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AERODYNAMIC NUMERIC MODELLING OF A SEMI RIGID HANG GLIDER/ULTRALIGHT WING

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ABSTRACT

TOP SECRET, a semi-rigid hang glider is currently being designed and built by La Mouette S.A., Dijon, France. This paper outlines the aerodynamic design of TOP SECRET. The 2D airfoil was analysed using EPPLER (Prof. Richard Eppler, University of Stuttgart) and XFOIL (Prof. Mark Drela, M.I.T.) software. Analysis on the 3D wing was done using Wessinger Extended Lifting Line Theory. The objective was to find the best linear twist angle distribution from root to tip to give the highest Lift/Induced Drag ratio. This is called the Minimum Induced Drag Criteria. The linear distribution was chosen to make construction easy and cheap. Validation using Lifting Surface Theory (Software SURF, Herve Bezard, ONERA) was also done for a "constant chord" and "no twist" wing. The best linear twist is 0° at root and 6° at tip. TOP SECRET was benchmarked against PEGASUS (Germany), a proven semi-rigid hang glider. At the same time, FLUENT computational fluid dynamics software was used to get the polars of the aerofoil for TOP SECRECT and the results was in agreement with the results from EPPLER and SURF.

INTRODUCTION

Rigid Hang Glider is the most current development in hang glider design. These types of hang gliders usually have a rigid D-Shaped composite leading edge that acts a spar and to this spar, foldable ribs are attached. Sailcloth made of either DACRON or MYLAR is then attached to the spar using VELCRO straps. The sail is made in two parts, top and bottom for each wing. The top and bottom surface sailcloth rest on the ribs solely by tension between the attach points at the leading edge and the trailing edge. The performance increase as compared with conventional hang glider (top of the range without kingpost model such as TOPLESS-La Mouette) is quite marked.[1]

TOP SECRET by La Mouette is one such glider. It has an aspect ratio of 7.96, 11 meters span and a 20° leading edge sweptback. The wing also has spoilers and flaps. They are all activated by a system of cables and pulleys. The control bar is of a standard triangular shape and the pilot is suspended from the keel in the classical prone position of normal hang gliders. [1] Refer to Figure 1 for general layout of TOP SECRET.

This paper discusses the aerodynamic design of the hang glider TOP SECRET. The choice and analysis of 2D airfoil was done carefully as the result would be used to estimate the 3D wing performance. The 3D wing analysis was done using Wessinger Extended Lifting Theory because it is a very quick method and the result from past experience (at La Mouette) is quite good. The design team at La Mouette, already have some ideas about how the twist angle should be distributed by observing other makes of rigid hang gliders. In essence, the method used is to confirm the intuition of the chief designer who has 25 years experience in designing hang gliders.

This work is also a collaborative effort between Faculty of Mechanical Engineering (FKM) and La Mouette S.A. Dijon to bring about competence in CFD methodology in our faculty and to solve real commercial engineering problems so that later on a team of dedicated engineers will be formed at our faculty. This is why we include the FLUENT software analysis calculations. In this way our faculty will be ready to embrace CFD as a tool for problem solving and hopefully FKM, UiTM be the center of excellence in fluid dynamics and applied aerodynamics to serve industries in Malaysia and abroad.

PROBLEM STATEMENT

The first element of the study is to find the polars of the airfoil of the hang glider. The method used is by solving the EULER equations using the software XFOIL, EPPLER and FLUENT. The second part is to calculate the performance of the glider wing using Extended Lifting Line Theory (ELL) and comparing it with the Lifting Surface Theory Software SURF. We then proceed to optimize the wing by studying the linear washout angle distribution along the span. The best washout distribution was incorporated in the prototype and subsequent production version. The most important part is the design and analysis methodology. With this research we at FKM, UiTM has already in place a design tool that can be used to analyze future semi-rigid and rigid hang glider wings. The design methodology must of course be updated as new powerful CFD tool and experimental facilities became available at FKM, UiTM

OBJECTIVES OF THE RESEARCH

The first objective is to optimize the design of a semi-rigid hang glider/ultralight wing using computer numeric method. At the same we want to create a team of applied aerodynamic practitioners with practical knowledge of computer numeric methods in the field of Low Speed Aerodynamics. When this is in place, we want these core people to initiate an Aerodynamic Numeric Laboratory for FKM, UiTM to serve as a teaching, research and consulting body to cater for the needs of academia and industry.

