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METHODOLOGIES AND EXAMPLE OF CONCEPTUAL DESIGN FOR A FOOT-LAUNCHABLE SPORT SAILPLANE

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Abstract

This work presents one design approach for a fixed-wing hang-glider (or Foot-Launchable Sport Sailplane). Several of these types of aircraft are result of a 'intuition-trial-and-error' process, with some group of empirical and theoretical support concepts. And apparently, theoretical or classical approaches for aircraft design are4242 not always applicable for these types of aircraft.

The main source of problems of 'classical' design techniques to these aircraft are the large effect of the human body in the aircraft shape, the spaces needed for a reasonable ergonomics and how to harmonize this with the -not large- aircraft size. Additionally, the required low take-off/landing speeds and the low overall mass, together with a suitable aerodynamics efficiency, low cost, easy maintenance, easy transportation, easy assembly/disassembly characteristics, are relevant and combined are special features of this type of aircraft that must be taken into account for a sound concept. Other classical features of manned aircraft, as good flying qualities (suitable stability and control, allowing safe flight characteristics) and crashworthiness, must also be taken into account. Some hang-gliders are intended for easy construction and easy assembly are not properly good flyers, other ones are aimed for cross-country but, as consequence of this type of mission, its wing-loading is more suitable for a towing launch than a foot-launch. All these aspects turn the design of a foot-launched aircraft to be a challenge in terms of the techniques and approaches used for a successful design.

One other very relevant aspect that should be considered, is that, differently of many other types, the aircraft of this category are aimed for leisure and sport activities. In other words, these aircraft are aimed for "flight for fun". And, if the leisure purpose itself is extended not only for the operation of the aircraft, but also to the design, technical research, and construction, this aspect can significantly affect the development process (concept, design, construction, tests).

The purposes of a work intended to be inherently performed for personal motivations can lead to differences starting in the basic requirements and the design philosophy, progressing to budget and milestones requirements, leading to both the design process and the final product to be very different from an aircraft intended to be economically profitable.

I. e., the purpose of conceive a development process of one aircraft intended to be not only flown-for-fun but also 'developed-for-fun' can result in different design approaches and strategies, different 'development and tests' timeframe and even a very different final configuration, compared to one aircraft intended to be economically feasible or profitable.

In this work, regarding the hang-glider specific operational features, some classical design techniques are identified, adapted, and complemented by other specific approaches, in order to define a suitable design path for such type of aircraft. The basic aim is to present the systematic approach for a feasible design and development process, to obtain as the result a suitable, practical, and safe aircraft.

A summarized history investigation is performed, aiming the identification of both: possible "good and forgotten solutions", and "not good solutions in which important lessons can be learnt". The basic task-flow diagram is elaborated, the most important steps in the design process are identified/defined, the main tools possible to be used are included, and one example of design, leading to one specific configuration is presented, based on the aircraft requirements established. The main weak points of the design chain are also identified as special points of attention in the process.

In function of the aspects found in the history investigation, some specific -and sometimes unusual- tasks and milestones are determined in order to smoothen the development process. The basic design and development sequence is presented as "a) basic concept definition and operation analysis; b) basic requirements; c) conceptual configuration design; d) design tools definition; e) overall design; f) proof-of-concept (POC) definition and strategy; g) POC design, construction, tests and conclusions; h) requirements update; i) design adjustment with POC trials and requirements update; j) ground and flight tests definition and planning; k) 1st aircraft manufacturing; l) ground and flight tests execution, and conclusions; m) aircraft and design adjustment after test results"; n) final test trials". One basic assumption is that, even considering the low aircraft weight and the aircraft purposes, the involvement with local airworthiness/certification authorities will occur during the development process whenever necessary.

In terms of design, considering the basic requirements, the process will follow an evolutive, iterative, approach. At the early phase simple concepts and tools in terms of aerodynamics, performance, stability, weight, and structures are used. When a good compromise is found, the achieved concept is checked against the requirements, before the detail design starts, in which more complex tools are used.

The early design phase, or the conceptual design phase, is identified as one of the most critical steps of the whole development, and so, it is one of the most explored subjects in this work. In this early design phase, the requirements regarding the typical aircraft mission and the main flight characteristics drive the aircraft possible configurations. The possible configurations are identified, checked and the ones judged as feasible are, after a focused evaluation, ranked for the next step. The best candidates are considered for the "aerodynamic, performance, stability, structure, weight" evaluation. In this 1st analysis, a convergence of values is pursued, and, if necessary, the requirements are reviewed or readjusted. In addition, in this phase, a large emphasis is performed in the cabin ergonomics and human-machine interface. In terms of ergonomics, several solutions of pilot positioning are considered, including the changes in pilot's positioning from take-off to fight. Details of 'control surfaces to pilot' chain are also taken into account. From the conclusions and findings of this early design phase, the overall planning can be readjusted. Additionally, the main points to be checked -if necessary- through a POC are defined, leading to the POC flight test campaign. If necessary, more than one POC is defined. The other parts of the development process are presented in less detail, since the focus of the work is the group of tasks related to the conceptual design phase.

As the results of this work, the overall development process diagram is presented for a foot-launched aircraft -focusing the conceptual design phase- together with the aircraft configuration obtained. The aircraft performance characteristics, the construction process and the proof-of-concept specimens are also defined. As a final remark, the evolution of the concept i. e., the next aircraft concepts that may be derived from the 'main concept' are also suggested.

The overall conclusion is that -even for this very special type of sport aircraft- the application of the classical design tools with some special strategies can be successful, generating feasible aircraft. The special strategies forementioned are obtained from investigation of previous development attempts and from studies to consider the specific features and challenges of this unique type of aircraft, the foot-launched ones.

Keywords: Hang-Gliding, Aircraft Design, Aircraft Development, Performance, Aerodynamics, Flying-Wing

1. Introduction, Initial Ideas and Main Concepts

The aim of this work is to present one systematic and feasible design approach for a specific type of Hang-glider aircraft: the rigid-wing, with conventional controls. The term "hang-glider" refers to a very light sailplane with the capability to be "Foot-Launchable" from a hill. It is one unpowered, manned aircraft, for leisure and sport purposes. The basic idea was to check the feasibility of apply the theoretical design approach, with the proper adaptations, to the challenge of perform the design of hang-gliding sport aircraft, improving the chances of success. The final target of this design and development process, is the definition of a suitable, practical, and safe Hang-Glider ('HG') aircraft.

Apparently, several examples of this type of aircraft are result of a 'trial-and-error' process -after some intuition and new ideas, supported by empirical and theoretical concepts. And apparently, theoretical or classical approaches for aircraft design are not always applicable for these types of aircraft. The classical approaches for aircraft design in the industry seem to be tailored and optimized for conventional aircraft. And Hand Gliders present some specific characteristics that may result in the conventional design approach to be not completely adequate for designing a HG. One of these characteristics is the large effect of the human body in the aircraft shape and mass. This requires special attention not only in the pilot positioning related to the aircraft during take-off, flight and landing, but also special attention on the spaces needed for a reasonable ergonomics and how to harmonize this with the -not large- aircraft size, and keeping good aerodynamics and good structural efficiency. All these aspects turn the design of a foot-launched aircraft to be a challenge in terms of using 'classical' design techniques for a successful design of one of these aircraft.

By other hand, some of the enthusiasts of the HG activities do not have the background of project management or design environment of one aeronautic/aerospace industry. Additionally, much of the people interested in HG activities for leisure and sport, and not as a profession. The HG history presented some booms in which solutions for easy, not expensive flight were achieved through the HG modality, but for several reasons, these booms have been dissipated. And it seems that, currently the HG development environment is concentrated in some very few and very good companies. So, apparently, except by some few and very good companies, there is a gap between the current aerospace knowledge and the HG development environment. Few very good companies have achieved this bridge, but it seems that it is not easy for a group of people, in their leisure time, to make efforts to obtain a suitable foot launchable flight machine. This work is one attempt to fill -at least partially- this gap.

In performing this work, the initial steps are to understand the classic aircraft development process, and understand special features of the HG. After this it is important to identify how these features can diverge from the classic aircraft development process, and to create means to adapt the classic development process -aimed for industry- for the design of a sport aircraft, that could also be developed as a leisure activity.

The basic sequence followed in this work is presented in the Figure 1

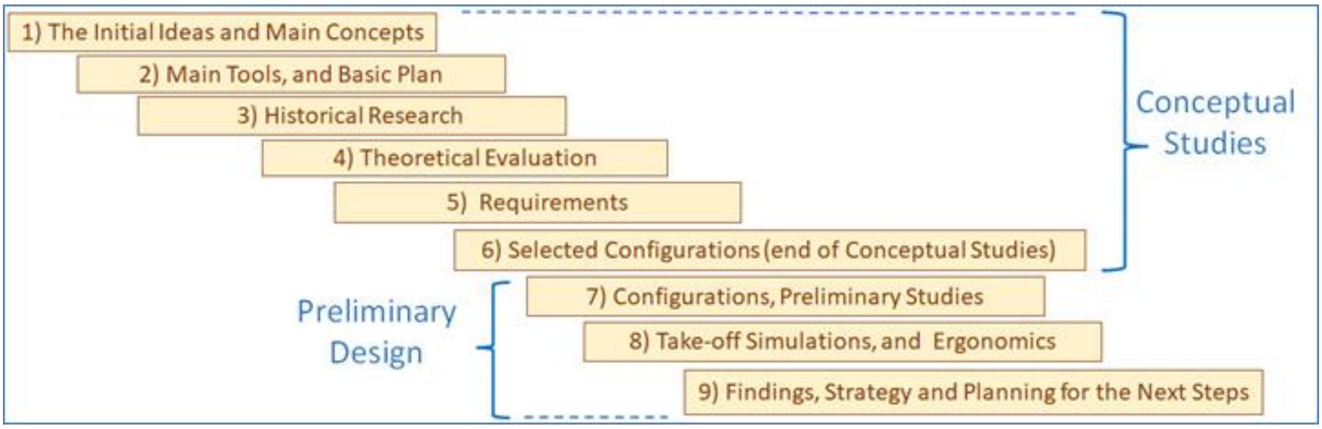

Figure 1 - Basic Sequence of this work

The sequence considered in this document is the attempt of presenting the main aspects in the "main cause and effect" logical order. But the definition and design process has happened in a very iterative way. This may be specially observed in sections 6 and 7.

The main motivation for this occurred years ago, during the research towards a lightly-powered sport hang-glider design. In a first and superficial evaluation at that time, it was noticed several aspects finally addressed through this work: several development processes of potentially good and promising configurations have been interrupted due to accidents, hang-gliders became exaggeratedly heavy when incorporated one engine, some new designs of hang-gliders were excessively focused in performance and became heavy and expensive.

Potentially, hang-gliders could be the easiest way to approach people to manned flight activities, and in some moments in history this has really happened.

It is perception from the author that one of the causes of difficulties presented for some hang-glider development is the absence of a design and development procedure as it exists for aircraft. And a good design and development procedure for a general aircraft does not fit completely on the HG design, in one analogous way as the design and development procedure for a commercial jet airplane does not fit completely in the design of one general aviation aircraft.

The main objectives with this effort have been to apply the theoretical background of aircraft design in the industry environment to one type of aircraft which have been developed based mostly in experience intuition, creativity and experiments. The purposes of a work intended to be performed by personal motivations -as research, learning, or spreading of aeronautical activities- can lead to differences starting in the basic requirements and the design philosophy, progressing to budget and milestones requirements, leading to both the design process and the final product to be very different from an aircraft intended to be economically profitable.

The Main Concepts associated to this work are:

- To consider the main tasks sequence of the “aircraft generic development and production plan”, presented in the next Section;
- to try to make the appropriate adaptations in the “aircraft generic development and production plan” in order to use it for the Hang-glider design;
- And in order to make these adaptations, to try to identify the specific characteristics of a Hang Glider design that shall be taken into account;
- To try to learn with the attempts of Hang-Gliders and the previous designs to identify trends, points of attention, risks and potential pitfalls;
- To identify what are the attractive points of a hang-glider;
- It is very important to avoid pursuing the performance characteristics of a high-performance sailplane;
- To observe the importance of Ergonomics or the man-machine interface or the pilot influence in the aircraft;
- Safety is more relevant than performance at least for a first development;
- To keep aware about the importance of the process to be stimulating and motivating (since it is to be carried on in the leisure time).

2. The Basic Plan and the current Tools

The Overall Plan is initially based on the scheme presented in the figure 2, “Aircraft Generic Development and Production Plan”. The figure 2 represents the Aircraft Development and Production Plan by technical standpoint (Marketing, Logistics, Financial and Technical Assistance not included). It is adapted from [1] and [2], based on author’s experience.

As mentioned in the introduction, the design and development process tend to happen in a very iterative way. The Conceptual Studies, the Preliminary Design and the Development phases, presented in Figure 2, correspond to “technical loops”. In each “loop” the same technologies are addressed (geometry, aerodynamics, performance, mass, systems, structure, propulsion, costs, logistics, manufacturing, tests, airworthiness, requirements and risks management), pursuing a convergence. And after a convergence is achieved, the new cycle starts with a deeper detailing level, up to the final definition of the product.

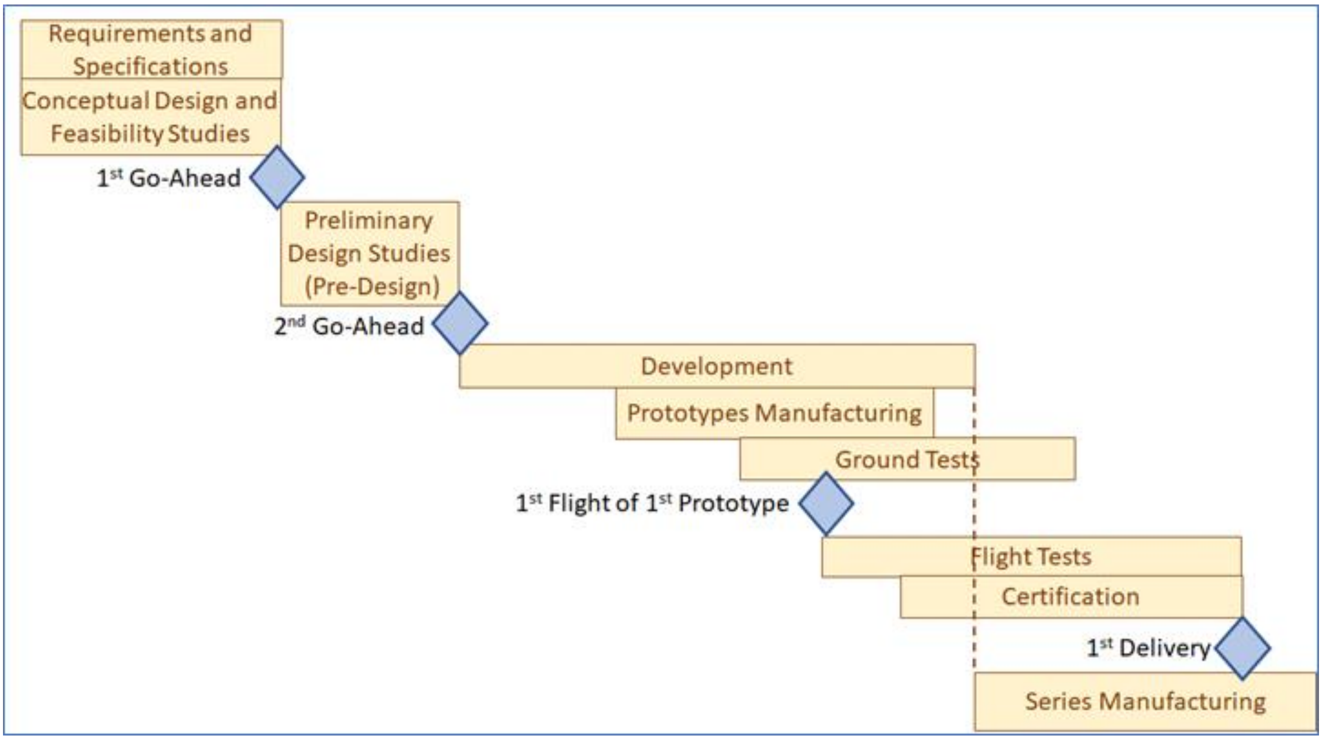

Figure 2 - Aircraft Generic Development and Production Plan

Taking this plan as the basis, most part of the work presented herein corresponds to the Conceptual Studies and the Preliminary Design, and the most important aspects have been -as also presented in Figure 1:

a) To perform the dedicated historical research (section 3);

b) From the historical research, to perform a theoretical evaluation selected aircraft (section 4);

c) From the findings of this evaluation, to readjust -if necessary- the basic plan and initial requirements (section 5);

d) Establishing 2 configurations as the best candidates to meet the requirement -i.e., to have their main characteristics defined and refined (section 6);

e) Performing the Preliminary Design regarding these configurations (sections 7 and 8), to be further considered for the development phase;

f) Identification of potential pitfalls in the process and definition of next steps and goals, (section 9).

