DEVELOPMENT OF A PRANDTLPLANE AIRCRAFT CONFIGURATION

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Abstract.

A PrandtlPlane aircraft configuration is based on the concept of "Best Wing System". Reference is made to a theoretical result published by Prandtl in 1924, showing that the lifting system with the minimum induced drag, under certain conditions, is a wing box in the front view. The properties of the Prandtl's Best Wing System are independent from the sweep angles of the wings and, then, an aircraft configuration based on these properties is valid also for the transonic range. This configuration, in honour of Prandtl, has been named as "PrandtlPlane". In order to develop a PrandtlPlane configuration, a large amount of aerodynamic analyses is needed. These computations can be carried out by means of Boundary Element method or CFD (Computational Fluid Dynamics) codes. The main problem connected to the application of the aerodynamic codes is the shape generation of the aircraft; even more so, in the case of such a complex configuration. At the University of Pisa, a proper code, named MSD (Multiple Shape Design), has been set up to generate any aerodynamic PrandtlPlane configuration. MSD is a parametric geometry generator which uses features typical of the commercial CAD codes for solid modelling, as extrusions, holes, intersections and generation of wing/wing and wing/body fillets, etc.. The last version of MSD makes use of NURBS (Non Uniform Rational B-Splines) geometrical entities. By means of MSD code and a CFD code, the PrandtlPlane configuration was developed. The application of the methodology is shown with reference to a very large aircraft. The configuration was changed having in mind both the Prandtl results on the best wing system (same total lift and same lift distribution on the two wings, butterfly shaped lift on the vertical wings) and the static stability of flight. The paper shows that, in general, the condition of static stability of flight could reduce the aerodynamic efficiency. The paper shows also that PrandtlPlane configurations exist in which the aircraft is stable as far as flight mechanics is concerned and, at the same time, the front and the rear wings are equally loaded. This configuration is completely different from a very large conventional aircraft. This PrandtlPlane concept is applicable to any kind of aircraft, when proper modifications are introduced. As an example, a two seat ultra light aircraft is presented. A scaled wind tunnel model was tested at the Technical University of Torino and some results are presented in this paper.

1. Introduction

The improvement of the aerodynamic design against drag is essential for the commercial success of any transport aircraft programme and for reducing pollution and noise. According to [1], a 1% reduction of drag for a large transport aircraft, saves 400.000 litres of fuel and, consequently, 5000 Kg of noxious emissions per year. In a large transport aircraft during cruise flight, about 90% of total drag is mainly due to friction drag and induced drag. Induced drag depends on the lift distribution along the wing span which, for today large transport aircraft, is so optimised that no significant induced drag reduction is now possible. Many non conventional aircraft were proposed in the past, especially multi-wing configurations. A significant activity was carried out in USA on joined wings, starting from a pioneer activity by Wolkowitch [2], the U.S. patents by Miranda [3] and Wolkovitch [4] on box wing. In spite of that, no application of these concepts to transport aircraft production was ever done in the past, because of many disadvantages, such as technical problems (aeroelasticity, structural efficiency, etc) and certification difficulties. The new requirements on noise and noxious emissions reduction and the need of cutting the Direct Operative Costs are opening new scenarios, because conventional aircraft have no chance to meet the new requirements. New configurations for future aviation are now of interest; in the V and VI European Framework Program, research activities on new configuration aircraft were encouraged. At Pisa University, a research activity is in progress from a decade on a new configuration. In this research programme, reference is made to a result by Prandtl in 1924 [5], showing that the lifting system with the minimum induced drag, under certain conditions, is a wing box in the front view. A closed form solution of this problem was given recently in [6]. Owing to the Munk theorems, this property is independent from the sweep angles of the wings and, then, the configuration is valid also for transonic aircraft. An aircraft configuration provided with such a lifting system has been named as "PrandtlPlane", in honour of Prandtl. In Italy, five universities (Pisa, Torino, Milano, Roma “La Sapienza” and Roma Tre), joined together in a coordinated national project to develop and optimise, at a multidisciplinary level, the PrandtlPlane configuration [7]. The aims of the project were to develop the configuration of a very large PrandtlPlane aircraft, and, together with this activity, to carry out the mathematical tools for the multidisciplinary design and optimisation of any PrandtlPlane aircraft. At the end of the project, after two years of activity, a new configuration was defined and the tools are now available.

The aerodynamic design of a PrandtlPlane aircraft has been conducted through the following steps: a) shape generation of the aircraft, b) aerodynamic computation, c) evaluation of aerodynamic efficiency and flight mechanics stability. The shape generation was carried out by a proper code, which was modified along with the PrandtlPlane aircraft (the shape generator code and the PrandtlPlane aircraft developed together). The code is fully parametric, in order to obtain new configuration quickly and efficiently. The shape modifications on the PrandtlPlane were conducted starting from the aerodynamic results obtained, following the requirements of the Prandtl’s Best Wing System (that is: same total lift on each horizontal wing and same lift distribution, and butterfly shaped lift distribution on the vertical wings); together with these requirements, the static stability of flight was requested. The modifications of the aircraft can involve all the possible parameters, as geometrical (plan form of wings, sideslip angles, etc.) or aerodynamical (airfoils, twist angle distribution, etc.).

The aerodynamic computation have been carried out by means of FLUENT ([8]), a CFD code commonly used in industry. At this stage of the design, information on friction drag were not necessary and, therefore, the viscous flow analysis was not activated. On the other side, the transonic effects on the aerodynamic loads are of major importance because they affect the lift distribution, the aerodynamic efficiency and the static stability of cruise flight. So, the Euler analysis was performed; as it will be shown later on, the Euler computation revealed that the presence of shock waves on the rear wing is a critical problem. After the aerodynamic field was obtained, the configuration was modified and this loop was repeated until the resulting configuration became satisfactory both from the points of view of the aerodynamic efficiency and the static stability of flight. The wing span parameter was not changed during the process; in particular, wing span was assumed as 78m, the maximum compatible with airport areas, in order to minimise the induced drag. A structural optimisation of the lifting system carried out at Technical University of Milano, showed that a reduction of wing span could produce a big weight saving. This result confirms once again that the PrandtlPlane optimisation can be carried out only in the framework of a multidisciplinary optimisation. When the wing span is changed, a new design loop is activated. After the end of the Italian project, all the numerical tools are now available for design and optimisation of any PrandtlPlane configuration.

