On the conceptual design of PrandtlPlane civil transport aircraft

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Abstract

According to aircraft manufacturers and several air transportation players, the main challenge the civil aviation will have to deal with in the future is to provide a sustainable growth strategy, in order to face the growing demand of air traffic all over the world. The sustainability requirements are related to air pollution, noise impact, airport congestion, competitiveness of the Air Transportation Systems in terms of travel time and passengers' comfort. Among the possible ways to allow a sustainable growth of the Air Transportation Systems, disruptive aircraft configurations have been object of study for several years, in order to demonstrate that the improvement of aircraft performance can enable the envisaged growth. This paper presents the study of a possible novel configuration called "PrandtlPlane", having a box-wing layout derived from Prandtl's "Best Wing System" concept .

The paper deals with the definition of top level requirements and faces the conceptual study of the overall configuration, focusing on fuselage sizing as well as on the aerodynamic design of the box-wing system. This latter is designed through an optimization-driven strategy, carried out by means of a low-fidelity aerodynamic tool, which simulates the flow condition in the subsonic range and introduces correction to take the transonic effects into account. Design procedures and tools are presented, showing preliminary results related to a PrandtlPlane compliant with ICAO Aerodrome Reference Code "C" standard, such as Airbus A320 and Boeing 737, whose wingspan is limited to 36m.

Activities and results here shown are part of the first phase of the research project "PARSIFAL" (Prandtlplane ARchitecture for the Sustainable Improvement of Future AirpLanes), funded by the

European Commission under the Horizon 2020 Program, which aims to demonstrate that the PrandtlPlane configuration can improve aircraft payload capability, keeping their dimensions compatible with present airport infrastructures.

1 Introduction

According to the studies carried out in the last years by the European Commission ([1]) and groups of experts from both industry and academia ([2], [3]), the key requirements for the future development of the Air Transport System in Europe can be summarized as follows:

- to satisfy the increase of air traffic demand improving flight safety;
- to cut CO2 and NOx emissions and noise per passenger kilometers;
- to make travelers within Europe able to complete their journey within 4 hours (door-to-door).

Among the possible ways to reach these goals, novel aircraft configurations have been proposed in order to satisfy these requirements: some of the candidate configurations for future aviation are based on the configurations shown in Figure 1: Blended Wing Body (BWB), Truss Braced Wings (TBW) and PrandtlPlane (PrP) concepts.

Figure 1: Concepts for Blended Wing Body from "Silent Aircraft Initiative" ([4]), Truss Braced Wings from "SUGAR" project ([5]) and PrandtlPlane from "PARSIFAL" project

The PrP is the application of the "best wing system" concept due to Ludwig Prandtl, who in [6] demonstrated that for given wingspan and lift the wing system with minimum induced drag is a box-wing with a proper lift distribution. Prandtl's studies have been continued by several research groups and, in particular, at University of Pisa: the aircraft configuration derived by the application Prandtl's concept has been called "PrandtlPlane".

Starting from 1990s, further studies have been focused both on the mathematical problem of the "best wing system" ([7]) and the several engineering aspects of the PrP design. In fact, although drag reduction is the main advantage of the PrP, other interesting benefits have been found for different aircraft categories. In fact, previous studies has shown that the PrP has a smooth stall behavior and post-stall is characterized by only a partial reduction of maneuverability and controllability ([8]), pitch control can be obtained by using counter-rotating elevators (on both front and rear wings) which can introduce a pitching moment without perturbation to lift ([9]), the pitch damping is higher than in the case of a wing-tail configuration, with benefits in terms of comfort and safety ([10]). In addition, as summarized in [11] and [12], the PrP configuration can be adopted for aircraft of very different dimensions, such as Light Sport Aircraft, ultra large airliners, freighter aircraft ([13]) or “cryoplanes” ([14]).

Concerning the potential solutions provided by the PrP for the growing air traffic demand, the exploitation of “best wing system” goes along the direction of improving the payload capabilities of a conventional airplane, while keeping the same wingspan. According to studies conducted in Pisa and other researches (e.g. [15]), this way it is possible to take advantage of the higher aerodynamic efficiency, i.e. L/D ratio, of the PrP layout, improving payload without penalizations in terms of fuel consumption.

Given such context, the present paper aims at presenting the approach adopted for the conceptual design of a PrP conceived for such purposes and carried out in the framework of the EU research project PARSIFAL (“Prandtlplane ARchitecture for the Sustainable Improvement of Future AirpLanes”), funded under the Horizon 2020 program and coordinated by the University of Pisa ([16]). Other partners of PARSIFAL project are Delft University of Technology (Delft, Netherlands), ONERA (Meudon, France), ENSAM (Bordeaux, France), DLR (Hamburg, Germany), SkyBox Engineering (Pisa, Italy).

As detailed in next sections, PARSIFAL project aims to demonstrate that the application of the PrP configuration to aircraft used for low-to-medium routes can improve the payload capabilities of about 50%, without an increase of overall dimensions (wingspan in particular), in order to preserve the compatibility with present airport infrastructures.

The present paper deals with the following aspects of the design: definition of top level aircraft requirements, conceptual design of the fuselage, procedures for the preliminary aerodynamic design of the box-wing system in transonic cruise condition and control surfaces at low speed.

2 Requirements definition

The Top-Level Aircraft Requirements (TLARs) of PARSIFAL project have been defined starting from the analysis of air traffic demand forecast, setting the time horizon to 2030s. As Figure 2 shows, forecasts indicate that the busiest routes in terms of number of passengers and flights are the short-medium ones, with a peak between 600–1000 km, especially for the European and Asian market ([17]).

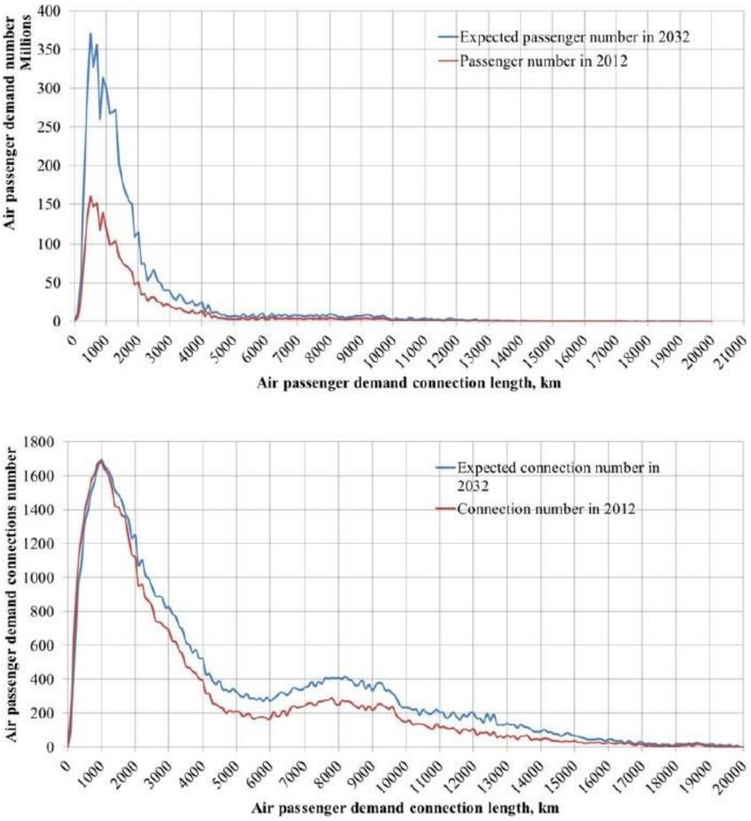


Figure 2. Predicted air traffic demand forecast growth from 2012 to 2032 in terms of passengers (top) and connections (bottom)

More in details, such results indicate that the regional-continental air traffic demand will increase significantly (Figure 2, top), while the number of connections will not change (Figure 2, bottom), which means that the envisaged air traffic growth has to take place using the airports today available. Such conclusion is in contrast with outcomes of studies from IATA [18] and European Commission [19], according to which in 2030s the problem of present airport saturation will be relevant and that, probably, the saturation will be total in 2040s.