Some tools have been developed for this work, and their use is commented along the text, They are:

- Fast Drag estimation (Drag polar);
- Performance Estimation (Gliding characteristics);
- The Aerology (wind/terrain) model;
- Geometry Visualization;
- Take-off simulation.

Also, not properly a tool, but the strategy of using scale flying models was extensively used to study the basic shape of the intended configurations, mainly regarding stability, structural arrangement, ergonomics, and assembly & storage solutions.

3. Historical Research

A summarized history investigation is performed, aiming the identification of both: possible "good and forgotten solutions", and "not good solutions in which important lessons can be learnt".

The importance of the historical research is -among other factors- to understand why some very promising concepts have been at least temporarily stopped or discontinued, some of them being re-achieved long time ahead.

The main historical aircraft, people and factors identified as related to hang-gliding history, for the purposes of this work, are summarized in the Figure 3. This represents the author's view supported by the several sources accessed, being the most important ones listed at References section. This is the result of the efforts of obtaining one overall view of the HG evolution and facts, to support this work and does not necessarily represent the "complete best, and final" sequence of the all the important events and representatives.

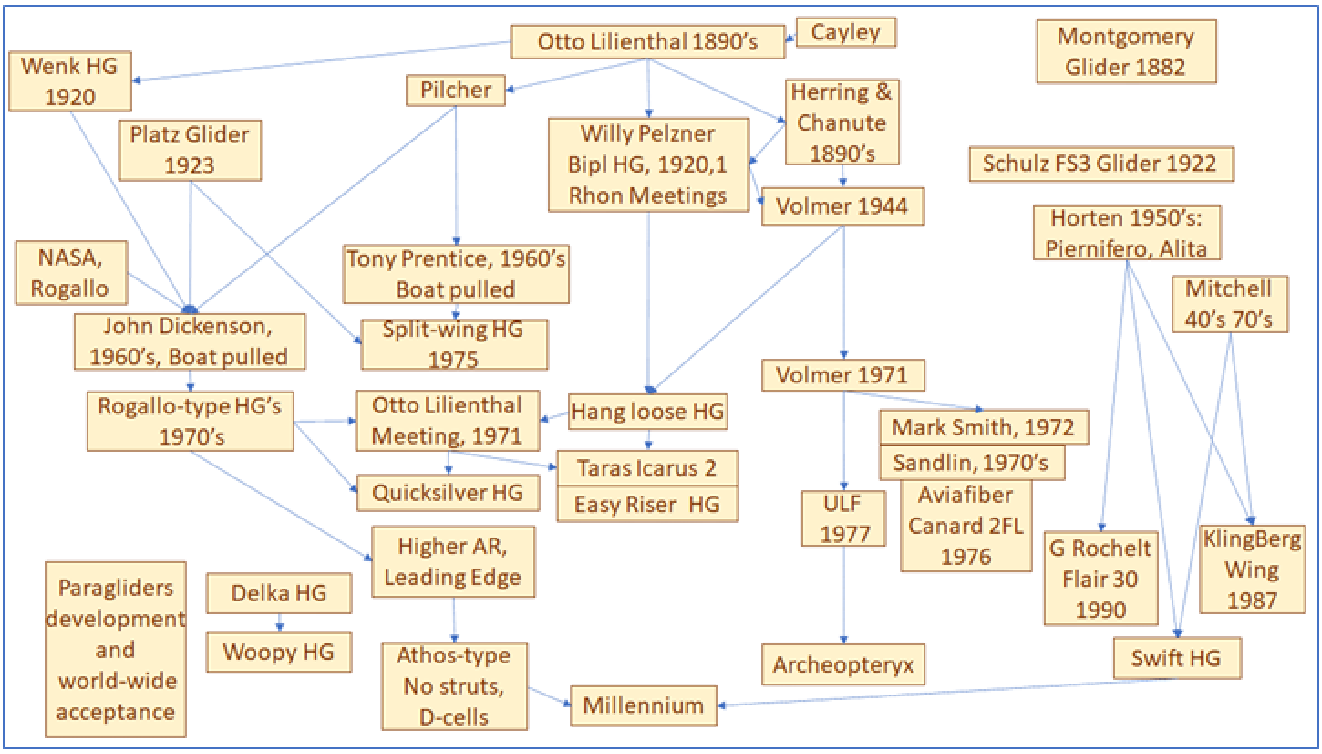

Figure 3 - The relevant aircraft, people and factors related to hang-gliding history;

From the historical research the main aspects identified are summarized as follows. The first successful, controlled, manned aircraft in history have been hang-gliders. After the first successful manned powered flights, the aircraft designs get more and more heavier and faster and become progressively apart from Hang Glider type. The practical function of Hang-gliders after 1900 has been sport, leisure, and to provide one easy access to flying activities, so promoting and disseminating flying activities, but not properly the "aviation progress". In terms of gliding flight, by 2 more decades the hand-glides were good representatives. After 1921 the sailplanes heavier than Hang-gliders started to present increasing better performance compared to HG, and except for few examples the hang-gliders entered in a hibernation period, up to the 1970 decade. So, at the beginning of 1970 decade, several different -feasible- concepts, and from different approaches and background emerged almost simultaneously, revealing a potential or hidden desire of several people, that suddenly came to practice. The Rogallo type in that moment has the greatest number of users. Since the 70's it has continuously evolved, increasing performance and safety, and currently its "descendants", the "delta-type" wing, is still being developed and used. Some of the aerodynamic improvements of the current delta-wing HG compared to the early Rogallos are the much higher aspect ratio, the airfoil-like leading edges, no wiring bracing, the fairing around the pilot.

The paragliding-type wing currently possibly is the most popular HG, as it could achieve the performance features of the delta-type wing, being also very compact for transportation and easy to prepare for flying. Some different designs of rigid wings still exist, presenting in general better performance than the flex wing aircraft. Otherwise, they are more demanding for assemble, disassemble, transport and store. They also tend to be more expensive, heavier -which can cause problems in take-off- and tend to demand larger previous flying experience.

Returning to the 1970 decade, at that time several hang-glider designs started to be successfully adapted to small engines. These HGs, the weight increasing due to the engine lead to the need of one undercarriage, which increased weight and drag, structure reinforcement was needed, sometimes a cockpit was also added. These changes resulted several times in the need a larger wing area, which again increased the drag and demanded for more powerful engine, and so on. This is a known phenomenon that tends to occur in aeronautic design and development, called Weight Spiral. The converged configuration in most of the cases was not a hang-glider anymore and was so defined as “ultralight aircraft”. The feature and characteristics of such aircraft got close to the successful Santos Dumont Demoiselle, of 1909, that, as the Otto Lilienthal hang-gliders, seemed to have hibernated from 70 years, returning after -as happened with the hang gliders- for sport and leisure purposes. Most of the users of hang-gliders apparently changed their preferences for the powered “ultralights”. The hang-glider users are now enjoying flights in high-performance paragliders, high-performance delta-wing types, and some rigid-wing aircraft.

It was also observed from the historical research that several good and promising designs have been discontinued due to accidents, during flight tests, and reportedly, sometimes some aircraft went to Flight Tests without the adequate preliminary procedures. This is definitely a point of attention.

Some hang-gliders which were intended for easy construction and easy assembly are not properly good flyers, but became surprisingly popular due to the positive characteristics. Some other HGs ones were aimed for cross-country (which means a high glide ratio at higher speeds, when compared to the average values of HGs), but as consequence of this type of mission, they became expensive, heavy -their wing-loading becoming more suitable for a towing launch than a foot-launch. Additionally, sometimes they became not suitably stable, increasing the occurrence and the risk of accidents.

Other interesting aspect identified is the group of attempts in transform the HG as a popular sport as to spread to more people the interest in flying. Some examples are:

- The magazine articles and lectures by Otto Lilienthal, from 1890 to 95, treating HG as a sport;
- The article in Popular Mechanics Magazine, 1909, by Carl S. Bates;
- The early flight meetings in Germany in 1920 and 21, in which one preeminent machine was the Pelzner Hang-glider;
- The Volmer VJ 11 Hang-glider, whose plans to build are made available for the interested people in 1944;
- The Jack Lambie Hang-Loose design (whose plans were also made available) and the “Otto Lilienthal” meeting of 1971;
- The quicksilver HGs, and easy riser HGs in the 1970’s;
- The Rogallo-wing boom in the 1970’s, and the advancements in delta wing HGs in the 1980’s;
- The paragliding boom in the 1990’s.

Just to illustrate one of the several attempts to produce more accessible flying machines, it may be useful to present the 6 requirements followed by Reinhold Platz to design his glider in 1923:

- Very low initial cost, as a good bicycle;
- Capable of dismantling into small parts in order to permit transport per passenger train;
- Insensitive to rough man-handling and shocks at any points;
- Rapid and easy assembly;
- Simple and cheap replacement of all parts;
- Must be capable of being carried by a single man.

One can notice the simplicity of the aircraft intended, which is also close to the characteristics of the HGs from Lilienthal and Pelzner. One also can note how these requirements approach to the ones defined for this work.

As a product of the historical research, some relevant aircraft have been selected for technical analysis and comparative study. The Selected aircraft and their main characteristics relevant for this work- are presented in the Table 1 and Table 2. It can be seen by these tables how different can be the design solutions and also how the different characteristics listed can be combined in different ways leading to each specific design.

Year	Aircraft	Mo [kg]	Mu [kg]	M [kg]	S [m2]	N	B [m]	A
1893	Lilienthal Monoplane	22	80	102	13.0	1	7.0	3.8
1895	Lilienthal Biplane	32	80	112	18.0	2	5.8	3.8
1920	Pelzner Biplane	10	75	85	14.0	2	5.4	1.3
1940	VJ 11	45	82	127	20.9	2	8.5	7.0
1961	Rogallo-Type	27	75	102	21.0	1	6.0	1.7
1971	Icarus 2	25	80	105	18.0	2	9.1	9.3
1971	VJ 23	45	80	125	17.6	1	9.9	5.6
1973	Quicksilver B	25	70	96	10.8	1	9.1	7.8
1974	Quicksilver C	29	80	110	14.9	1	9.8	6.4
1974	Mitchell Wing	36	85	121	12.3	1	10.4	8.8
1975	VJ 24	50	82	132	15.1	1	11.1	8.2
1975	Easy Riser	26	80	106	16.3	2	7.8	7.5
1977	ULF	55	80	135	13.4	1	10.4	8.1
1989	Swift	59	80	139	12.5	1	12.3	12.1
1990	Agena 28, Paraglider	17	68	85	25.3	1	8.9	3.1
1999	Millennium	43	80	123	13.9	1	11.3	9.1
2011	Woopy	17	75	92	20.5	1	9.7	4.6

Table 1- Main Characteristics of the Selected Aircraft

Aircraft	Rigid Wing ?	Bi-plane ?	H-Tail?	Stream-lined Cockpit?	Any Control by CG shift?	Braced Wing?	Easy to Flight? (*)	Easy to Store?	Easy to build?	Is the level of Performance acceptable?
Lilienth. Mono	Y		Y		Y	Y	S. N.	Y	Fair	N
Lilienthal, Bipl	Y	Y	Y		Y	Y	S. N.	Y	Fair	Marginally
Pelzner Bipl	Y	Y	Y		Y	Y	Y	Y	Y	Marginally
VJ 11	Y	Y	Y			Y	Y	N	Y	Y
Rogallo-Type					Y	Y	Y	Y	Y	N
Icarus 2	Y	Y			Y	Y	S. N.	N	Fair	Y
VJ 23	Y		Y				Y	N	N	Y
Quicksilvers	Y		Y		Y	Y	S. N.	Y	Fair	Y
Mitchell Wing	Y						S. N.	Y	N	Y
VJ 24	Y		Y			Y	Y	Y	Fair	Y
Easy Riser	Y	Y			Y	Y	S. N.	Med	Fair	Marginally
ULF	Y		Y	Y			Y	N	N	Y
Swift	Y			Y			S. N.	Y	N	Y
Agena 28					Y	Y	Y	Y	N	Y
Millennium	Y?			Y			S. N.	Y	N	Y
Woopy					Y		Y	Y	N	Y

Table 2- Configuration and operational characteristics for the selected aircraft (* S.N.: Skills Needed)

4. Evaluation of Selected Existing Aircraft

The aircraft selected above have been evaluated through the steps below:

a) The evaluation of drag coefficient, and secondarily the lift coefficient;

b) The evaluation, based on the aerodynamic values obtained, of its flying performance (focusing in Glide Ratio, Sinking Ratio, and airspeeds);

c) To understand the HG specific characteristics and to develop design guidelines metrics from correlations and trends related to the mass, aerodynamic, and performance parameters;

d) To build one simplified aerology model and, once known the performance characteristics of the selected aircraft, to use this aerology model to compare the soaring heigh achieved by different HGs.