RESEARCH METHODOLOGY

The analysis performed can be categorized in three steps. Firstly a 2D analysis of the airfoil using EPPLER, XFOIL and FLUENT was done to get the polars. The polars are necessary because they will be fed into the 3D wing analysis. A 3D wing performance code in FORTRAN was written using Extended Lifting Line Theory of Weissinger as the basis of performance calculation. This program was called ELL. The results of the analysis were compared with the Lifting Surface Software SURF of ONERA in the case of an untwisted wing. This was done to see the limitations the program ELL. As the corresponding results were good, we proceed to use ELL to calculate the optimum linear washout distribution for the wing TOP SECRET. A whole range of practical washout distribution was investigated and the best result was chosen.

2-D AIRFOIL ANALYSES

The airfoil chosen was the PEGASUS airfoil. We have the airfoil coordinates but we don't have the performance data. Analysis was done using XFOIL first and later using EPPLER. In the end we choose the EPPLER data, primarily because Prof. Eppler has developed a set of airfoil series (E344) specifically for sweptback flying wings. He is also an expert in glider design. [2]. Please refer to Figure 2 and Figure 3 for airfoil characteristics. We also use FLUENT software version 3 to get the polars for our airfoil. FLUENT V is old and has its limitations. Nevertheless, we mange to get some very good analysis done using FLUENT and we have a pool of talented FLUENT users. We can count on them to be the key members of our CFD group once FKM, UiTM has at its disposal more powerful software and supercomputers.

Airfoil chosen should be relatively thick for structural and fabrication considerations. The airfoil should also be relatively flat after the quarter chord line. On the top surface, there should not be any reflex. This is due to the fact that the sailcloth is not fixed to the ribs. It is tensioned from the attach VELCRO point at the D-Section leading edge to the tips of the ribs at the trailing edge.

Airfoils for tailless airplanes or gliders are always governed by very strict conditions for C_{MO} (Coefficient of Moment). If no sweepback or sweep-forward is intended, C_{MO} = 0.05 is required, which is necessary for longitudinal stability. If sweep is intended, a twist of the wing contributes to the longitudinal stability. In this case the root of the sweptback wing has a higher C_L than the tip. But still, the average C_{MO} must be as low as possible because it determines the amount of twist, which is necessary for longitudinal stability. Too much twist increases the induced drag and penalised the overall performance. It must be noted that our calculations are purely based on the aerodynamic consideration rather than flight mechanic considerations. However, the basic fundamental requirement of longitudinal stability is never neglected. [2]

3-D WING ANALYSES

We use Weissinger Extended Lifting Line Theory to calculate the Lift and Induced Drag. In the Simple Lifting Line theory, it was assumed that the circulation representing the wing was concentrated on one line. This concept is a fairly good approximation for a real wing, only when its chord is much smaller than its span (High Aspect Ratio Wings). This assumption is not valid for wings of small aspect ratio, for sweptback wing and for delta wing. The performance of these types of wings can be predicted using Lifting Surface Theory and Extended Lifting Line Theory.

Extended Lifting Line Theory is a simplification of the Lifting Surface Theory. It has been shown that Extended Lifting Line Theory may be transformed into the Simple Lifting Line Theory for high aspect ratio wings. [3].

The basis for the computation of the circulation in the lifting surface theory is that the lifting surface carrying the vortices is a stream surface. What it means is that the normal component of the resultant velocity is equal to zero on this surface. This condition is called kinematics flow condition. The Lifting Surface Theory is transformed into Extended Lifting Line Theory by replacing the continuously distributed circulation along the chord by a vortex line, arranged at a suitably chosen station on the local chord. Usually the quarter chord line is chosen for this purpose. The kinematics flow condition can be satisfied in this case at one point of the chord only. This control point is usually the three quarter chord station measured from the leading edge. This is in accordance with the Theorem of Pistolesi. [3], [4].