In this design process mentioned before, the geometry generation is the fundamental tool of the loop. A possible way to generate a PrandtlPlane aircraft is that of using a commercial CAD software. At the beginning of the research, when knowledge in differential geometry was insufficient and information on possible problems of the aircraft were not available, code Pro-Engineer ([9]) was applied for generating a PrandtlPlane configuration shown in [10]; the procedure adopted can be summarised as follows: (1) generation of the aerodynamic volume, (2) starting from it, the aerodynamic configuration of the (half-)PrandtlPlane was “excavated” from one face; (3) surface (fine) grid generation on the aerodynamic configuration (aerodynamic surface grid); (4) (course) grid generation on the outer faces of the volume (external grid), (5) automatic FEM volume mesh generation (by a standard FEM mesh generator) starting from the

aerodynamic surface grid up to the external grid. This procedure allowed us to design the starting configuration of the aircraft, but it revealed unsatisfactory in the case, as the actual, of a very complex configuration. There are many reasons for that as, for example, (i) a complex system as a PrandtlPlane is generated as a chain of sub-systems and, when modifying the shape, the constraints between the sub-elements are changed, (ii) modifications of important parameters as twist angles along the span, sweep angles or chord distributions, etc. can't be applied easily (iii) no modification of the code is possible. The experience gained indicated that, for developing a complex configuration as a PrandtlPlane, a proper geometry generator was needed. So, a proper code was developed together with the evolution of the aircraft and, when the different (and, seldom, unexpected problems) emerged, new code releases were introduced. The general strategies of design were also changed. In the first release of the code [11], mixed Splines and Nurbs surfaces were generated. The shape of the aircraft was made of points, which defined both the aerodynamic shape and the surface grid. The aerodynamic shape was generated by means of Splines and NURBS, having the points as a support and the surface grid was obtained and optimised by acting on the positions and the densities of the points. In the first stage of the research, this strategy proved to be successful, because the same basic elements (points) were used to define both the aerodynamic configuration and the surface grid. Afterwards, when more refined configurations were requested, the same strategy became a drawback, and new releases of the code were written, in which the problems of aerodynamic shape generation and grid surface generation were separated. This was possible because Gambit ([12]), the grid generator of FLUENT, became more and more efficient, independently from the positions and densities of the generation points. In this strategy, it appeared as convenient to make an extensive use of NURBS (Non Uniform Rational B-Splines) functions (reference can be made to, e.g., [13]), which have been extended to the whole 3D model. The code uses features typical of the commercial CAD codes for solid modelling, as extrusions of profiles, holes, intersections and generation of wing/wing and wing/body aerodynamic fillets. Solid surface modelling is much more reliable and robust using NURBS and, moreover, holes, intersections, etc., are more easily generated.
This paper aims at presenting the shape generation code and a brief overview on the development of the PrandtlPlane configuration, taking aerodynamical efficiency and static stability of flight into account.

2. Geometry generation and aerodynamic modelling.

For improving an innovative PrandtlPlane aircraft, a large number of configurations must be investigated; to do this, the shape generation of the aircraft needs to be defined by a large set of parameters and, besides, the generation code is required to be reliable, flexible and robust. The flexibility of the today industrial CAD packages is unsatisfactory when the shape is modified, because the objects are obtained as a chain of sub-elements and, in order to carry out a modification, most of the constraints between the sub-elements must be changed. After preliminary attempts to use an industrial CAD package, it was realised that, without a specific geometry generation tool, the development of the aircraft was not allowed.
A first version of the new code was called "PrandtlPlane Shape Design" (or PSD). The structure of the code was very simple and written specifically for the generation of only a PrandtlPlane configuration; the whole configuration was controlled by means of, about, 70 parameters. Geometric items were limited to one fuselage, a box wing system, a vertical fin, four engines with fixed positions (two under the aft wing and two under the rear wing). This code allowed us to carry out a preliminary development of a very large PrandtlPlane aircraft, but it showed also a number of limitations. So, the code was completely modified according to the experience gained, so as to result more flexible and to be applied also to different fields of engineering. So, it was named as MSD (Multiple Shape Design), because it is applicable to a wide range of configurations, not only in the aerospace field. The software is written in Matlab® ([14])

and makes use of some implemented GUI (Graphic User Interfaces) for handling the design parameters friendly. The creation of the main features of the code, that is bodies, wings, holes, rounds and fillets are presented in this paper. All the features are created by means of a two-dimensional database of sections and airfoils, written in .Dat format.

2.1 MSD modelling of bodies.

MSD code allows one to model symmetric (and also non-symmetric) bodies, where XZ is the symmetry plane, as shown in figure 1.

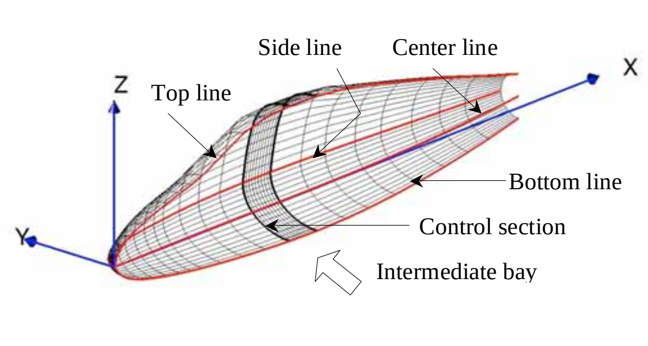


Fig. 1 Definitions of the main geometric parameters.

With reference to the positive y axis in fig. 1, three main characteristic lines are defined in the geometry generation, that is "center line", "support lines" ("top line", "side line", "bottom line"), and "control sections lines". The experience gained when modelling the fuselage with code PSD, suggested a new methodology in MSD. Fuselage in MSD is generated section by section. The (half)body is also divided into an upper part and a lower part, separated by a "side line", that is the line defining the lateral contour of the body over the XY reference plane. The center line is the curve of the origins of the local coordinate systems. The control section lines define the body shape along the longitudinal direction. They are obtained from a normalised curve, that is a curve defined in an unit square and stretched, by a proper choice of parameters, to the selected shape.