The Drag Coefficient *CDo* obtained for the selected aircraft and the breakdown of this coefficient is presented in the Figure 4

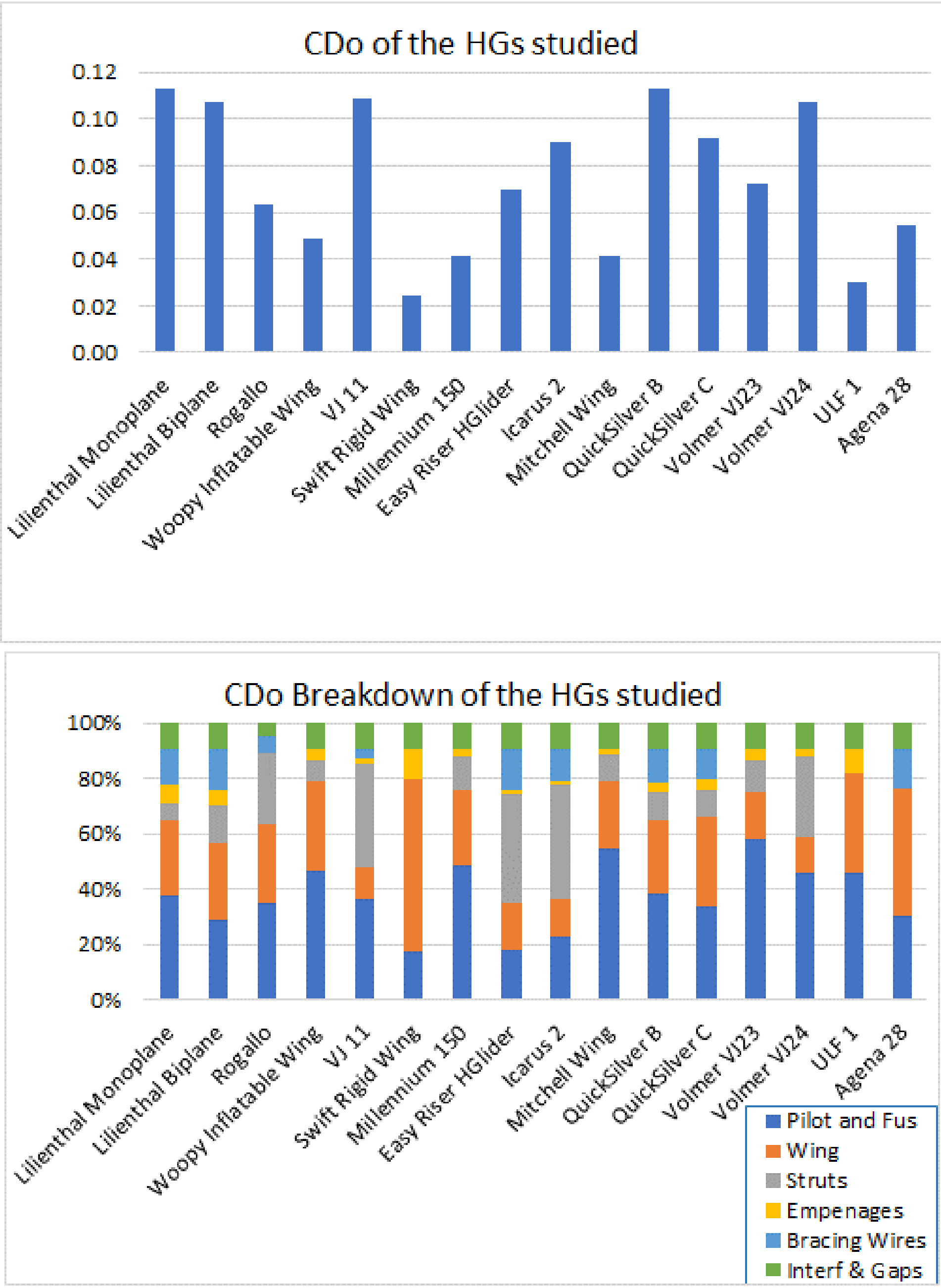

Figure 4 - Comparison of *CDo* of the aircraft studied and the Breakdown of the *CDo*

In terms of performance, it was identified that the main characteristics to highlight are the Glide Ratio *E* and the Sinking Ratio *VZ*. The calculated values for each aircraft are presented in the Figure 5. Whenever available, the corresponding reported values are included for comparison. It can be seen that there is a good correlation between the calculated and the reported values available.

In one attempt to present one overall scenario of HG technical characteristics, the most important parameters in terms of mass, aerodynamics and performance (Wing area, Wing Loading, Span, calculated Cdo, Highest Glide Ratio, Lowest Sinking Ratio) obtained for the analyzed HG are presented as function of their Aspect Ratio in the Figure 6.

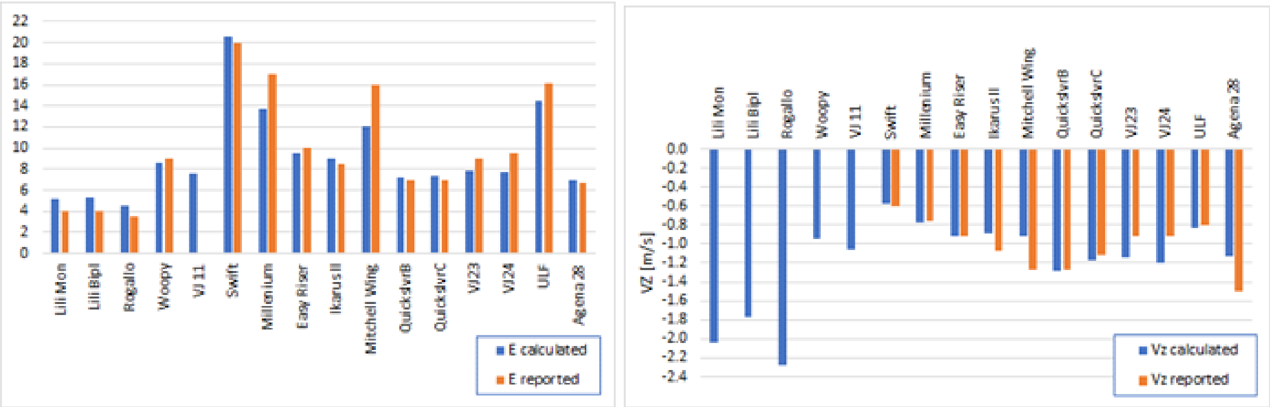

Figure 5 - Calculated and Reported values of Glide Ratio *E*, and Sinking Ratio *VZ*.

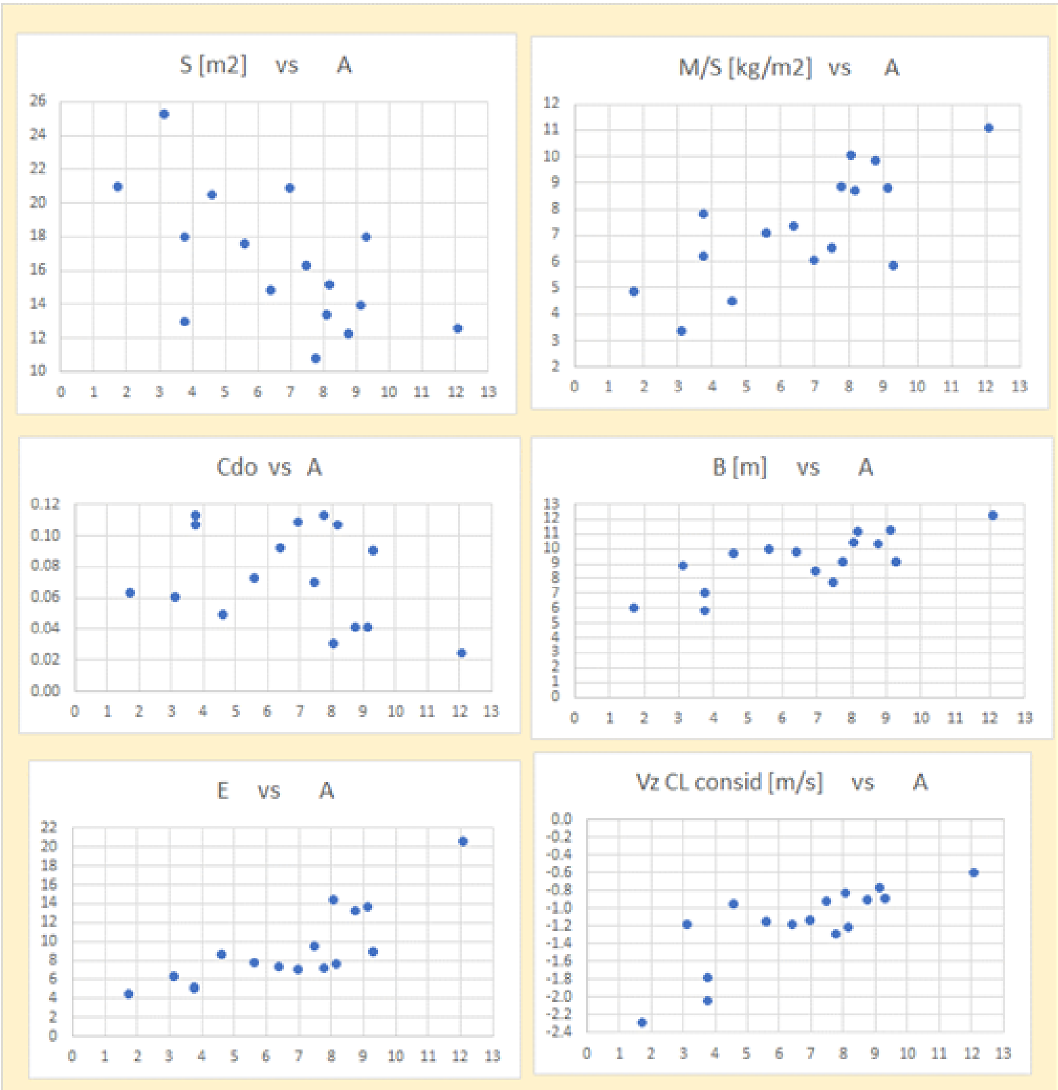

Figure 6 - Characteristics obtained from the HG studied, in function of the aspect ratio.

From the analysis performed, it is possible to generate a time-wise evaluation of the drag coefficient

CDo of the HGs, as presented in figure 7. In this figure the hang gliders' *CDo* reduction is compared with the timewise variation of *CDo* of conventional, powered aircraft. It can be observed that:

- Some HG presented, the same drag in 1960 as the successful pioneers from 1890's. This possibly happened due to the hang-gliders 'hibernation period' of 1900 up to 1960.
- During the 1970's one fast improvement on the aerodynamics apparently happened;
- the *CDo* of the hang gliders achieved low level of 0.02 some 55 years after the conventional aircraft had achieved this level.

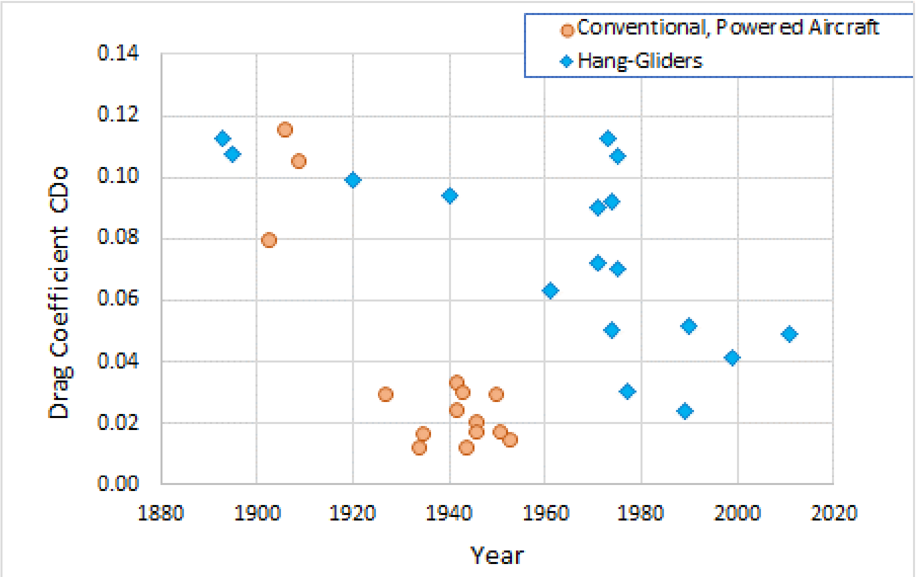

Figure 7 - Historical Evolution of CDo of Hang Gliders and Conventional aircraft

Additionally, the two next figures present the evolution of the performance of the Hang Gliders, in terms of increasing of glide ratio, and reduction of the magnitude of the Sinking Ratio VZ. Among the aircraft investigated, Glide Ratios as high as 20 and Sinking Ratios with magnitudes as low as 0.8 m/s have been observed.

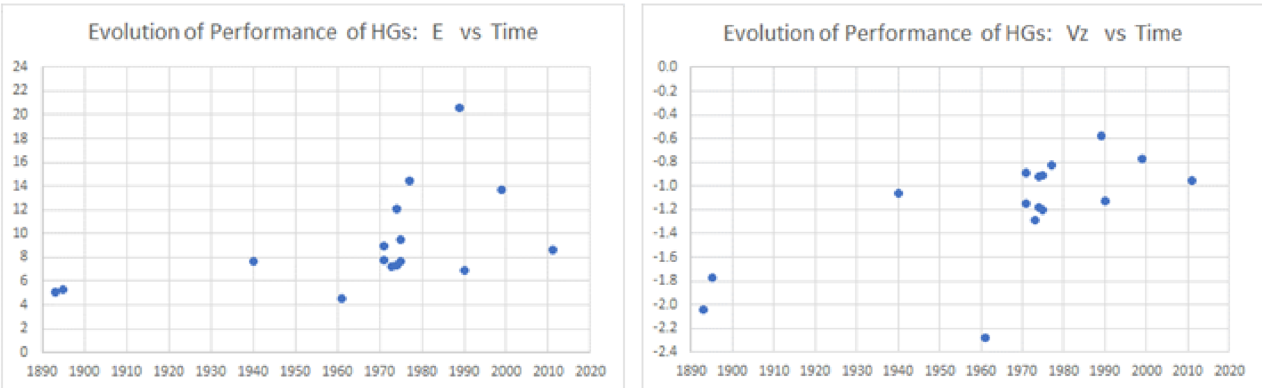

Figure 8 - Historical Evolution of Glide Ratio *E* and Sinking Ratio *VZ* in Hang Gliders

Also, from the historical analysis, it is possible to generate some evaluation and trends regarding mass characteristics. of the aircraft. The percentages of pilot's mass compared to the total mass of the analyzed aircraft are presented in the Figure 9. It can be noticed that in general, the pilot represents about 65% to 70% of the aircraft mass. This mass ratio is one very remarkable characteristics of this type of aircraft, and represents one of the strongest challenges in terms of design, as commented in the Introduction of this work.

The Aircraft Empty Masses (the aircraft mass, without the pilot) for the aircraft considered in the historical research are presented in the Figure 10, in function of aircraft total mass, stall speed, CDo, Glide Ratio, Span, wing area, and aspect ratio. The corresponding trend curves for these plots are also presented. These curves are potentially useful for new designs, as will be shown further.

