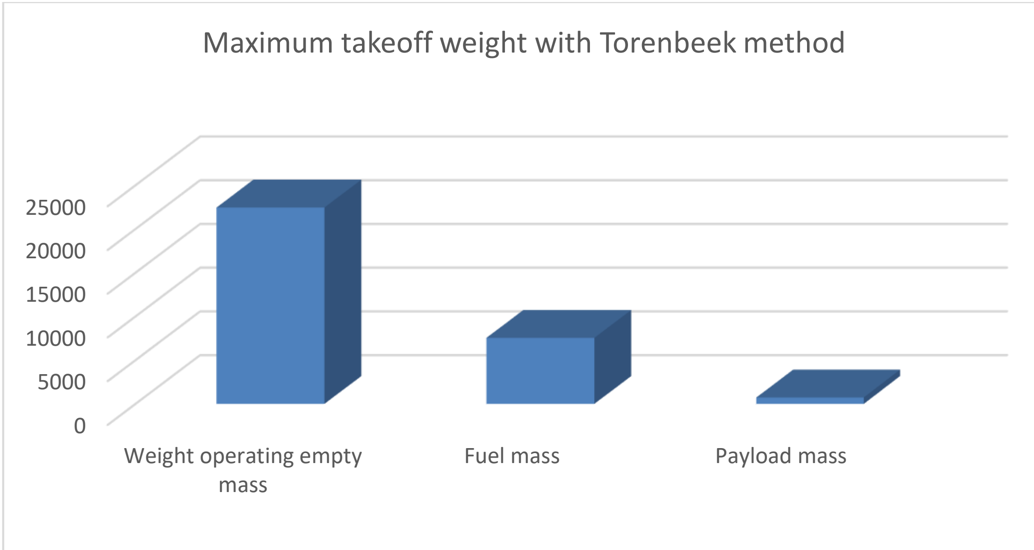



*Figure 72 Maximum takeoff weight with Torenbeek method, case of suborbital flight*

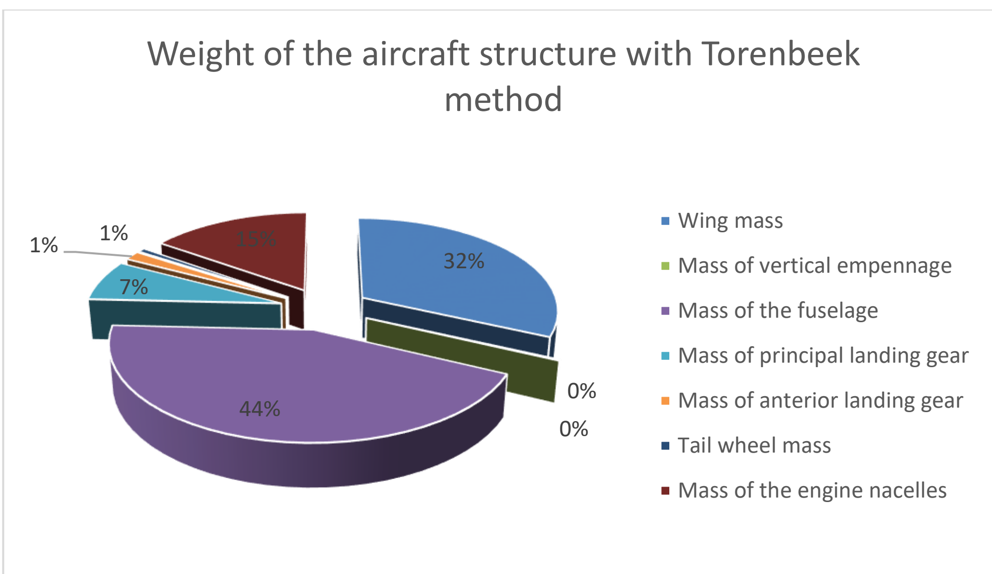



*Figure 73 Pei chart weight of the aircraft structure with Torenbeek method, case of suborbital flight*

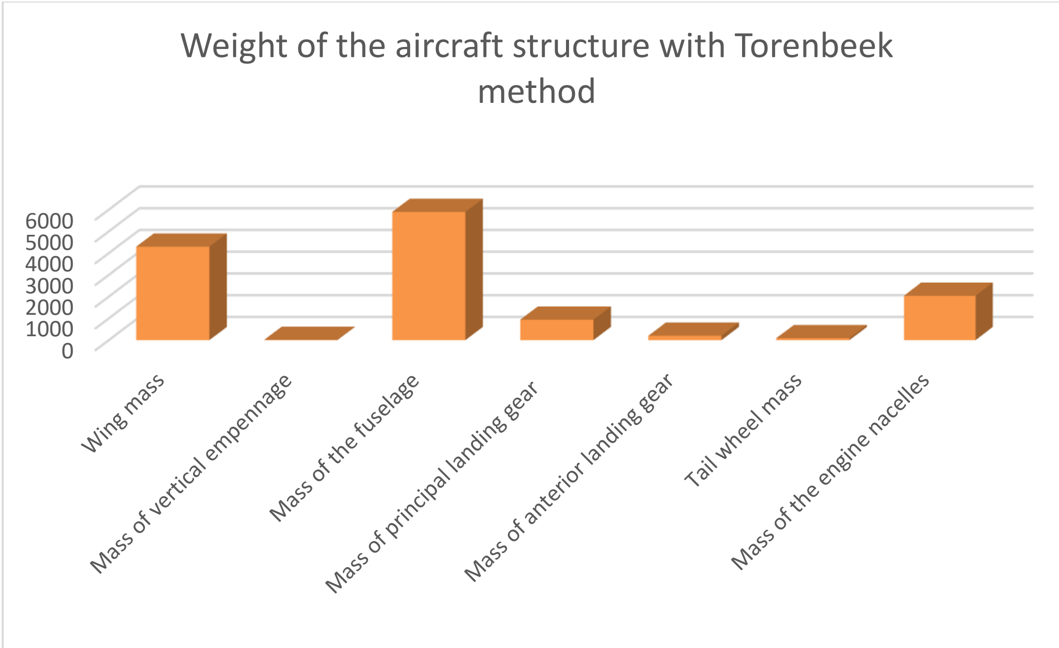



*Figure 74 Weight of the aircraft structure with Torenbeek method, case of suborbital flight*

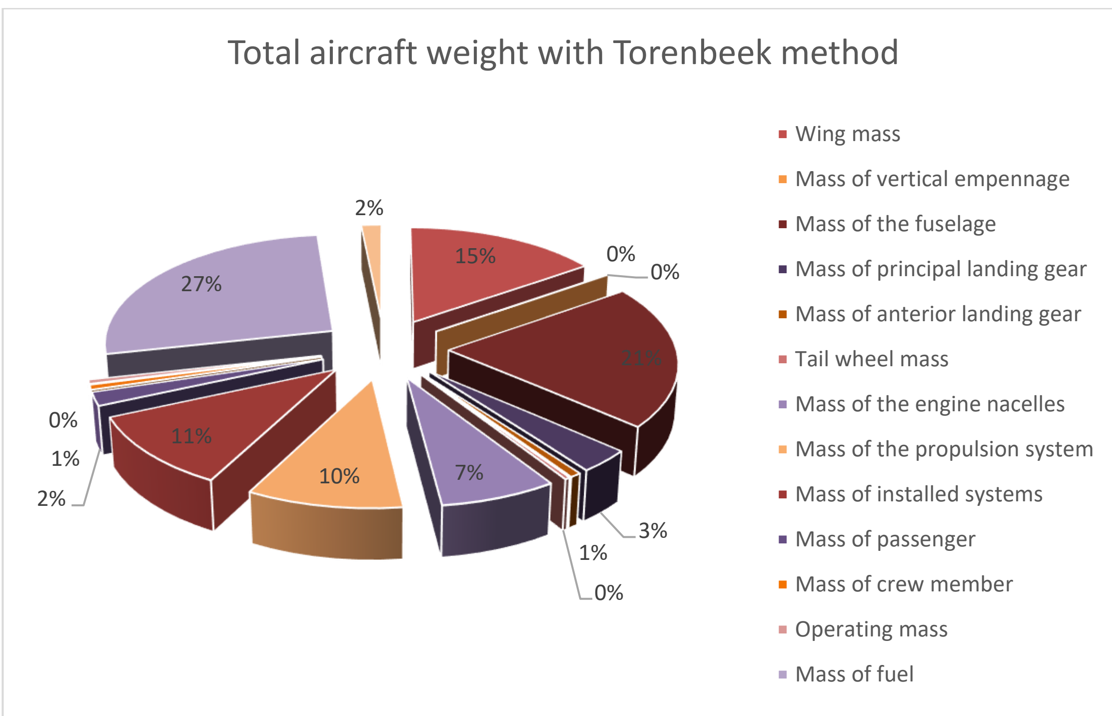



*Figure 75 Pei chart total weight with Torenbeek method, case of suborbital flight*

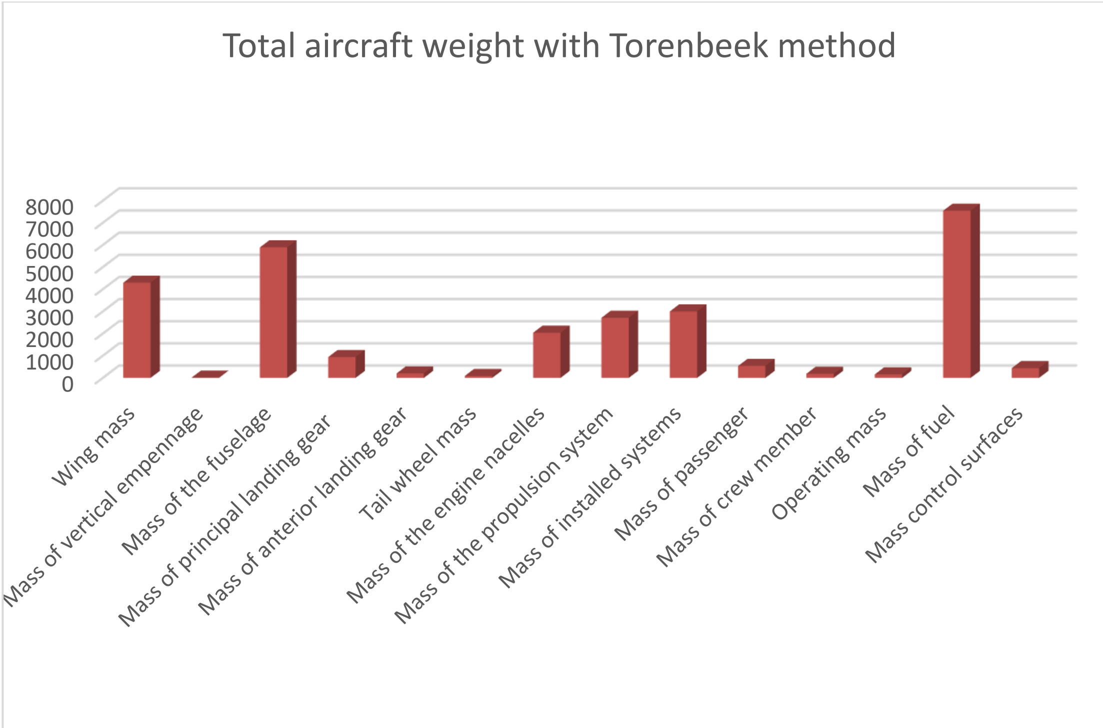



***Figure 76 Total weight with Torenbeek method, case of suborbital flight***

At this point the position of the center of gravity is calculated. Proceed following the instructions in the previous paragraph.
The results obtained are shown below.

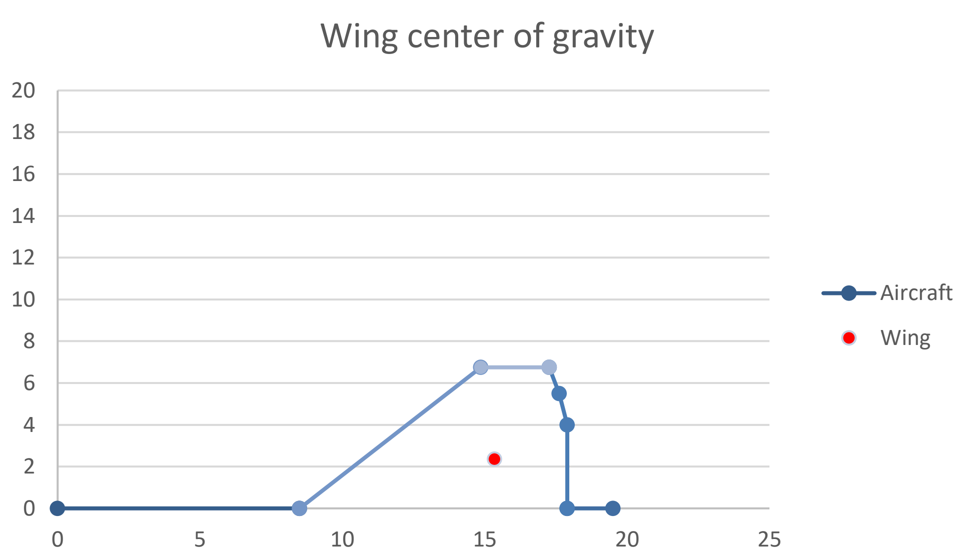



***Figure 77 Wing center of gravity, case of suborbital flight***

All the values of the barycenters of the individual components of the aircraft were then defined. Of which there is also a graphic visualization:

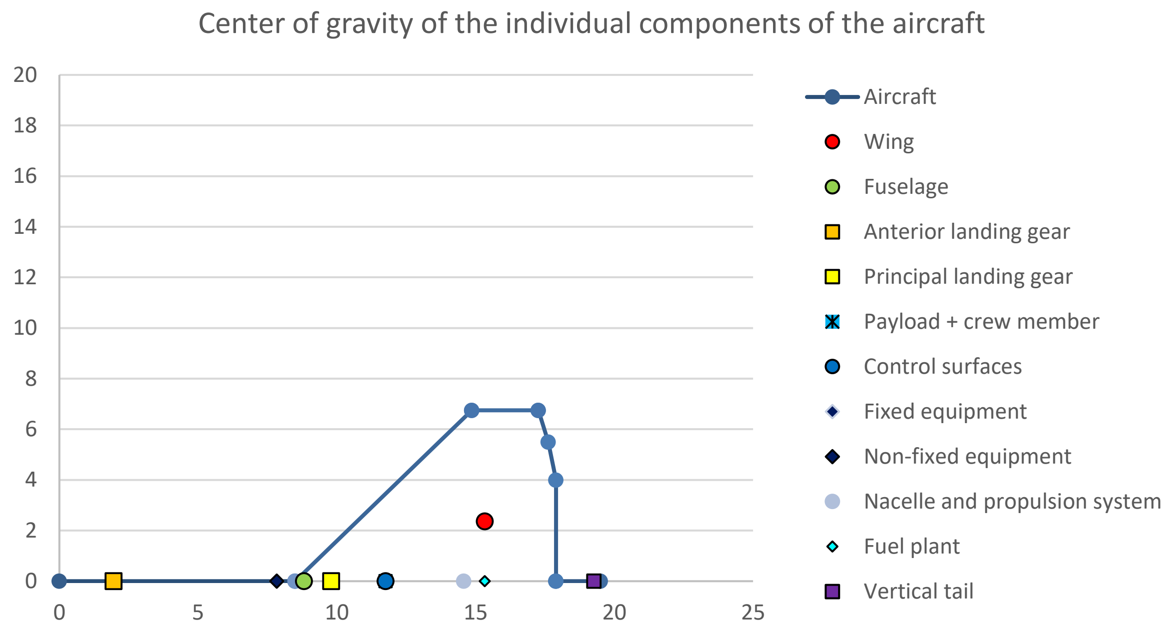



***Figure 78 Center of gravity of the individual components of the aircraft, case of suborbital flight***

From these values it is possible to calculate the overall center of gravity of the aircraft using the following formulas:

$$X_{CG} = \frac{\sum m_i * X_i}{\sum m_i}$$

$$Y_{CG} = \frac{\sum m_i * Y_i}{\sum m_i}$$

$$Z_{CG} = \frac{\sum m_i * Z_i}{\sum m_i}$$

Where:

- $m_i$ = mass of the single component
- $X_i$ , $Y_i$ , $Z_i$ = values of the center of gravity referred to the single component

from which it is derived:

$$X_{CG} = 10.020638 \text{ m}$$
$$Y_{CG} = 0 \text{ m}$$
$$Z_{CG} = -0.1629259 \text{ m}$$

There is also a graphical view of the position of the overall center of gravity of the aircraft:

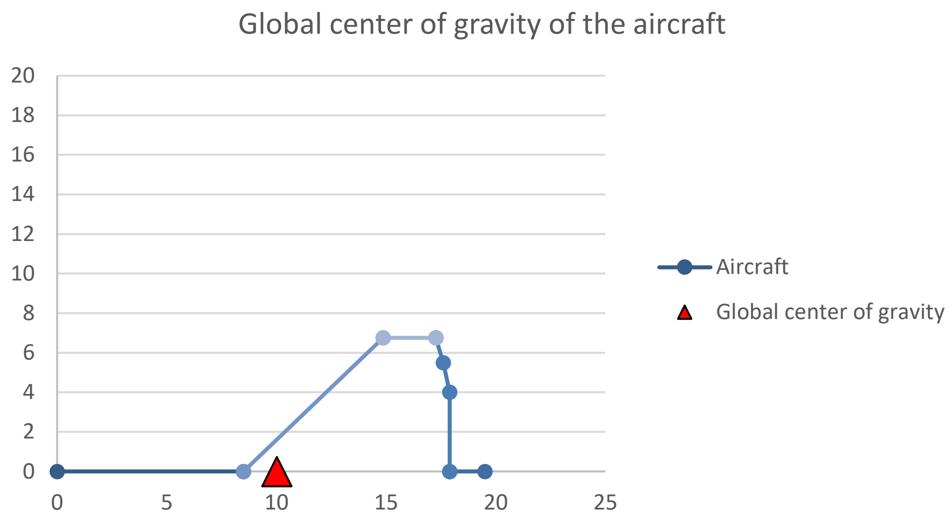



***Figure 79 Global center of gravity of the aircraft, case of suborbital flight***

Point to point mission
For the integration of the components, proceed as indicated in the previous paragraph.
The results are shown below.

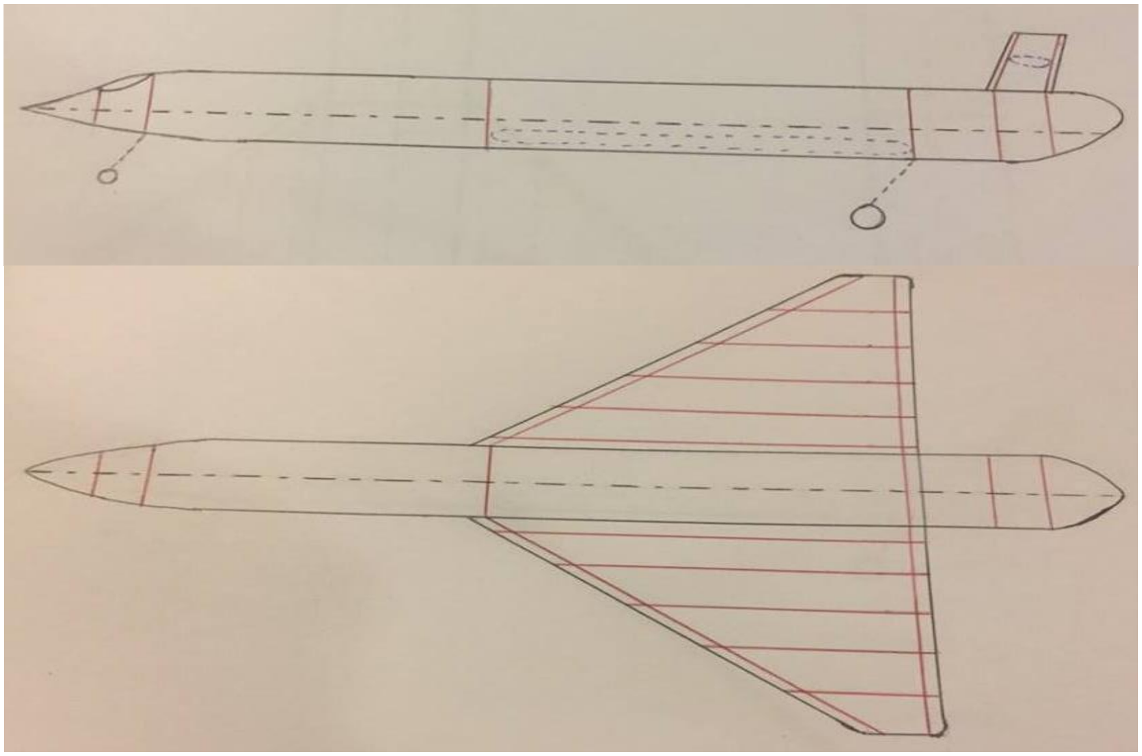


*Figure 80 Fuselage, Wing and main subsystems integration, case of point to point mission*

Regarding the estimation of the weights and the positioning of the barycenter, the results obtained are as follows.

| OUTPUT WEIGHTS | |
|---|---|
| Wing mass | 10587,1505 |
| Mass of horizontal empennage | 1111,07734 |
| Mass of vertical empennage | 1768,47813 |
| Mass of fuselage | 13214,2432 |
| Mass of principal landing gear | 3137,35174 |
| Mass of anterior landing gear | 533,128414 |
| Tail wheel mass | 292,571225 |
| Mass of the engine nacelles | 6188 |
| Mass of the propulsion system | 2714 |
| Mass of installed systems | 3000 |
| Mass of passenger | 14400 |
| Mass of crew member | 438 |

| | |
|---|---|
| Operating mass | 2574,27384 |
| Mass of fuel | 32671,7785 |
| Mass control surfaces | 1005,83448 |

***Table 86 Estimation of the weights, case of point to point mission***

For a better understanding of weight distribution, both pie and histogram charts have been developed.