The solution investigated in PARSIFAL is the application of the PrP configuration to the aircraft category mainly adopted for short-to-medium routes, which today consists of single aisle aircraft with not more than 230 passengers, such as aircraft from Airbus 320 or Boeing 737 families According to the 2018-2037 global market forecast of both Boeing ([20]) and Airbus ([21]), in fact, the market share of such aircraft category will about 75% in terms of units delivered and 55% in revenues. In order to be comparable to A320, B737 and similar aircraft, the wingspan limitation to 36m has been taken into account, introducing the compliance with ICAO Aerodrome Reference Code “C” specification as a requirement ([22]).

Therefore, the following top-level aircraft requirements have been considered as main drivers for the design of the PARSIFAL PrP: number of passengers between 250 and 320, maximum range covered with maximum payload (320 passengers) of 2160 NM, initial cruise altitude of 36000ft, Mach number in cruise flight not lower than 0.7 and compliance with the ICAO Aerodrome Reference Code “4C”, where:

- “4” indicates a Take-Off Field Length longer than 1800m;
- “C” refers to a wingspan limited to 36m and wheel span between 6m and < 9m.

3 Conceptual design of the fuselage

The request of embarking a number of passengers not lower than 250 while keeping the same overall dimensions of a A320 or B737, leads to the adoption of a twin-aisle cabin. Figure 3 shows two possible concepts for the cabin section, whose height is almost equal to that of present aircraft, whereas width is enlarged.

As shown in Figure 3, the first solution has 8 seats abreast in a 2-4-2 arrangement, whereas the second one has 10 seats abreast in a 3-4-3 arrangement. The resulting cargo bay would allow to house LD3 and LD1 standard containers, respectively. Given a useful internal cabin length of about 25 m and assuming a high-density layout with a seat pitch of 29 inches, it is possible to house up to 32 rows, thus achieving 256 and 320 passengers, for the two proposed solutions, respectively.

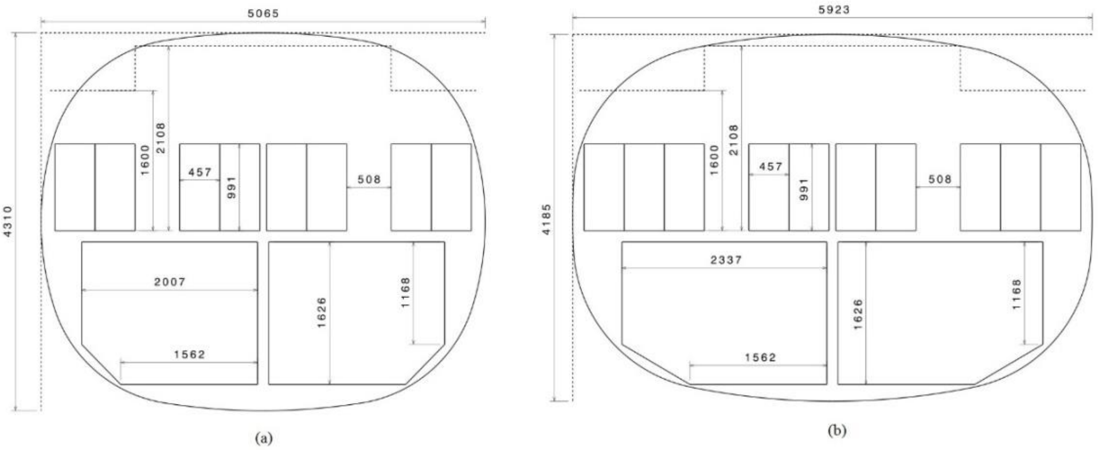


Figure 3: Sketch of two possible cabin sections with 8 (left) and 10 (right) seats abreast

The fuselage cross sections are composed of circular arches with different curvatures, tangent each other in order to minimize stresses. Given an internal volume, such shapes allow to minimize the wet surface and, consequently, the friction drag; furthermore, these solutions provide a larger fuselage width in the aft zone, which can give a proper support for the connection of rear wing through vertical twin tails, chosen to prevent flutter as described in [23]. Figure 4 shows an outline representation of the internal boundaries of the minimum wetted surface solution described before.

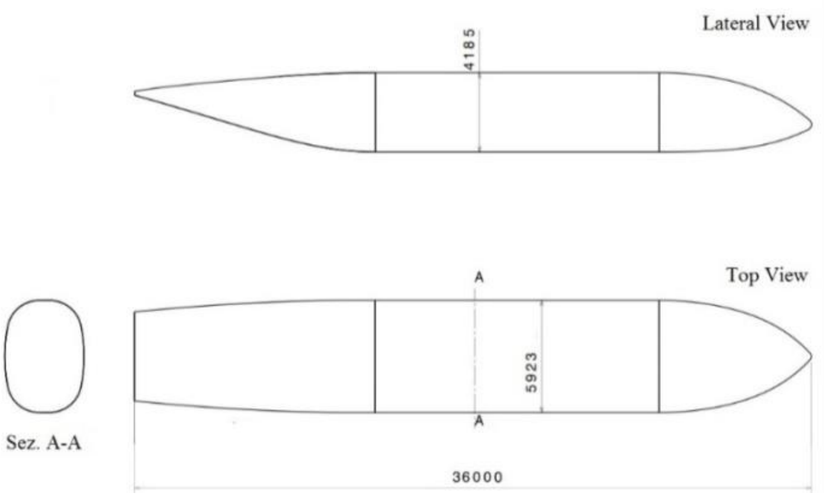
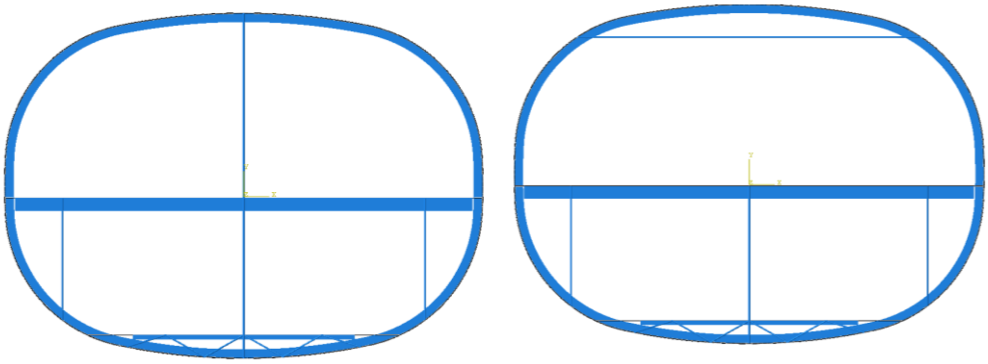


Figure 4: Lateral view and top view of a 3-4-3 configuration

A new concept for the design of the fuselage cross section also is accomplished by innovative structural solutions; it is under study the possibility to connect the upper and lower part of each fuselage frame by means of a vertical truss, made in composite, which undergoes tension when pressurization loads are applied (Figure 5, a). Another solution under study is to position a stiffening crossbeam in the upper part of the frame (Figure 5, b), or a combination of the two solutions. In both solutions, a central support is introduced under the floor beam.