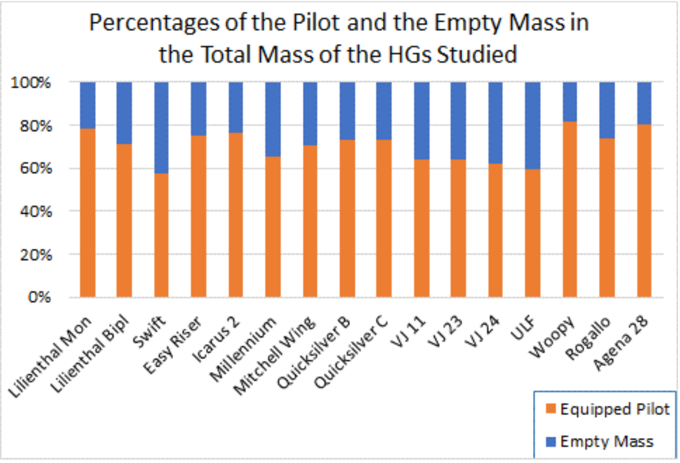

Figure 9 - Percentages of the Pilot and the Empty Mass in the Total Mass of the Hang Gliders

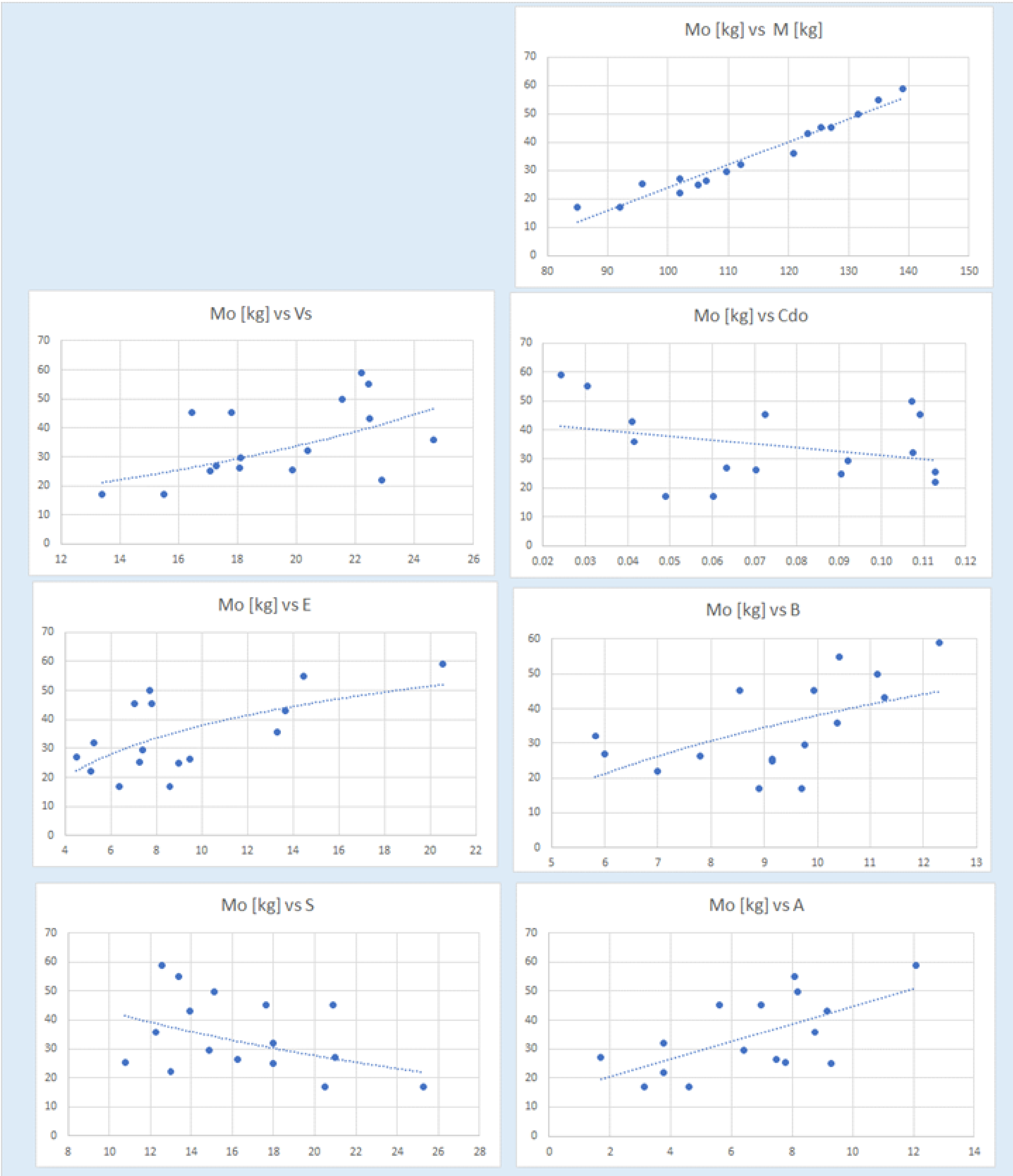

Figure 10 - HG empty masses in function of
aircraft total mass, stall speed, *CDo*, glide ratio, span, wing area, and aspect ratio.

The Aerology analysis i.e., the atmosphere and topography of a launching site" is presented as follows. One of the most important HG characteristics, is the take-off and the soaring above the take-off hill. In order to allow for a theoretical approach for this condition, a 2D model of the wind affected by a hill – also considered as the launching site - is elaborated, using potential flow approach, based on [3] and [4], and presented in the Figure 11. In this figure the wind profile is represented by streamlines along the vertical-longitudinal plane. Based on this wind profile, he distribution of the vertical speed in the obtained flow field can be determined. This is determined from the streamlines' distribution, as presented in the 'iso-intensity' curves below. The curves are defined in terms of the Speed Ratio *VZ/V* (*VZ* is the Wind Vertical Speed and *V* is the initial wind speed without the presence of the hill.

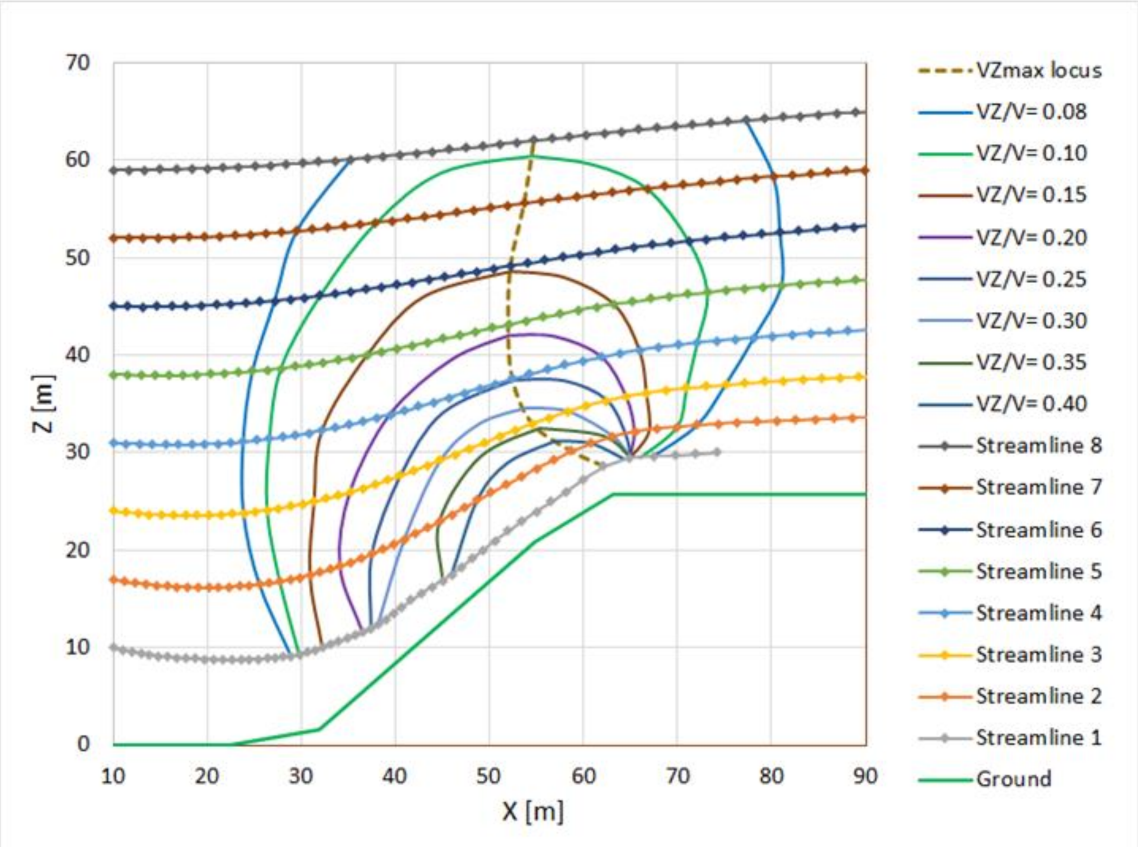

Figure 11 - Aerology Model: Wind, facing a ramp-shaped ground, Streamlines and distribution of Wind Vertical Speed Ratio *VZ/V.*

Considering the obtained curves of *VZ/V,* and selecting four aircraft whose aerodynamic characteristics were obtained, it is possible to 'place' these aircraft in the velocity field considered. The aircraft are Millennium, Easy Riser, Rogallo-wing and Quicksilver C. They are positioned in the speed field for two different wind speeds *V*, 18 and 25 km/h, as presented in Figure 12. From this results, one can notice the influence of the aircraft Sinking Ratio on the height achieved by the aircraft due to the orographic wind only, no thermals. The relative disposition of the aircraft - higher positioning of Millennium related to the Easy Riser and of the higher positioning for the Quicksilver related to the Rogallo wing - is consistent with the comparative positions observed for these aircraft in real flight.

One important conclusion from this analysis -of combining the aerology of the launching site with the aircraft characteristics- is that it is possible now to confirm that the main performance characteristic to be pursued in the current design is the Sinking Ratio. Additionally, as the outcomes from this analysis match qualitatively with recorded observations of some good soaring HGs, it is possible to define what can be a reasonable value of this parameter for the requirements, to drive the design.

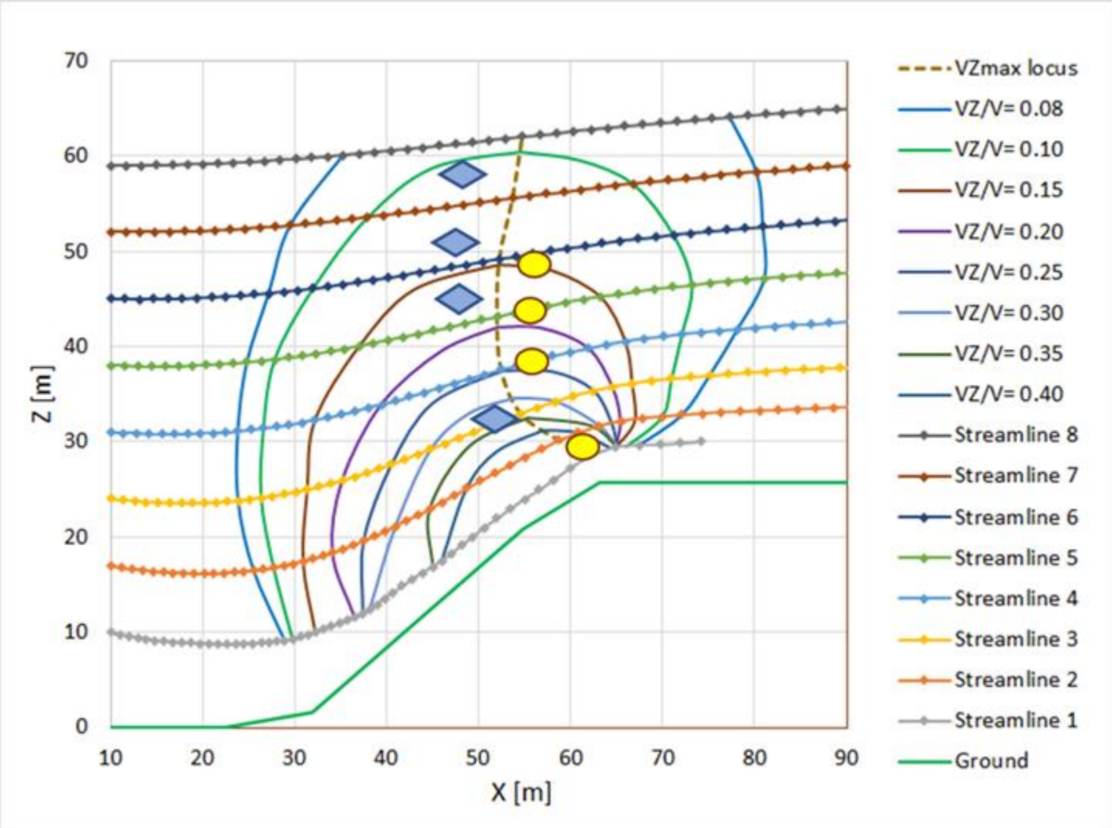

Figure 12 - Positioning of 4 characteristic HG in the Wind field of the previous figure. The Rhombi correspond to wind of 25 km/h and the ellipses correspond to 18 km/h.

5. The Main Requirements

In the early phase, initial requirements have been defined. After the historical and aerology research, the basic requirements have been re-shaped to the list below.

Group 1) Regarding the configuration, Performance, the hang-glider concept shall

- Present the magnitude of the Sinking Ratio lower than 180 ft/min, or 1.0 m/s;
- Present Glide Ratio higher than 10:1
- Present stall speeds not higher than 27 km/h, without flap, and desirable, not higher than 25 km/h with flaps.
- Be able to carry 1 pilot of 70 kg, in the range of +3,5, -1,5 g's, and maximum speed of 75 km/h.

Group 2) Regarding the configuration, Operational Characteristics, the hang-glider concept shall be:

- Easy to assembly, disassembly, transport, store
- Easy to build even compromising performance
- Easy to be flown even compromising performance
- Easy to take-off and land even compromising performance
- "As safe as possible" even compromising performance

Group 3) Regarding the process of development:

- The development shall be performed with the support of one or more Proof-of-Concept (PoC)
- The PoC should be simpler than the final hang-glider concepts, but should be considered as one intermediate step in the direction to the final hang-glider concepts; i.e. the PoC should present

features that are close to the concepts to be applied in the final hang-glider concepts.

- The PoC(s) should: a) provide data to support design decisions; b) be used to explore aspects difficult to be analyzed only theoretically; c) be used to mitigate the risks of the configuration, construction, and handling: d) validate aspects as the stability solutions, intended performance and structural solutions; e) be unmanned; f) have one assembly time lower than 20 mins

The main differences from the revised and initial requirements are the deeper details of the revised requirements, as expected, and -most important- in terms of process, the perception that a PoC will be needed. It is good to highlight, just as one reflex of the iterative nature of this work, it is natural that some of the requirements, along the process are revisited and readjusted. One example is the stall speeds presented above.

6. Closing of Conceptual Design Phase: Basic definitions for the configurations

The configurations selected, two manned configurations, candidates to be built, and the unmanned PoC, are presented as follows.

Considering the maximum lift of coefficient of 1.50, Mass of 100 kg sea level, ISA conditions, and the required stall speed of 25 km/h, the area of 22 m^2 is defined.

Considering the Mass of 100 kg, the *VS* of 25 km/h, the minimum glide ratio of 10, the Aspect ratio of 5 to 8, and the trends presented in Figure 9, the target empty weight of the aircraft is obtained as 30 kg. So, the design pilot weight is 70 kg.