The basic geometry of the body is obtained by positioning a set of control section lines along the longitudinal axis in order to fit the intersections between the support lines, previously defined, and the plane to which the control section line begins.

Once the skeleton geometry has been defined, a custom routine is used to interpolate all the sections with a local bi-cubic interpolating NURBS surface.

In conclusion, the geometry generation of the body can be summarised as follows:

-identification of the four main lines (center, top, side, bottom),

-sketch of the four main lines, exported in (.dat) file format.

-identification of control sections and bays

-sketch of control sections, exported in (.dat) file format

-generation of the body geometry by means of NURBS interpolation.

2.2 MSD modelling of wings

The generation process of the wings is similar to that for the body. The wing is created by adding bay to bay, from the first to the last airfoil. The airfoils are defined by: sweep, twist, dihedron and are referred to the main reference system of the wing itself.

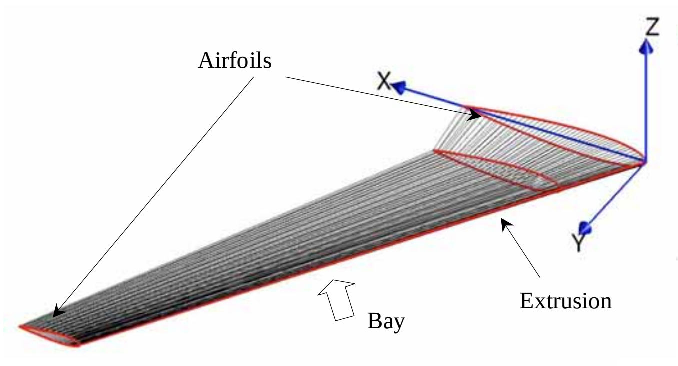


Fig. 2. Extrusion of wing parts.

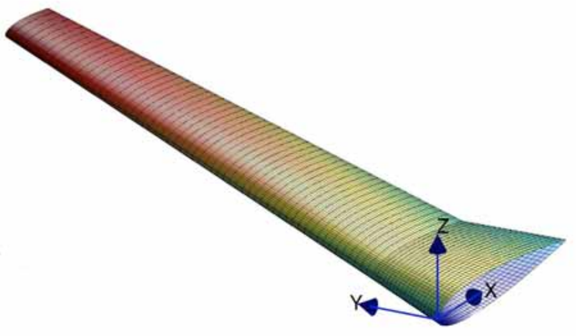


Fig. 3. Typical wing design and aerodynamic grid.

Each bay is generated by extrusion, where the leading edge line, in figure 2 defines the direction of extrusion.

The position of the wing is referred to the symmetry plane of the aircraft. Once more, the process of geometry generation is achieved by piece-wise NURBS interpolation through the specified airfoils (figure 3).

2.3 MSD modelling of holes

The "holes", in this contest, are geometric entities defined as intersections between wing and wing or wing and body. The hole is generated by a wing, which is considered as the penetrating object and another wing or body which are the penetrated objects. The first step of the hole generation process is that of defining the traces of the penetrating object on the surface of the penetrated body. To do this, we developed a custom routine in order to intersect 2 NURBS surfaces or a NURBS surface and a NURBS curve; these routines allowed us to save a significant amount of time to find out the intersection points, going from several minutes down to 10 – 20 seconds to find over 400 intersection points. Once the projection points are obtained, the points are interpolated with a custom local-interpolation routine to build a closed NURBS curve to be stored into the output IGES file.

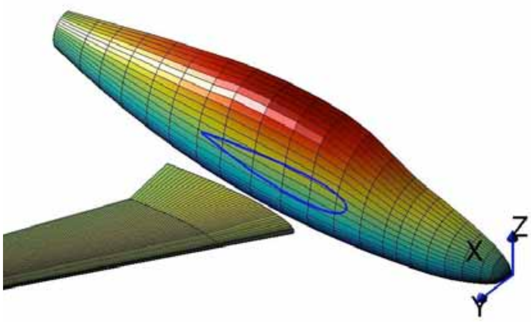


Fig. 4. "Hole" in a body**.**

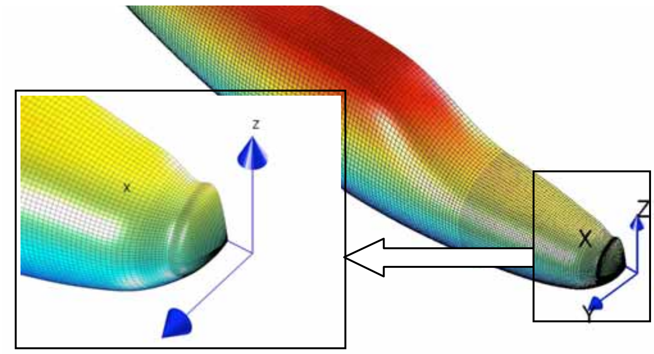


Fig.5. Typical interpolation problem by using Splines

The result is usually a closed curve or profile as shown in fig. 4, relevant to the projection of a wing over a body. Moreover the instability problems that could occurred when interpolating with a cubic spline (figure 5), have now almost disappeared thanks to the NURBS interpolating routine