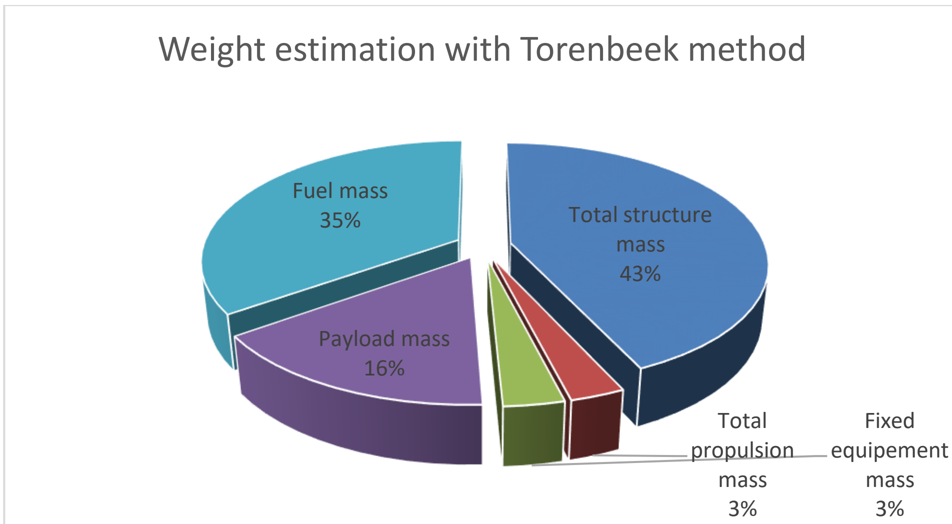



***Figure 81 Pei chart weight estimation with Torenbeek method, case of point to point mission***

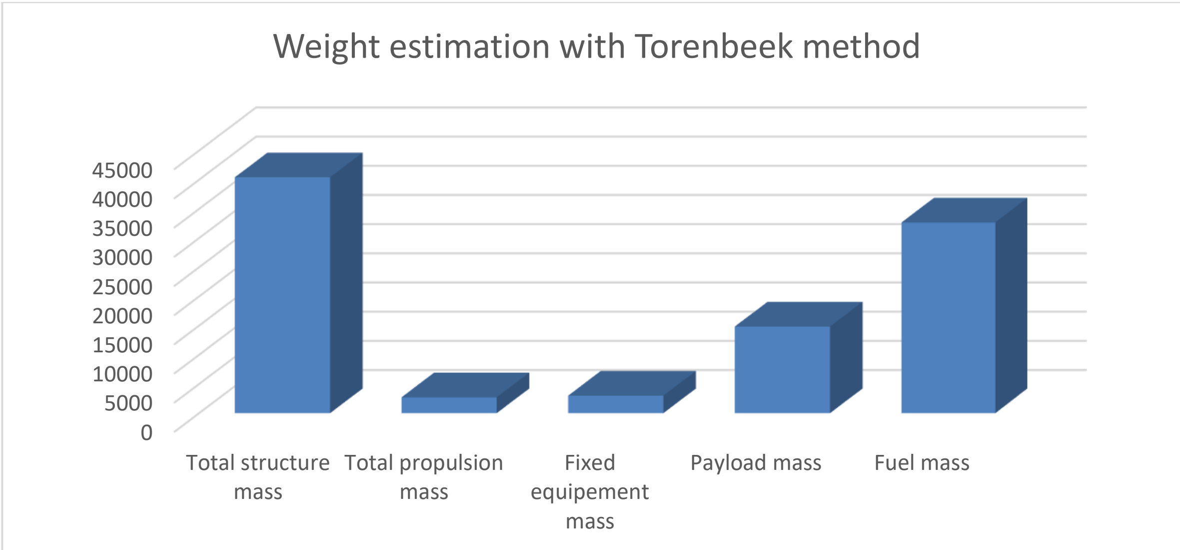



***Figure 82 Weight estimation with Torenbeek method, case of point to point mission***

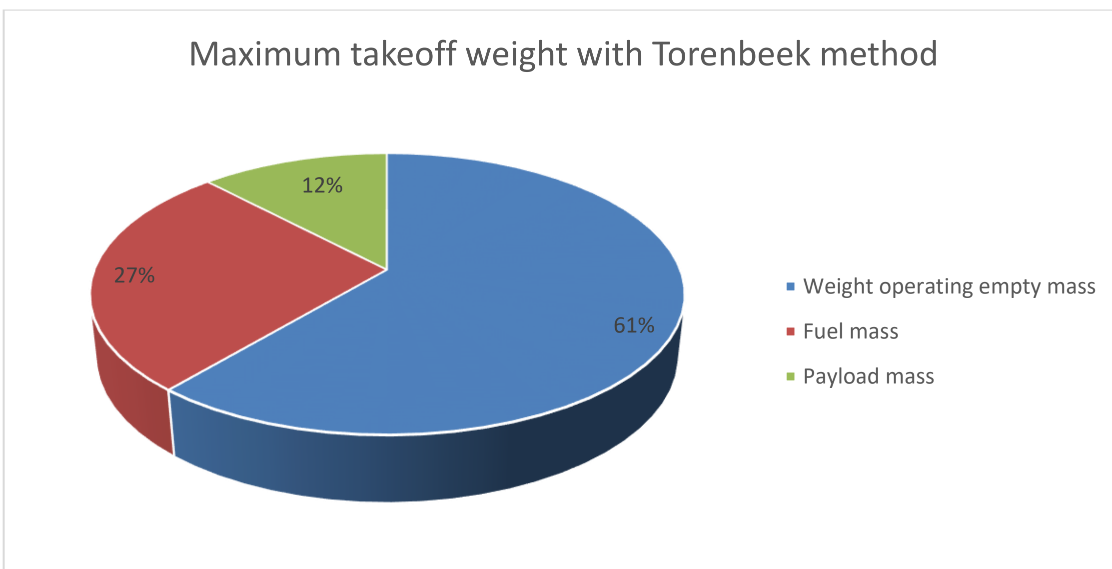



***Figure 83 Pei chart maximum takeoff weight with Torenbeek method, case of point to point mission***

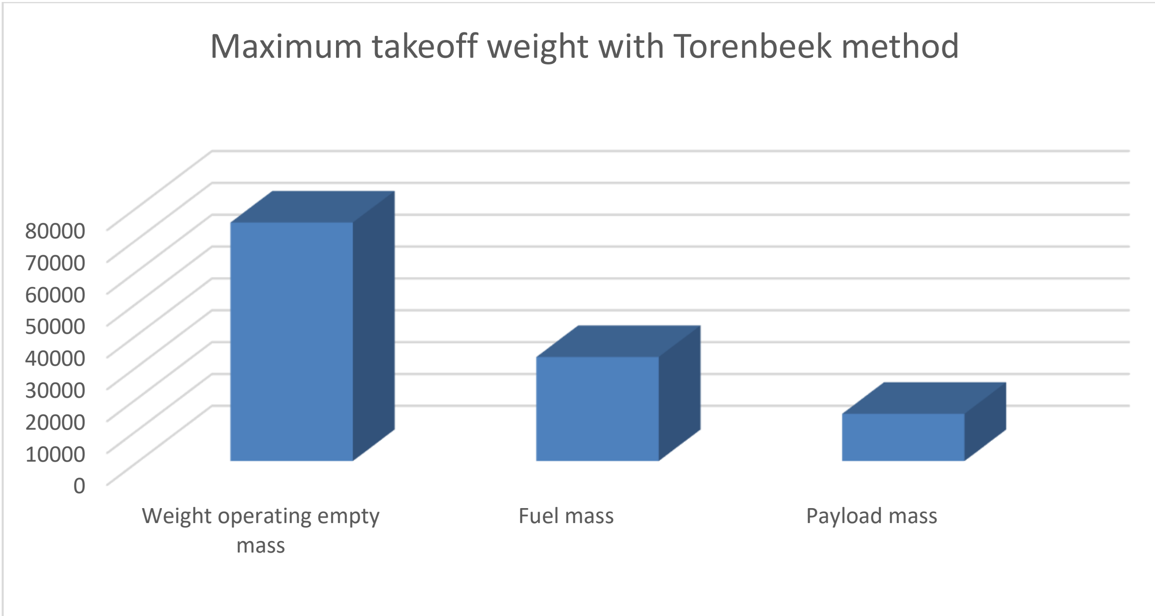



***Figure 84 Maximum takeoff weight with Torenbeek method, case of point to point mission***

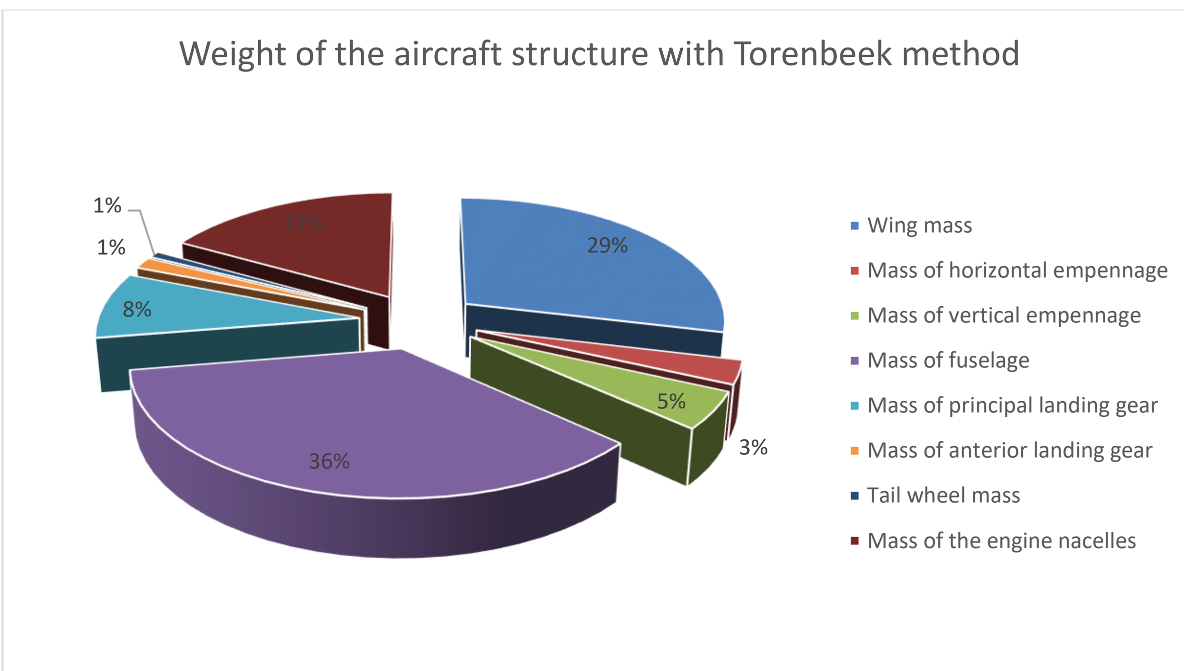



***Figure 85 Pei chart weight of the aircraft structure with Torenbeek method, case of point to point mission***

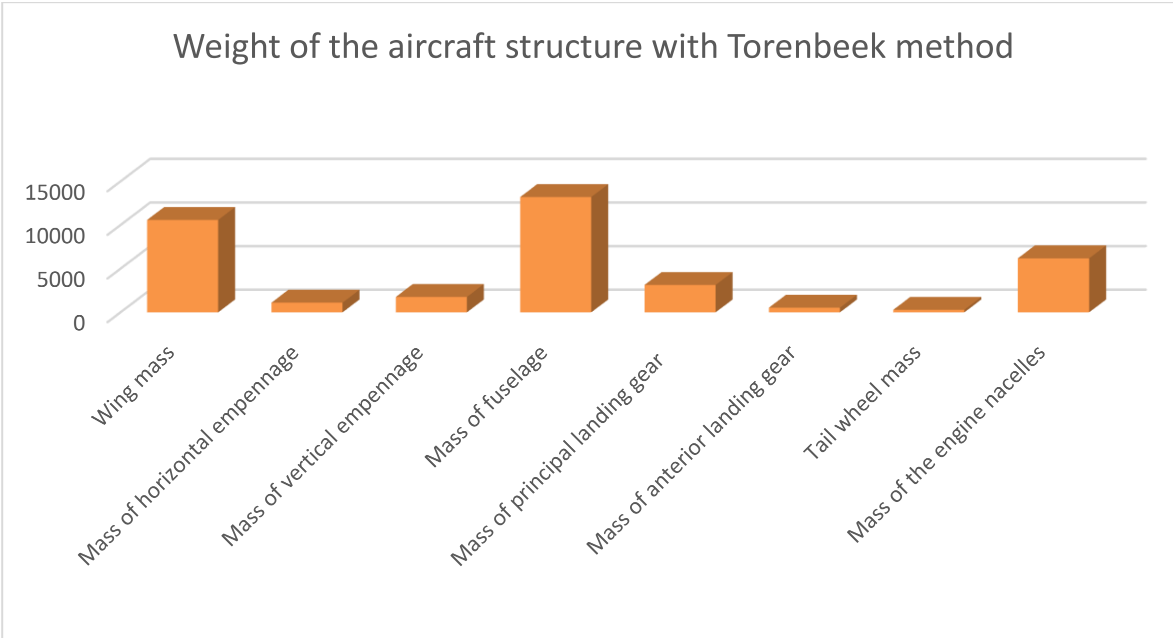



***Figure 86 Weight of the aircraft structure with Torenbeek method, case of point to point mission***

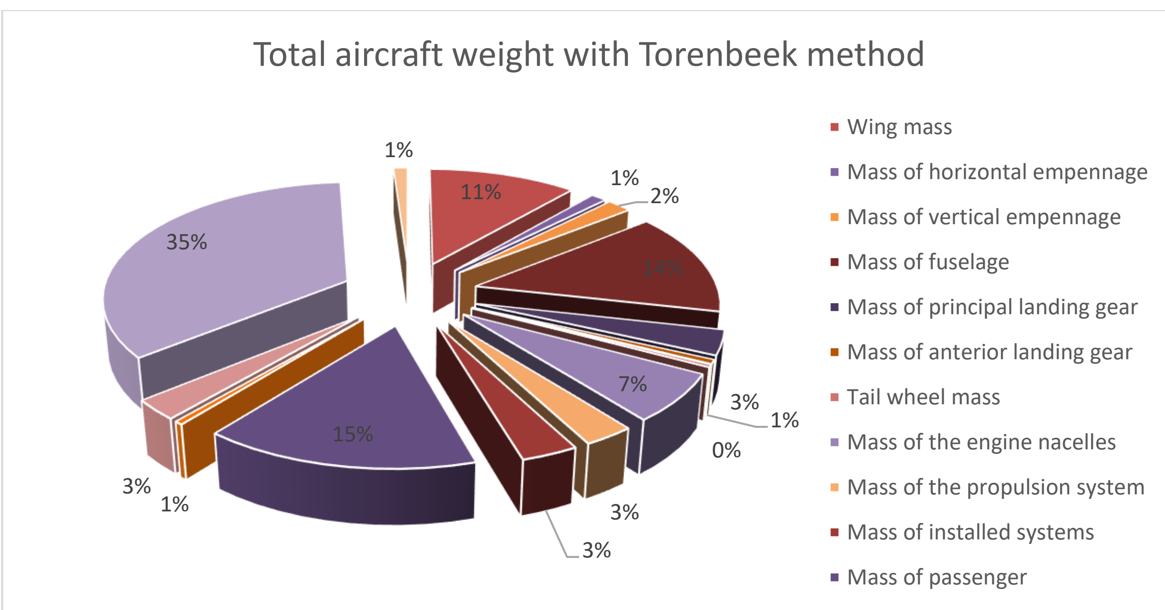



***Figure 87 Pei chart total weight with Torenbeek method, case of point to point mission***

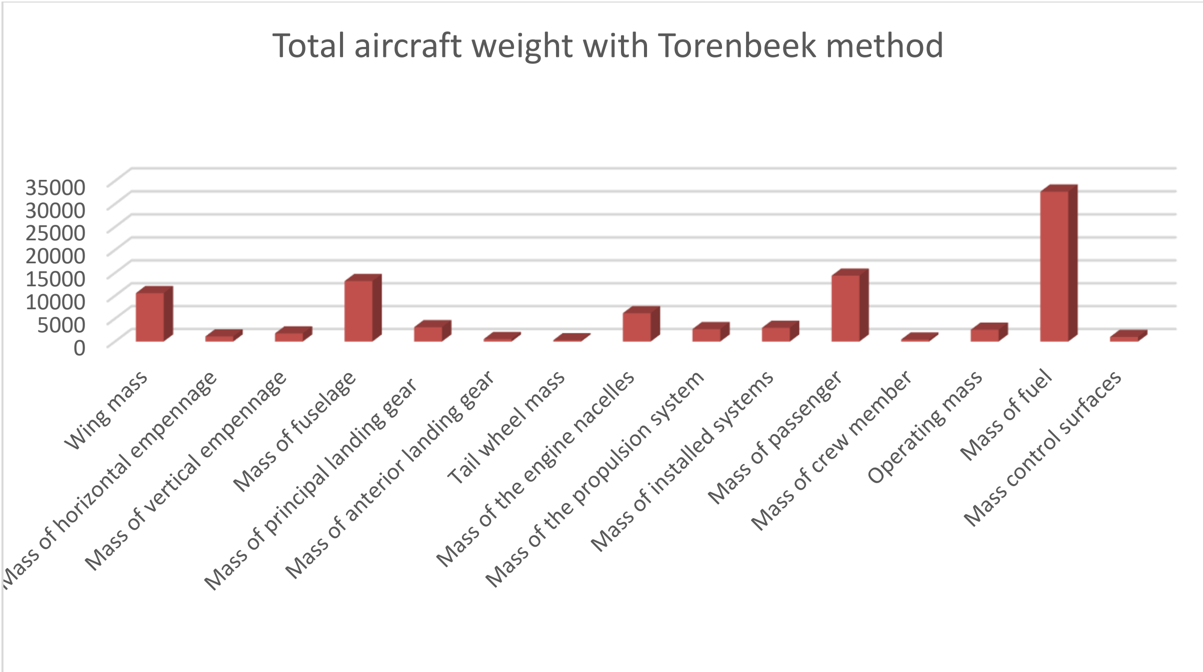



*Figure 88 Total weight with Torenbeek method, case of point to point mission*

At this point the position of the center of gravity is calculated. Proceed following the instructions in the previous paragraph.
The results obtained are shown below.

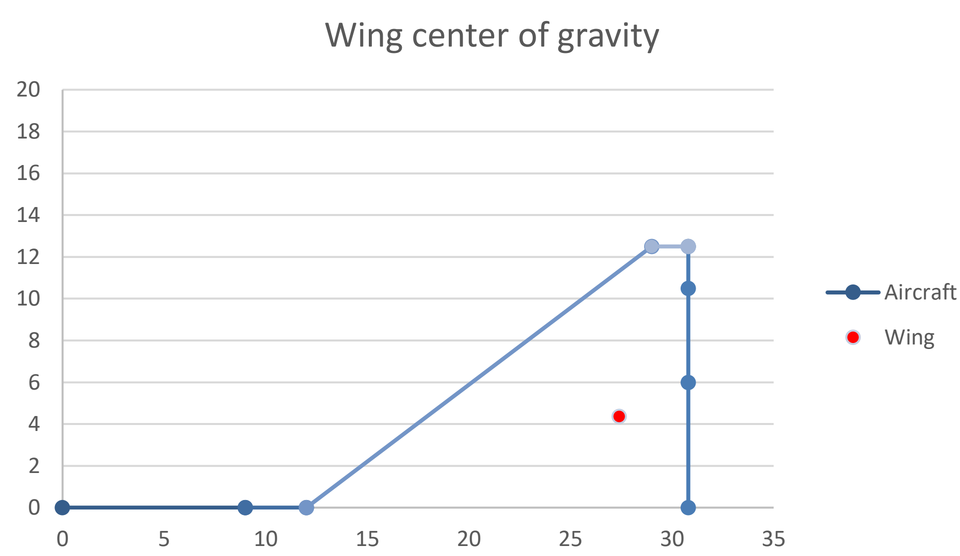



*Figure 89 Wing center of gravity, case of point to point mission*

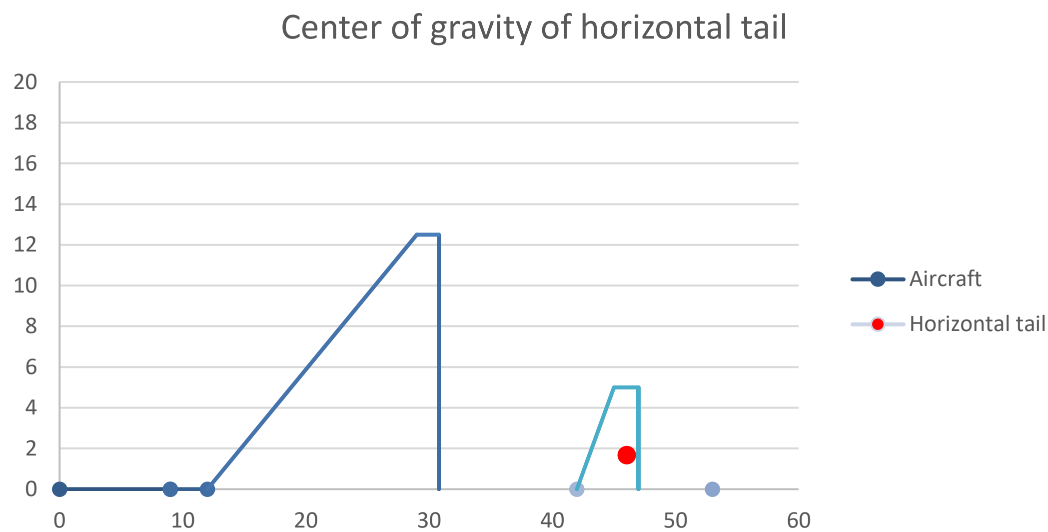



***Figure 90 Horizontal tail center of gravity, case of point to point mission***

All the values of the barycenters of the individual components of the aircraft were then defined. Of which there is also a graphic visualization:

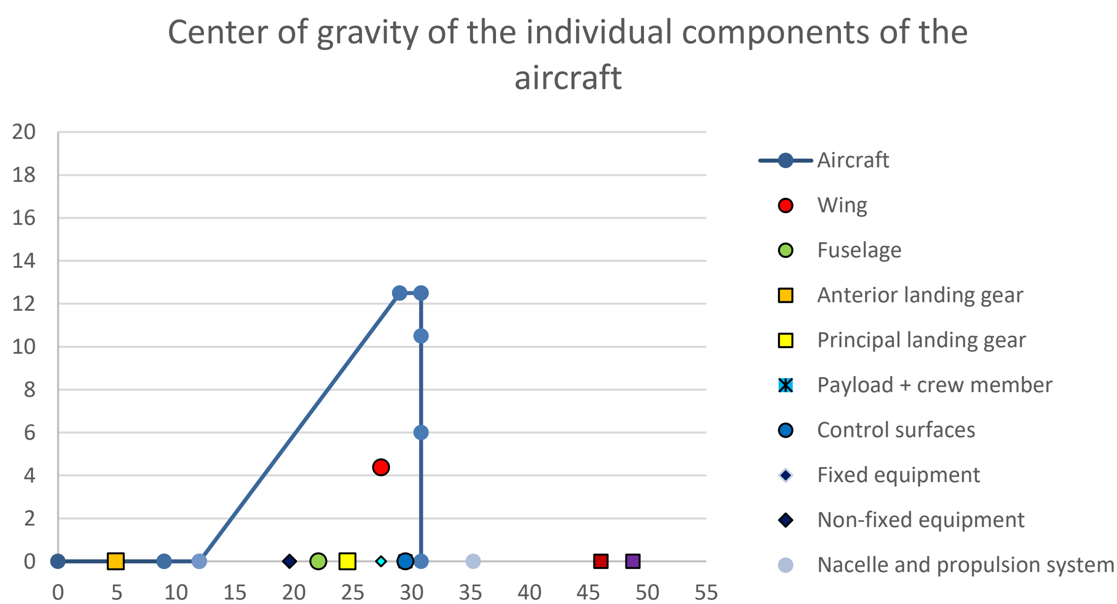



***Figure 91 Center of gravity of the individual components of the aircraft, case of point to point mission***

From these values it is possible to calculate the overall center of gravity of the aircraft using the following formulas:

$$X_{CG} = \frac{\sum m_i * X_i}{\sum m_i}$$

$$Y_{CG} = \frac{\sum m_i * Y_i}{\sum m_i}$$

$$Z_{CG} = \frac{\sum m_i * Z_i}{\sum m_i}$$

Where:

- $m_i$ = mass of the single component
- $X_i$ , $Y_i$ , $Z_i$ = values of the center of gravity referred to the single component

from which it is derived:

$$X_{CG} = 21.004179 \text{ m}$$
$$Y_{CG} = 0 \text{ m}$$
$$Z_{CG} = 0.2092686 \text{ m}$$

There is also a graphical view of the position of the overall center of gravity of the aircraft

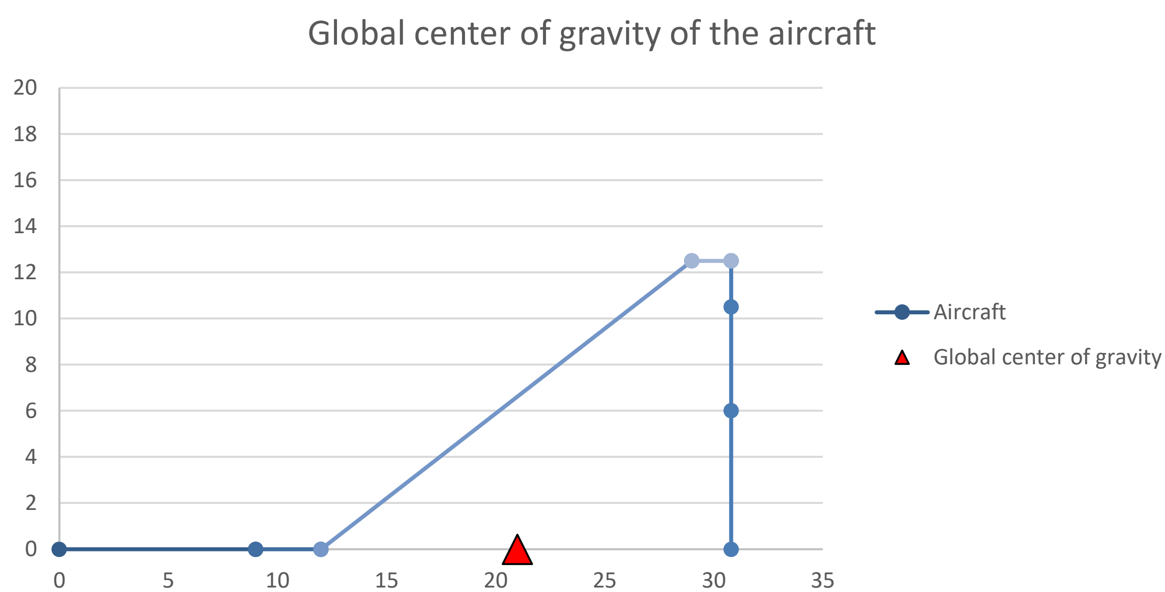



***Figure 92 Global center of gravity of the aircraft, case of point to point mission***

Reusable launcher

For the integration of the components, proceed as indicated in the previous paragraph.
The results are shown below.

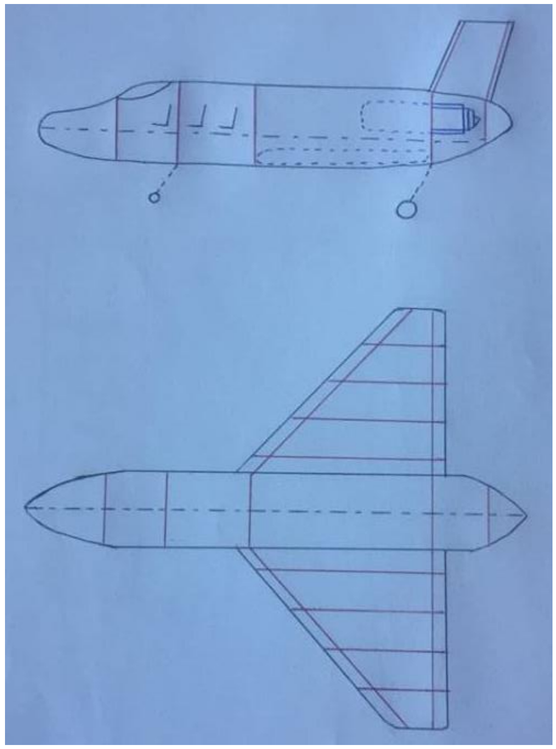


***Figure 93 Fuselage, Wing and main subsystems integration, case of reusable launcher***

Regarding the estimation of the weights and the positioning of the barycenter, the results obtained are as follows.

| **OUTPUT WEIGHTS** | |
|---|---|
| Wing mass | 2285,3701 |
| Mass of vertical empennage | 649,724288 |
| Mass of the fuselage | 2256,54803 |
| Mass of principal landing gear | 575,821192 |
| Mass of anterior landing gear | 135,943702 |
| Tail wheel mass | 54,0553871 |
| Mass of the engine nacelles | 1020 |
| Mass of the propulsion system | 2714 |
| Mass of installed systems | 3000 |
| Mass of passenger | 360 |
| Mass of crew member | 186 |

| | |
|---|---|
| Operating mass | 94,5841848 |
| Mass of fuel | 2787,38743 |
| Mass control surfaces | 309,253196 |

***Table 87 Estimation of the weights, case of reusable launcher***

For a better understanding of weight distribution, both pie and histogram charts have been developed.

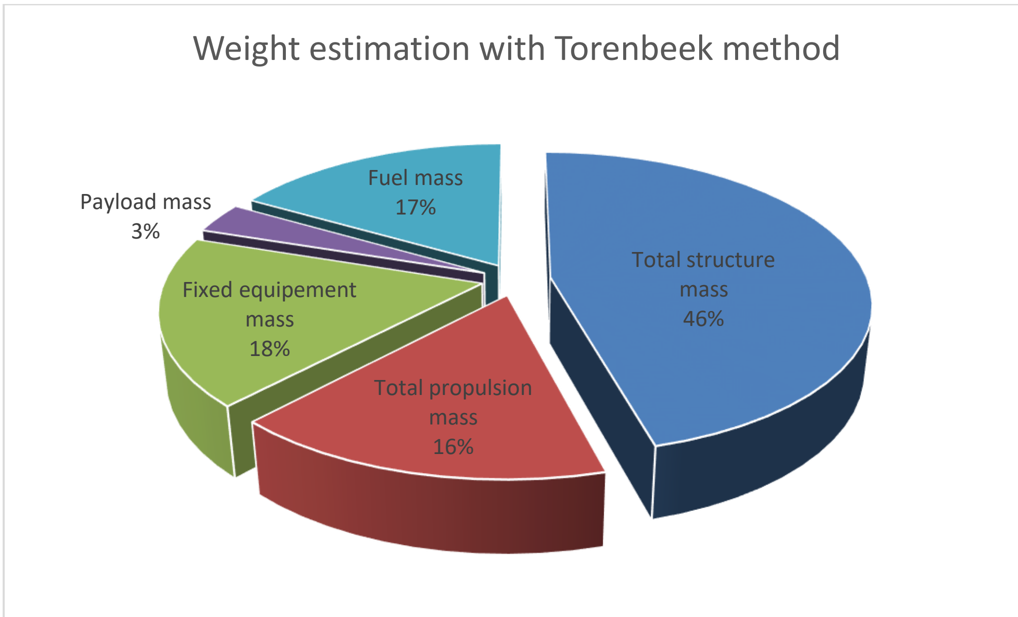



***Figure 94 Pei chart weight estimation with Torenbeek method, case of reusable launcher***

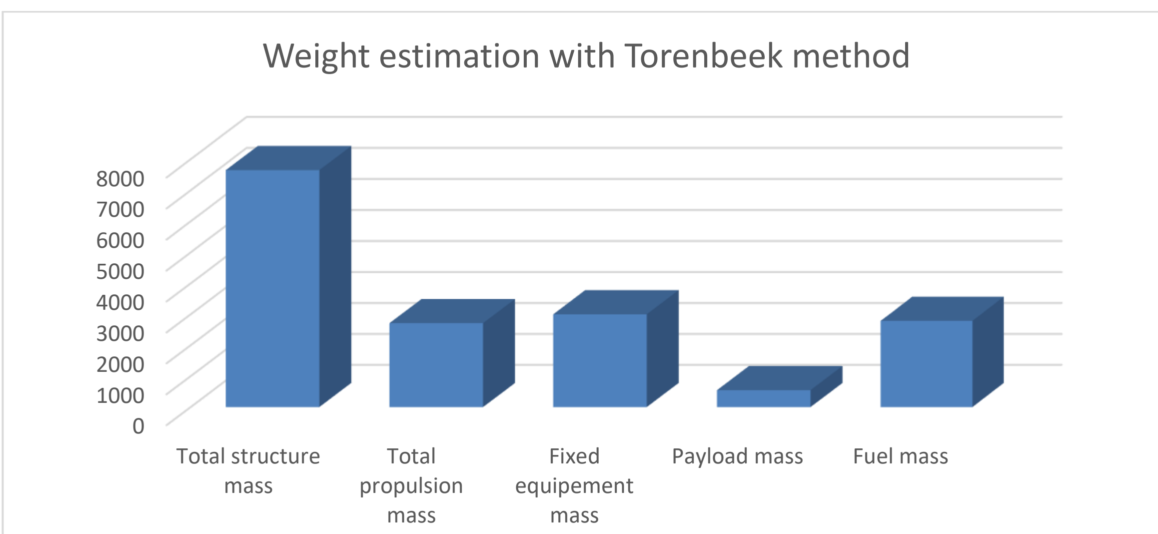



***Figure 95 Weight estimation with Torenbeek method, case of reusable launcher***

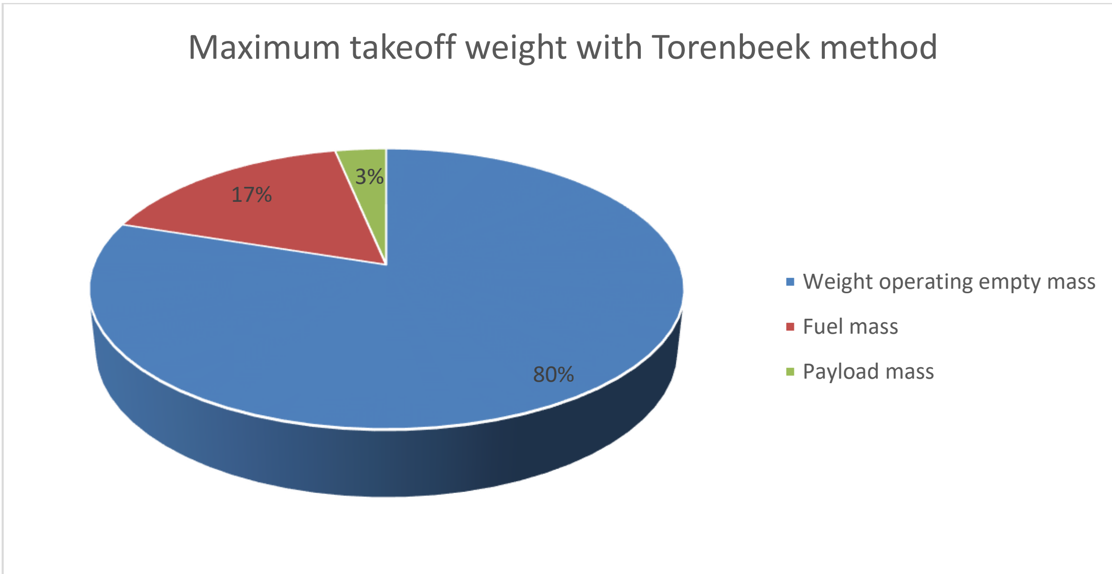



***Figure 96 Pei chart maximum takeoff weight with Torenbeek method, case of reusable launcher***

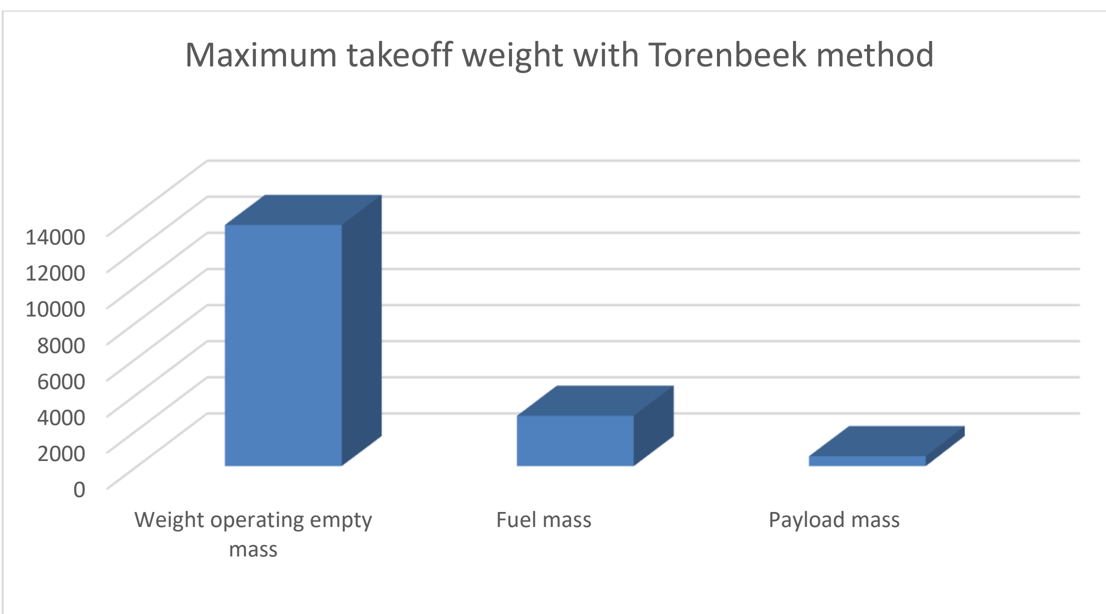



***Figure 97 Maximum takeoff weight with Torenbeek method, case of reusable launcher***

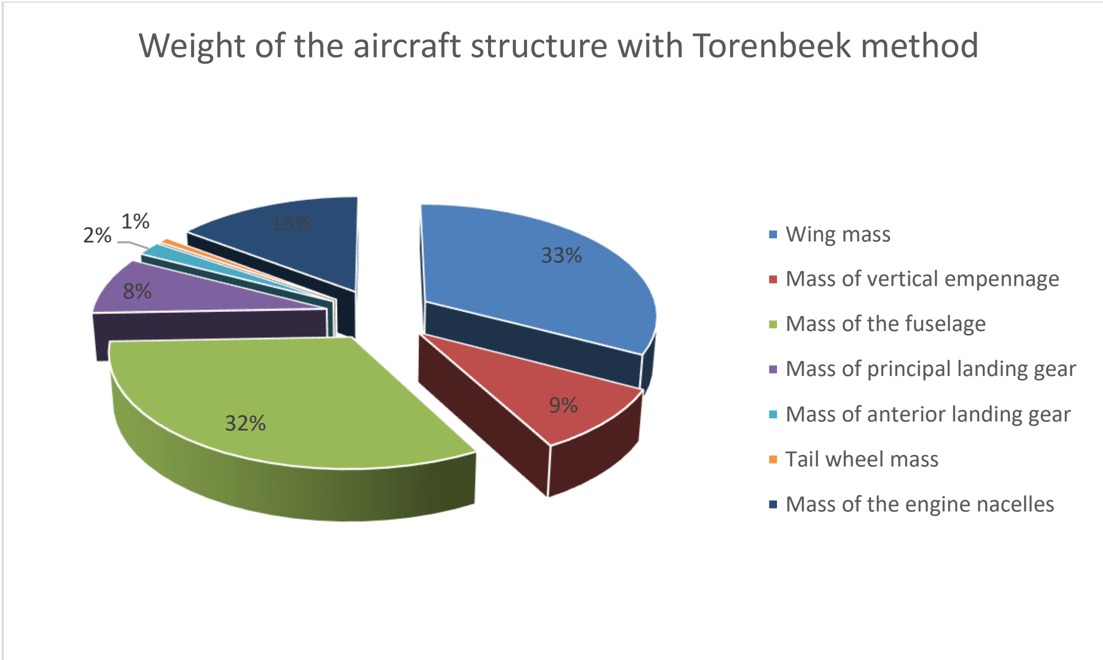



*Figure 98 Pei chart weight of the aircraft structure with Torenbeek method, case of reusable launcher*

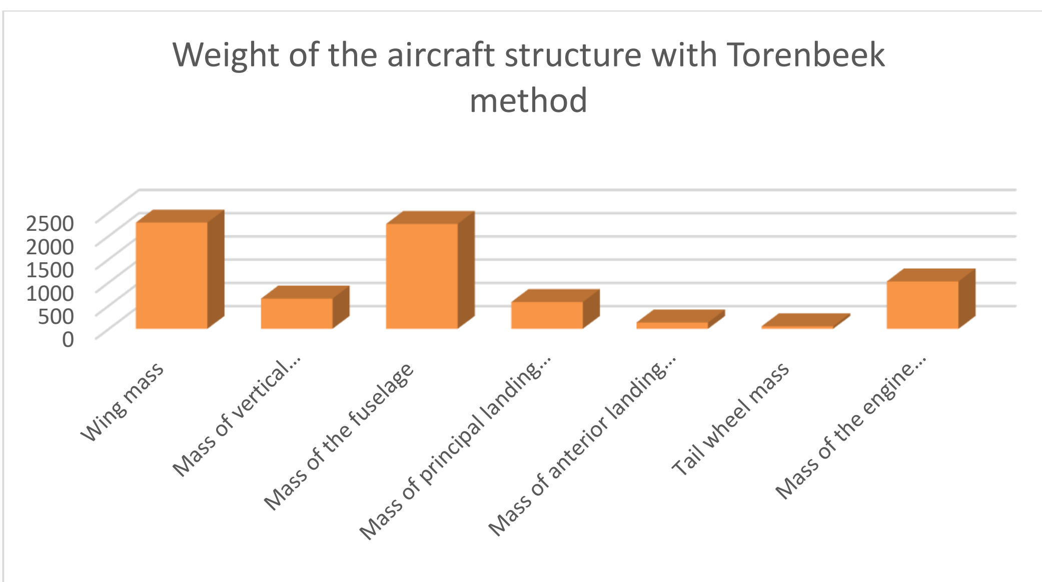



*Figure 99 Pei chart weight of the aircraft structure with Torenbeek method, case of reusable launcher*

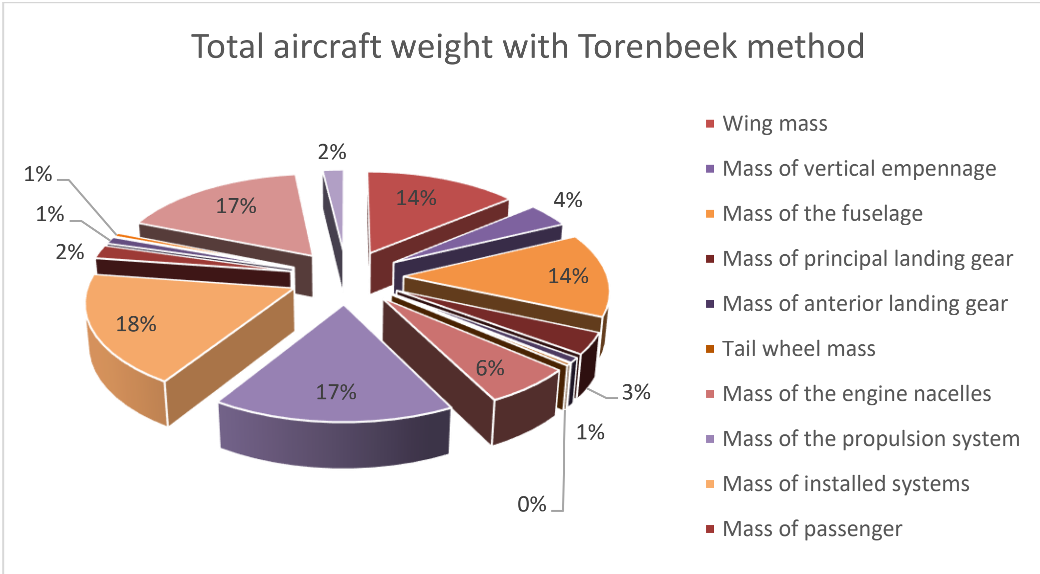



*Figure 100 Pei chart total weight with Torenbeek method, case of reusable launcher*

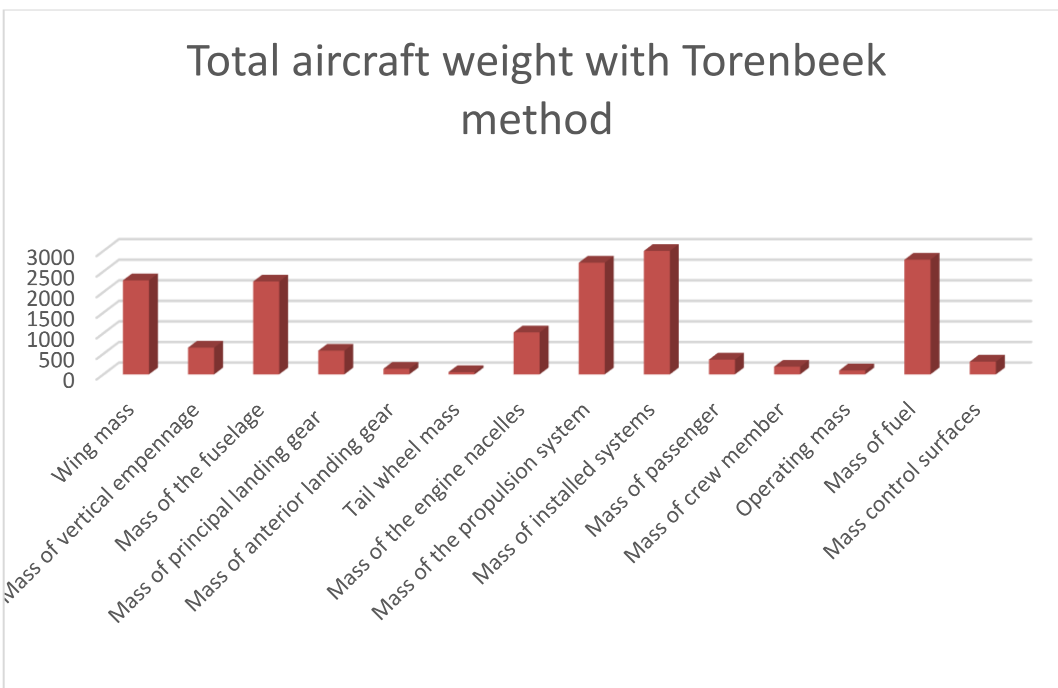



*Figure 101 Total weight with Torenbeek method, case of reusable launcher*

At this point the position of the center of gravity is calculated. Proceed following the instructions in the previous paragraph.
The results obtained are shown below.