Please refer to Schlichting [3] and Weissinger [5] for full mathematical treatment of the extended lifting line theory and manual worked examples. We wrote our own FORTRAN program ELL to analyse the wing.[1]. It is not our aim to explain how to derive the integral equations because it is well explained in many good aerodynamic texts written by renowned aerodynamicists. Our objective is to use the available theory to try and solve a practical problem. The detailed explanation on the theory is best left in the original books, which can easily be referred to by the interested reader.

This Extended Lifting Line Theory is also called the three quarter point method. Its great advantage over Simple Lifting Line Theory is that it can be applied to yawed and sweptback wing. As TOP SECRET has a 20^0 sweptback, this method is more appropriate than Simple Lifting Line Theory even though the aspect ratio of 7.96 is quite big.

ANALYSIS OF DATA

Hang gliders are flown at various speeds depending on the phase of flight they are currently on. A design point has to be chosen. This design point is to start the initial performance calculation. It is also used as a baseline to determine the twist angle optimization.

CHOICE OF DESIGN POINT

The wing TOP SECRET was divided into 11 strips of elemental wings. Therefore we have 11 control points. We have to know the aerodynamic characteristics of the profile used at each station. These come from the result of the 2D analysis by EPPLER. These data should be obtained in the range of Reynolds Numbers relevant to the operation of the wing.

The typical speed range for TOP SECRET is between 30 km/hr and 120 km/hr with 0^0 to 15^0 flap setting. As a premier design point we have to choose a speed to do performance analysis for various washout distribution. This was done without flap deflection.

Hang gliders hardly ever need to fly at the speed, which yields the best Lift/Drag ratio or flattest glide in still air. As a rule, they are either soaring or penetrating. When penetrating a speed faster than that for Lift/Drag max is needed. For example, if the hang gliders' best Lift/Drag speed is 50 km/hr and it faces a wind of slightly more than that speed, flight at best Lift/Drag speed will cause it to move backwards relative to the ground. A higher speed would enable some forward progress to be achieved, albeit at a high rate of descent. In addition, between up current zone, thermal or hill lift, there is almost always sinking air. What it means is that the hang glider pilot is always penetrating to search for thermals to have the longest duration and distance. [6].

When soaring we want to sink as little as possible so that the thermal will bring us as high as possible. Usually hang glider pilots turn in circles to climb in thermals. Flight at minimum sinking speed is slow at high C_L. The minimum rate of descent occurs when the ratio of $C_L^{1.5}$ to C_D is highest. This ratio is often termed the power factor. The power factor should not be confused with the maximum Lift/Drag ratio. The flattest glide, covering the greatest distance over the ground in still air is not the best trim for minimum sinking speed, which requires slower flight at higher C_L. Depending on the wing profile, the minimum sinking speed may occur at angles of attack fairly close to the stall, or in many cases at a flight speed of about 75% of that for best Lift/Drag. This is the trim to be sought when a glider is soaring. [6]

Based on the penetrating phenomena and La Mouettes' extensive World Hang Gliding Championship experience, we chose the premier design point as V_∞ = 18.05 m/s (65 km/hr) and the Angle of Attack = 5^0. The washout distributions studied were 0^0,1^0,2^0,3^0,4^0.5^0,6^0,7^0 and 8^0 washout angle at tip with 0^0 twist at the root of the wing.
Variations of twist angle are linear from root to tip. The results are shown in Figures 2 to 6.
The best washout distribution obtained is 6^0 at tip. This result is comparable to the washout used on the PEGASUS. [1]. The L/Di data is shown on Figure 4.

COMPARISON BETWEEN EXTENDED LIFTING LINE SOFTWARE PROGRAM, ELL AND LIFTING SURFACE SOFTWARE, SURF.

A comparative study between the Extended Lifting Line Theory software program, ELL and Lifting Surface Software, SURF was done for an untwisted wing. The wing chosen was of 11 meters span, 1.29 meters constant chord and 8.53 aspect ratio. The airfoil was E344 throughout the span. Comparisons were done at the premier design point described earlier. The results for Cdi are shown on Figure 5. [1].