2.4 <u>MSD modelling of fillets.</u>

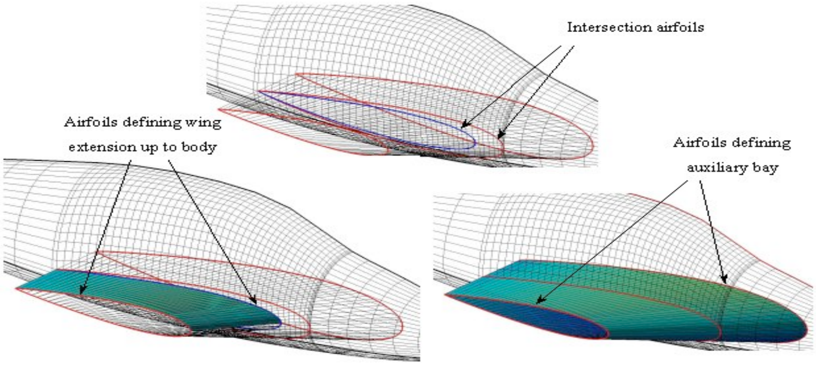


Fig.6. Generation of fillets

Fillets are objects joining wing to body or wing to wing. A wing to wing fillet is simply created using linear interpolations between the two airfoils to be joined. In the case of wing to body fillet, the generation is more complex; besides, for aerodynamic reasons, the smoothness of the fillet needs to be controlled in an accurate way. The shape of a wing to body fillet can have a remarkable influence on the local aerodynamic field, especially in the transonic range. During the development of a very large PrandtlPlane aircraft, it is convenient to avoid generating a fillet until a satisfactory shape is obtained. So, code MSD can allow one to join wing to body without and with fillet; in the first case, the hole in the body is introduced by the prolongation of the wing and, in the second case, a second (larger) hole has to be generate. This last hole is the fillet contour on the body and is obtained by an "auxiliary bay". The auxiliary bay is obtained by a linear interpolation between the wing root airfoil and an auxiliary airfoil positioned inside the body (in the symmetry plane, for simplicity sake). The auxiliary bay allows us to define the final contour of the fillet on the body. Of course, the root airfoil of the auxiliary bay is generated independently of the wing characteristics and it is varied until a satisfactory fillet contour on the body is obtained (figure 6). Once the airfoil on the wing and the fillet contour on the body are generated, the fillet surface can be obtained parametrically, by using NURBS. The fillet surface is obtained by means of NURBS curves; they are the root wing airfoil, the wing/body hole and the auxiliary bay/body hole. So, for any curve, three points are defined on the three curves, as shown in figure 7.

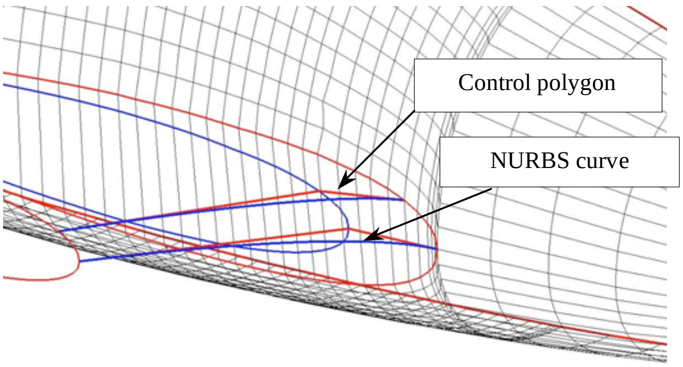


Fig. 7. Fillet generation by Nurbs

The control polygon of each curve is composed by three points: a start point on the wing root airfoil, a central point on the wing intersection profile and an end point on the fillet contour on the body.

Given these points a NURBS surface is generated by selecting an appropriate knot vector in the *y* direction. A typical result of fillet generation and also of grid generation is shown in figure 8.

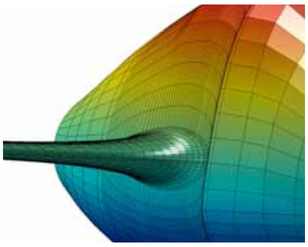
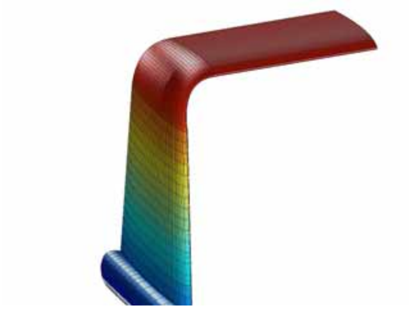
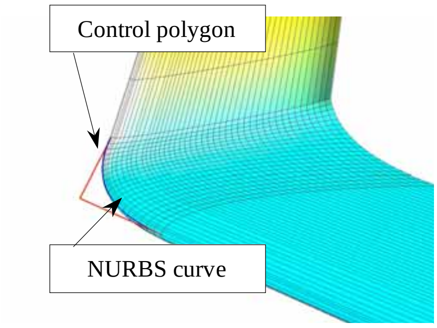


Fig. 8. Aerodynamic grid of a fillet

2.5 Modelling of “rounds”

In a PrandtlPlane configuration, the wing system is made of horizontal and vertical wings, joined by round trunks of wings. These geometric elements, named “rounds” in the rest of the paper, could be critical from the aerodynamical point of view. Moving from the beginning of a “round” (say, on the horizontal wing) to the end (on the vertical wing) we define a local reference system, along which the airfoil, radius of curvature, etc, change with certain laws. Therefore, shape and grid of the round elements are defined by a set of parameters, to be changed during the optimisation process of the aerodynamic development. “Rounds” are geometric elements properly defined in the case of a PrandtlPlane configuration. The process of geometric and grid generation is similar to that of fillet creation, using NURBS curves. Each curve is generated with reference to a control polygon defined by three control points as shown in figure 9.





The surface grid for aerodynamic computation is obtained by introducing control sections along the local reference system.

Fig. 9. Generation of a round.

3 Exportation tools: IGES translation and CFD analysis

Once the geometric generation is complete in Matlab format, the data file is translated into a proper IGES format to be read by a CFD or BEM aerodynamic code. A proper code filter, called IGES TRANSLATOR, was written in this research programme and used in the Splines-NURBS mixed geometry generator. A new IGES filter is now in progress to include all the advantages of the new fully NURBS geometry description. A single element of the surface structured grid is a single IGES surface (data type 128); so, the translator code is very simple, but the amount of generated information is large. This solution allowed us to develop the aircraft configuration up to a maximum number of elements but, when more refined meshes were needed, the previous procedure proved to be unsatisfactory, because the amount of data became too large. The new IGES generation uses curves and surfaces generated by NURBS and the data files are much more compact. As an example, a 2MB IGES file, containing all the information of the large PrandtlPlane fuselage can be reduced to less than 200kB. The surface geometry, exported in IGES format, can be read into an external CFD code (in our case GAMBIT/FLUENT® package) to generate the volume grid, starting from the aircraft surfaces towards the outer faces of reference volume.