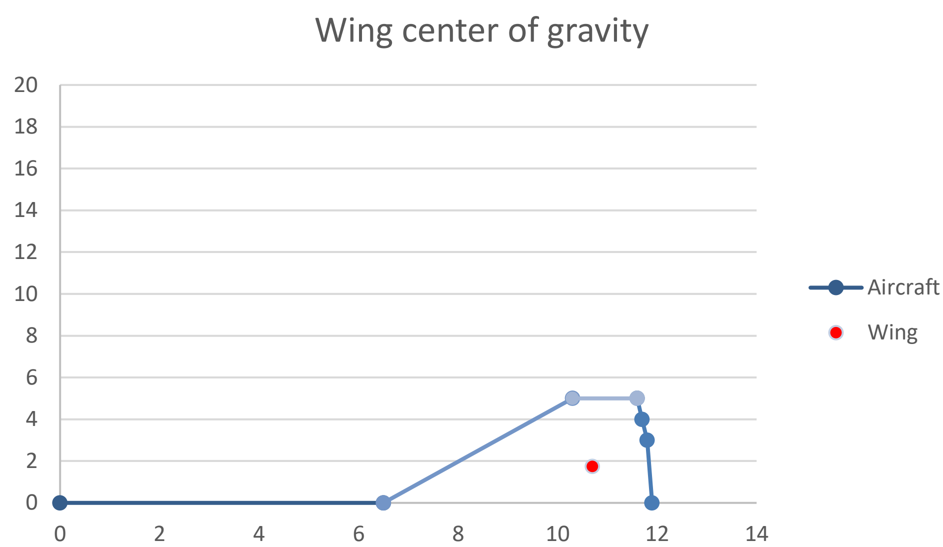



***Figure 102 Wing center of gravity, case of reusable launcher***

All the values of the barycenters of the individual components of the aircraft were then defined. Of which there is also a graphic visualization:

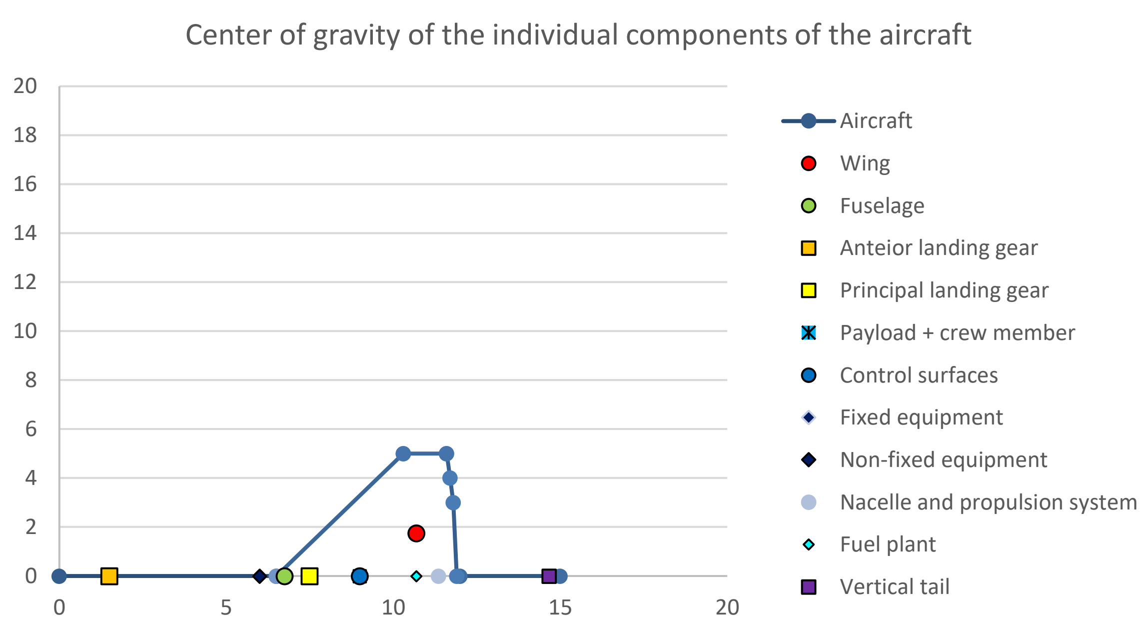



***Figure 103 Center of gravity of the individual components of the aircraft, case of reusable launcher***

From these values it is possible to calculate the overall center of gravity of the aircraft using the following formulas:

$$X_{CG} = \frac{\sum m_i * X_i}{\sum m_i}$$

$$Y_{CG} = \frac{\sum m_i * Y_i}{\sum m_i}$$

$$Z_{CG} = \frac{\sum m_i * Z_i}{\sum m_i}$$

Where:

- $m_i$ = mass of the single component
- $X_i$ , $Y_i$ , $Z_i$ = values of the center of gravity referred to the single component

from which it is derived:

$$X_{CG} = 8.16029465 \text{ m}$$
$$Y_{CG} = 0 \text{ m}$$
$$Z_{CG} = -0.2274364 \text{ m}$$

There is also a graphical view of the position of the overall center of gravity of the aircraft

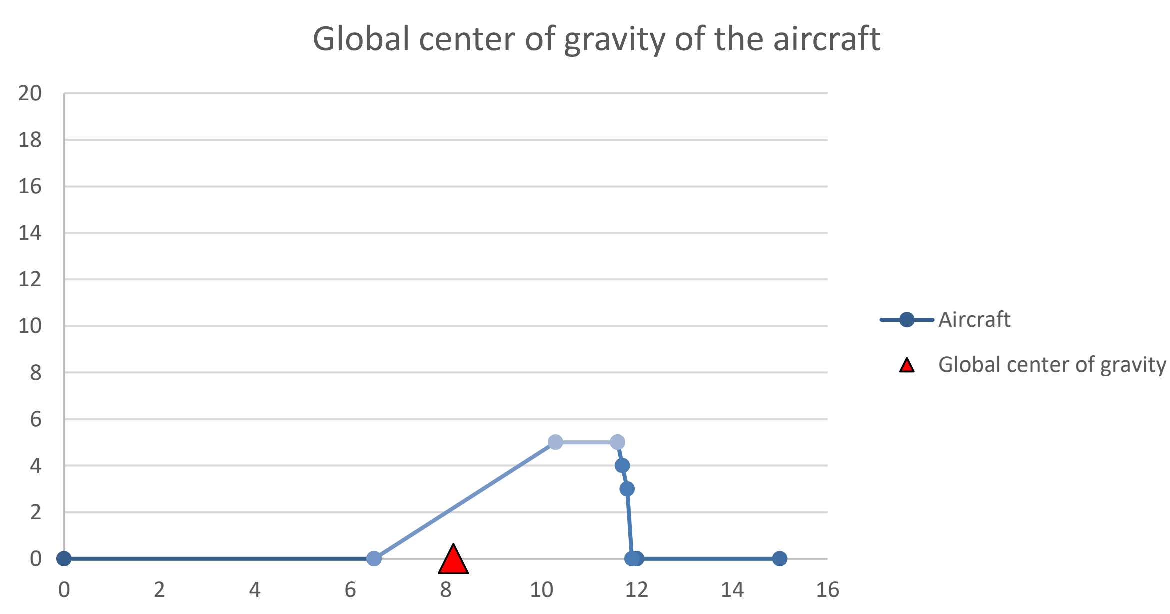



***Figure 104 Global center of gravity of the aircraft, case of reusable launcher***

Reusable launcher
For the integration of the components, proceed as indicated in the previous paragraph.
The results are shown below.

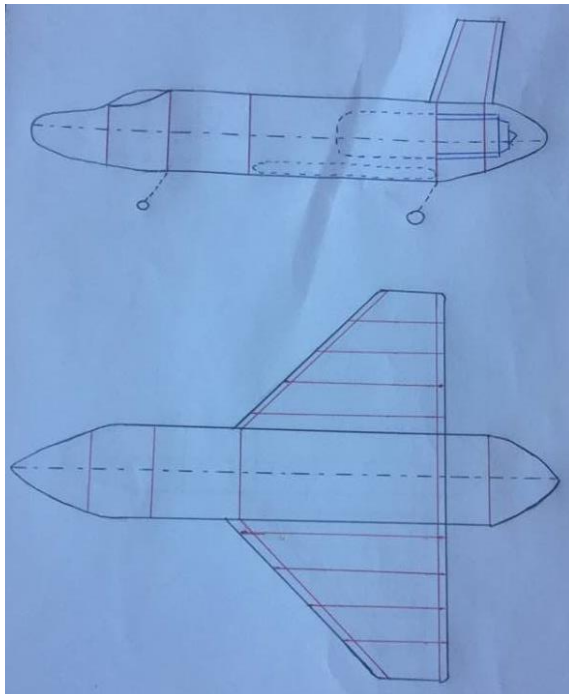


*Figure 105 Fuselage, Wing and main subsystems integration, case of reusable launcher*

Regarding the estimation of the weights and the positioning of the barycenter, the results obtained are as follows.

| OUTPUT WEIGHTS | |
|---|---|
| Wing mass | 3757,88794 |
| Mass of vertical empennage | 12,9944858 |
| Mass of the fuselage | 4779,58335 |
| Mass of principal landing gear | 959,790425 |
| Mass of anterior landing gear | 204,200005 |
| Tail wheel mass | 91,1842575 |
| Mass of the engine nacelles | 1768 |
| Mass of the propulsion system | 2714 |
| Mass of installed systems | 3000 |
| Mass of passenger | 6000 |
| Mass of crew member | 0 |
| Operating mass | 80,1554775 |
| Mass of fuel | 4851,55503 |
| Mass control surfaces | 447,677007 |

*Table 88  Estimation of the weights, case of reusable launcher*

For a better understanding of weight distribution, both pie and histogram charts have been developed.

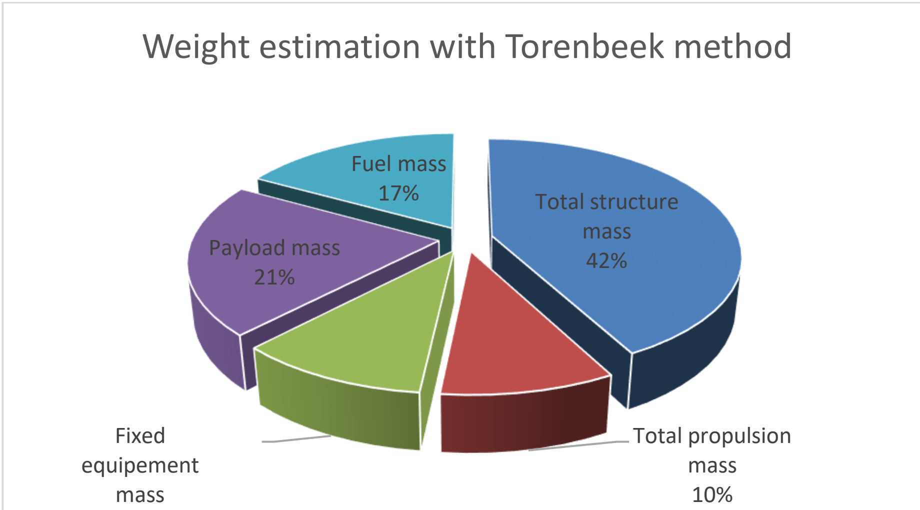



***Figure 106 Pei chart weight estimation with Torenbeek method, case of reusable launcher***

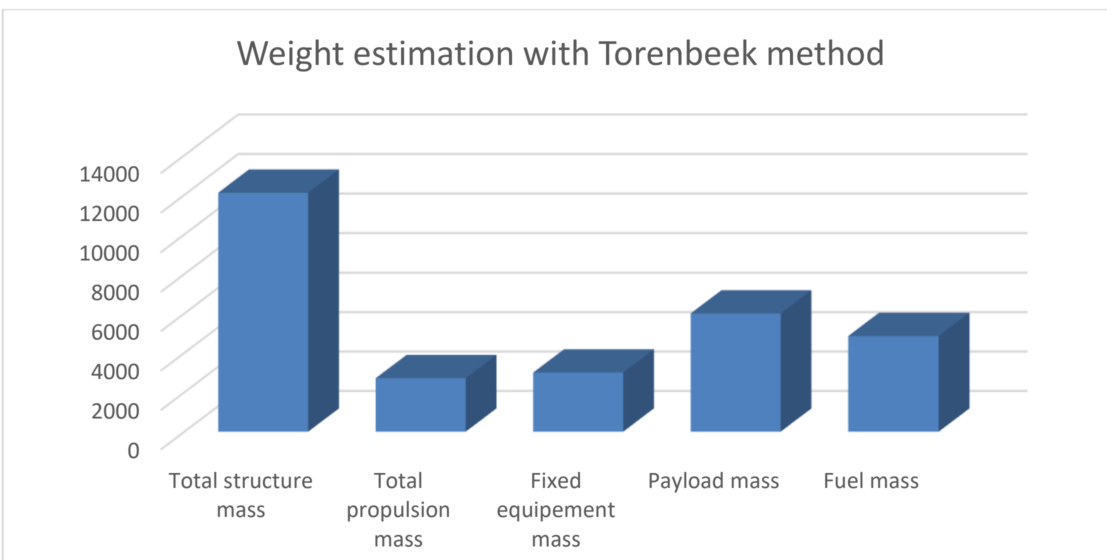



***Figure 107 Weight estimation with Torenbeek method, case of reusable launcher***

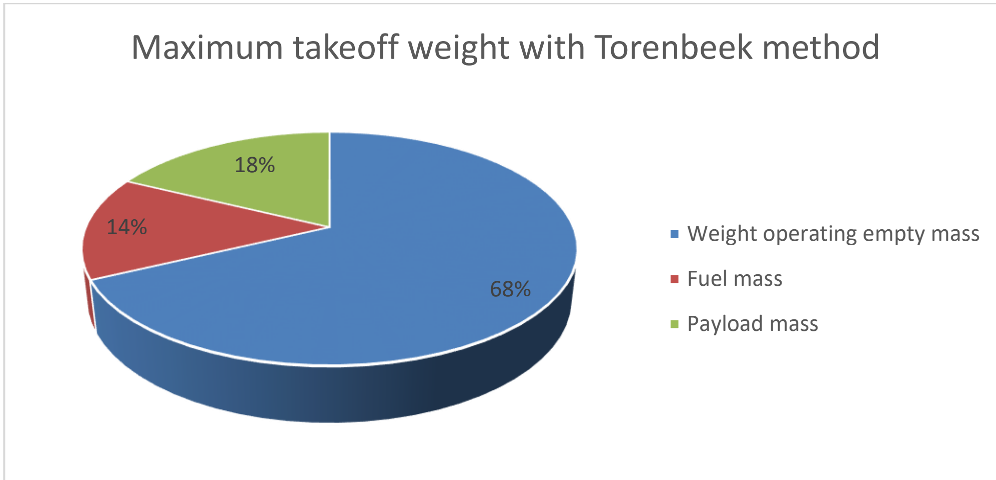



***Figure 108 Pei chart maximum takeoff weight with Torenbeek method, case of reusable launcher***

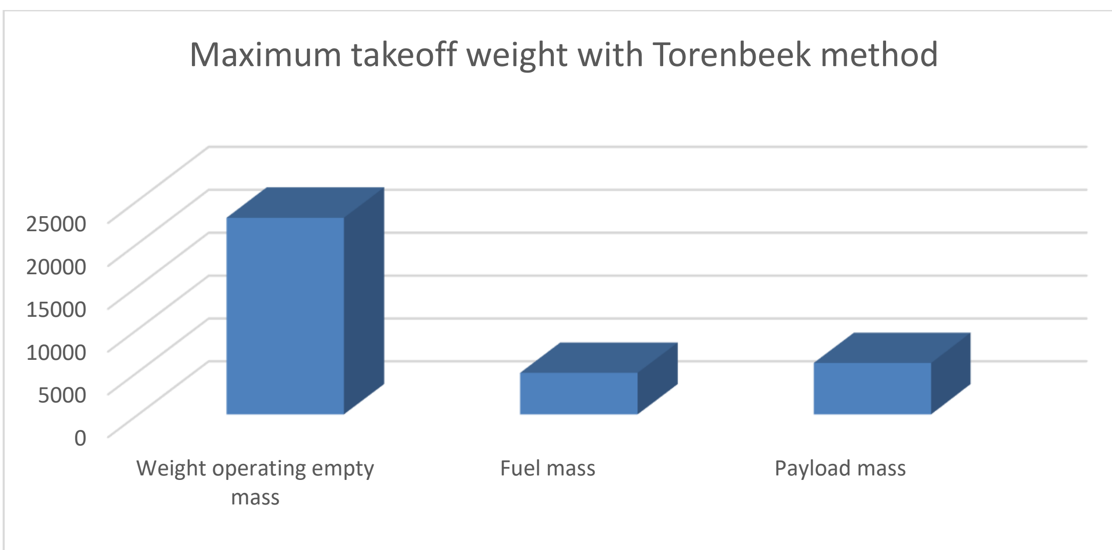



***Figure 109 Maximum takeoff weight with Torenbeek method, case of reusable launcher***

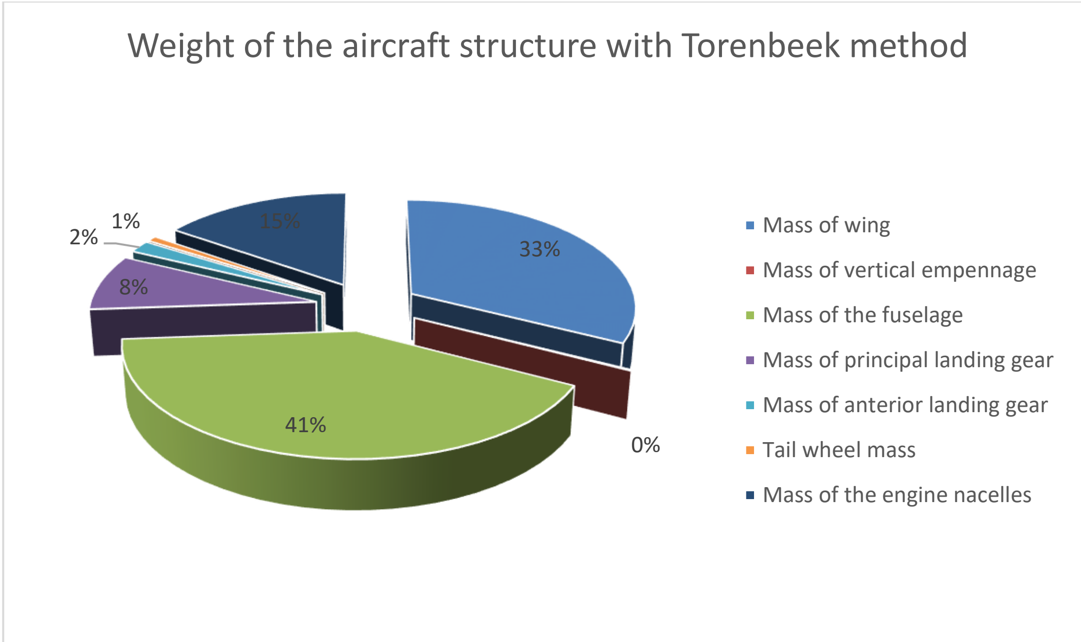



***Figure 110 Pei chart weight of the aircraft structure with Torenbeek method, case of reusable launcher***

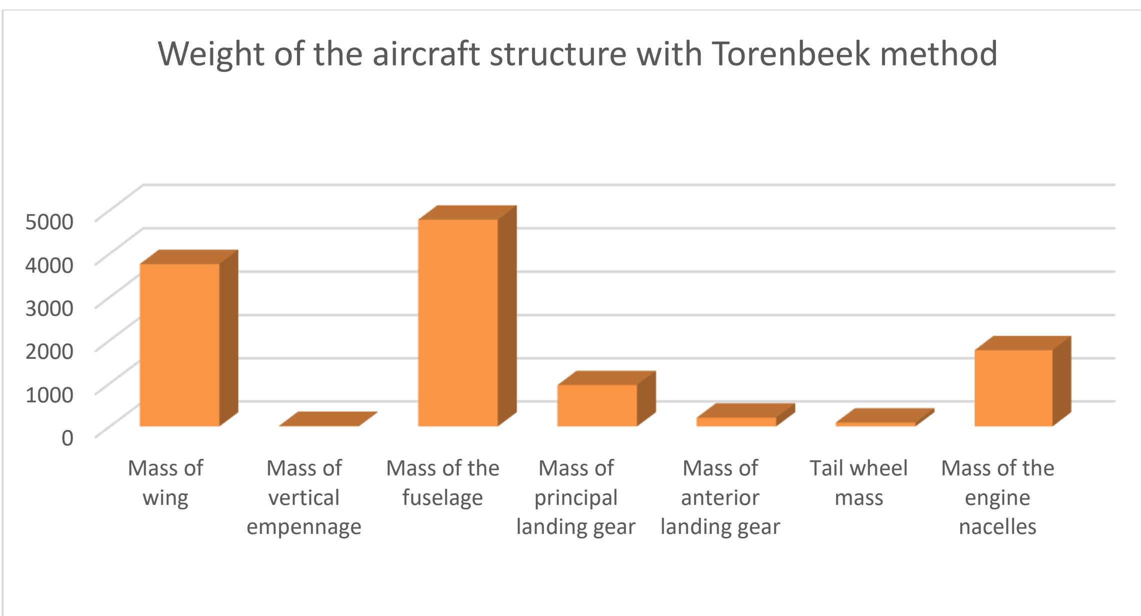



***Figure 111 Weight of the aircraft structure with Torenbeek method, case of reusable launcher***

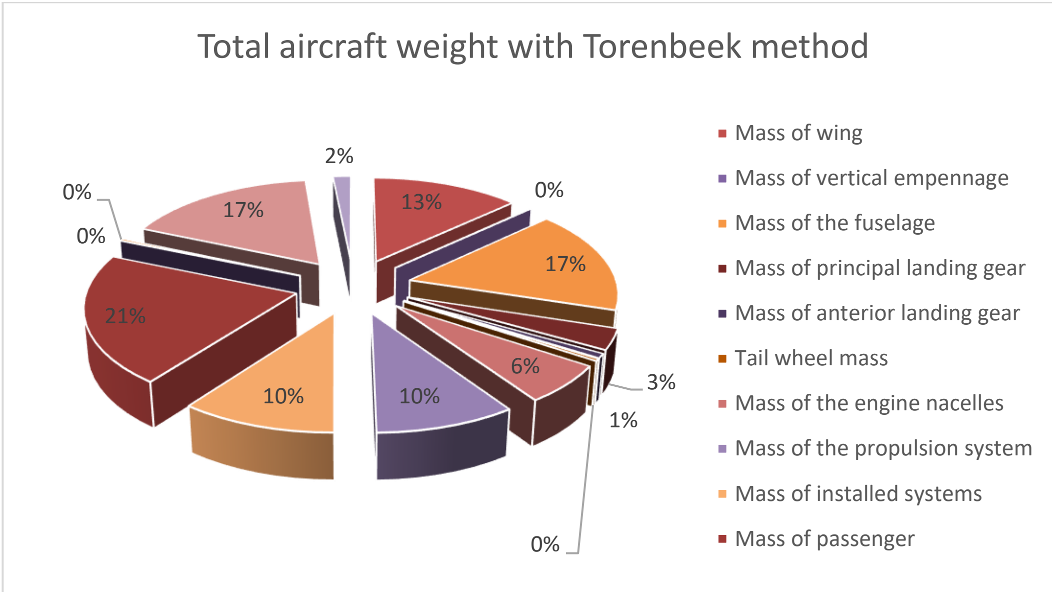



*Figure 112 Pei chart total weight with Torenbeek method, case of reusable launcher*