The Extended Lifting Line Theory is a simplification of the Lifting Surface Theory. However, in our case the results indicate that at the design point, the difference is not much.

CONCLUSION

Extended Lifting Line Theory can be used to do quick aerodynamic design of rigid hang gliders. Of course, in the end the choice of aerodynamic tailoring depends ultimately on the designer. The cheapest way is still by varying the twist angle along the span. For TOP SECRET, the best downwash angle based on purely aerodynamic considerations is 6^0 at tip. Newer CFD methods are available but experimental validation by flight test of hang gliders are still in infancy.[7]. Furthermore the sailcloth actually flaps during flight and to simulate this on CFD package is quite difficult. Hang glider wings can be used as microlight or ultralight wings and this will create a lot of demand for better performance wings. Whoever can come up with a better design analysis tool specifically for hang gliders and hence design a better wing can expect great rewards. This methodology of design analysis can also be applied to other interesting products where applied aerodynamics play a big role.

FURTHER RESEARCH

We want to develop a complete structure and aerodynamic optimization package. The next step will be the complete interfacing between the structural drawing either from AUTOCAD, CATIA or UNIGRAPHICS to direct Navier-Stokes Solver or Euler Solvers Software. Proper Boundary Layer modeling and Turbulence modeling must be incorporated especially for real 3D wing. The results must be presented in a graphics form by using graphics software such as TECPLOT or others. In such a way we can calculate and show the aerodynamic performance related to any design change in the production drawing. These methodologies will reduce design and production costs in the long run and will create K-workers in the domain of Fluid Mechanics. With these tools in place and competent and dedicated team available at FKM, we can undertake more serious and profitable research and consultancy projects. At the same time we can train our students so that they have the competence to compete globally.

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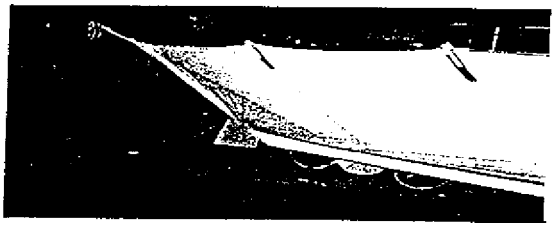
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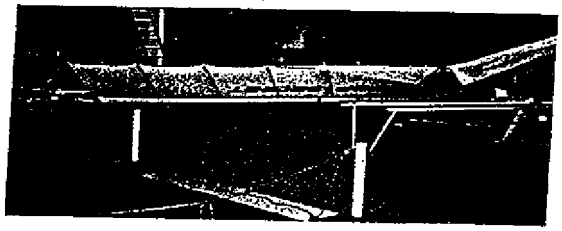