4 Development of the PrandtlPlane configuration.

The conditions of Prandtl's Best Wing System are assume as leading criteria for designing any PrandtlPlane aircraft. The aerodynamic optimisation is mainly influenced by possible transonic phenomena, static stability of flight requirement and structural design. In order to take into account the compressibility effects, a CFD Euler analysis is performed. The condition of static stability of flight can influence, even significantly, the aerodynamic efficiency; so, aerodynamics and static stability of flight are strictly connected and are studied together. The structural design of the lifting system is a fundamental aspect, due to the peculiarities of the project (wings over-constrained to fuselage, innovative design of the wing box sections, new materials, etc.). A proper optimisation tool of the wing structures was set up in the framework of the before mentioned joint research project, carried out by five Italian universities. The computational tool was set up by the Technical University of Milano ([15]) in order to optimise the structural configuration, taking the constraints of structural stability and aeroelasticity (in particular, flutter) into account, both at cruise condition and high load factors. In the rest of this paper, we will deal with development of the configuration, taking into account only aerodynamics and static stability of flight. The geometry generator, described before, is the fundamental tool for carrying out this activity.

Figure 10 ([16], [17]) is a reference configuration of a very large PrandtlPlane aircraft, resulting from the geometry

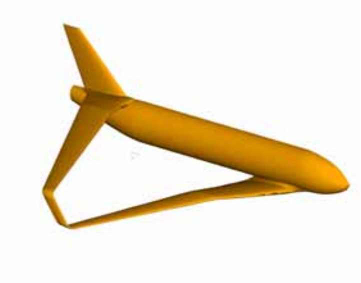


Fig. 10.

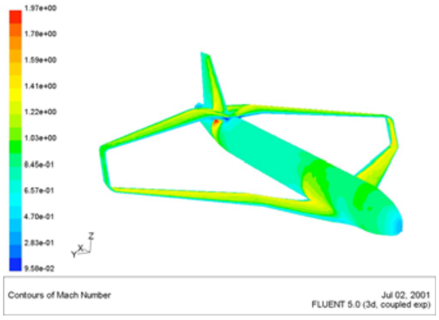


Fig. 11.

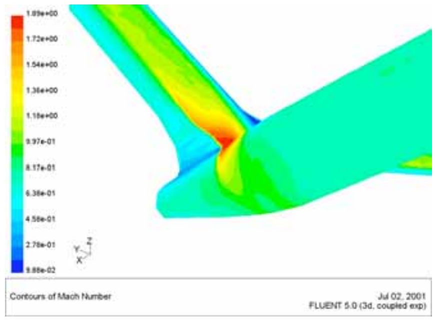


Fig. 12.

generator using a commercial CAD code; figures 11 and 12 show the Fluent results in terms of Mach number. The aerodynamic performances of the rear wing close to the root are reduced by the presence of shock waves, due to the interference between rear wing and fuselage; the presence of the fin improves the interference (fig. 11). Due to these problems, the configuration was proved to be unstable or weekly stable unless the position of the centre of pressure could be close to the front wing. But, in this situation, the front wing is more loaded than the rear one and the Best Wing System conditions are not fulfilled. In general, as said before, the flight mechanics stability produces less aerodynamic efficiency. As a further example of configuration, figure 13 shows a modification of fuselage in order to change the local design and modify the aerodynamic field. The results in figure 14 show that the advantages are modest. Figure 15 shows another configuration, designed in order to produce equal lift on the wings, together with static stability of flight. All the configurations tested, obtained by changing the local aerodynamic parameters, proved to be unsatisfactory.

The outputs of the aerodynamic computation are presented in a compact way; a typical example is shown in figure 16, in which the following data are shown: (a) a scaled wing plan-form, with the chord lengths and the twist angles along the span, (b) the (half)wing surface, (c) the sweep angles, (d) the lift on a single wing, (e) positions of the centre of pressure of the single wings and whole aircraft, (f) same data of (e), relevant to variations of pressure (relevant to 1° of angle of attach), (f) margin of stability in meters.

Figure 17 shows also the contribution to pitch moment of front (low) wing, rear (up) wing and fuselage (fusoliera). The lesson learned is that, in order to control the stability of flight, the lift repartition (between the wings) and the lift distribution (along the span), we need to modify both the twist angles along the span and the geometrical parameters of the wing (chord distributions, sweep angles, etc.). By modifying all these parameters, it resulted that the best repartition of lift associated with static stability of flight was of the order of 70% on front wing and 30% on rear wing. On the other end, the structural efficiency due to connection between rear wing and fuselage is high. In the configurations shown before, the very large fuselage is similar to that of Airbus A380; the fuselage is enlarged vertically and the resulting gaps (ratio between horizontal wing distance and span) are high.

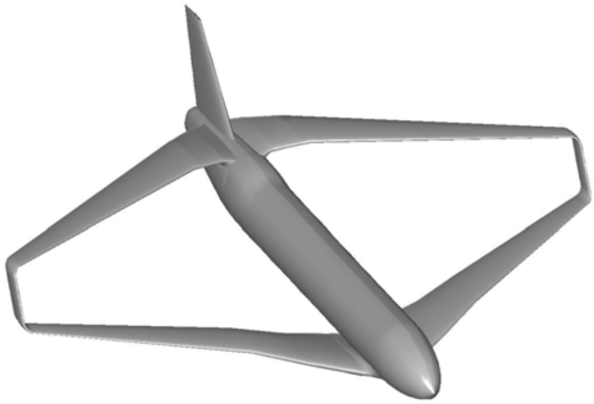


Fig. 13. Modification of the rear wing-body connection

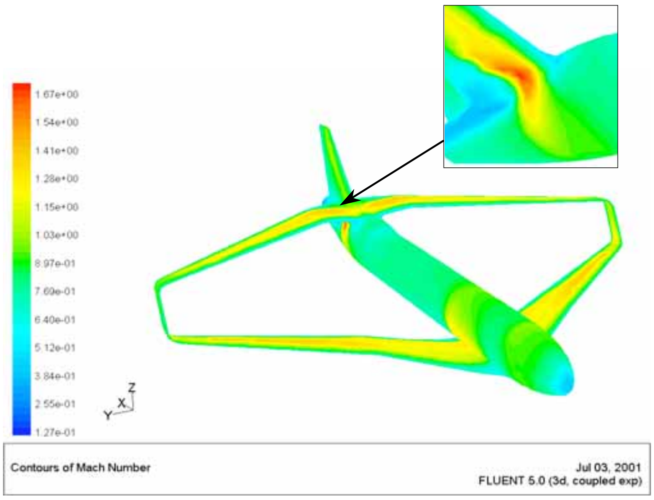


Fig. 14. Typical aerodynamic result; shock wave on the rear wing.