The lift coefficient here is a very important assumption. If the value stated is not naturally achieved, a small amount of flap displacement can be used.

A brief explanation of the reasons for definition of the two configurations is presented as follows. The Aspect ratio and overall drag coefficient are so determined in function of the basic requirement of *VZmin*. This is presented in the sequence. The aircraft lift coefficient corresponding to the minimum magnitude of sinking speed can be derived as:

$$CL^{**} = (3\ \pi\ CDo\ A.e)^{1/2} \quad (1)$$

This value of CL must be checked in terms of the limitation to the aircraft max lift coefficient for clean configuration (no flaps), which in general is about 1.2 to 1.6. A margin between *CL*** must exist for safe flight, so it can be assumed a CL** about 1.10.

Once determined the *CL***, the corresponding Drag coefficient is given by

$$CD^{**} = CDo + CL^{**\,2} / (\pi\ A.e) \quad (2)$$

And the corresponding *VZ* can be derived as:

$$VZ = (2\ .\ g / \rho\ .\ M/S\ .\ CD^2 / CL^3)^{1/2} \quad (3)$$

being *g* the gravity acceleration and *ρ* the air density at sea level, ISA conditions.

Examining the equations (1) to (3) one can conclude, that considering the same wing Loading *M/S*, there are different combinations of *CDo* and *A.e* that can lead to the same value of *VZ*. The plot of *VZ* in function of *A.e* and *CDo* is presented in the Figure 13 below.

Considering this plot, it is now possible to express our “design space” numerically:

- *VZ* with magnitude lower than 1 m/s (as per the requirements);
- *CDo* between 0.02 (practical feasibility limit for a 1st HG) and 0.05 (no challenge above this value)
- Effective aspect ratio *A.e* between 4 (to avoid large reduction of *CLmax*) and 9 (too much challenge for building a 1st HG with value above this)

The “design space” is a very important concept here. It is the region, in a diagram, in which solutions are feasible. This is a very important means to document, to discuss, to communicate and to clarify -and so to keep trackable- the scenario considered and the solutions adopted. This design space is also represented in the shadowed region of Figure 13.

Once defined this design space, 2 different design points have been defined to be studied as the configuration candidates, conf1 and conf2, as also presented in the Figure 13.

The reasons for considering the two configurations are trying different ways to explore Aspect ratio and *CDo*, both obtaining the desired sinking speed. So, one aspect ratio close to each boundary of the design envelope was chosen. Form this point, some basic geometries with these aspect ratios have been examined. The Conf1 with aspect ratio of 5 would be a conventional flying wing in which due to large chord -derived from the large area and low *A.e*- the pilot could be partially accommodated inside the wing, which can collaborate to achieve the desired *CDo* level of about 0.02.

The Conf2 with aspect ratio 8, would not allow the pilot to be installed inside. By other hand, as a 1st design, the large span associated to the aspect ratio would be risky considering the target empty weight and the higher and higher structural complexity generally required for larger span. So since for a larger Aspect ratio a higher *CDo* is allowable to achieve the same sinking speed as shown in Figure 13, a non-usual arrangement was found as very promising to be at least checked: the biplane. One configuration of the type as Icarus 2 or easy riser should be interesting, but just to use the opportunity to check one still-not-well-explored configuration, it was decided to consider Conf 2 as a biplane-diamond wing configuration, a la Charles Ligeti’s Stratos ultralight aircraft. One of the advantages -among others- is that the necessary structure that links the two wings by their centre lines can be also used to accommodate the pilot, without significant increasing in drag. This structure can be named as the “fuselage”. Additionally, potentially this configuration also does not need a H-tail, as the flying wings, since the rear (or upper) wing can partially act as the H-tail. And the necessary links of the wings by the wingtips can also act as vertical tails, as also the rear part of the “fuselage”.

The decision for these configurations was supported by tests of free-flight scale models representative of these arrangements. Other alternative shapes have also been tested to provide comparisons.

The drag analysis was performed, and after some interaction -mainly in Config 2- in which some shape adjustment was done considering the desired *CDo*, and the values of *CDo* are the ones presented in Figure 13.

One can note that the 2nd configuration presents a better (lower magnitude) of *VZ* than the 1st configuration. Anyway, both are meeting the requirement of *VZmin* with magnitude lower than 1m/s. It can be said that configuration 2 presents a large margin regarding this requirement than Config 1.

Once defined the two configurations, it was clear that one interim step was needed: the proof-of concept, PoC. The PoC was defined as one intermediate step between the small-scale models used and the prototypes, and also as a means of obtain insights of which of the two configurations can be the most advantageous to enter in the detail design phase, to be manufactured and flight-tested. It is expected that the decision of which configuration will be manufactured occurs up to about 2/3 of the PoC flight tests were performed.

In this sense, the configuration of the PoC was carefully defined to be also intermediate between the Conf1 and Conf2: The span is slightly larger than the two configurations, but in the same order of magnitude. It is a monoplane as conf1, but it has the aspect ratio close to the one of Conf2. The Design point corresponding to the PoC is also presented in the Figure 13.

In parallel to this evaluation, some configuration studies have been performed, using scale models, from scale 1:10 to 1:3, trying different shapes, and mainly checking the stability features in free-flight, and secondarily exploring the construction, assembly, disassembly, transportation and storage characteristics. The theory presented in [1], [2], [3], [5], [6], [7], [8] has largely used. The definitions of sweep, taper ratio, CG position done using theoretical information have been checked with of these small-scale free-launch models.

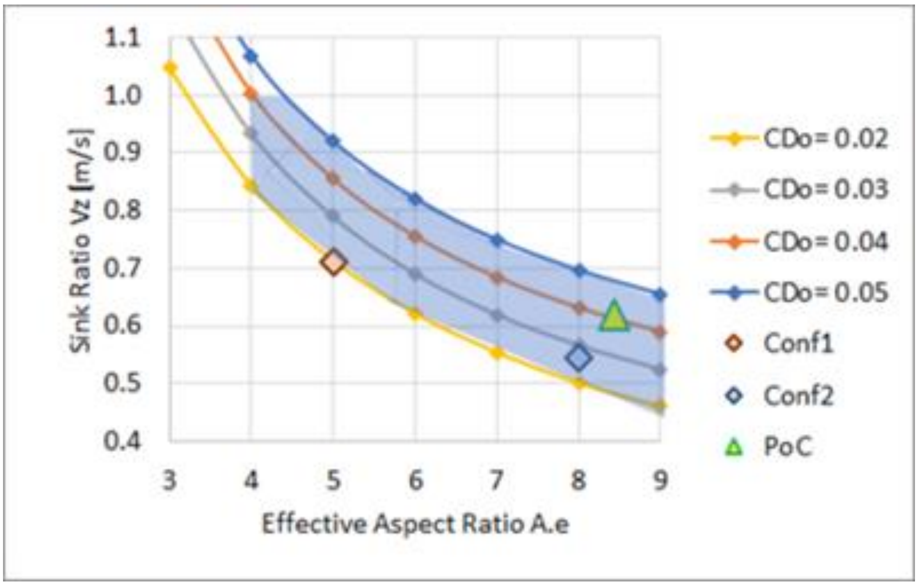

Figure 13 - Sinking Ratio vs Aspect Ratio for several *CDo's*. also presenting the design space

The main characteristics aimed of both prototype candidates “Conf1” and “Conf2” and the PoC are presented in the table 3. The PoC characteristics are presented for 2 extremes of payload weight.

The basic geometries of the 2 configurations and the PoC are presented schematically in the Figure 14. The large ‘X constant’ bar on the wings represent the best CG positioning related to each wing.

Regarding the Aircraft “Development and Production” Plan shown in Figure 2, this Section determines the closing of the Conceptual Studies phase, to be followed by the Preliminary Design Studies phase. The 1st Go-Ahead is declared.

Configuration	Conf1	Conf2	PoC	
			Light payload	Heavy payload
Mo [kg]	30.0	30.0	10.0	
Mu [kg]	70.0	70.0	1.0	45.0
M [kg]	100.0	100.0	11.0	55.0
S [m2]	22.0	22.0	13.1	
N	1	2	1	
B [m]	10.5	9.4	10.5	
C [m]	2.1	1.2	1.3	
A	5.0	8.0	8.42	
CL max	1.3	1.4	1.2	
VS, no flaps	26.9	25.9	12.0	29.3
E*	14.1	15.7	12.6	12.6
VZ min [m/s]	-0.7	-0.5	-0.3	-0.7
Airspeed for E* [km/h]	41.1	33.5	12.9	31.4
Airspeed for VZ min [km/h]	31.2	26.9	12.6	30.6
Never-Exceeded Speed [km/h]	80	75	75	
Max (limit) Flight Load Factors	3.5	3.5	3.2	2.8
Manoeuvre Speed [km/h]	50	50	22	50
Min Required Power for Level Flight [hp]	1.3	1.0	0.1	0.8

Table 3 - The characteristics of the 3 configurations, “Conf1” and “Conf2” and the PoC.

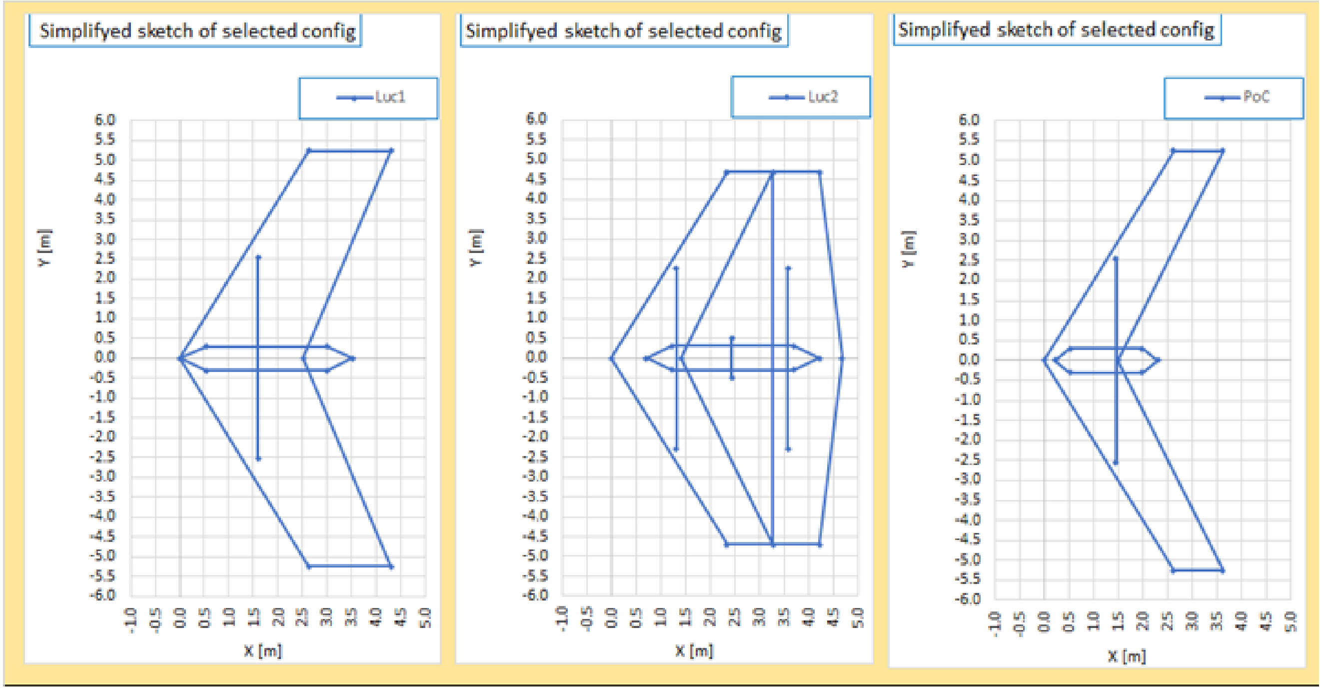

Figure 14 - The simplified geometries defined for the 2 configurations and the PoC, obtained from the Conceptual Design Studies.

7. Starting of Preliminary Design Studies: The 3 configs in more detailed way

After the definitions obtained from the conceptual studies, the 3 aircraft design receive their 1st detailing. The configurations obtained are presented in the figures 15 to 17. The main aspects taken into account to meet the requirements can be qualitatively express as: keeping the wing area, pursue the low weight, clean aerodynamics, and good stability, with good structural arrangement and good ergonomics.

For the 2 manned configs, in order to reduce the drag as much as possible, and also to allow a good positioning of the pilot, the ergonomics of the pilot in the cockpit during the phases of ground handling, take-off and flight are specially focused. The structural arrangement was adjusted in order to allow the volume to be occupied by the pilot in the cockpit considering the 3 basic positions: a) ground handing plus take-off run, which can be also the landing position; b) flight c) transition between (a) and (b). The pilot shall be positioned as close as possible of the aircraft CG. The empty weight of the aircraft shall present its CG as close as possible from the CG of the aircraft with pilot.

The arrangement of the cockpit -and the both aerodynamic shape of the aircraft and the structural arrangement - shall be such to allow the positioning of the pilot in the three phases presented above without changing the aircraft CG. Also, the pilot must have a good visibility in flight and a minimum visibility in take-off position. During take-off the pilot need to have means of keep a position to easily lift/support the aircraft and at the same time to access the aileron and rudder controls. In order to protect the pilot from injuries, it must exist in the cockpit space enough to give freedom to the pilot to by lied in prone position in the case of the pilot stumbles during the ground run. The harnesses to attach pilot to aircraft shall be designed in regard to this condition.

In order to allow the structure to be positioned as close as possible to the best load paths considering the constraint of the pilot's cockpit space (regarding the cockpit requirements presented above), and considering the thicknesses needed for spars, the wing shape (both planform and airfoil sections) received small adjustments from its optimum (i.e., both the planform and the airfoil sections are slightly compromised). For aerodynamic evaluations and decisions regarding geometric adjustments, the airfoils of NACA four digits 4412 and 4415 have been considered as temporary references for wing and NACA 0012 and 0010 have been considered for the Vertical Tails. The basic criteria are the availability of information, good stall and easy construction characteristics of these airfoils. During the next phase, Development (see Figures 2 and 24) which includes the PoC detailed definition, manufacturing and flight tests, the airfoils will be detailed and checked, before the manufacturing of the prototype.

The current positioning of the vertical tails and control surfaces have been preliminarily defined using theoretical information [5] and checked with a number of different down-scaled free-launch models. More information before the construction of the prototype will be obtained from the PoC tests.

The main constraints of the structural arrangement are, by using the minimum number of items, to allow space for a person inside, without large modifications from one initially conceived “ideal” structure -in terms of load paths – without the pilot.

The materials defined to be used in the structures are basically wood and aluminum. Depending on the availability of infra-structure -to be checked during PoC manufacture- some parts -preferably, the leading-edge skins- will be built in composite materials. The skins of the parts after the main spars are intended to be manufactured using low-weight nylon cloth. The techniques of construction and the materials applicability and ‘adequate ability’ will be checked and confirmed with the PoC experiments. Before the flight tests of the PoC in heavy configuration, and the manned prototype, structural non-destructive tests of the main structural components shall be performed. The loads to be considered for the tests shall correspond to at least 2 G flight loads. The control surfaces deformations under high-speed loads, i.e., to loads expected to occur at speeds corresponding to 4 times the stall speed shall be checked on ground loading testing, prior to the flights.