(a) (b)

Figure 5: Possible fuselage cross section schemes: solutions with vertical truss (a) and horizontal crossbeam (b)

The effect due to the introduction of the vertical truss has been preliminary studied with a FEM in-plane beam model, whose validation is presented in [24]. Such model allows to minimize the total mass of section structures (i.e. frame segments, floors' beams and truss) under given pressurization loads. By modifying the ellipticity of the cross-section, defined as the ratio between overall width and height, as well as considering the presence or the absence of the truss, FEM optimizations have been performed in order to evaluate the effects of such parameters on the section mass, chosen as objective function. It is worth to note that section height has been kept constant, hence the ellipticity has been varied only modifying fuselage width.

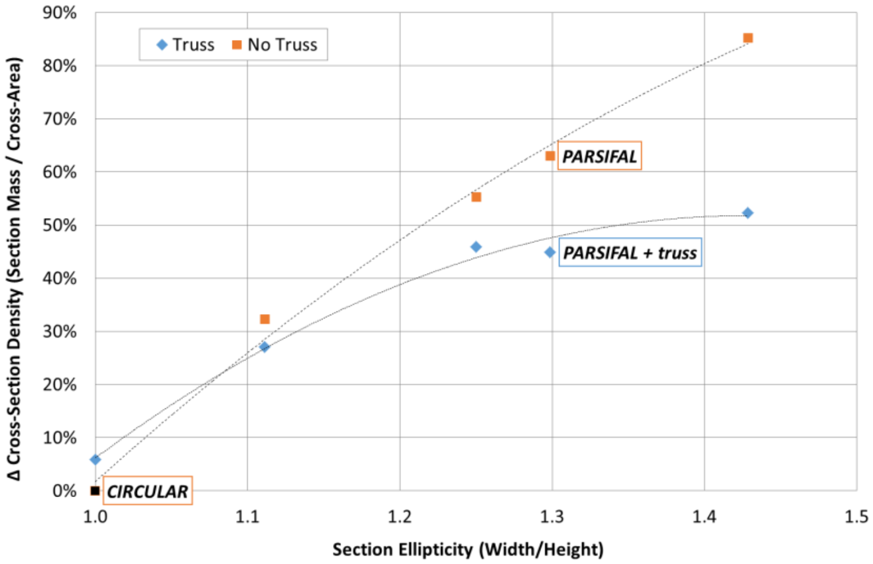
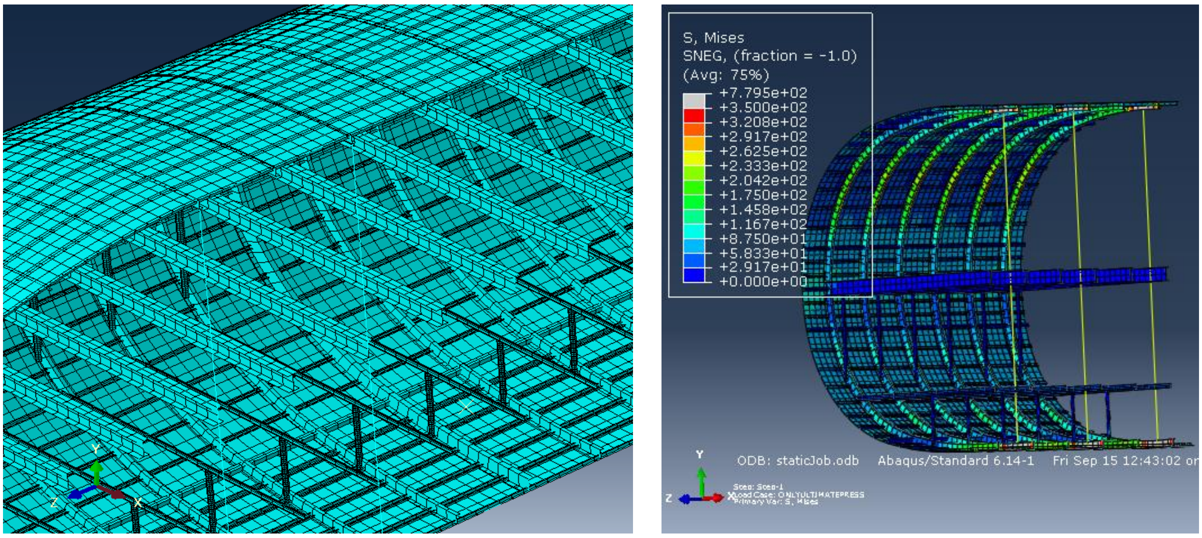


Figure 6: Section ellipticity and truss influence on the variation of section mass/cross-area ratio

Results are reported in Figure 6, where the comparison takes the variation of the internal volume into account, by beans of the introduction of a “cross-section density”, defined as the section mass to cross-area ratio. Thus, considering the circular section without truss as the baseline case, it is possible to see that cross-section density increases significantly with ellipticity and, also, that truss provide an opposite contribution for ellipticity values above 1.1. For the PARSIFAL case in Figure 5-a, where ellipticity is 1.3, the cross-section density rises of about 45%, as the result of a 63% increase due to section ellipticity and a 18% reduction introduced be the truss. Further details can be found in [25].

Results obtained through such in-plane model have been compared to more accurate tridimensional Finite Element Method simulations, for which an in-house parametric FEM model generator, called “WAGNER”, has been used ([26]). Being the truss present or not, WAGNER and the beam model provide section mass evaluations which are in good accordance, with errors below 5% that may depend by the fact that the beam model allows circumferential variations of frame dimensions, whereas this is not allowed in WAGNER. Figure 7 shows an example of 3D FEM model and results generated by using WAGNER together with a commercial FEM solver.



(a) (b)

Figure 7: Example of a 3D FEM model generated through “WAGNER” (a) and Von Mises stress (b)

In addition to the advantage of carrying a larger number of passengers, the PrP configuration would also benefit of the aft position of fuselage-front wing intersection, which allows to have an interrupted cargo deck for almost the whole cabin length, with the possibility of reducing the time spent in loading and unloading operations.