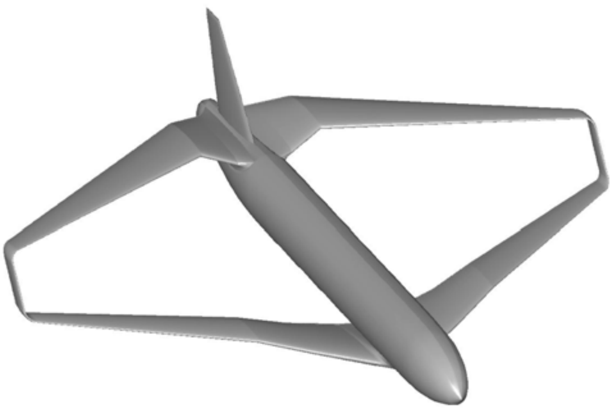


Fig. 15. Modified PrandtlPlane configuration

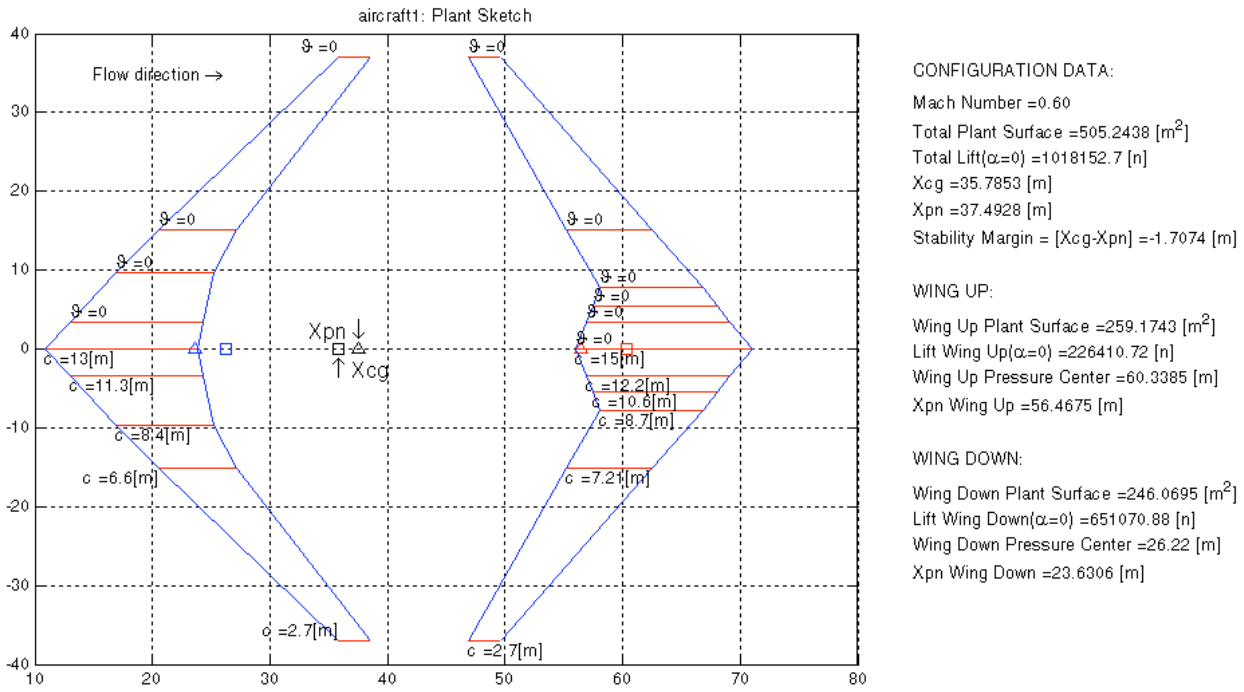


Fig. 16. Typical output of an aerodynamic computation

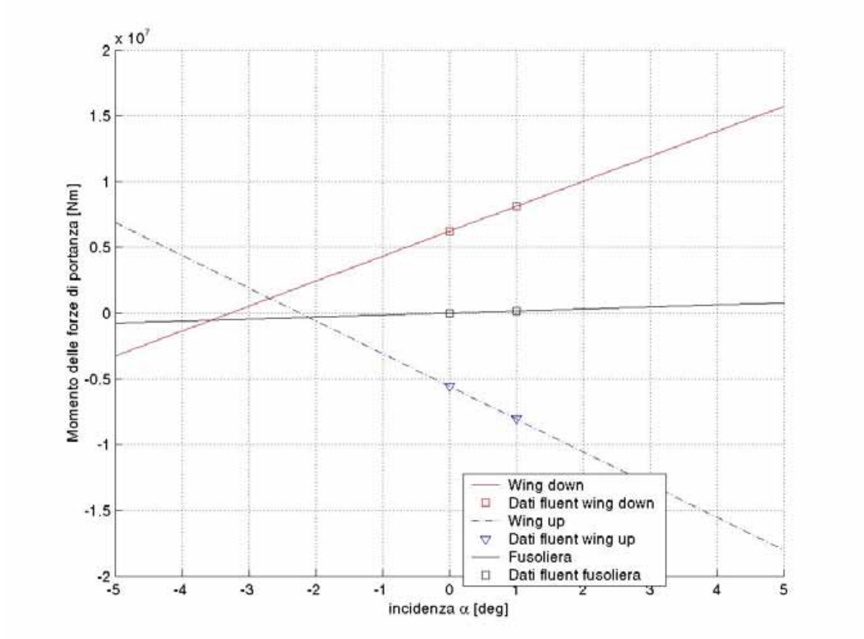


Fig. 17 Contribution to pitch moment of front wing (down), rear wing (up) and fuselage (fusoliera

A possible alternative solution is shown in figure 18 ([18]). In this configuration, the rear wing is continuous, passing over the rear fuselage and connected to said fuselage by means of two fins. The aerodynamic channel, formed by top fuselage, bottom rear wing and lateral fins, plays a key role on the aerodynamic efficiency of the rear wing. It results that the aerodynamic efficiency of the central trunk of the rear wing is higher than the correspondent central front wing and, owing to this property, the stability of flight becomes possible with an equal repartition of lift between rear and front wings. A typical result obtained by Fluent code is shown in figure 19.