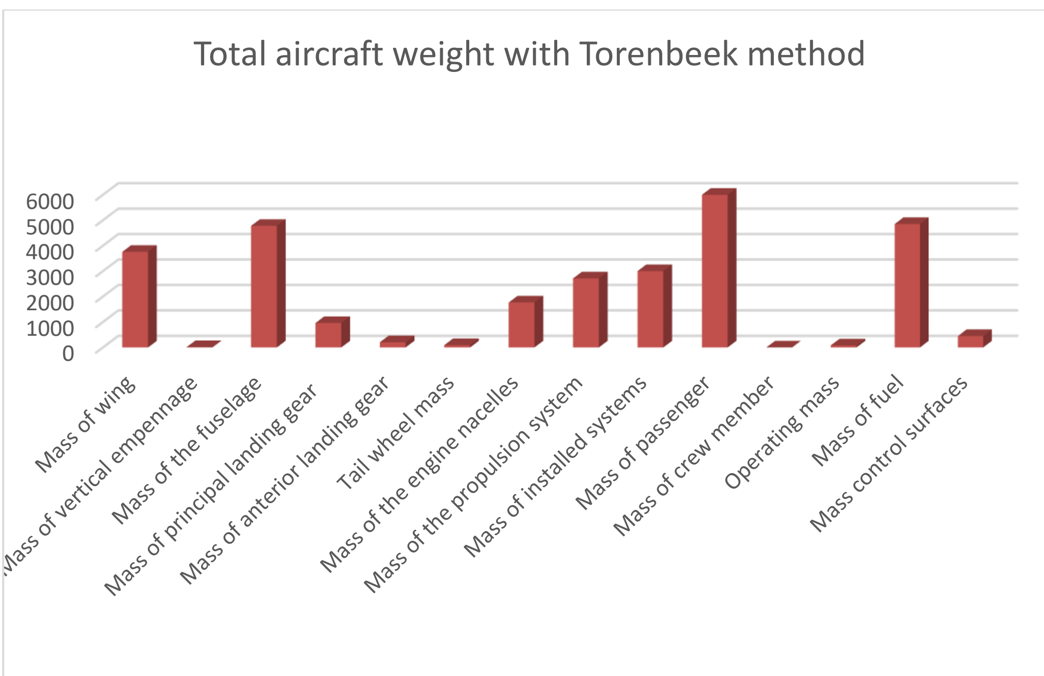



*Figure 113 Total weight with Torenbeek method, case of reusable launcher*

At this point the position of the center of gravity is calculated. Proceed following the instructions in the previous paragraph.
The results obtained are shown below.

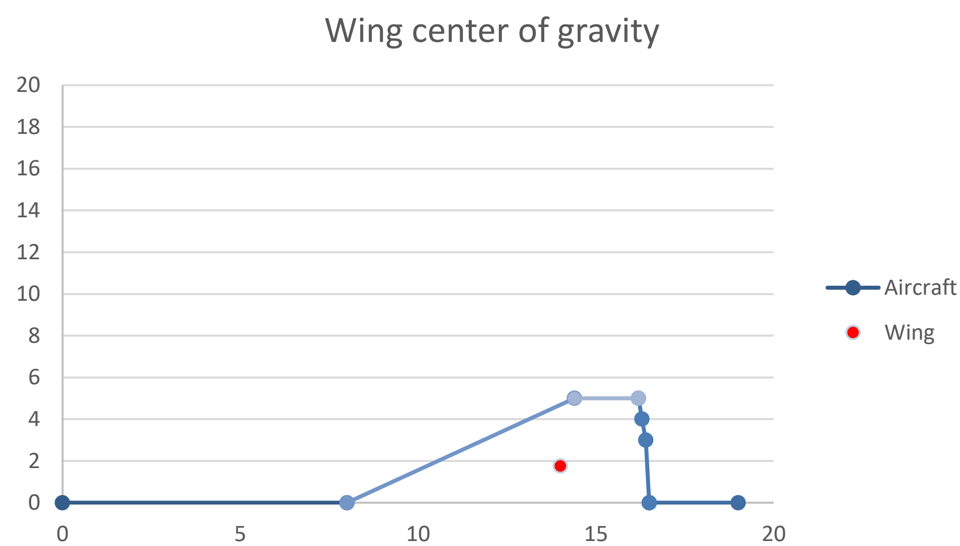



***Figure 114 Wing center of gravity, case of reusable launcher***

All the values of the barycenters of the individual components of the aircraft were then defined. Of which there is also a graphic visualization:

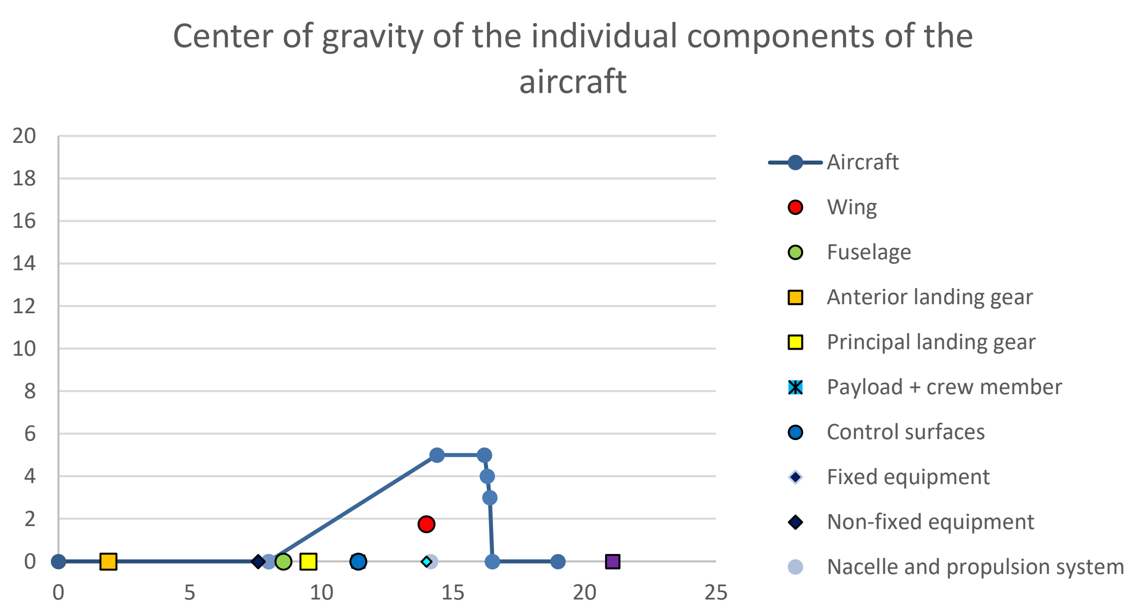



***Figure 115 Center of gravity of the individual components of the aircraft, case of reusable launcher***

From these values it is possible to calculate the overall center of gravity of the aircraft using the following formulas:

$$X_{CG} = \frac{\sum m_i * X_i}{\sum m_i}$$

$$Y_{CG} = \frac{\sum m_i * Y_i}{\sum m_i}$$

$$Z_{CG} = \frac{\sum m_i * Z_i}{\sum m_i}$$

Where:

- $m_i$ = mass of the single component
- $X_i$ , $Y_i$ , $Z_i$ = values of the center of gravity referred to the single component

from which it is derived:

$$X_{CG} = 10.4274 \text{ m}$$
$$Y_{CG} = 0 \text{ m}$$
$$Z_{CG} = 0{,}0382972 \text{ m}$$

There is also a graphical view of the position of the overall center of gravity of the aircraft

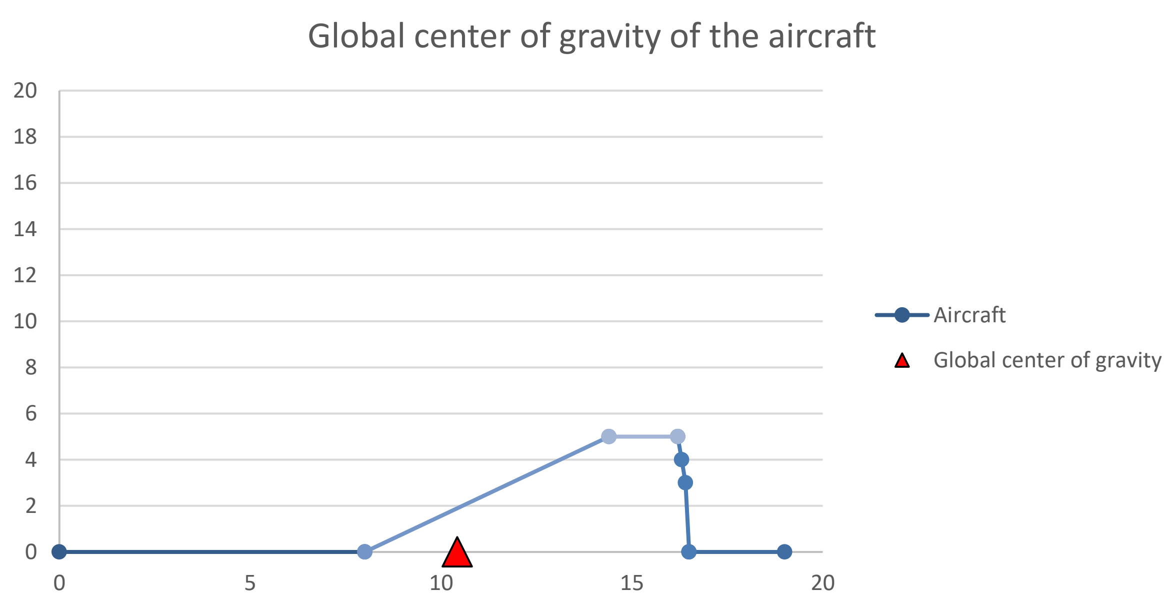



***Figure 116 Global center of gravity of the aircraft, case of reusable launcher***

# 4 TOOL IMPLEMENTATION

In this chapter, the ad-hoc built in tool developed in Matlab will be presented. The tool allows an interactive use of the implemented functions, which starting from certain choices of the user will be able to provide in output information on the design of the aircraft. In particular, results regarding the configuration, the fuselage and the wing will be provided.

## *4.1 General aspect of a GUI*

Before entering into the details of the Tool a brief introduction will be made, in which the general aspects of a GUI and the various graphic components that can be inserted in it will be explained in order to guarantee a better understanding of the work.
A GUI (Graphical User Interface) is a graphical interface, which consists of a series of windows that appear on the monitor, which, as mentioned before, allows an interactive use of the implemented functions. The interactive use of these functions is allowed by a series of control components. Most of these elements are created for pursuing an action, modifying impositions for future actions or displaying results.
The components that have been used for the realization of the aforementioned Tool are listed and briefly described below.

- Push Button: It represents an action, and for this reason it is labeled with a verb or a word that calls it to the mind in an intuitive way. This button generates the same type of action each time it is pressed and does it instantly.
- Static Text: It allows the control of textual display but does not initiate any type of action; it is generally used as a label for other control components.
- Check Box: It generates an action if selected and is useful for indicating the status of an option. It has two possible states: on, where the square box contains a check, and off, at which the box is empty.
- Pop-Up Menu: drop-down menu that opens down allowing the choice between only one of the options on the list.
- Axes: component that allows the GUI to display image and plot.
- Table: it can contain text strings or numbers in its own boxes; the dimensions of the table automatically adapt to the dimensions of the content or can be imposed in the coding; it is possible to make some columns fully editable.
- Panel: it allows the graphic subdivision of the figure. Each panel can have a title and its own objects inside it.

Before proceeding with the creation of the GUI one must have clear who will use it, so to realize the interface adapting it to the user's knowledge. After that the available data and the outputs to be obtained are analyzed. At this point a prototype of the GUI is drawn. And in the end, it goes to actually implement the GUI. It can be done using a guide for graphic obstruction or by programming the GUI completely. In the first case, the graphic part is constructed more immediately. When you go to insert an element, a code file is created containing the callbacks. The programmer only has to go to add in this code file, control and command lines. While in the second case, the programmer will completely program its graphical interface, i.e. it will completely extend a code file. In this way the figure is created, not reopening the FIG-file automatically saved as with GUIDE, that is as in the first case, but by launching the file with the code created specifically.
The Matlab Tool that will be presented in this chapter will be made referring to the first case, and therefore not going to completely program the code.

## 4.2 *Implementatation*

The tool has been conceived to support the design activity, obtaining information regarding the preliminary design of an aircraft, starting from qualitative and quantitative data entered by a user.
The program created with the Matlab software was born with the purpose of:

- Facilitate the problem definition process;
- Simplify design iterations;
- Provide further design support.

The Matlab code implements the general approach described in chapter 3. In particular, the user, interacting with the GUI, makes the first selections, such as the type of mission required and the maximum Mach number. These simple data are sufficient to start the general design process. In particular, starting from these choices, the software, implementing all the results of the research activity reported in the previous chapters, is able to generate a list of requirements, which will impact on design. The program in this way will be able to provide the user with suggestions regarding: Propulsive Strategy, Staging Strategy, Take-off and Landing strategy, Aerothermodynamic configuration and will also be able to provide indications about the fuselage (diameter and length) and the wing, of the what will be suggested, at first, the vertical position of the wing; while at a later time, after the user has made his choice, the tool will suggest an appropriate wing profile. Then the geometry is defined.
The data will then be saved in a document that will summarize the advice given to the designer, the choice of the designer and an updated list of the various requirements.
In addition, the output obtained should be used to update a CAD model, which in turn would be imported to Simulink in order to allow simulation, thus solving some problems related to integration. This was not treated in this thesis. It is focused on the realization of the Matlab code.

The GUI that has been created consists of several sub-interfaces. After selecting the 'Input' button, the first sub-interface will be opened, through which the user will make the first selections.

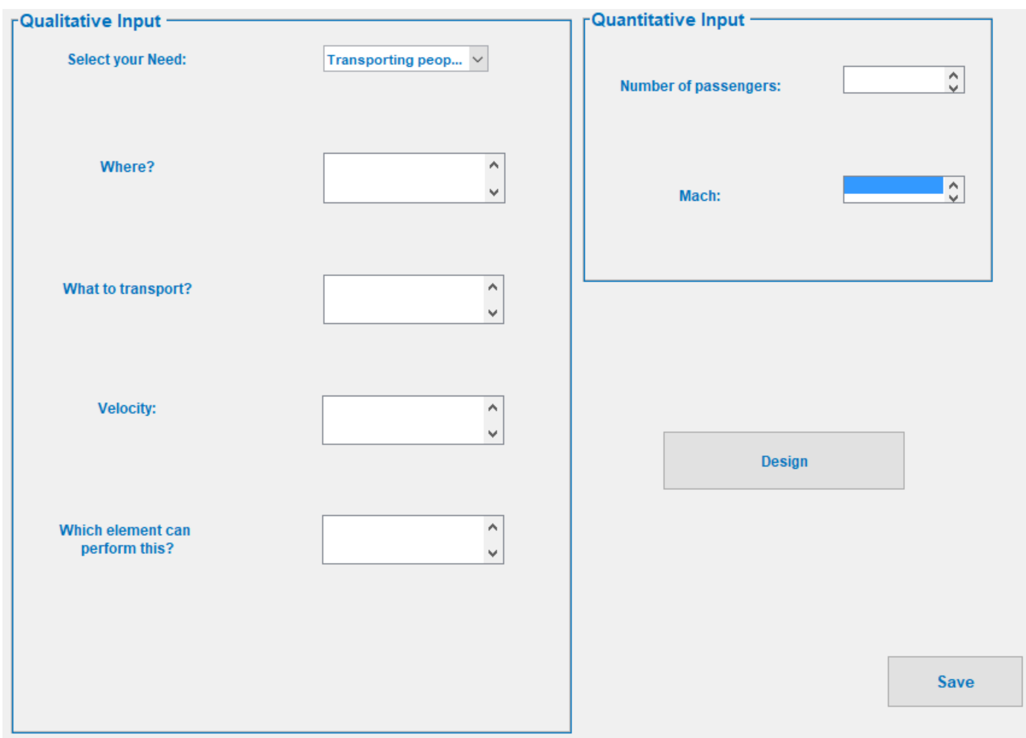



*Figure 117 Qualitative and quantitative input*

In particular, as can be seen from the figure above, the user will make first qualitative and quantitative choices, such as the maximum number of Mach reachable.

The first thing that will be selected by the user is the type of mission, in particular his need.

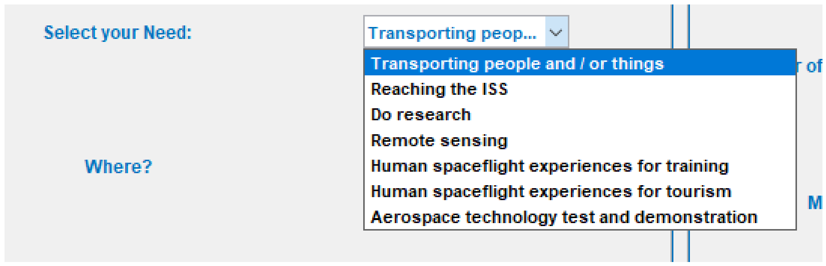



***Figure 118 Selection of need***

The various Needs among which the user can choose, are those that have come out of the stakeholders analysis carried out in chapter 2.
On the basis of the necessity that is selected, other choices will be made, for example the environment in which the mission will take place and what the airplane will have to transport. In other words, the mission elements will be defined. The mission elements are precisely the object of the mission, the payload, the operating environment, etc., they depend strongly on the type of mission that one wants to carry out. Once the mission elements have been defined, the program will be able to define the high-level requirements, which will impact on the design.

Once the user enters the various data required by the program, through the 'Design' button the following window will open:

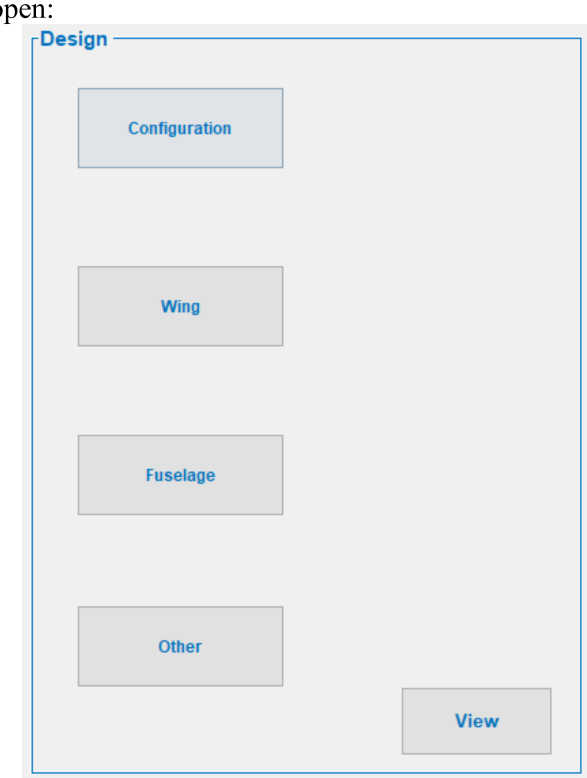
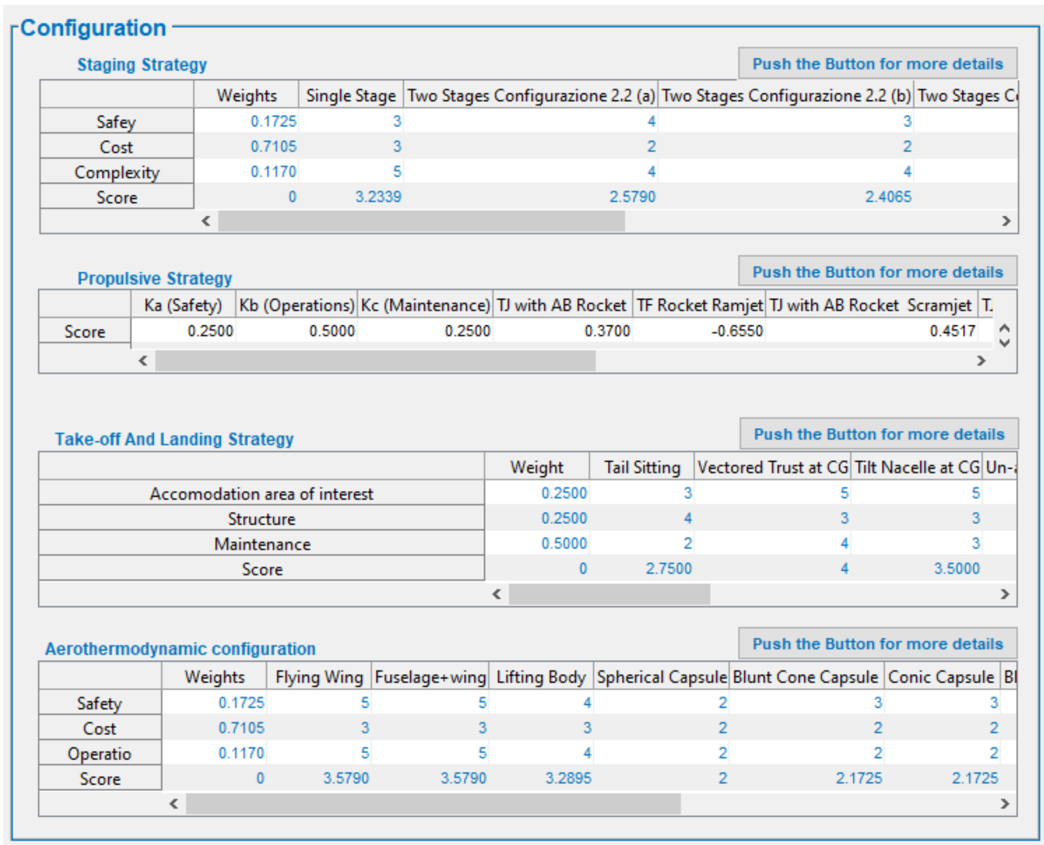



***Figure 119 Design***

Which, in fact, consists of a series of Push Button which will provide information regarding the design of the aircraft.
In particular, by pressing the Push Button 'Configuration' a window will open in which are shown:

- Staging Strategy;
- Propulsive Strategy;
- Take-off and Landing Strategy;
- Aerothermodynamic configuration.