Two transportation packages for the disassembled parts shall be designed and built, the first one for the PoC, and the 2nd one for the configuration chosen to be built.

The arrangements of the 3 configurations as defined after the preliminary design are presented in the Figures 15, 16, 17.

It can be seen the details added during the preliminary designs by comparison with the corresponding configurations, as by the end of the conceptual studies, Figure 14. It can also be seen through these figures that the most important features defined in the conceptual studies have been followed in the preliminary design.

8. Take-off Simulations, and Ergonomics

Due to the special features of HG and considering the focus on the Sinking Ratio -which is important during take-off phase and just after it- occurs specific for this design, it has been realized that the two aspects -apparently distant each other- of Take-off and Ergonomics should be considered together.

Regarding the ergonomics for landing phase, in the mode of a “on-feet” landing instead of a landing on skids, most of the ergonomics of take-off can be also considered.

The solutions obtained for the Ergonomics of the Take-off, and the transition for the soaring flight are -by now, considering the definitions needed from the preliminary design phase for the development phase- taken as satisfactory.

Considering that one of the critical aspects related to HG development is the take-off conditions and in order to better understand this flight phase and to better adjust the design regarding this phase, a specific simulation of take-off was focused. The Figures 19 and 20 present some examples of results, comparing the configurations defined and two Lilienthal gliders. The conceptual changes in the pilot’s position during the transitions from ground handling to airborne are presented in the Figures 21 and 22 for configuration 1 and 2 respectively.

And-as presented above- in order to reduce design risks concerning stability, structural solutions, manufacturing, assembling, and repairing, it was decided to include the PoC in the development process. And due to the size determined for the PoC to be valid and achieving its purposes, it can be also used for checking and validating part of launching process, also regarding ergonomics. So, a space to allow the person to launch the PoC is defined (and a proper geometry is adjusted) in a way to approach (or even be representative of) the man-machine interactions needed during ground handling and launching, even the PoC being unmanned in flight. This can be seen in Figure 18, and also in the take-off sequence presented in Figure 23.

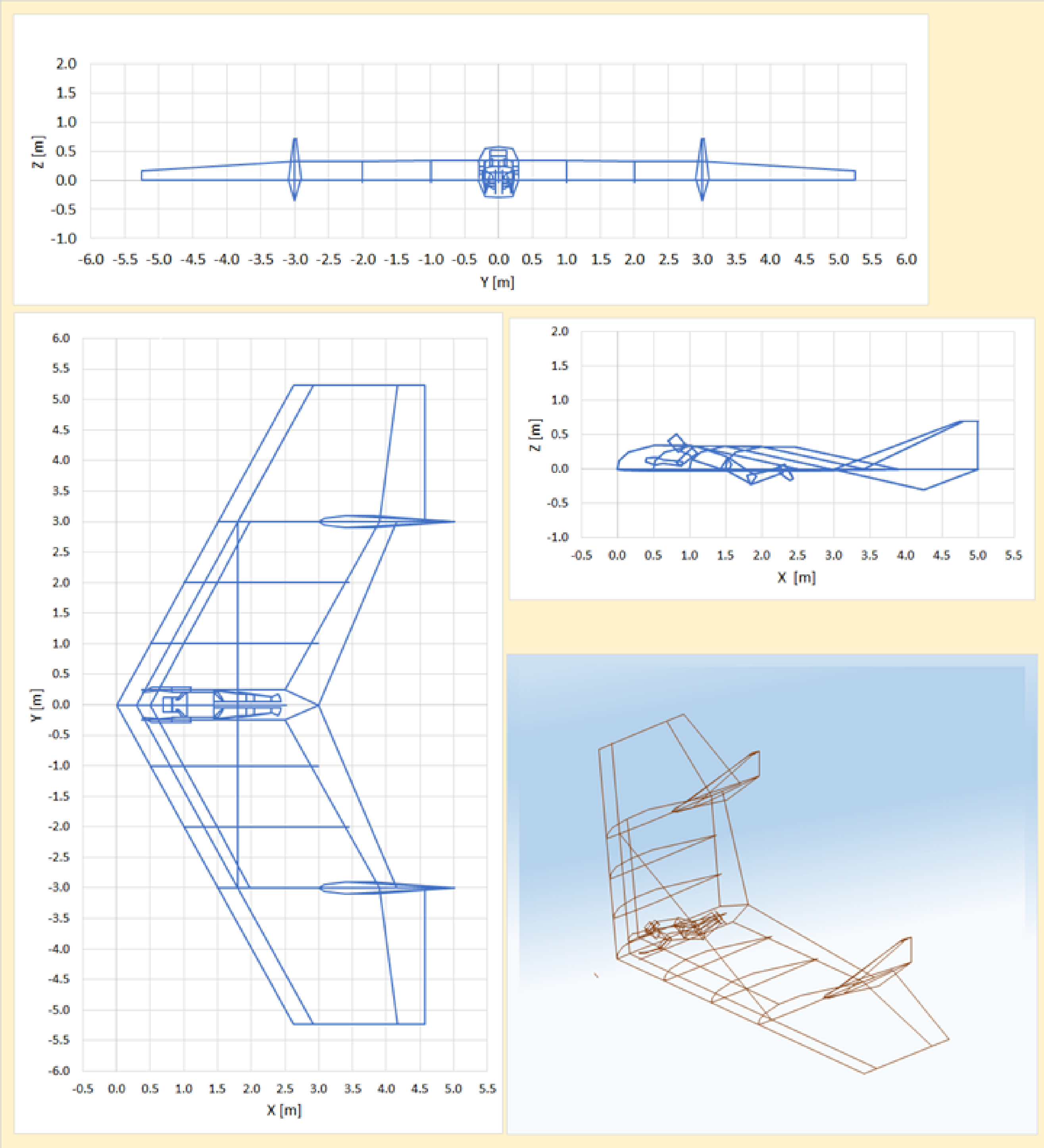

Figure 15 - Views of the 1st configuration, “Conf 1” proposed after detail design.

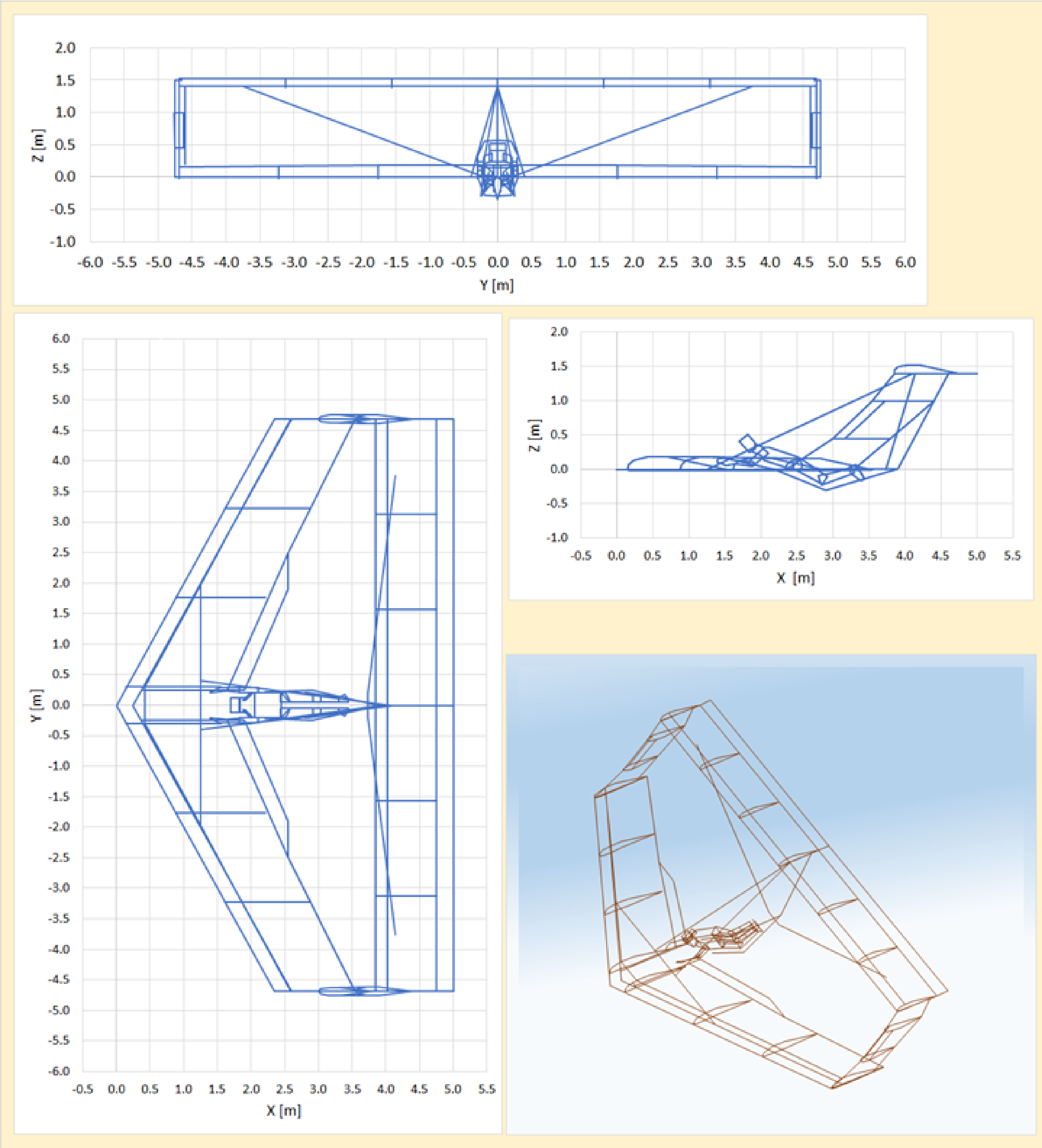

Figure 16 - Views of the 2nd configuration, “Conf 2” proposed after preliminary design.

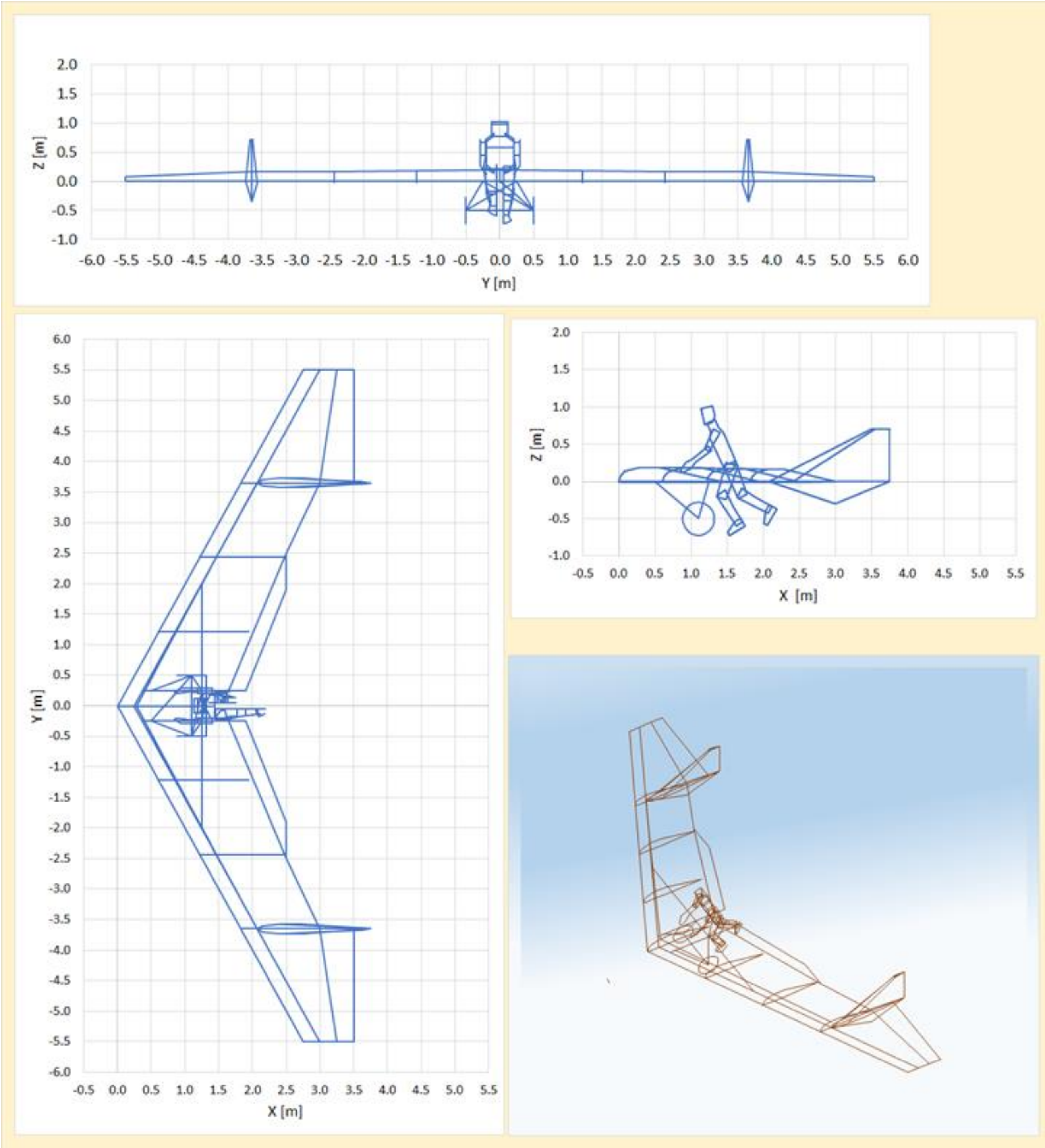

Figure 17 - Views of the PoC proposed after preliminary design.