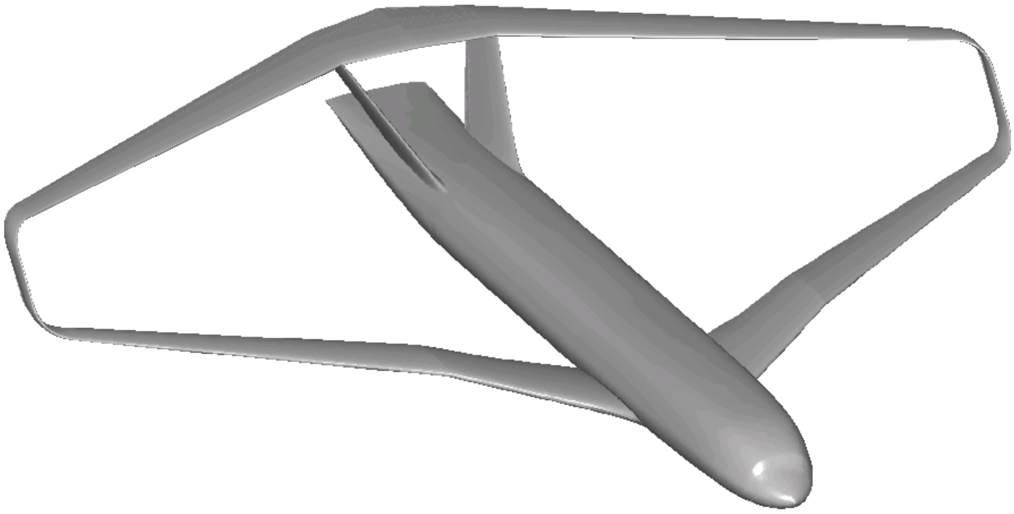


Fig. 18.. Double fin PrandtlPlane configuration

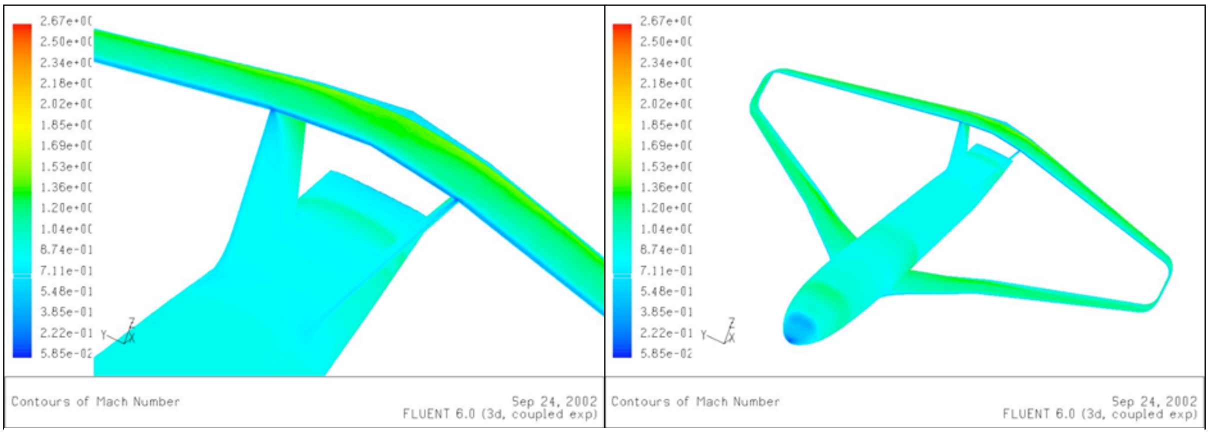


Fig. 19. Typical aerodynamic output of the double fin PrandtlPlane very large aircraft.

The results show that the fillet between rear wing and fin is critical for shock waves, which can be reduced by means of a suitable local design. The configuration in figure 20 realises a nearly equal repartition of lift and, also, cruise flight is stable. The structural analysis reveals that the solution is not optimum from the structural point of view. In order to improve the efficiency, the local chord distribution can be improved (a margin of 200 square meters is available with respect to A380) or the wing span can be reduced; in this last case, a reduction of 8m span (from 78m to 70m), produces a weight reduction of 30%.

A final decision on the configuration to be adopted will be based on low speed aerodynamic design, in the presence of the high lift devices and on the aerodynamic analysis in the presence of longitudinal and lateral controls.

The aircraft shown in figure 20 is totally different from an equivalent aircraft , like A380. The fuselage is enlarged horizontally with only one deck for passengers, the gap has no limitations, etc;

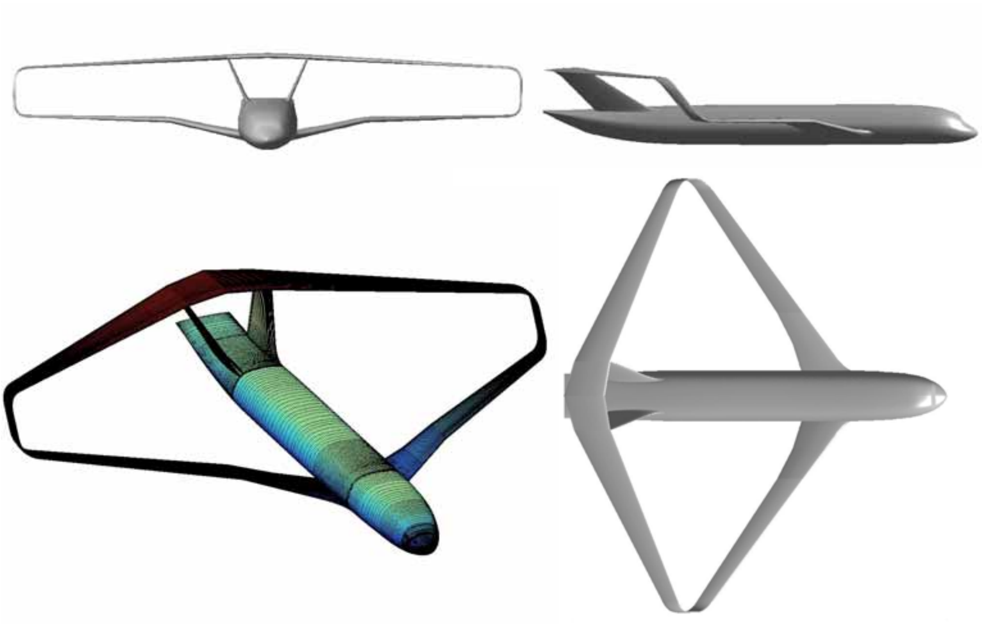


Fig. 20. Very large PrandtlPlane aircraft, with equal lifts and stable in cruise flight

A second example of PrandtlPlane aircraft is showed in figure 21 ([19]).It is a two-seat ULM (ultra-light aircraft) or an UAV aircraft.