Figure 1. TOP SECRET

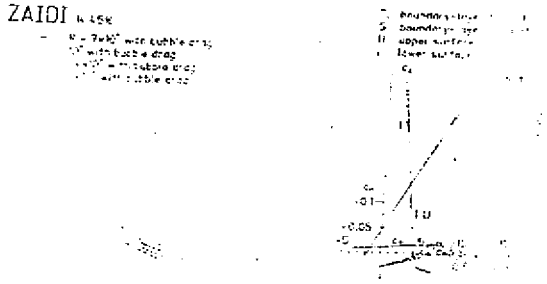


Figure 2. POLAR USING EPPLER

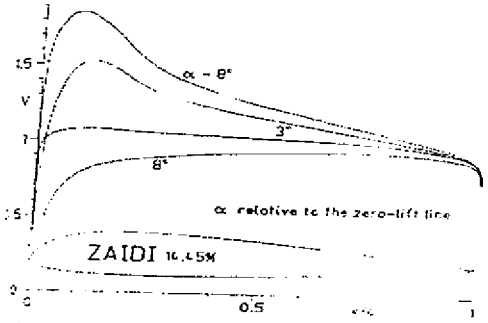


Figure 3. 2D AIRFOIL

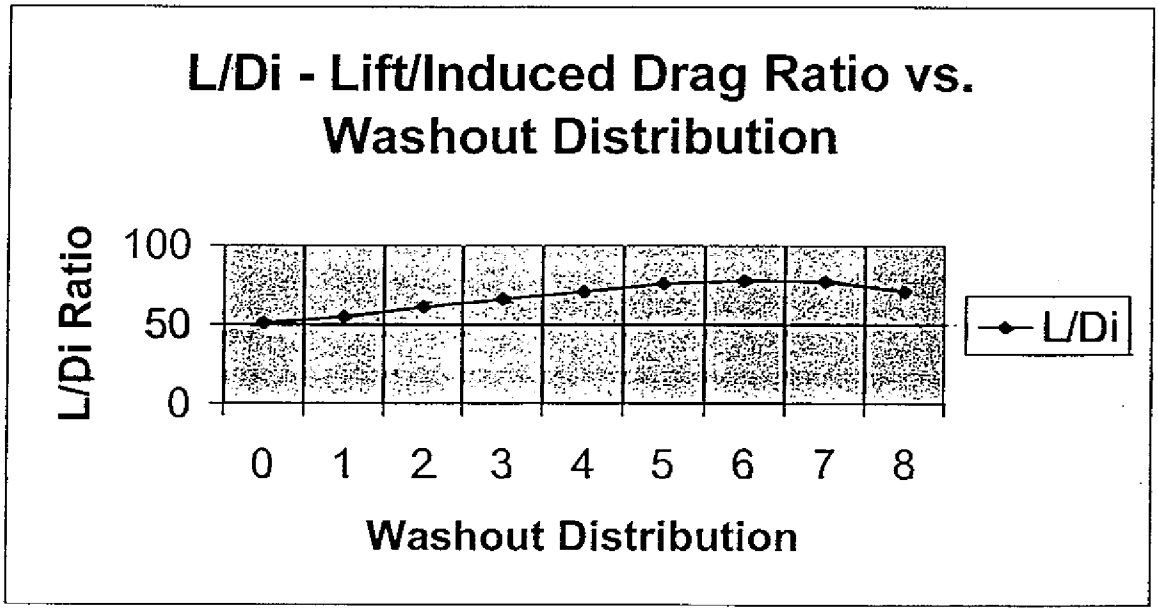


Figure 4. BEST L/Di RATIO

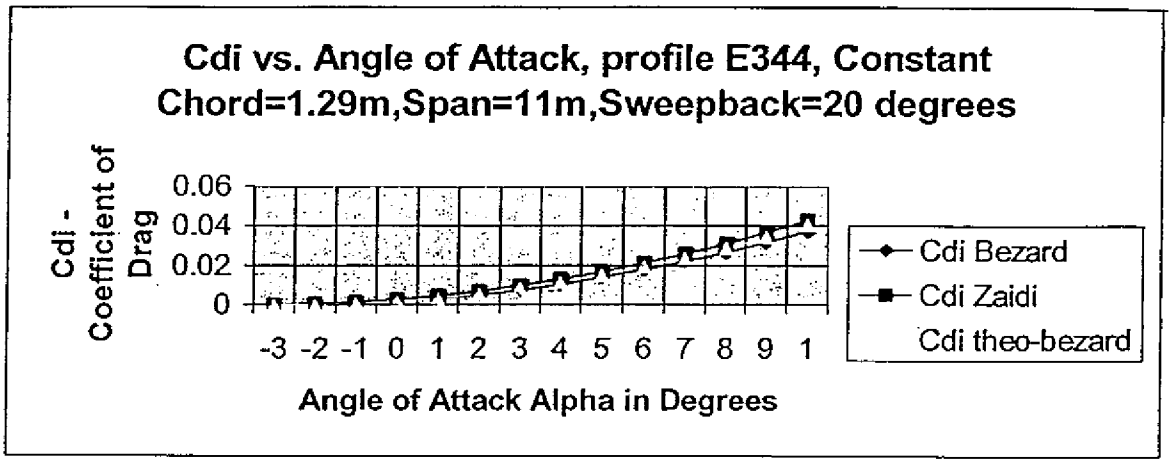


Figure 5. VALIDATION OF Cdi BETWEEN SURF AND ELL