In terms of components’ integration, the larger width of the fuselage allows also to allocate the main landing gears on its sides, adding two sponsons in order to reduce aerodynamic drag. According to the preliminary design described in [27], the main landing gear can be installed without any interference with the cargo bay. In addition the presented solutions would be compatible with built-in airstairs.

The possible drawbacks of this fuselage configuration are mainly related to the current uncertainty to obtain better global performance in terms of manufacturing costs, compared to conventional solutions. Anyway, the sketched solutions represent guidelines for the following detailed design, which must take additional constraints into account, like volumes required for systems such as electric wirings, air conditioning, pneumatic and hydraulic pipes.

4 Procedures for the aerodynamic design of the box-wing system in cruise condition

In the conceptual stage of the design process it is necessary to evaluate the largest possible number of configurations with reduced computational cost, in order to detect the most relevant trends between performances and design parameters, as well as to identify a group of initial configurations for the following detailed analyses. A low fidelity design procedure has been defined in this context; it is based on an optimization process calibrated on the main requirements of the aircraft and the analyses have been carried out with an in-house code called *AEROSTATE*.

According to previous aforementioned research and other authors, such as [28], the main drivers for the optimization of a box-wing configuration are related to flight mechanics requirements concerning equilibrium, stability and controllability.

In PARSIFAL, the constrained optimization problem is formulated for cruise condition, in order to obtain a set of possible box-wing configurations, each of which described through a set of geometric parameters. The mathematical formulation, introduced in [29] and then adopted in other researches such as in [10], is the following:

$$\begin{cases} \min\left(-\frac{L}{D}(\boldsymbol{x})\right) \\ W_{des} - \varepsilon \leq L(\boldsymbol{x}) \leq W_{des} + \varepsilon \\ SM_{min} \leq SM(\boldsymbol{x}) \leq SM_{max} \\ \left(\frac{W}{S}\right)_{min} \leq \left(\frac{W}{S}(\boldsymbol{x})\right)_{wing} \leq \left(\frac{W}{S}\right)_{max} \\ \max\left(C_l(y)\right) \leq C_{l_{max}} \\ \lambda_{bay} < 1 \\ \boldsymbol{lb} < \boldsymbol{x} < \boldsymbol{ub} \end{cases}$$

where the first expression defines the minimization of the objective function, corresponding to the maximization of the aerodynamic efficiency (L/D) in cruise condition, $\boldsymbol{x}$ is the design parameters vector, whose components can vary into the design space defined by lower boundaries ($\boldsymbol{lb}$) and upper boundaries ($\boldsymbol{ub}$), and the other expressions are the constraints imposed into the process. In particular:

- the lift, $L(\boldsymbol{x})$, must be equal to the design weight W_{des} (with a tolerance ε), in order to satisfy the vertical equilibrium;
- the static margin, $SM(\boldsymbol{x})$, must be in a prescribed range, in order to obtain longitudinally stable as well as maneuverable configurations;
- the wing loading of every lifting surface, $\left(\frac{W}{S}(\boldsymbol{x})\right)_{wing}$, must be within a range fixed by the designer;
- the local lift coefficient at every wing section, $C_l(y)$, cannot exceed a threshold value ($C_{l_{max}}$);
- the wing bay taper ratio, λ_{bay}, defined as the ratio between the tip and root chords of the considered bay, must be lower than 1.

The design parameters define completely the lifting system (chords, twists, sweep angles, dihedral angles, limits for the longitudinal position of lifting surfaces), whereas wingspan is fixed to 36 meters for both wings, in accordance with ICAO Aerodrome Reference Code “C” requirement.

The estimations of weight and center of gravity position, are conducted with first-approximation methods, whereas the aerodynamic evaluations are carried out with the Vortex Lattice Method code *AVL*. This solver has been chosen for the very low computational time required for each aerodynamic calculation; however, potential methods are not able to consider compressibility effects, in term of drag increase due to the presence of shock waves on the airfoils. Consequently, it has been necessary to calibrate the whole design procedure by means of a series of increasing-fidelity analyses, with the aim of taking these transonic effects into account.

The capability of the tool *AEROSTATE* to find feasible solutions is strictly related to a proper definition of upper and lower boundaries applied to design parameters, therefore the methodology here presented is also focused on the calibration steps which have been performed in order to refine the definition of ***ub*** and ***lb*** values, as well as other design constraints.

The first step has been carried out with a low-fidelity model which needs very low computational times, according to the chart presented in Figure 8.

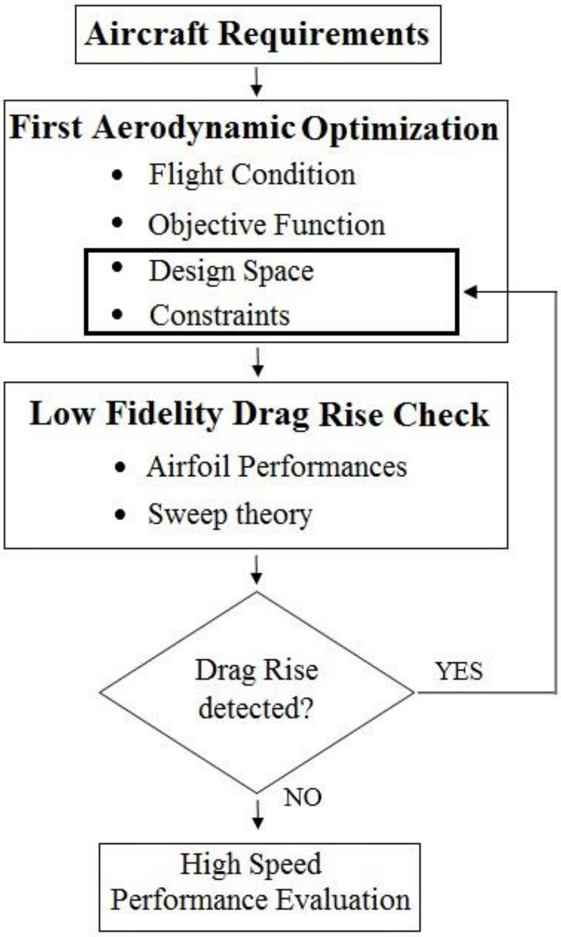
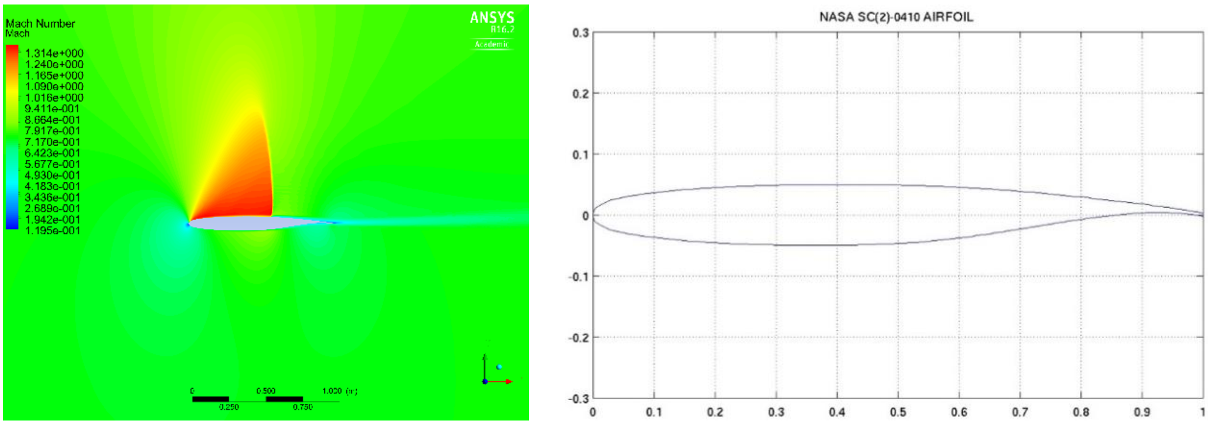