The design principles are the same as before, with an aerodynamic channel (as defined before), the rear wing positioned

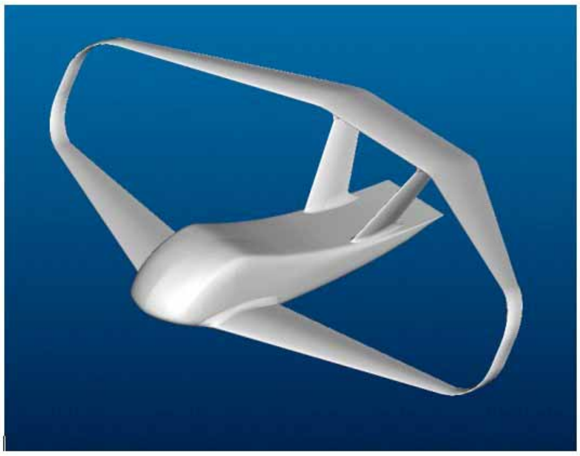


Fig.21. ULM or UAV PrandtlPlane aircraft

Fig. 22. Wind tunnel tests on scaled model in Torino

over the top fuselage, and the same rules for having equal repartition and stability of flight. This configuration, in particular, can be easily modified to become an amphibious aircraft (the piston engine is positioned high, on the rear wing between the fins). Wind tunnel tests on a scaled model of the small aircraft were carried out at the Technical University of Torino (figure 22), in the framework of the before mentioned Italian project ([20]) The results obtained show that: the aircraft stall is week (figure 23), the aircraft is stable (figure 24) and the efficiency is satisfactory, even though no optimisation has been performed yet.

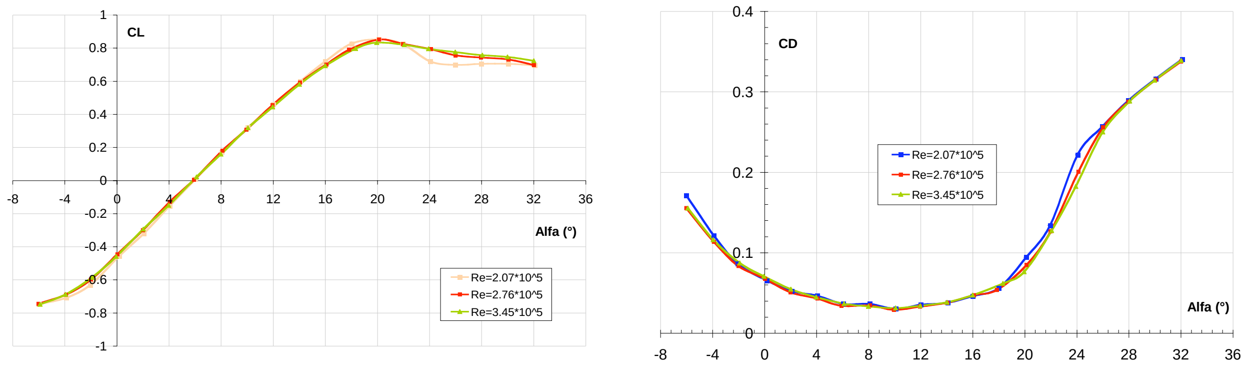


Fig.23. Wind tunnel results on lift and drag

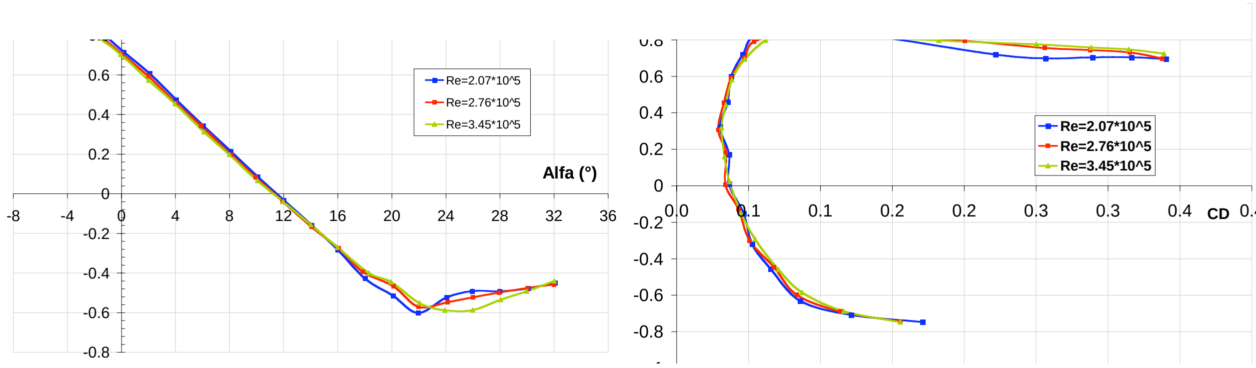


Fig. 24. Wind tunnel result on pitch moment and efficiency

5. **Conclusions.**

The main results shown in this paper are:

- non conventional configurations are of interest for the future transport aviation,
- a configuration aiming at reducing the induced drag has been studied, following the guidelines of the Prandtl's Best Wing System; it was named as "PrandtlPlane, in honour of Prandtl.
- A project was carried out in Italy, with a fundamental financial support of the Ministry of University. Five Italian Universities participate to the project.
- As a result of the project, the main computational tools for design and optimisation of a PrandtlPlane configuration are now available.
- A PrandtlPlane very large aircraft was developed at a preliminary aerodynamic design, taking the transonic effects and flight mechanics stability into account.
- Other PrandtlPlane configurations can also be designed with the same concepts; as an example, a ULM or UAV aircraft is shown.

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