For each of them are reported the possible solutions available and the related table of trade-offs, which shows a score (it was calculated as shown in chapter 3) for each solution. The solution with the highest score is the best for that particular mission.


Configuration

Staging Strategy

Push the Button for more details

| | Weights | Single Stage | Two Stages Configurazione 2.2 (a) | Two Stages Configurazione 2.2 (b) | Two Stages C |
|---|---|---|---|---|---|
| Safey | 0.1725 | 3 | 4 | 3 | |
| Cost | 0.7105 | 3 | 2 | 2 | |
| Complexity | 0.1170 | 5 | 4 | 4 | |
| Score | 0 | 3.2339 | 2.5790 | 2.4065 | |

Propulsive Strategy

Push the Button for more details

| | Ka (Safety) | Kb (Operations) | Kc (Maintenance) | TJ with AB Rocket | TF Rocket Ramjet | TJ with AB Rocket Scramjet | T. |
|---|---|---|---|---|---|---|---|
| Score | 0.2500 | 0.5000 | 0.2500 | 0.3700 | -0.6550 | 0.4517 | |

Take-off And Landing Strategy

Push the Button for more details

| | Weight | Tail Sitting | Vectored Trust at CG | Tilt Nacelle at CG | Un- |
|---|---|---|---|---|---|
| Accomodation area of interest | 0.2500 | 3 | 5 | 5 | |
| Structure | 0.2500 | 4 | 3 | 3 | |
| Maintenance | 0.5000 | 2 | 4 | 3 | |
| Score | 0 | 2.7500 | 4 | 3.5000 | |

Aerothermodynamic configuration

Push the Button for more details

| | Weights | Flying Wing | Fuselage+wing | Lifting Body | Spherical Capsule | Blunt Cone Capsule | Conic Capsule | Bl |
|---|---|---|---|---|---|---|---|---|
| Safety | 0.1725 | 5 | 5 | 4 | 2 | 3 | 3 | |
| Cost | 0.7105 | 3 | 3 | 3 | 2 | 2 | 2 | |
| Operatio | 0.1170 | 5 | 5 | 4 | 2 | 2 | 2 | |
| Score | 0 | 3.5790 | 3.5790 | 3.2895 | 2 | 2.1725 | 2.1725 | |

***Figure 120 Configuration informations***

On each table you can see a Push Button, which will provide more information for that particular choice.

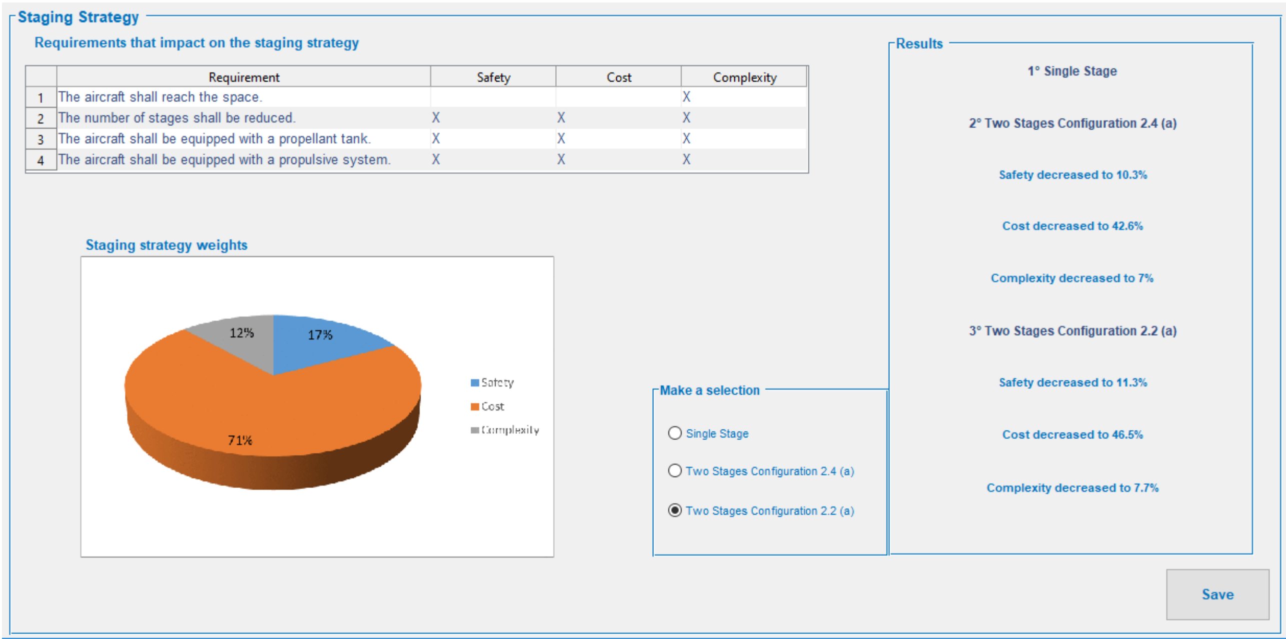



*Figure 121 Results of Staging Strategy*

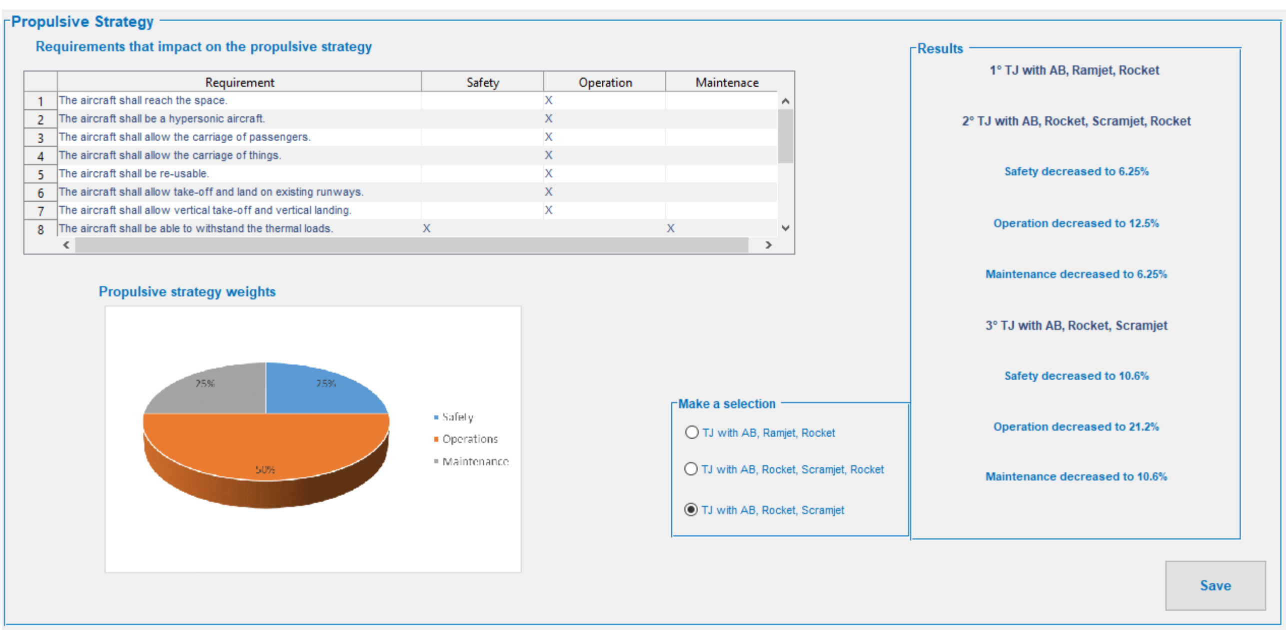



*Figure 122 Results of Propulsive Strategy*

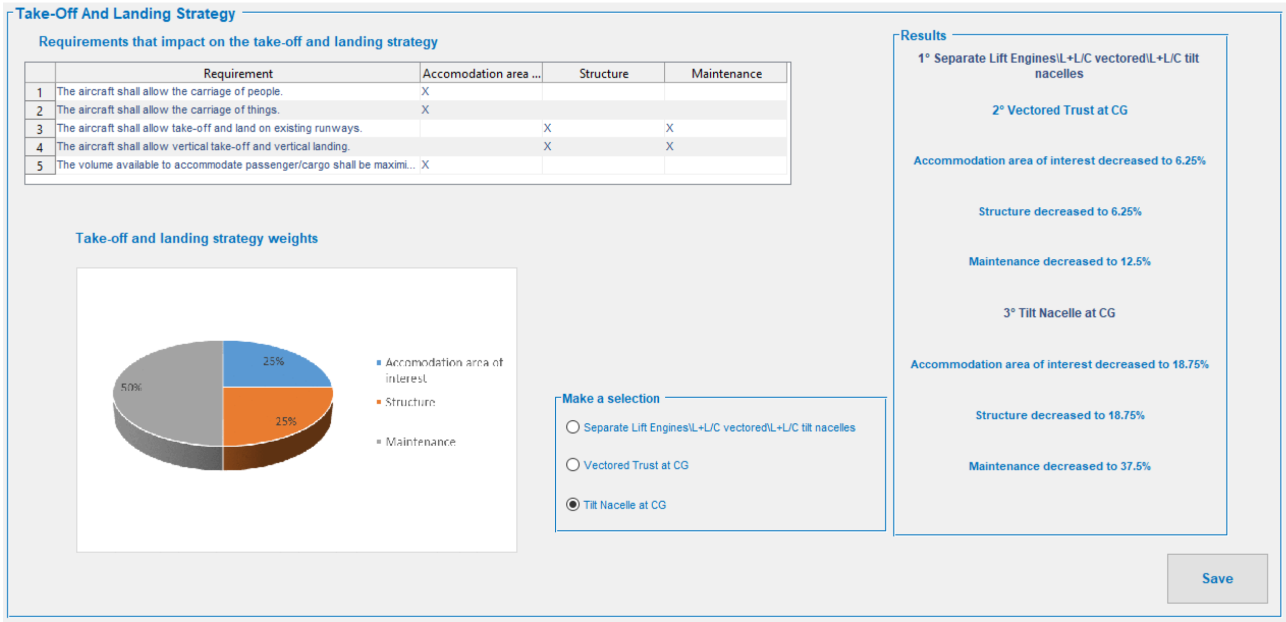



*Figure 123 Results of Take-off and Landing Strategy*

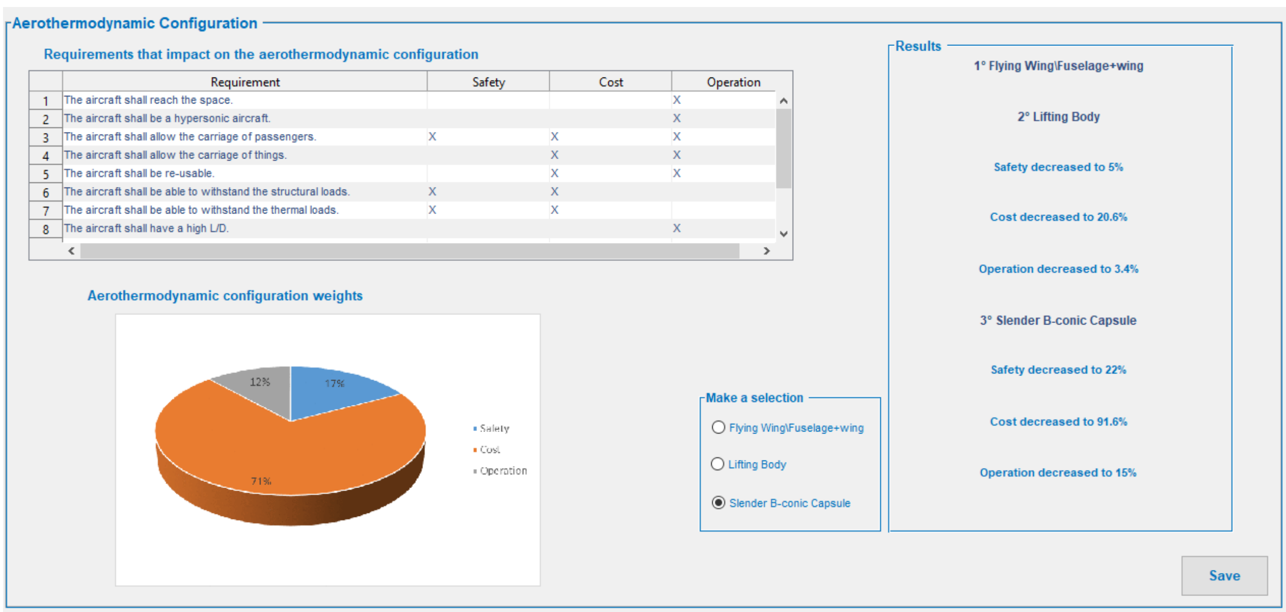



*Figure 124 Results of Aerothermodynamic configuration*

In particular will be shown the requirements that have impacted on the choice, the figures of merit on which they have impacted and the three best alternatives. The user can decide to accept the tool's suggestion and then proceed in the design process with the first configuration assigned. Or, you can choose one of the other two configurations, accepting relative pros and cons.

By pressing the Push Button 'Wing' instead, the following window opens:

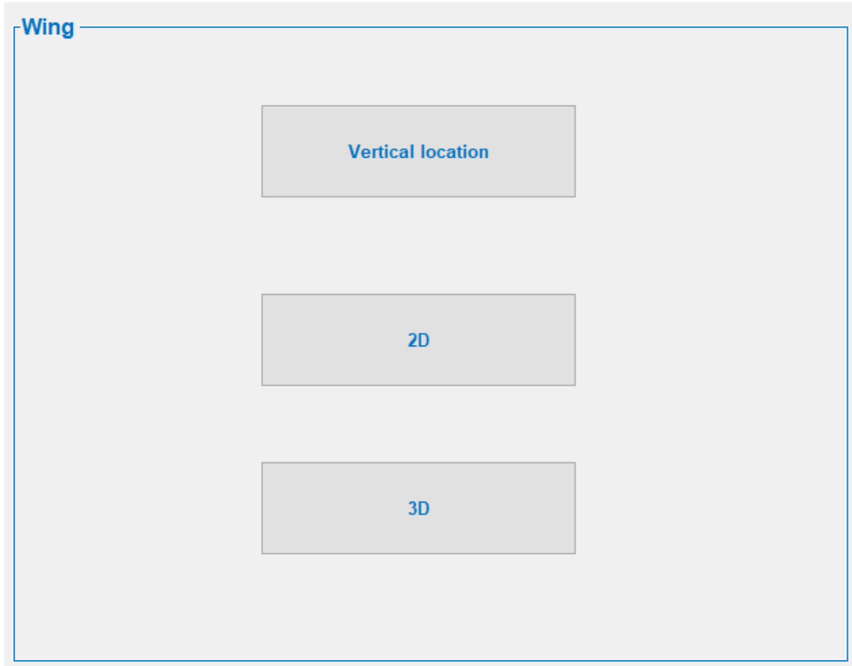



***Figure 125 Wing***

As for the vertical location of the wing, the program is going to provide the following results:

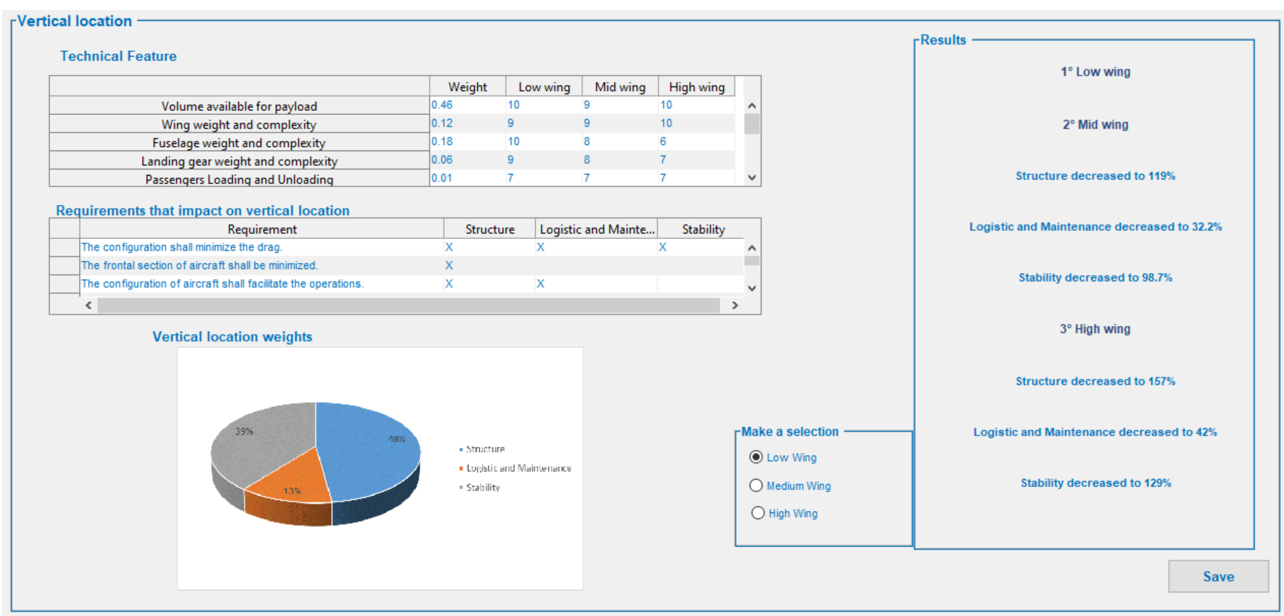



***Figure 126 Wing vertical location***

As for the 'Configuration' case, the program provides the table of the trade-off, the requirements that have impacted on the choice and the relative figures of merit on which they are going to impact. Furthermore, the user can decide to accept the tool's suggestion and then proceed in the design process with the first configuration assigned. Or, you can choose one of the other two configurations, accepting relative pros and cons.

Regarding the airfoil, the results provided are as follows:

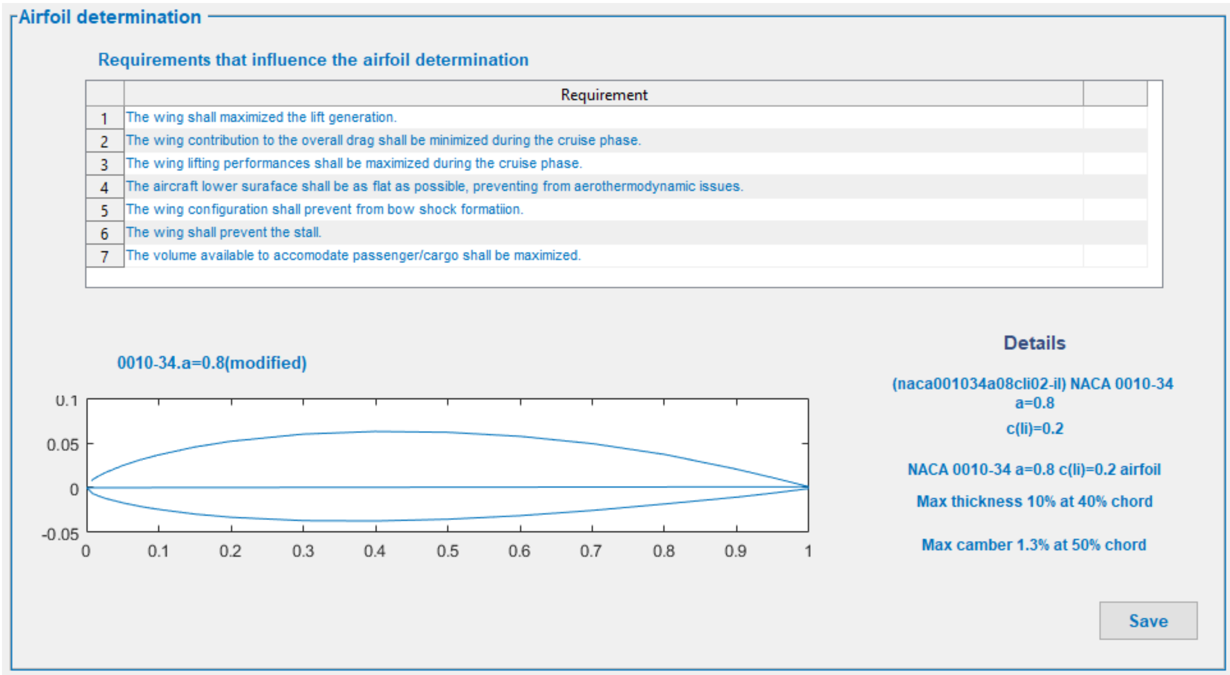



*Figure 127 Airfoil determination*

The program, therefore, will be able to provide the appropriate profile for the selected mission and the related requirements that have impacted on the choice of it.

At this point the wing geometry is defined.