Figure 8: Low fidelity calibration procedure

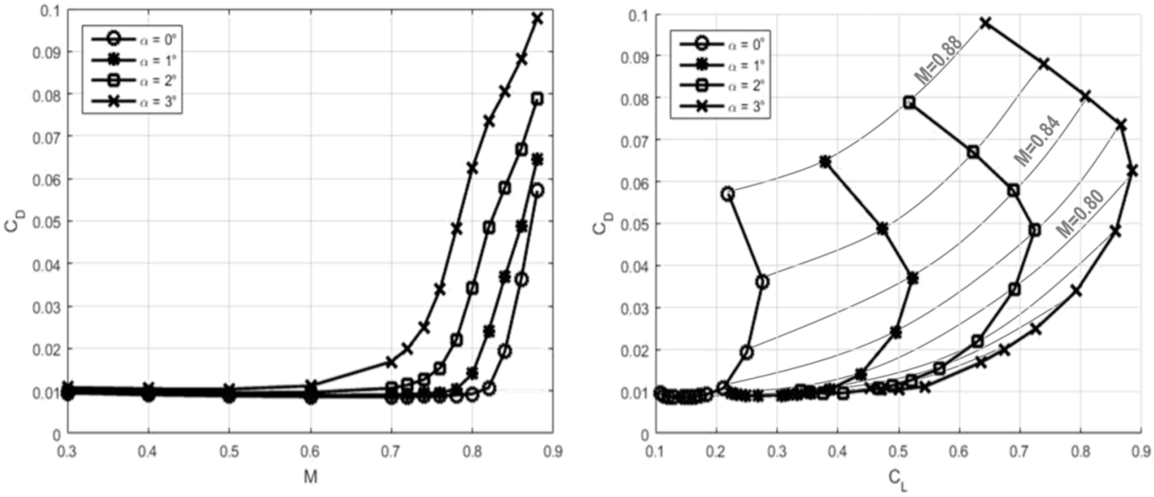
A group of supercritical airfoils has been chosen and a performance database has been created; the aerodynamic characteristics of the airfoils have been assessed by means of two dimensional CFD analyses, varying Mach number, thickness-to-chord ratio and lift coefficient. Figure 8 shows an example of a two-dimensional CFD analysis in the case of a transonic airfoil.



(a) (b)

Figure 9: Generic Mach contour plot (CFD analysis, $\alpha = 3°, M = 0.76$) for the NASA SC20410 airfoil (a) and airfoil sketch (b)

Figure 10 shows the characteristics of the NASA SC20410 profile: Figure 10-a shows the C_D vs M curve and it is apparent how the angle of attack (or C_L) influences the drag rise and how C_D is almost constant for Mach numbers below 0.6; Figure 10-b is the polar curve and, again, the importance of the transonic effect increases, especially at high Angles of Attack (AoA).



(a) (b)

Figure 10: C_D vs M and polar curves (b) of NASA SC20410 airfoil at different angles of attack

It can be noticed that, for any given AoA value, increasing the Mach number results in higher values of both C_L and C_D until stall conditions are reached. After that point, shock-induced stall determines a reduction of C_L, whereas C_D continues to rise. In addition, as described by polar curves in Figure 10, shock-induced stall occurs at lower Mach numbers as AoA increases.

These compressibility effects are taken into account in the adopted design procedure, with main consequences on wings' sweep angles and additional constraints on twist angles. The implementation procedure is here described:

- given a configuration resulting from the first design run, the lifting surfaces are divided in a number of strips along the span (excluding the tip and the root zones, where the local, three-dimensional effects influence significantly the aerodynamics);
- the geometric properties of any strip are known, including airfoil shape and sweep angle;
- C_l distributions along the wingspan are known as well as the asymptotic Mach;
- by means of the simple sweep theory ([30]), the actual properties of each section are derived and then compared with the data stored in the supercritical airfoil database;
- it is possible to identify the wing portions in which shock waves may be generated (a generic example is shown in Figure 11) and, therefore, to define whether the configuration can be affected by drag rise.

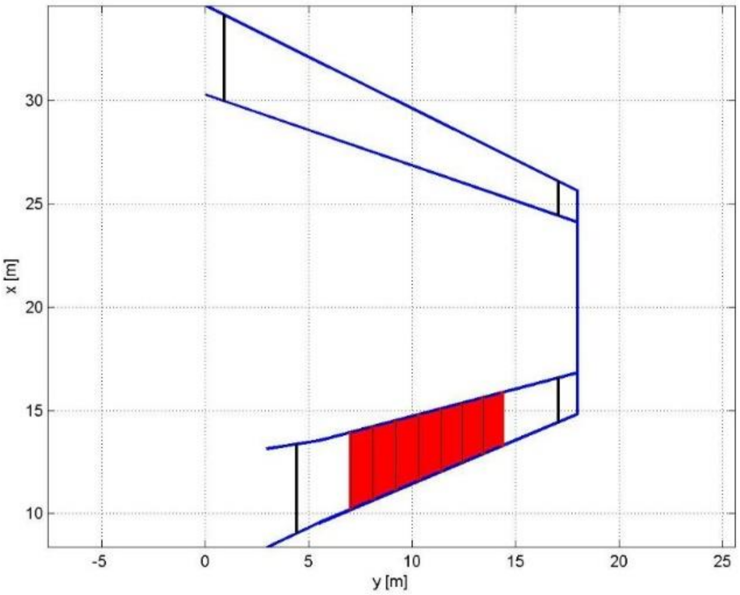


Figure 11: Example of detection of wing section where shock waves may be generated

In the example of Figure 11, the red strips indicate, for the given box-wing geometry and lift distribution, the location and the extension of the wing region in which shock waves can occur. Therefore, in a conceptual design phase, the adoption of a low fidelity model for drag rise prediction is useful not only for design purposes, but also to have a quick understanding of the influence of box-wing parameters on transonic phenomena.

A new calibration of the lower and upper boundaries of the design space, and also of the constraints, has been made at the end of this procedure in terms of maximum local C_l, sweep angles, wing loading, etc.

Since it is extremely difficult to obtain reliable results related to the transonic range with low fidelity models, a further calibration of the optimization parameters has been carried out by means of high fidelity analyses, with CFD computations (RANS models) on a certain number of reference configurations; a flow chart of the correction procedure is shown in Figure 12.