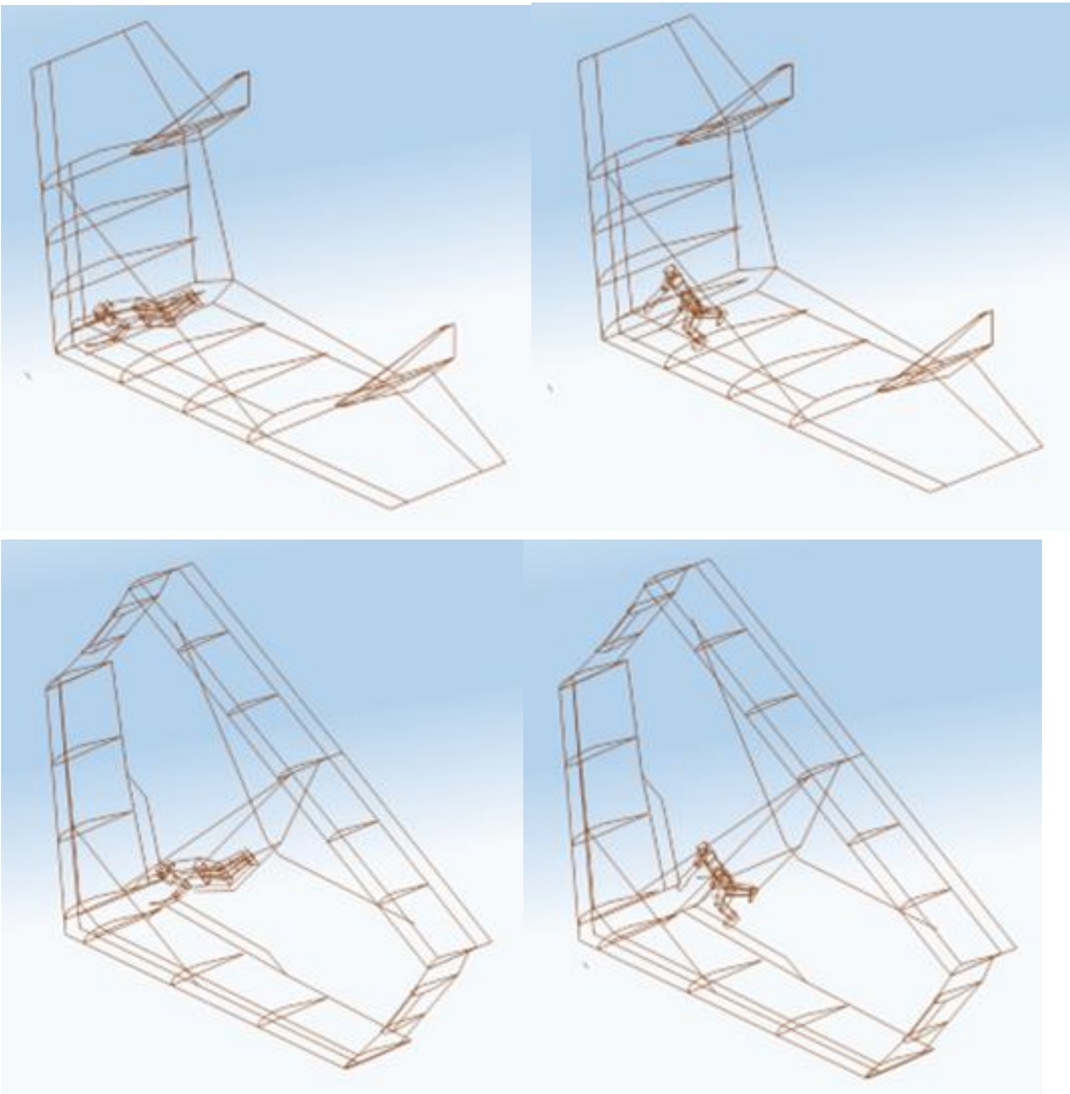

Figure 18 - Positioning of the pilot during ground run (left) and flight, for the 2 configurations.

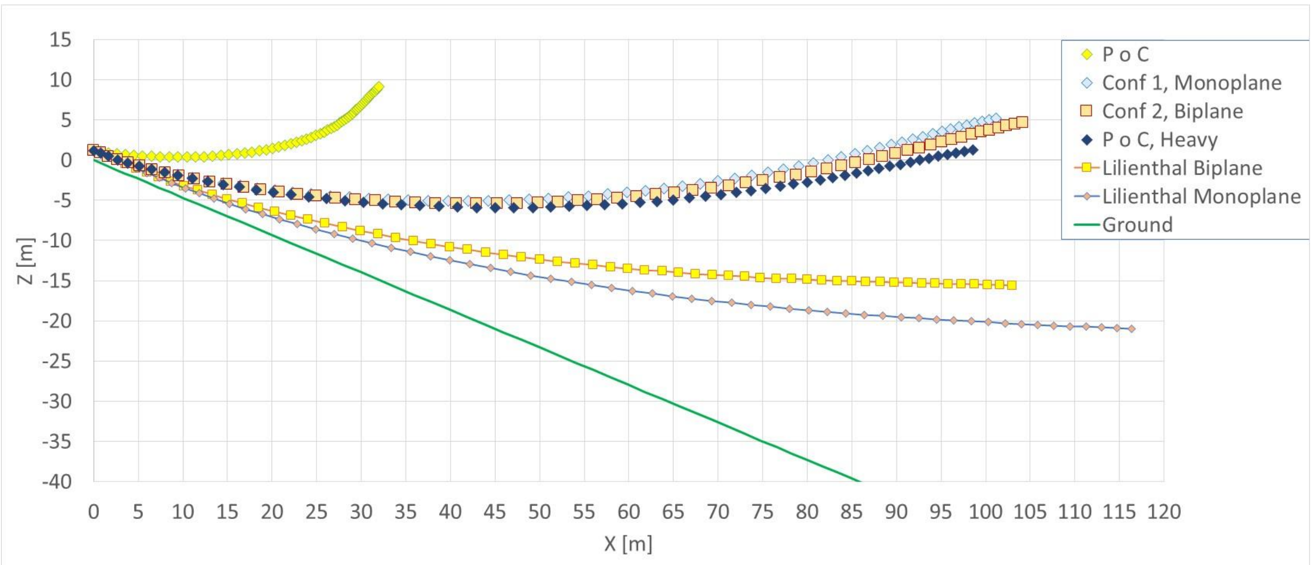

Figure 19 - Simulated Take-off of 5 gliders from a ramp subjected to constant front wind of 10 km/h.

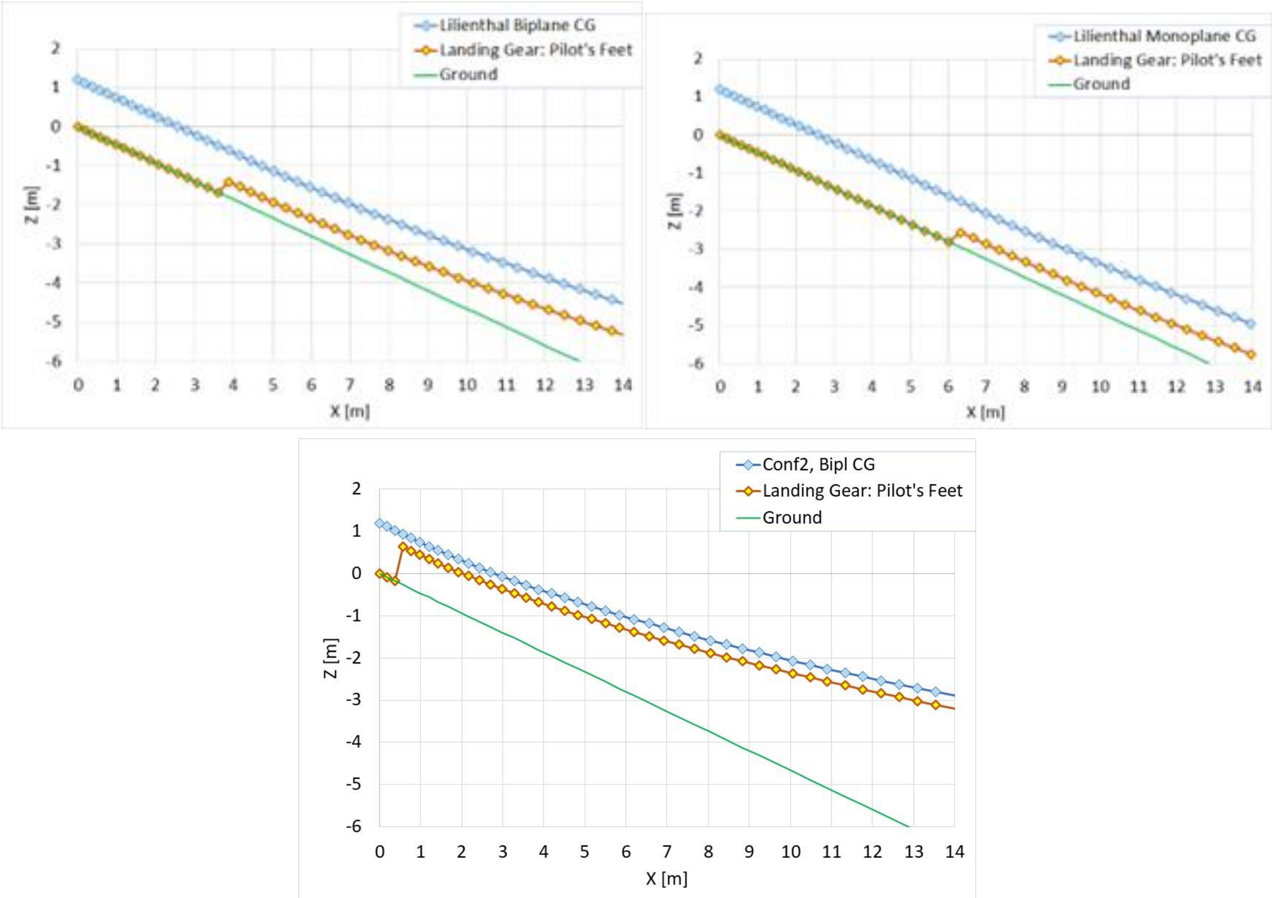

Figure 20 - One Detail of the take-off for 3 gliders: The take-off run.

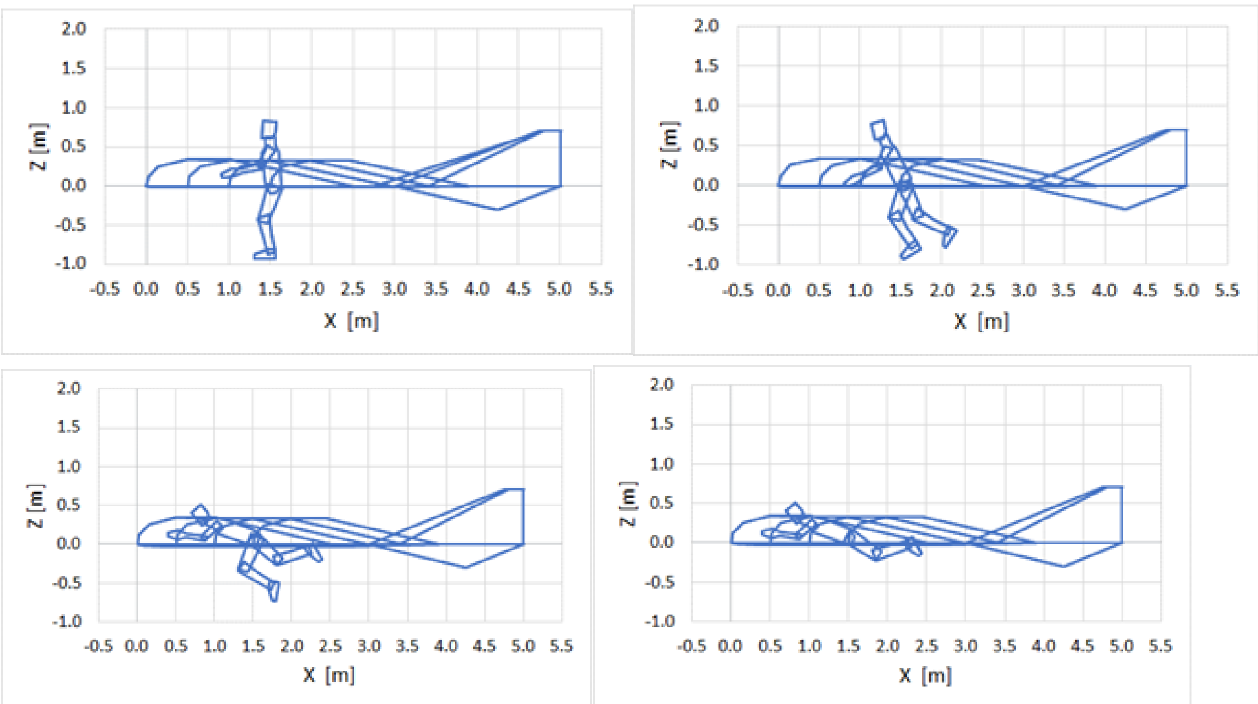

Figure 21 - Configuration 1, Sequence of positionings of the pilot
from ground handling, ground take-off run, transition, and flight, from upper left to lower right.

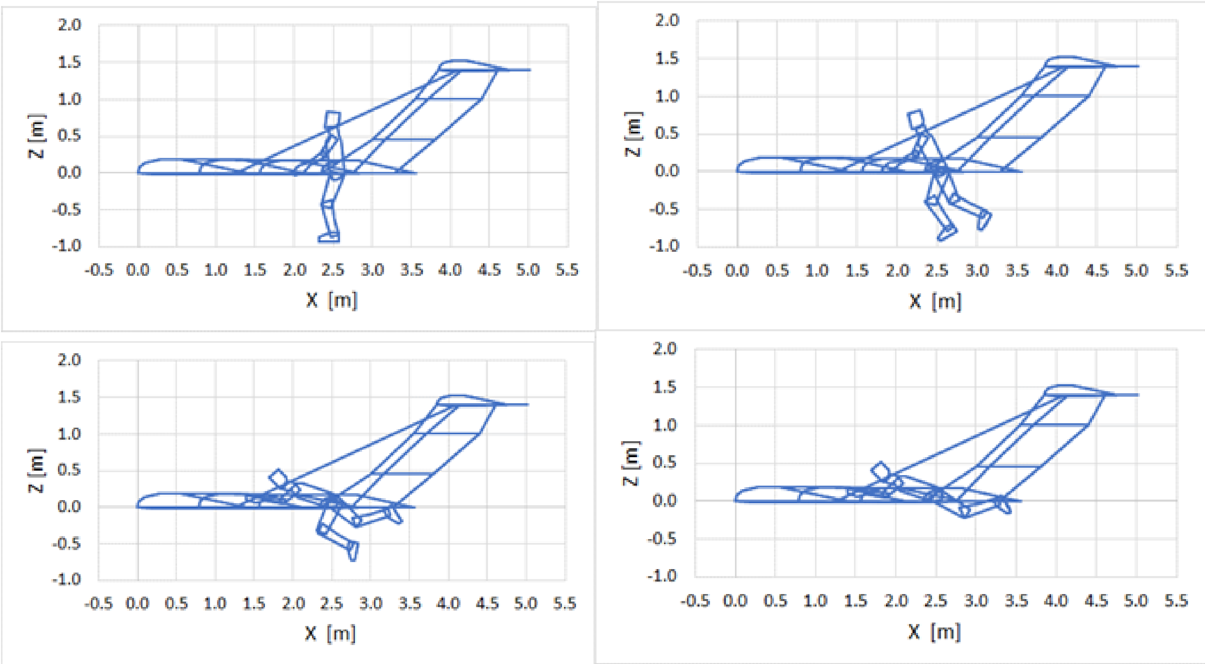

Figure 22- Same sequence as from previous figure, here for Configuration 2.