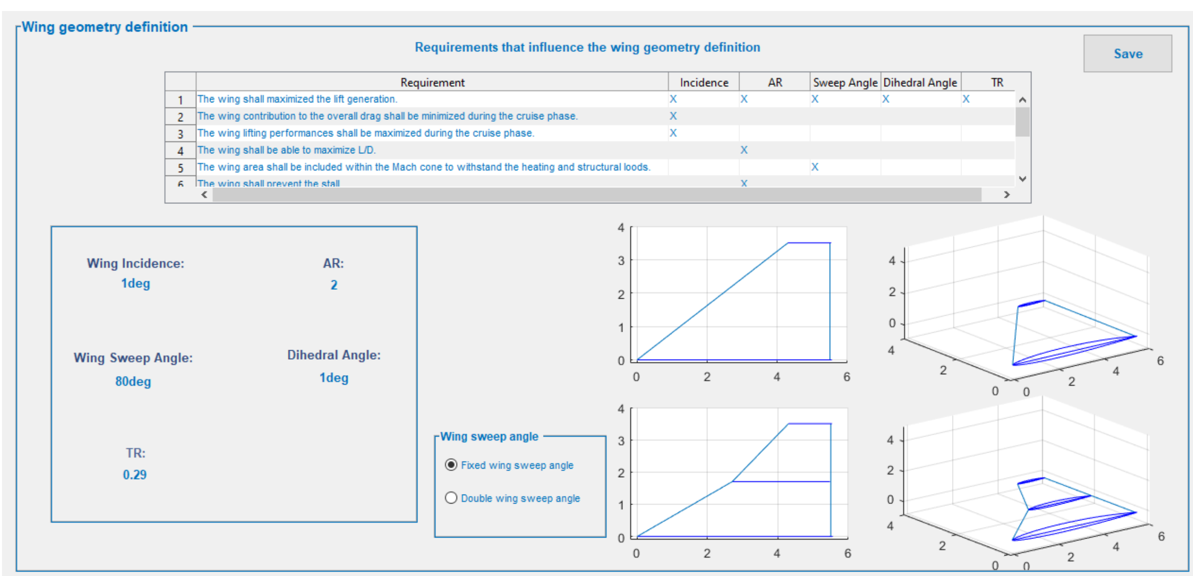



*Figure 128 Wing geometry definition*

The program will provide the values related to: Wing incidence, Aspect Ratio, Wing Sweep Angle, Dihedral Angle, Taper Ratio. In addition, the requirements will be shown, which have impacted on each of them, and a sketch of the wing.

By pressing the Push Button 'Fuselage' instead, the following window opens:

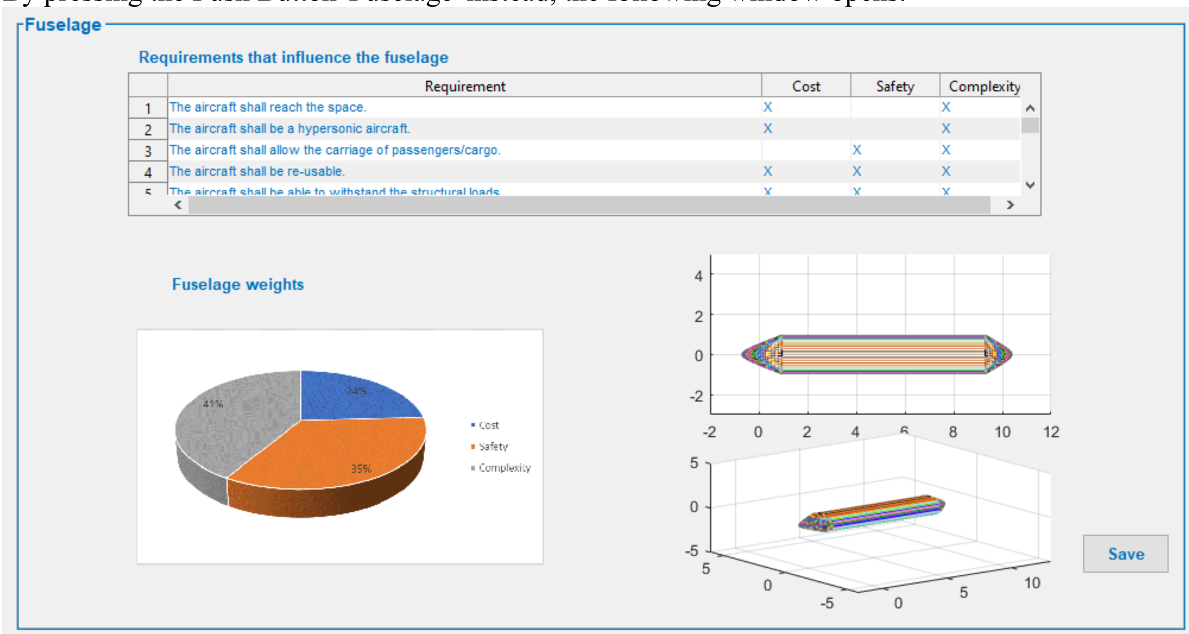



*Figure 129 Fuselage*

The program, as in the previous cases, will provide the requirements that have affected the design of the fuselage. A sketch of the fuselage will also be provided.

Finally, by pressing the Push Button 'View', the program shows the sketch of the complete aircraft.

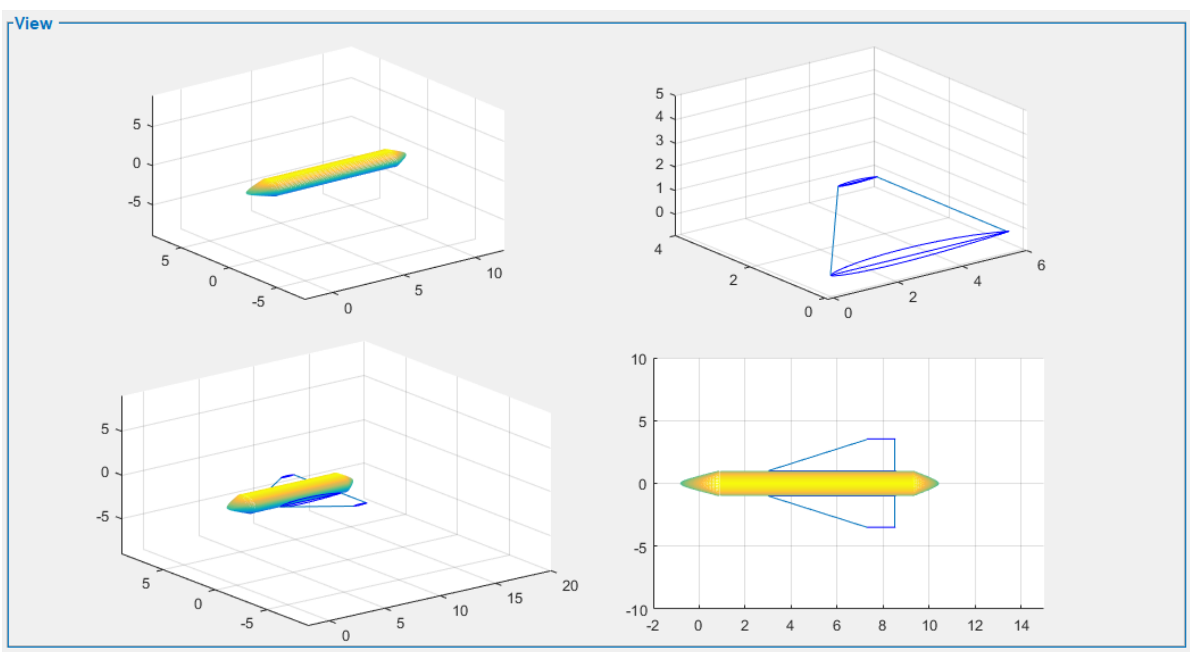



*Figure 130 View of the aircraft*

As previously mentioned, the data obtained will be saved in a document which will summarize the advice given to the designer, the choice of the designer and an updated list of the various requirements.

As an example, below, the case of Suborbital flight is treated. The program, after the user has made his choices, will return the following results:

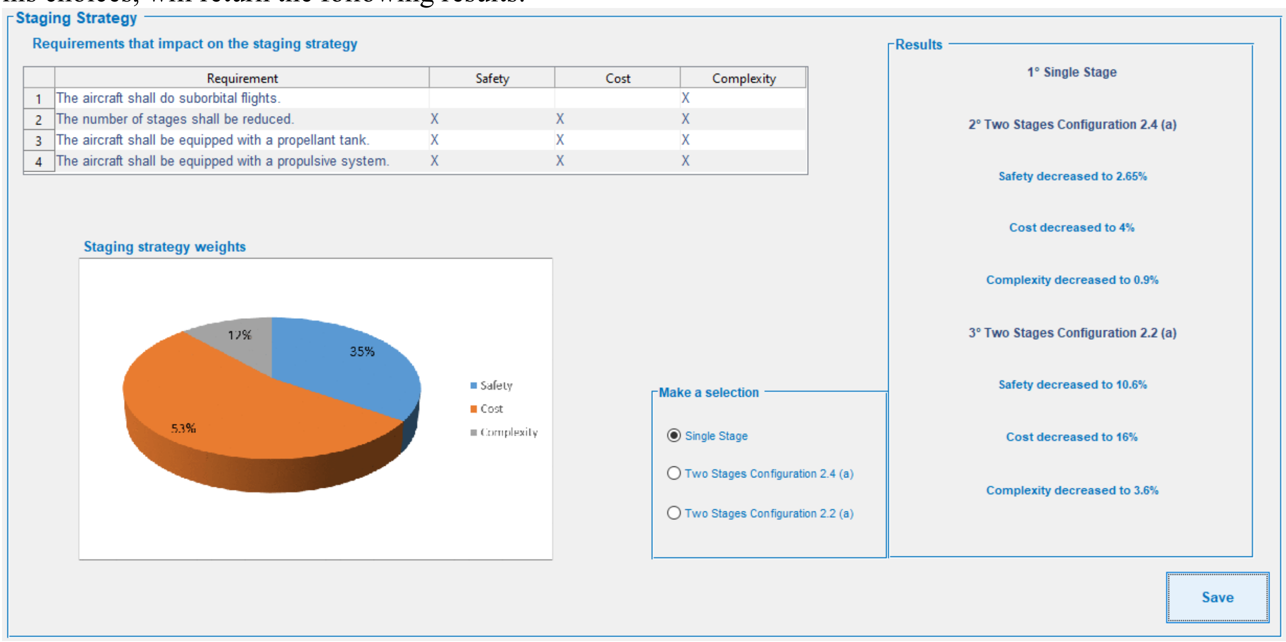



***Figure 131 Results of Staging Strategy, case of suborbital flight***

As for the staging strategy, the winning solution is the single stage configuration. The single stage configuration consists of a single vehicle, which should contain all the subsystems. It is very similar to a conventional aircraft, thus avoiding the technical complexities linked to the integration of several stages and decreasing the risk linked to the separation phase.

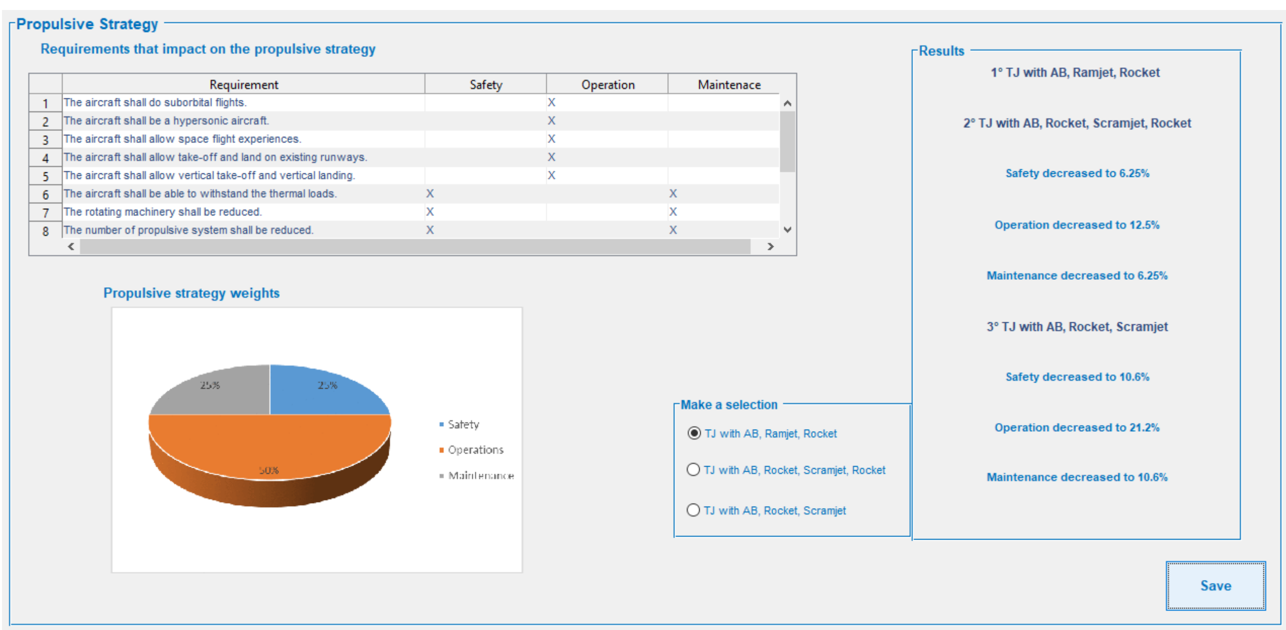



***Figure 132 Results of Propulsive Strategy, case of suborbital flight***

As for the propulsion strategy, the winning solution is TJ with AB, Ramjet, Rocket. In particular, this solution allows the aircraft to operate in different operating environments and at different speeds, ensuring high performance.

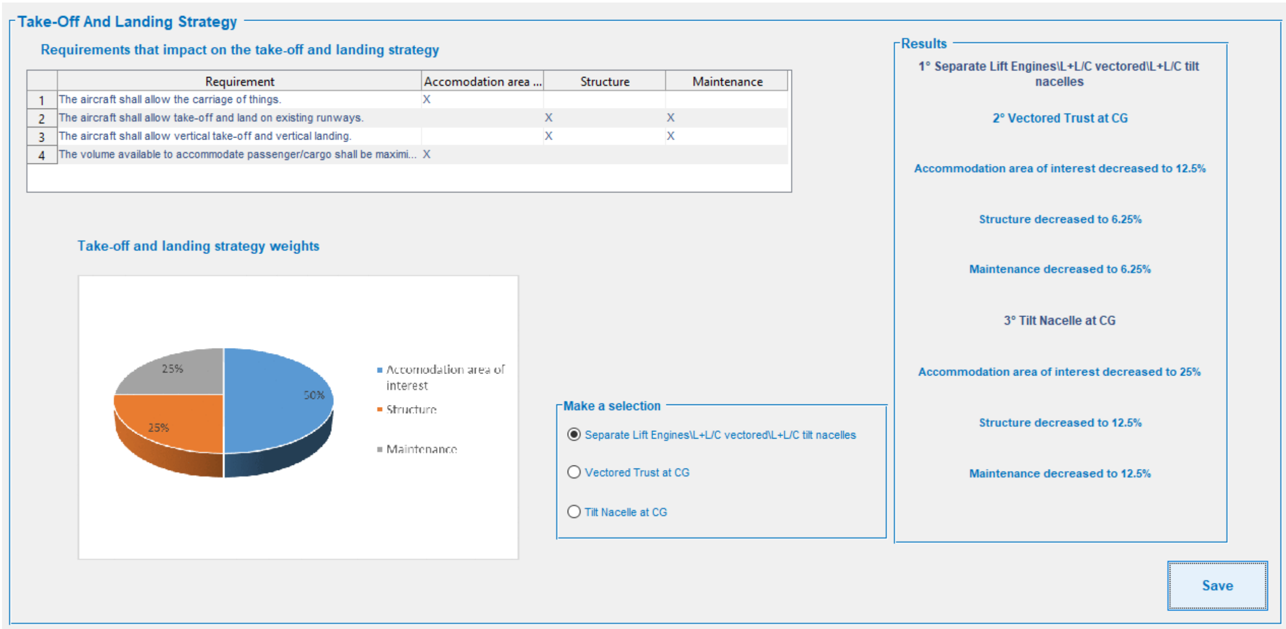



***Figure 133 Results of Take-off and Landing Strategy, case of suborbital flight***

Regarding the take-off and landing strategy, the winning strategies for this particular mission are: Separate Lift Engines, L+L/C vectored and L+L/C tilt nacelles.

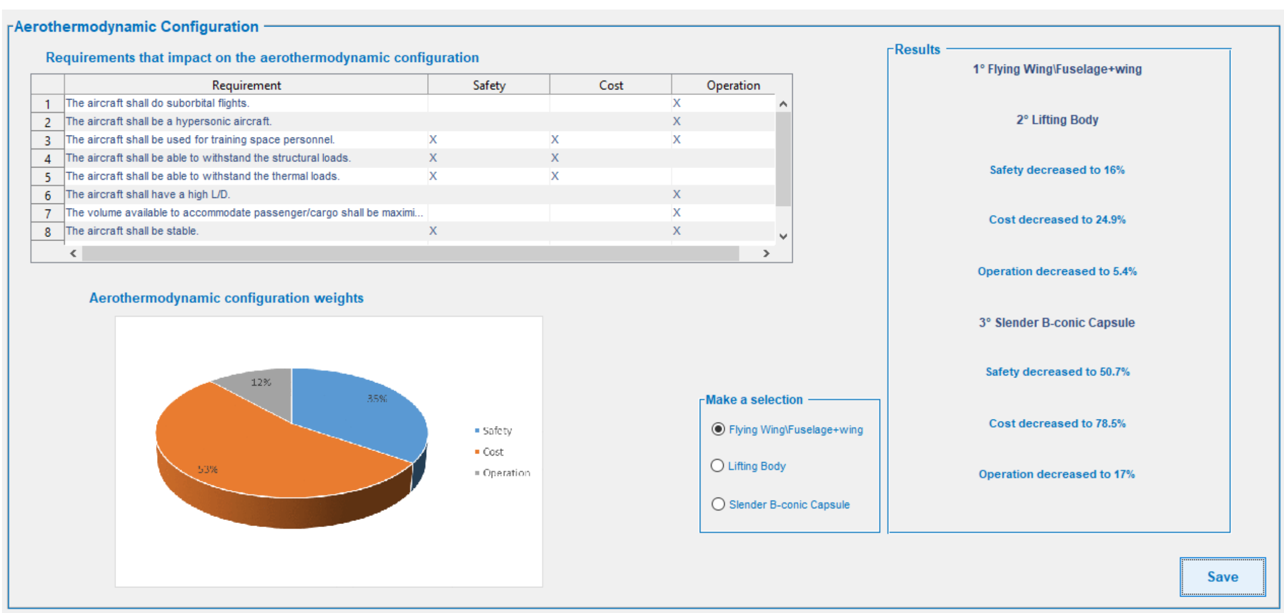



***Figure 134 Results of Aerothermodynamic Configuration, case of suborbital flight***

As for the best aerothermodynamic configurations, for this mission, are the traditional configurations, as these configurations are a good compromise between the different needs of the mission and also allow you to transport a large amount of payload.

Regarding wing and fuselage, the results obtained for this mission are shown in the following figures.