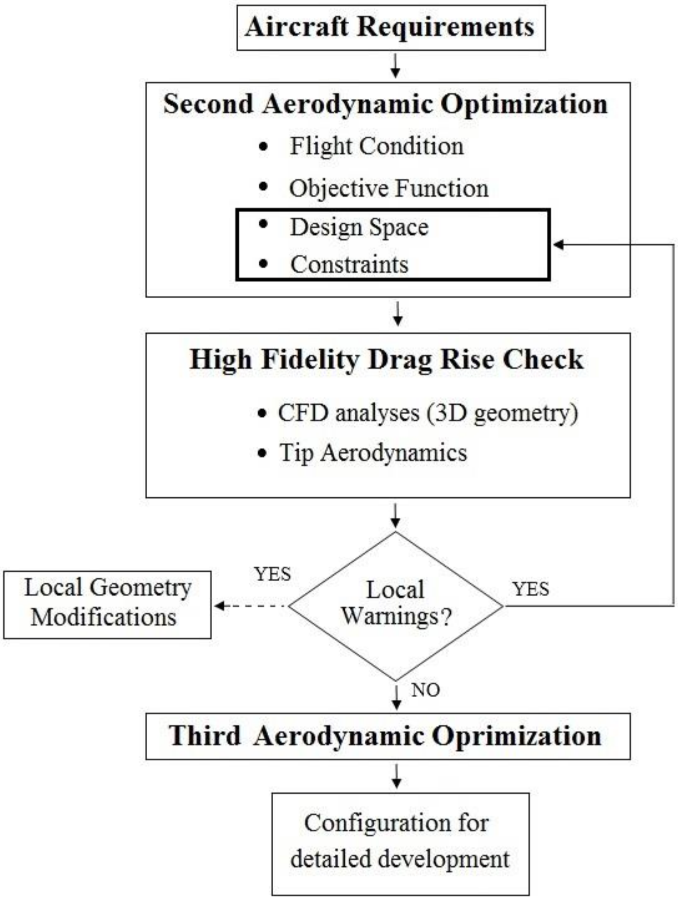


Figure 12: High Fidelity correction procedure

This second aerodynamic optimization process has been conducted under the inputs originated by the first lower fidelity calibration. Some reference configurations have been chosen in the set of the optimized ones to perform more detailed analyses; in particular, these analyses have been focused on the aerodynamic behavior of the tip zones where three-dimensional effects due to the influence of horizontal and vertical wings are present.

As detailed in [31], Figure 13 is a typical example of the presence of shock waves originated by different causes, such as: airfoil thickness, local twist angle of the wing, local shape modifications, mutual influence of the vertical and horizontal wings. Starting from these results, the boundaries of optimization parameters have been calibrated, for a third more refined aerodynamic optimization.

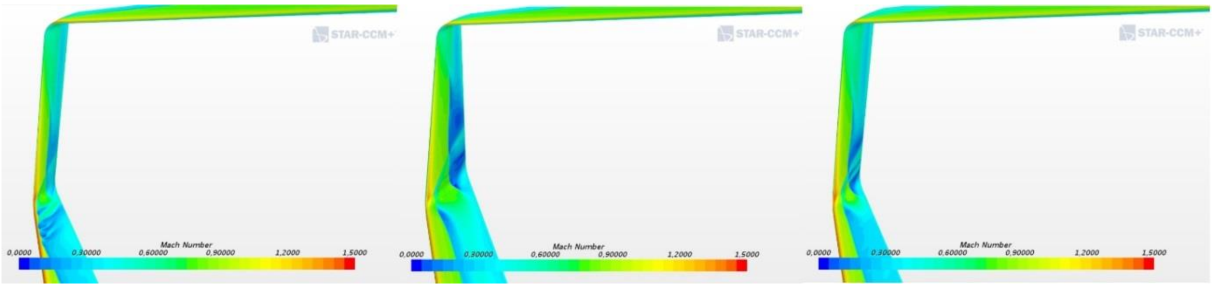


Figure 13: An example CFD result and local shape modification [31]

In particular, wing loading limitations have been assessed through CFD analyses, focused on studying the sensitivity to wing geometry (at tip, in particular), in order to avoid the detrimental shock-induced separations in the boundary layer, clearly visible in Figure 13 (left). Outcomes of such assessment have been then introduced in the design loop, to correct the input parameters of the whole procedure. Further details concerning CFD analyses can be found in [31].

Figure 14 shows some typical results obtained after modifications of the front wing tip of a generic configuration. Each point corresponds to a local minimum of the objective function, i.e. a solution that maximizes the aerodynamic efficiency (E=L/D) in cruise flight, for the given set or constraints and design parameters boundaries. Results are presented as families of configurations with the same wing loading, showing that aerodynamic efficiency increases for higher wing loading.

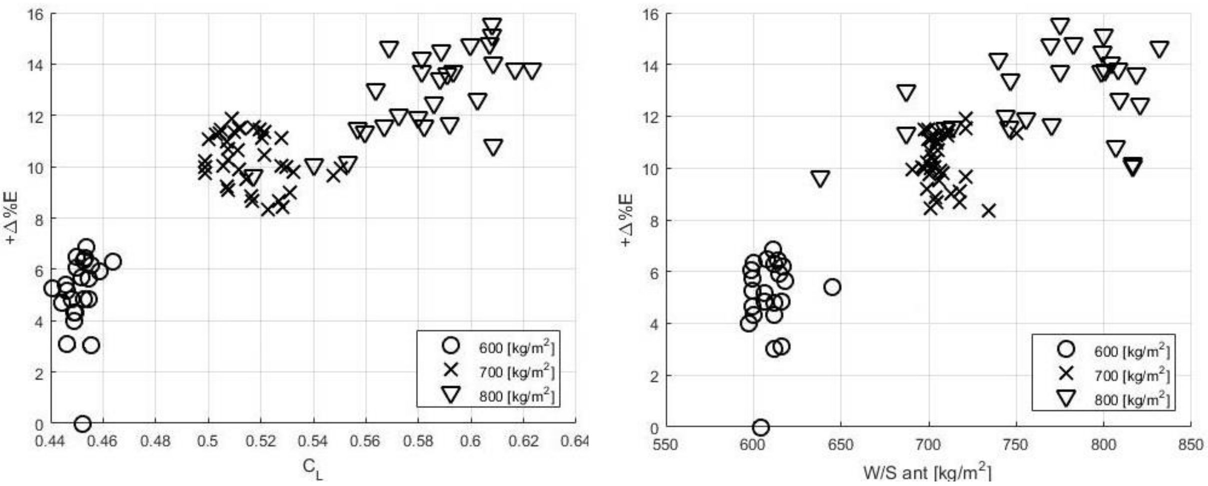


Figure 14: Aerodynamic efficiency (E=L/D) results for some generic groups of configurations

At the end of these procedures, a subset of configurations has been chosen for further detailed analyses, in order to focus on the best design ranges in term of wing loading and drag minimization, taking the presence of local aerodynamic effects into account. Figure 15 reports the geometry of four choses configurations, having the front wing loading equal to *500*, *600*, *700* and *800* kg/m^2.