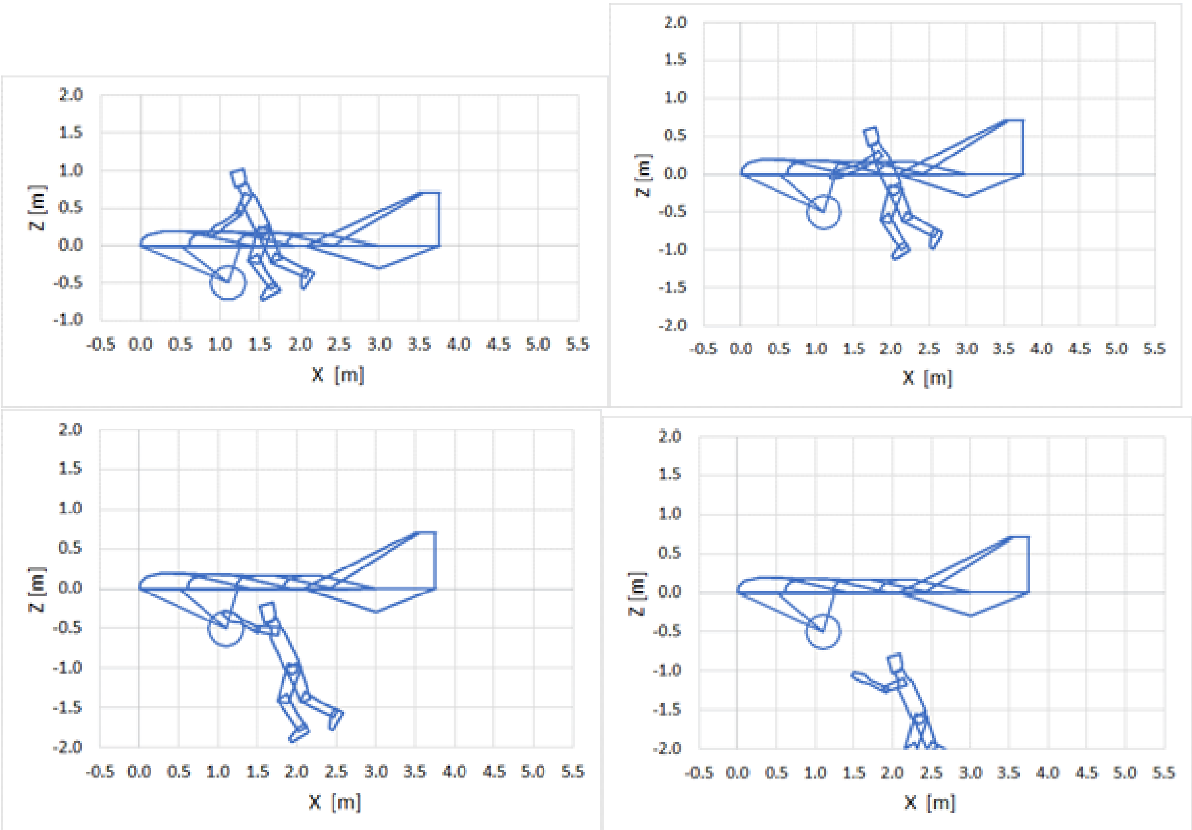

Figure 23 - Sequence of relative positionings between launcher and the PoC during PoC take-off.

9. Closing of the Premilitary Design Phase: Findings, Strategy, and next steps

One of the main results of this work, is the example of design, leading to the specific configuration presented in the previous section, based on the aircraft requirements established.

The other important results are shown in this section:

- The main findings, and main potential pitfalls Identified;
- The Strategy, also for risk mitigation, and Planning for the Next Steps and goals;

- The Revised Plan, in function of the findings mentioned above.

The main findings, the main weak points of the design chain identified as special points of attention (main potential pitfalls Identified) in the process are:

- One important main source of difficulties from 'classical' design techniques to be applied on these aircraft are the large effect of the human body in the aircraft shape, the spaces needed for a reasonable ergonomics and how to harmonize this with the -not large- aircraft size.
- Additionally, the required low take-off/landing speeds and the low overall mass, together with a suitable aerodynamics efficiency, low cost, easy maintenance, easy transportation, easy assembly/disassembly characteristics, are relevant and combined are special features of this type of aircraft that must be taken into account for a sound concept.
- Some design targets as very large aspect ratio, or very good glide ratio, at high speeds (compared to HG), with values close to the ones as normal sailplanes can be achieved, but put the design in a very narrow design and operation space, and there is a large risk of the final aircraft presents stability, weight excess, cost, and transportation/assembly issues.
- There is a Gap between small scale models (useful to check the HG basic configuration, structural, aerodynamic, stability, assembly characteristics) and the final, large-and-light (span about 10 m, 30 kg) aircraft. The size of the final aircraft compared to small models, and the ground handling issues related to the human-machine interface, characterizes a relevant gap. A specifically tailored PoC -as conceived in several aircraft developments in the industry- should be a good alternative, to bridge this gap.
- Other classical features of manned aircraft, as good flying qualities (suitable stability and control, allowing safe flight characteristics) and crashworthiness, must also be taken into account.
- One other very relevant aspect that should be considered, is that, differently of many other types, the aircraft of this category are aimed for leisure and sport activities. In other words, these aircraft are aimed for "flight for fun".

A large part of the strategy i.e., the development plan and the definition of the next steps, has been aimed for risk mitigation, considering the findings gathered throughout this work.

The Revised Development Plan (task-flow diagram), in function of the findings mentioned above, is shown in the Figure 24.

One basic assumption is that, even considering the low aircraft weight and the aircraft purposes, the involvement with local airworthiness/certification authorities will occur during the development process whenever necessary.

In terms of design, considering the basic requirements, the process up to now has followed an evolutive, iterative, approach. This will likely keep occurring in the development phase.

At the early phase simple concepts and tools in terms of aerodynamics, performance, stability, weight, and structures have been used. When a good compromise has been found, the achieved concept has been checked against the requirements. This has been performed before the detail design of the development phase starts, in which more complex tools shall be used.

As a general summary of the process up to now: The early "conceptual and feasibility studies" phase is identified as one of the most critical steps of the whole development, and so, it is one of the most explored subjects in this work. In this phase, the focus has been in the basic requirements for the aircraft regarding its typical mission, from which the main flight characteristics arose to drive the aircraft possible configurations. Two possible configurations are identified, selected, and properly studied, to be ranked in the next step.

The 2 configurations candidate for the development and manufacturing will be checked in a more detailed evaluation regarding "aerodynamics, performance, stability, structure, weight, ergonomics, construction".

In this 1st group of analysis (conceptual and preliminary studies), a convergence of values has been pursued and achieved. When necessary, the requirements have been slightly readjusted.

A large emphasis has been performed in the cabin ergonomics and human-machine interface. In terms of ergonomics, different positions of the pilot have been considered, including the transition in pilot's positioning from take-off run to fight.

The other parts of the development process are presented in less detail, since the focus of the work is the group of tasks related to the conceptual design phase.

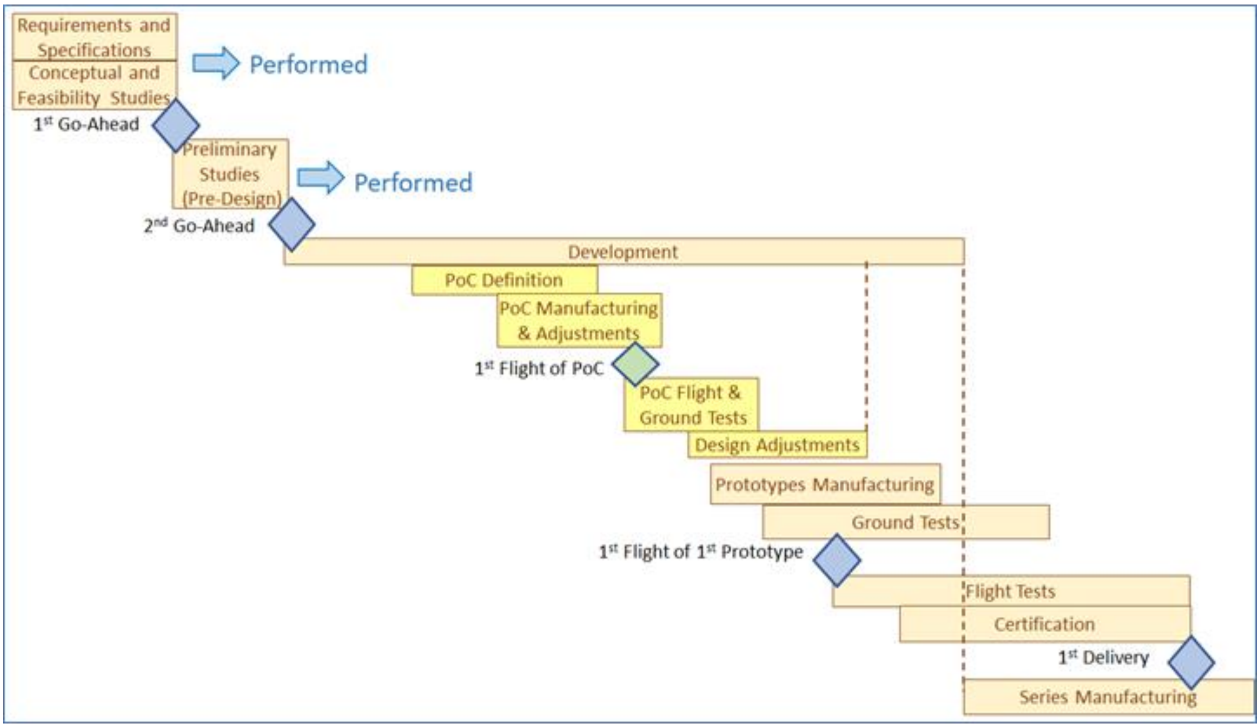

Figure 24 - Aircraft "Development and Production" Plan,
adjusted to overcome the challenges identified.

The Next Steps are:

- To study a) Details of 'control surfaces to pilot' chain; b) The necessary changes in Conf 2 for pilot position in sitting instead of prone position;
- To build a cabin mock-up for Conf1 and Conf2, and check the human machine aspects as accessibility of the pilot to the controls and his comfort and safety during the typical mission. Also, safety in emergency scenarios shall be addressed through specific evaluations and checks using these mock-ups.
- For both configurations: To Perform structural analysis using simplified methods a la L' Aliante [9], and check the structural weight based on the thickness of the structural components; the total structural weight (aircraft without, fairings, skins, harnesses, control chains and panel, and with the control surfaces and leading edges) should be lower than 70% of the intended empty weight.
- To check, using potential flow tools: a) The effectiveness of the currently adopted wing washout for good stall characteristics, for both configurations; b) for Conf 2: the differences of incidence between rear/upper wing related to front/lower wing; the effectiveness in terms of stability and lift coefficient, of the currently adopted horizontal and vertical; the distances of the wings, compared to a conventional, tailed biplane, and compared to Conf 1.
- To iteratively detail the structural arrangement and the airfoil sections.
- To define the assembling-disassembling procedures for both configurations.
- To Make the basic aircraft drawings, and drawings of the parts of the aircraft when disassembled.

After the tasks above, and the findings of the 1st flights of the PoC, to define which candidate, Conf 1 or Conf 2, will receive the last detailing work to be manufactured and ground/flight tested.

PoC Tests will be:

- Ground Tests: Geometric check; check of weight and cg; structural non-destructive test on main structure parts, corresponding to flight with load factor about 2 Gs;
- Flight tests: 1) gliding with no wind, free launch; 2) gliding with wind, free launch; 3) gliding with no wind, remote control; 4) gliding with wind, remote control, check of controllability; 5) gliding with wind, remote control, check of performance, soaring capabilities;
- Decision of which of the from the configurations Conf 1 and Conf 2 will be developed;
- Development, of the selected configuration;
- Manufacture and test of the Prototype according to the detailed configuration.

Prototype ground and flight tests. Tests will be:

- Ground Tests: The same as the PoC, plus Ergonomic tests (pilot-to-cockpit interface), in the 6 typical phases, including ground handling, soaring flight, landing; Ergonomic tests, for emergency conditions; surfaces free-play, control chain rigidity; Assembly, disassembly, transportation, and storage check and training.
- 1st Flight Tests sequence: 1) Ground handling no wind; run and stop; 2) Ground handling moderate wind;.3) Run and take-off, moderate wind, moderate ramp slope, short distance, landing on skids and wheels; 4) Run and take-off, moderate wind, moderate ramp slope, short distance, landing on legs; 5) Run and take-off, moderate wind, normal HG ramp slope; stability and control evaluation, landing on legs or skids; 6) Soaring attempt;7) soaring capability, and stability and performance on thermals.

The “series manufacturing” mentioned in figure 23 refers, in this case, to a possible cooperative work of a group of 3 to 5 enthusiasts potentially interested in the concept. This could be achieved after -if necessary- positive positioning from the airworthiness authorities.

Taking into account the figures 1, 2, and 23, the requirements presented for the aircraft [section 5], and now considering the results of the 2 configurations Conf1 and Conf2 proposed as candidates and the configuration for PoC [sections 7 and 8], and, the findings, the revised plan and the next steps presented in this section, the Premilitary Design (or Pre-Design) phase is considered and concluded, and the 2nd the Go-ahead for Development phase can be declared.

10. Conclusion

In this work, in order to define a suitable design path for such type of aircraft, and regarding the hang-glider specific operational features, some classical aircraft design techniques are identified, adapted, and complemented by other specific approaches.

A summarized history investigation has been performed, aiming the identification of both “good and forgotten solutions”, and “potential pitfalls”, and this was crucial for the progress of the design.

As main results, the process corresponding to the Aircraft “Development and Production” Plan is elaborated; and using the initial part of this process, two specific configurations are presented.

The main weak points of the design chain (process) are also identified as special points of attention.

In function of the aspects found in the history investigation, some specific -and sometimes unusual- tasks and milestones are determined in order to smoothen the development process.

Considering the specific example presented, the initial planning is readjusted after the findings obtained throughout the early (i. e., “conceptual” and preliminary) design phases. Additionally, it was identified the need for a Proof-of-Concept aircraft, the PoC, bringing important adjustments to the

"Development and Production" Plan. One of the adjustments is the specific flight test campaign, required for the PoC.

The overall conclusion is that -even for this very special type of sport aircraft- the application of the classical design tools with some tailored strategies can be successful, generating a feasible aircraft.

If the efforts continue and the flight aircraft succeeded, one natural next step should to check of the feasibility of installing a small engine to support the cruising flight. If the power remains low, the aircraft weight plus energy source can be not very impacting in terms of weight and space requirements, in order to the aircraft keep being a hang-glider. And the same design approach presented here could be used for this new step ahead.

And this can be the subject for next works to be continued opportunely.

11. Acronyms and Abbreviations

HG Hang-Glider
CDo Aircraft Parasite Drag coefficient
CD Aircraft Drag coefficient
CL Aircraft Lift coefficient
*CL*** Lift coefficient corresponding to VZmin
*CD*** Drag coefficient corresponding to VZmin
Mo Aircraft Empty Mass
Mu Aircraft Useful Mass
M Aircraft Mass = Mo+Mu
VZ Aircraft sinking ratio at glide
VZmin Aircraft sinking ratio, lowest magnitude
VZ/V ratio wind ascending speed/wind speed
E Aircraft Glide Ratio
*E** Aircraft Best Glide Ratio
B Aircraft Span
S Aircraft Area
n number of wings (*n=1*: monoplane, *n=2*: biplane)
A, AR Aircraft aspect Ratio = B2 / (S/n)
A.e Aircraft equivalent aspect Ratio
e Oswald Factor
PoC Proof of Concept
EAS Aircraft Equivalent Airspeed
Vs Aircraft Stall Speed
CG Aircraft Centre of Gravity
ρ Air Density
G, g gravity acceleration
X, Y, Z coordinates in the space

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