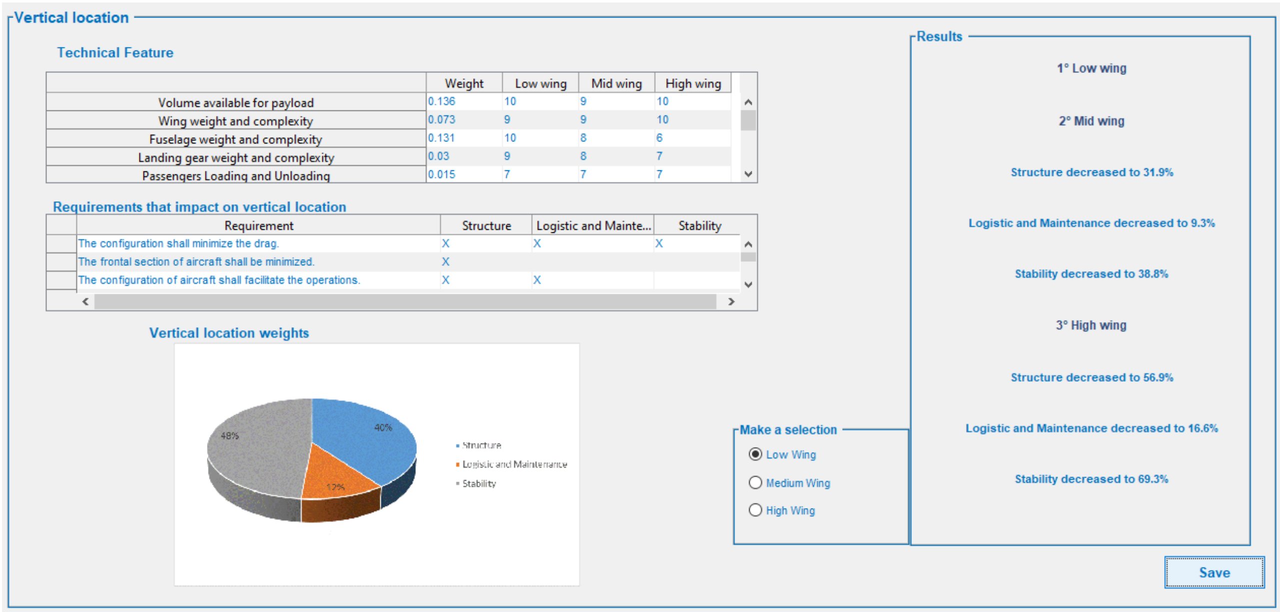



*Figure 135 Wing vertical location, case of suborbital flight*

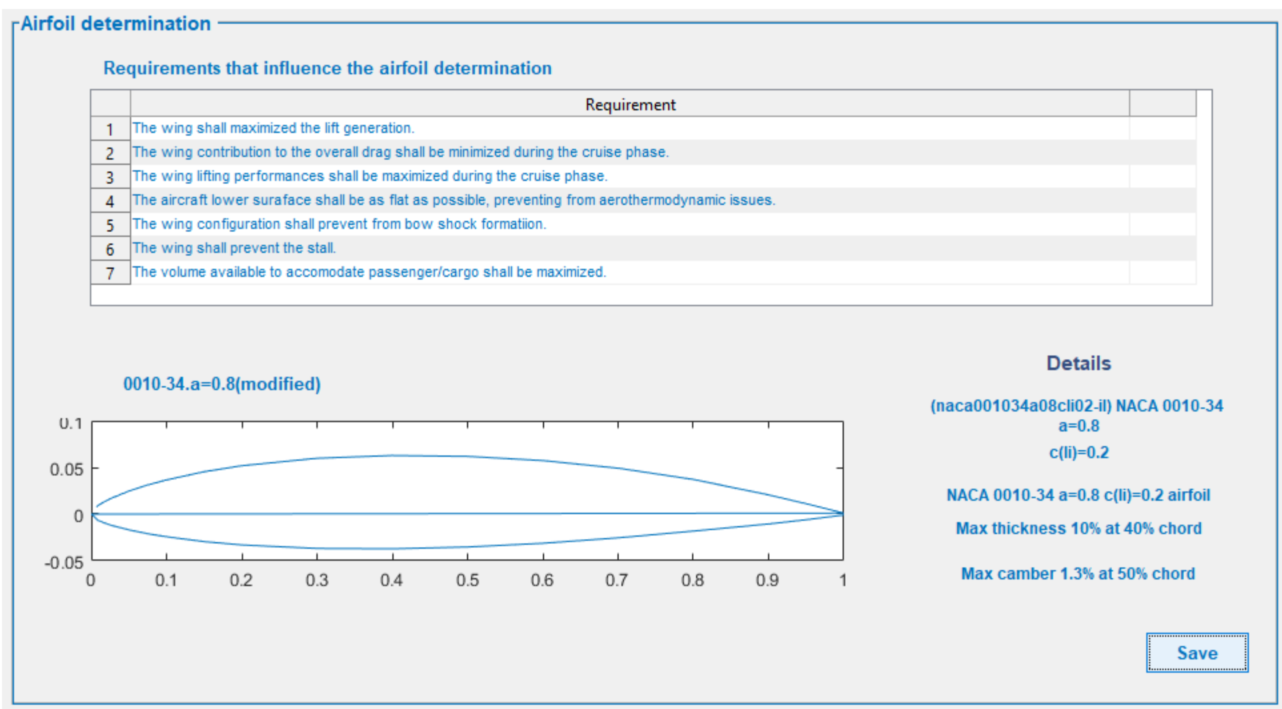



*Figure 136 Airfoil determnation, case of suborbital flight*

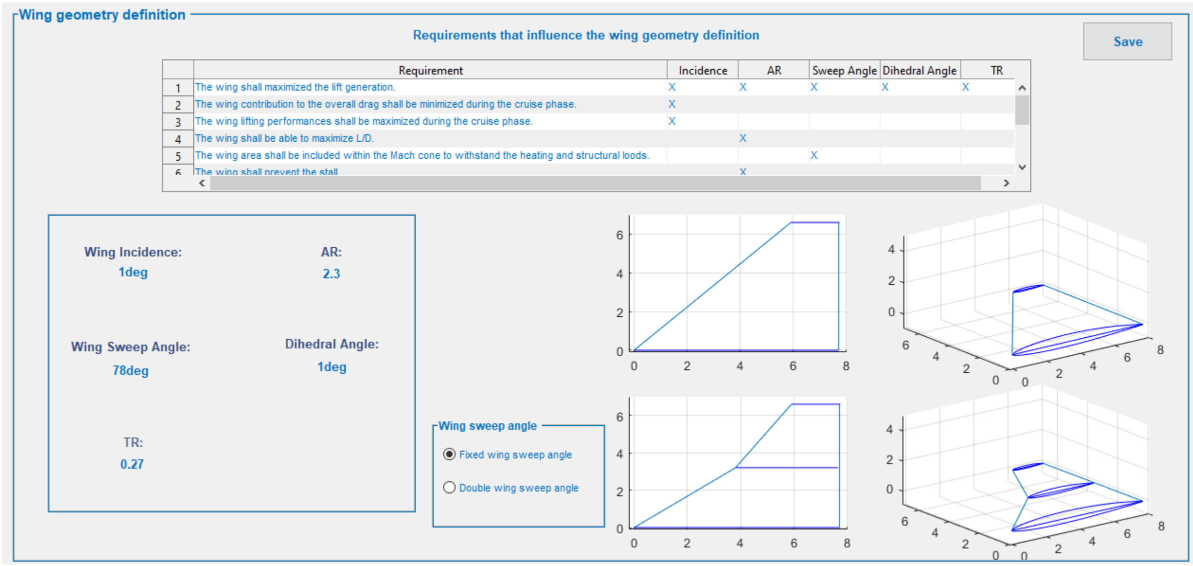



*Figure 137 Wing geometry definition, case of suborbital flight*

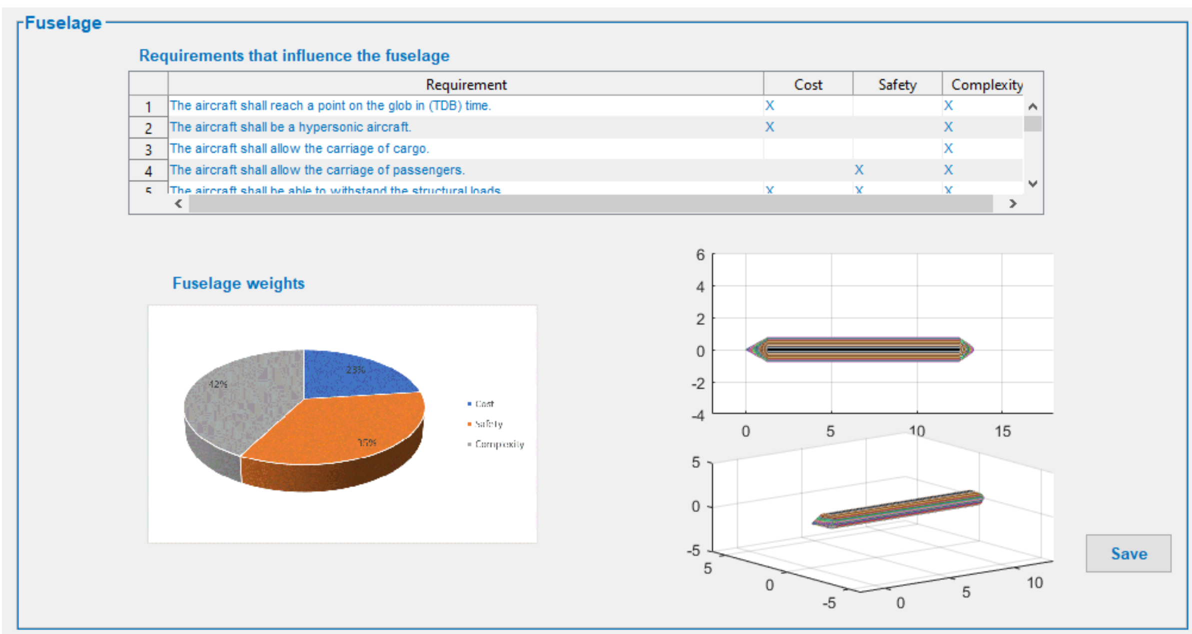



*Figure 138 Fuselage, case of suborbital flight*

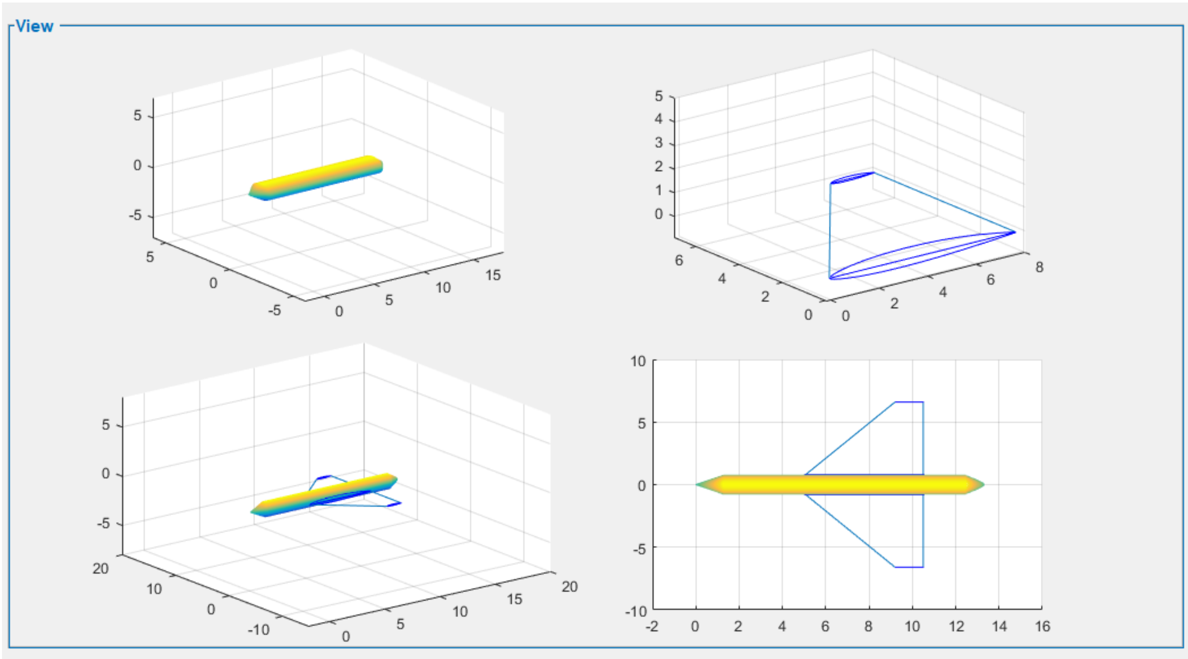



*Figure 139 View of the aircraft, case of suborbital flight*

Eventually, the suggestions for the designer as well as its selections are saved in a file together with the list of requirements, so as to allow traceability of the results obtained.
The results obtained are as follows:

Mission type:
Human spaceflight experiences for training.
---------------------------------------------------------------
High level requirements:
The aircraft shall do suborbital flights.
The aircraft shall be a hypersonic aircraft.
The aircraft shall be used for training space personnel.
The aircraft shall allow aerospace testing and demonstration.
The aircraft shall allow take-off and land on existing runways.
The aircraft shall allow vertical take-off and vertical landing.
---------------------------------------------------------------
---------------------------------------------------------------
Requirements that impact on the staging strategy:
The aircraft shall do suborbital flights.
The number of stages shall be reduced.
The aircraft shall be equipped with a propellant tank.
The aircraft shall be equipped with a propulsive system.
---------------------------------------------------------------
Results of Staging Strategy:
1° Single Stage
2° Two Stages Configuration 2.4 (a)
Safety decreased to 2.65 percent
Cost decreased to 4 percent
Complexity decreased to 0.9 percent
3° Two Stages Configuration 2.2 (a)
Safety decreased to 10.6 percent

Cost decreased to 16 percent
Complexity decreased to 3.6 percent
----------------------------------------------------------------
Choice of the user:
Single Stage
----------------------------------------------------------------
----------------------------------------------------------------
Requirements that impact on the propulsive strategy:
The aircraft shall do suborbital flights.
The aircraft shall be a hypersonic aircraft.
The aircraft shall allow space flight experiences.
The aircraft shall allow take-off and land on existing runways.
The aircraft shall allow vertical take-off and vertical landing.
The aircraft shall be able to withstand the thermal loads.
The rotating machinery shall be reduced.
The number of propulsive system shall be reduced.
The aircraft shall work in different operative scenarios.
The propulsive system shall able to re-start.
The propulsive system shall able to throttle.
The propulsive system shall provide high thrusts.
The propulsive system shall provide high specific impulse.
The aircraft shall able to reach the desired Mach.
----------------------------------------------------------------
Results of Propulsive Strategy:
1° TJ with AB, Ramjet, Rocket
2° TJ with AB, Rocket, Scramjet, Rocket
Safety decreased to 6.25 percent
Operation decreased to 12.5 percent
Maintenance decreased to 6.25 percent
3° TJ with AB, Rocket, Scramjet
Safety decreased to 10.6 percent
Operation decreased to 21.2 percent
Maintenance decreased to 10.6 percent
----------------------------------------------------------------
Choice of the user:
TJ with AB, Ramjet, Rocket
----------------------------------------------------------------
----------------------------------------------------------------
Requirements that impact on the take-off and landing strategy:
The aircraft shall allow the carriage of things.
The aircraft shall allow take-off and land on existing runways.
The aircraft shall allow vertical take-off and vertical landing.
The volume available to accommodate passenger/cargo shall be maximized.
----------------------------------------------------------------
Results of Take-Off and Landing Strategy:
1° Separate Lift Engines2° Vectored Trust at CG
Accommodation area of interest decreased to 12.5 percent
Structure decreased to 6.25 percent
Maintenance decreased to 6.25 percent
3° Tilt Nacelle at CG
Accommodation area of interest decreased to 25 percent
Structure decreased to 12.5 percent
Maintenance decreased to 12.5 percent
----------------------------------------------------------------
Choice of the user:
Separate Lift Engines L+L|C vectored L+L|C tilt nacelles

----------------------------------------------------------------
----------------------------------------------------------------
Requirements that impact on the aerothermodynamic configuration:
The aircraft shall do suborbital flights.
The aircraft shall be a hypersonic aircraft.
The aircraft shall be used for training space personnel.
The aircraft shall be able to withstand the structural loads.
The aircraft shall be able to withstand the thermal loads.
The aircraft shall have a high L/D.
The volume available to accommodate passenger/cargo shall be maximized.
The aircraft shall be stable.
The aircraft shall be maneuverable.
The aircraft must be controllable.
----------------------------------------------------------------
Results of Aerothermodynamic Configuration:
1° Flying Wing2° Lifting Body
Safety decreased to 16 percent
Cost decreased to 24.9 percent
Operation decreased to 5.4 percent
3° Slender B-conic Capsule
Safety decreased to 50.7 percent
Cost decreased to 78.5 percent
Operation decreased to 17 percent
----------------------------------------------------------------
Choice of the user:
Flying Wing / Fuselage+wing
----------------------------------------------------------------
----------------------------------------------------------------
Requirements that impact on vertical location:
The configuration shall minimize the drag.
The frontal section of aircraft shall be minimized.
The configuration of aircraft shall facilitate the operations.
The configuration of aircraft shall guarantee a proper pilot visibility.
The wing weight shall be minimized.
The fuselage weight shall be minimized.
The aircraft to be easy to be maintained.
The volume available to accommodate passenger/cargo shall be maximized.
----------------------------------------------------------------
Results of Wing Vertical Location:
1° Low wing
2° Mid wing
Structure decreased to 31.9 percent
Logistic and Maintenance decreased to 9.3 percent
Stability decreased to 38.8 percent
3° High wing
Structure decreased to 56.9 percent
Logistic and Maintenance decreased to 16.6 percent
Stability decreased to 69.3 percent
----------------------------------------------------------------
Choice of the user:
Low Wing
----------------------------------------------------------------
----------------------------------------------------------------
Requirements that influence the airfoil determination:
The wing shall maximized the lift generation.
The wing contribution to the overall drag shall be minimized during the cruise phase.

The wing lifting performances shall be maximized during the cruise phase.
The aircraft lower surface shall be as flat as possible, preventing from aerothermodynamic issues.
The wing configuration shall prevent from bow shock formation.
The wing shall prevent the stall.
The volume available to accommodate passenger/cargo shall be maximized.
------------------------------------------------------------------
Airfoil
001034
------------------------------------------------------------------
------------------------------------------------------------------
Requirements that influence the wing geometry definition:
The wing shall maximized the lift generation.
The wing contribution to the overall drag shall be minimized during the cruise phase.
The wing lifting performances shall be maximized during the cruise phase.
The wing shall be able to maximize L/D.
The wing area shall be included within the Mach cone to withstand the heating and structural loods.
The wing shall prevent the stall.
The excursion of angle of attack during take-off shall be maximized.
The stall speed shall be increased.
The wing weight shall be minimized.
The aircraft controllability shall be guaranteed.
The aircraft maneuverability shall be guaranteed.
The aircraft stability shall be guaranteed.
------------------------------------------------------------------
Wing Incidence:
1deg
AR:
2.3
Wing Sweep Angle:
78deg
Dihedral Angle:
1deg
TR:
0.27
------------------------------------------------------------------
------------------------------------------------------------------
Requirements that influence the fuselage:
The aircraft shall do suborbital flights.
The aircraft shall be a hypersonic aircraft.
The aircraft shall be used for training space personnel.
The aircraft shall be able to withstand the structural loads.
The aircraft shall be able to withstand the thermal loads.
The volume available to accommodate passenger/cargo shall be maximized.
The aircraft shall be stable.
The aircraft shall be maneuverable.
The aircraft shall be controllable.
The aircraft shall be able to reach the desired Mach.
The fuselage weight shall be minimized.
The configuration of aircraft shall facilitate the operations.
The configuration shall minimize the drag.
The configuration of aircraft shall guarantee a proper pilot visibility.
The aircraft shall be easy to maintain.
------------------------------------------------------------------
------------------------------------------------------------------

# 5 CONCLUSION AND FUTURE ACTIVITIES

In the present work a methodology and an ad-hoc developed tool are presented to support the conceptual design of trans-atmospheric vehicles. Special attention has been devoted to the selection of proper Staging Strategy, Propulsion Strategy, Take-Off and Landing Strategy, Aerothermodynamic Configuration as well as to the Fuselage and Wing geometry definition. The methodology used here is adequate to deal with the first design phase of an innovative aircraft, in fact in this thesis the hypersonic aircraft was taken as a case study. In carrying out this work, first the stakeholder analysis was carried out and starting from it the mission statement was written, from which high-level requirements were defined. Based on these requirements, the preliminary design of the aircraft was addressed. Three different missions have been carried out, which see the hypersonic aircraft operating in three different scenarios. The missions dealt with are: Suborbital Flight, Point to Pont mission and reusable launchers. In this way it was possible to mark the importance of the stakeholders on the design of the aircraft; in particular, it has been noted that as the needs of the stakeholders change, the design of the aircraft changes. This approach guarantees complete traceability throughout the design process, guaranteeing the possibility to have an idea of the main parameters involved starting from a list of stakeholder needs.

Moreover, the results obtained have been used to create a Matlab Tool, where the user, interacting with the GUI, makes the first selections, such as the type of mission required and the maximum number of Mach. This will start the general design process. Starting from these choices, the software is able to generate a list of requirements, which will impact on design. In this way the program will be able to provide the user with suggestions regarding: Propulsive strategy, staging strategy, Take-off and Landing strategy, Aerothermodynamic configuration and will also be able to provide indications about the fuselage and the wing. The data was finally saved in a document that summarizes the advice given to the designer, the choices of the same and an updated list of the various requirements. The Matlab code was created with the aim of facilitating the process of defining the problem, simplifying the design iterations and providing further support for the design itself.

In the following works, one might think of extending the program to other types of aircraft, not just hypersonic ones, the outputs obtained might be used to update a CAD model, which in turn would be imported to Simulink in order to allow simulation, thus solving some problems related to integration.

Furthermore, the requirements would be imported on DOORS. It is a requirement management tool. The following are examples of importing requirements.

| ID | Space Transport Requirements (STR) |
|---|---|
| STR1 | **1 High level requirements** |
| STR2 | The aircraft shall reach the Space. |
| STR3 | The aircraft shall be a hypersonic aircraft. |
| STR4 | The aircraft shall allow the carriage of people and things. |
| STR5 | The aircraft shall be re-usable. |
| STR6 | The aircraft shall allow take-off and land on existing runways. |
| STR7 | The aircraft shall allow vertical take-off and vertical landing. |
| STR8 | The aircraft shall reduce the launch costs. |
| STR9 | **2 Staging Strategy Requirements** |
| STR10 | The aircraft shall reach the space. |
| STR11 | The number of stages shall be reduced. |
| STR12 | The aircraft shall be equipped with a propellant tank. |
| STR13 | The aircraft shall be equipped with a propulsive system. |
| STR14 | **3 Propulsive Strategy Requirements** |
| STR15 | The aircraft shall reach the space. |
| STR16 | The aircraft shall be a hypersonic aircraft. |
| STR17 | The aircraft shall allow the carriage of passengers. |
| STR18 | The aircraft shall allow the carriage of things. |
| STR19 | The aircraft shall be re-usable. |
| STR20 | The aircraft shall allow take-off and land on existing runways. |
| STR21 | The aircraft shall allow vertical take-off and vertical landing. |
| STR22 | The aircraft shall be able to withstand the thermal loads. |
| STR23 | The rotating machinery shall be reduced. |
| STR24 | The number of propulsive system shall be reduced. |
| STR25 | The aircraft shall work in different operative scenarios. |
| STR26 | The propulsive system shall able to re-start. |
| STR27 | The propulsive system shall able to throttle. |
| STR28 | The propulsive system shall provide high thrusts. |
| STR29 | The propulsive system shall provide high specific impulse. |
| STR30 | The aircraft shall able to reach the desired Mach. |

***Figure 140 Space Transport Requirements***

| ID | High Level Requirements |
|---|---|
| HLR1 | The aircraft shall reach the Space. |
| HLR2 | The aircraft shall be a hypersonic aircraft. |
| HLR3 | The aircraft shall allow the carriage of people and things. |
| HLR4 | The aircraft shall be re-usable. |
| HLR5 | The aircraft shall allow take-off and land on existing runways. |
| HLR6 | The aircraft shall allow vertical take-off and vertical landing. |
| HLR7 | The aircraft shall reduce the launch costs. |

***Figure 141 High Level Requirements***

| ID | Staging Strategy Requirements |
|---|---|
| SSR1 | The aircraft shall reach the space. |
| SSR2 | The number of stages shall be reduced. |
| SSR3 | The aircraft shall be equipped with a propellant tank. |
| SSR4 | The aircraft shall be equipped with a propulsive system. |

*Figure 142 Staging Strategy Requirements*

| ID | Propulsive Strategy Requirements |
|---|---|
| PSR1 | The aircraft shall reach the space. |
| PSR2 | The aircraft shall be a hypersonic aircraft. |
| PSR3 | The aircraft shall allow the carriage of passengers. |
| PSR4 | The aircraft shall allow the carriage of things. |
| PSR5 | The aircraft shall be re-usable. |
| PSR6 | The aircraft shall allow take-off and land on existing runways. |
| PSR7 | The aircraft shall allow vertical take-off and vertical landing. |
| PSR8 | The aircraft shall be able to withstand the thermal loads. |
| PSR9 | The rotating machinery shall be reduced. |
| PSR10 | The number of propulsive system shall be reduced. |
| PSR11 | The aircraft shall work in different operative scenarios. |
| PSR12 | The propulsive system shall able to re-start. |
| PSR13 | The propulsive system shall able to throttle. |
| PSR14 | The propulsive system shall provide high thrusts. |
| PSR15 | The propulsive system shall provide high specific impulse. |
| PSR16 | The aircraft shall able to reach the desired Mach. |

*Figure 143 Propulsive Strategy Requirements*

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