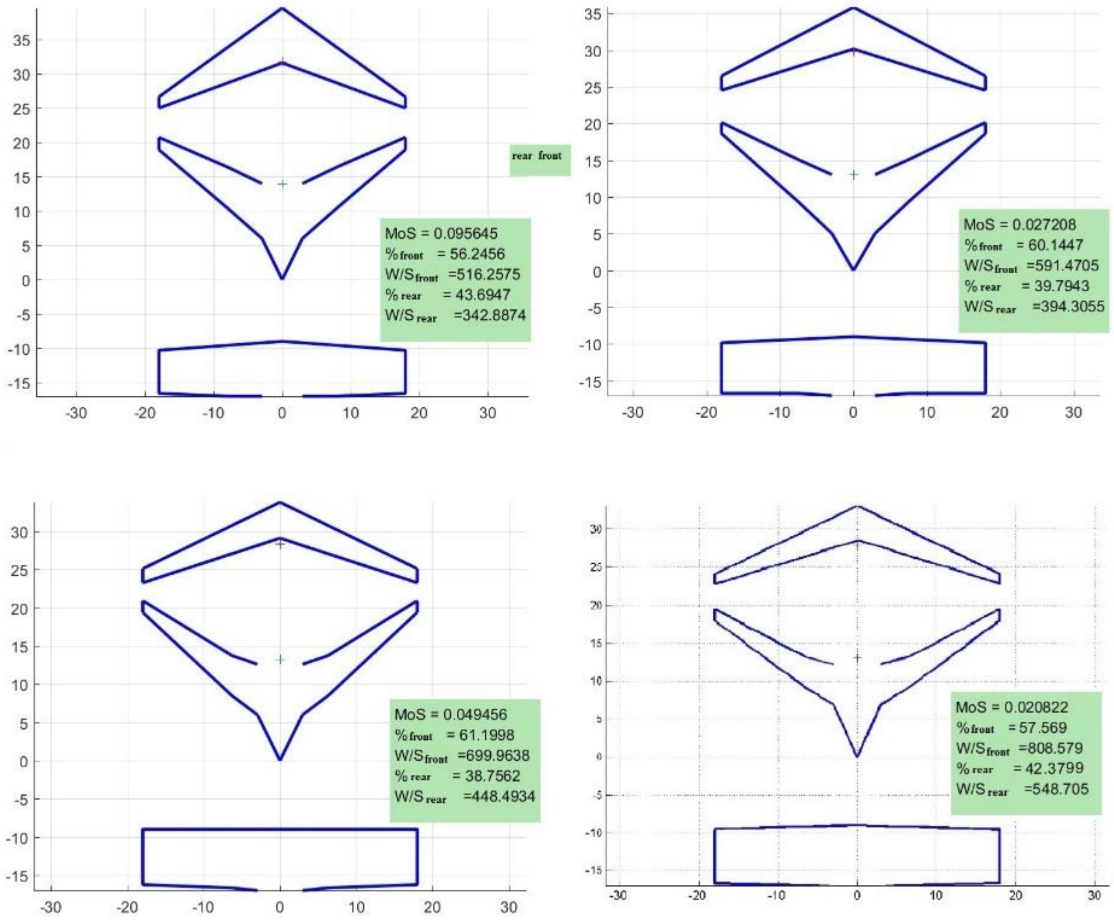


Figure 15: Four configuration with different wing loading

The symbols in Figure 15 indicate the static margin (SM), wing loading (W/S) and the percentage of lift on front and rear wings.

5 Procedures for the conceptual design of high-lift devices and control surfaces

The PrandtlPlane configuration allows to choose several different solutions for the positioning of control surfaces on both wings; in this stage of the design, a first sizing of control surfaces and high lift system has been performed according to the following guidelines:

- the elevators are placed at the root region of each lifting surface;
- the ailerons are installed on the tip of both wings,
- the remaining space in wing-span is reserved to trailing edge high lift devices.

In analogy with experimental results shown in [9], the elevators can be designed to be counter-rotating and generate a pure pitching moment: in this way, the pitch control effectiveness is improved and the variation of vertical force due to elevators deflection is minimized. This solution increases the safety of flight, as, for example, in the event of a low altitude pull up maneuver (landing aborted). Figure 16 shows a sketch of this layout.

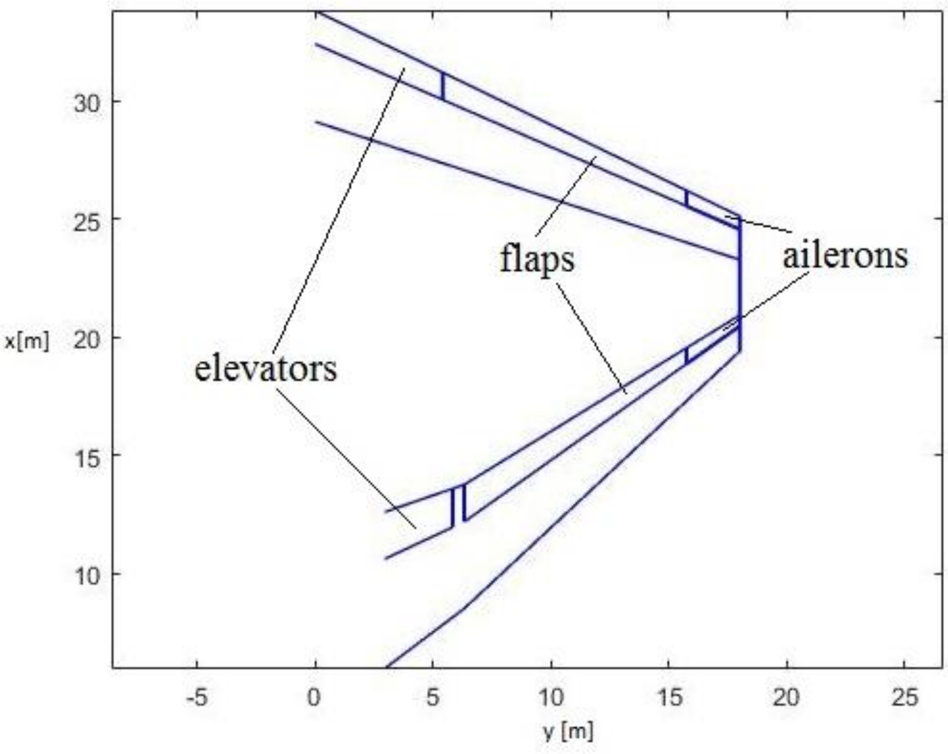


Figure 16: General layout of control and high lift devices surfaces

A preliminary sizing procedure for both elevators and flaps has been defined in approach condition; the procedure is initialized with a first sizing of the ailerons (based on statistical data of jet-liners), in order to identify the available span in which flaps and elevators can be allocated.

The aileron preliminary sizing has been done according to [32]: the aileron effectiveness is evaluated in terms of capability to set the aircraft to a prescribed bank angle $\bar{\varphi}_{\infty}$. The aileron motion is modeled as an impulsive function and the steady value of bank angle φ_{∞} is evaluated using an approximated roll dynamic with 1 degree-of-freedom. An initial aileron span is given in order to initialize the calculation; then, AVL is used to calculate the aileron control derivative $C_{l\,\delta a}$, useful to extract the approximated value of φ_{∞}. If $\varphi_{\infty} \geq \bar{\varphi}_{\infty}$the procedure is complete, otherwise the aileron span is iteratively increased, until the requirement is reached.

Once the conceptual layout for the control surface system has been established, including a first sizing of the elevators and the flaps, it is possible to evaluate the performance of the lifting system with the high lift devices activated, by means of an approximated procedure from [33], which provides an estimation of C_{Lmax}. Then, it is possible to solve the low speed trim problem, defined as follows with the conventional meaning of the symbols:

$$\begin{cases} C_L = C_{L\alpha}\alpha + C_{L\delta e}\,\delta_e + C_{L\delta f}\,\delta_f \\ 0 = C_{m0} + C_{m\alpha}\alpha + C_{m\delta e}\,\delta_e + C_{m\delta f}\,\delta_f \end{cases}$$

The trim problem is solved by using the AVL code; in particular, once flap deflection δ_f is provided as input, the elevators deflection ($\delta_{e\,trim}$) and the angle of attack (α_{trim}) are calculated by the solver in order to fulfil pitch moment equilibrium and the condition $C_L = C_{L\,approach}$.

The flight condition is defined as follows:

- $\mathrm{h} = 0$ m, Sea-Level flight altitude
- $\mathrm{W} = \mathrm{MLW}$, Maximum Landing Weight
- $\mathrm{V} = \mathrm{V}_{\mathrm{approach}} = 1.3\mathrm{V}_{\mathrm{stall}}$

The procedure of trim solving and elevators and flaps sizing is iterative, since the elevator deflection cannot exceed a threshold (from statistical reference values). If this constraint is not satisfied, the span of the elevator is increased until its deflection is inside the fixed range. Obviously, the increase of the elevator span causes a decrease of flap span, with a consequent variation of the flapped lifting system’s performance. The design procedure is schematically reproduced in Figure 17.

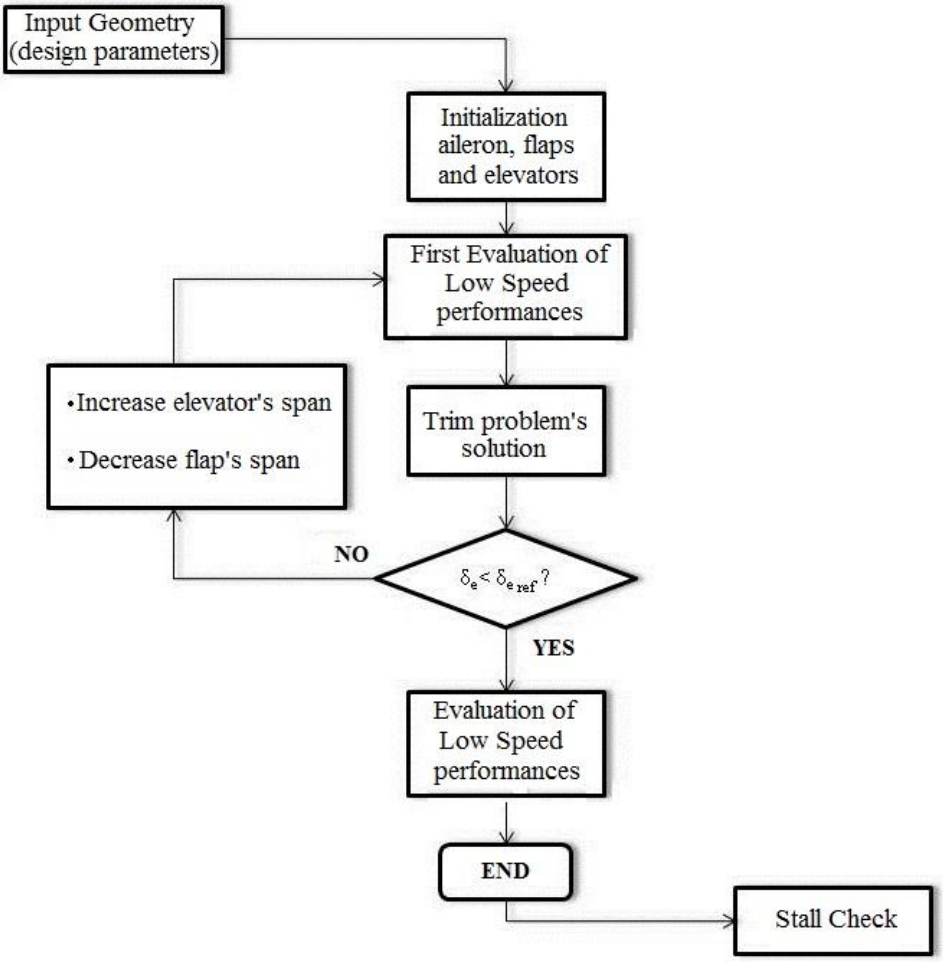


Figure 17: Preliminary sizing procedure

Starting from an initial configuration, several different solutions are obtained in terms of span and deflections of flaps and elevators, and also in terms of global low speed performances. As an example, setting N different flap deflections for the front wing, and, for each of them, M deflections for the rear wing flaps, the resulting N x M different combinations can be evaluated, in order to find the best trade-off between the trim requirements and the performances. The last step of the process is a preliminary check of stall on each configuration calculated; the check is done by comparing the calculated C_l span distribution with the $C_{l\,max}$ of the flapped airfoil.

The results obtained by this procedure represent a first guideline for the following detailed design, and they provide some interesting preliminary indications on the performances and the influence on these of the principal design parameters, like the wing loading, the maximum landing weight, the shapes of the lifting system and flaps.

6 Conclusions

Methods, procedures and tools for the conceptual design of a box-wing aircraft, called “PrandtlPlane”, are presented in this paper.

Such research activity is contextualized in a 2030s scenario, where air traffic demand is expected to grow significantly for short-to-medium routes, meanwhile requirements on noise and emissions reduction becomes stricter.

Taking Airbus 320 and Boeing 737 family aircraft as a reference, the PrandtlPlane is proposed as an alternative, since it can take advantage of its higher aerodynamic efficiency (i.e.: lift to drag ratio), by improving the payload capability of about 50% without affecting the overall dimensions and the compatibility with present airports. In particular, the wingspan is limited to that of reference aircraft, which does not exceed 36m. Such limitation and other requirements are then included in a set of Top Level Aircraft Requirements, which are adopted for the following design activity.

Therefore, the paper goes through the several aspects of the conceptual design of PrandtlPlane fuselage and box-wing, facing problems related to the introduction of an unconventional 2-aisles fuselage with an elliptical cross-section, illustrating the approach adopted for the aerodynamic design of a box-wing system in transonic conditions and the procedures for the preliminary sizing of high-lift devices and control surfaces.

Activities here reported are part of an on-going research project called PARSIFAL (“Prandtlplane ARchitecture for the Sustainable Improvement of Future AirpLanes”), which makes use of the presented design tools and methods in order to reach the goal of designing a PrandtlPlane and assessing its performance, in view of the forecasted air traffic scenario.

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