Wing Design of a High Altitude and Long Endurance Aircraft

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Summary

This paper describes the approach used for the structural design of the wing of a **H**igh **A**ltitude and **L**ong **E**ndurance (HALE) **U**nmanned **A**erial **V**ehicle (UAV).

The wing is entirely in composite materials: the elements subjected to bending moment and axial force (spar caps and integrated stringers) are devised in high strength carbon unidirectional epoxy material, while the skin in honeycomb core sandwich panels.

The fundamental step in the approach is a **M**ulti-**L**evel **I**ntegrated **P**rocedure (MLIP) developed for the sizing of structures in composite materials [1]. The procedure is based on several levels characterized by growing detail levels, and integrates several in-house developed codes with a general purpose finite element software and a dedicated commercial software.

The design is performed according to JAR 25 requirements [2]; in particular, the wing is sized using the loads provided by Continuous Turbulence Analysis (ACJ-JAR 25.341(b) paragraph). All the aeroelastic analyses (trimmed aircraft, gust loads and flutter analysis) are performed using an in-house software.

Wing configuration

In the table 1, the main dimensions and weights of the aircraft are listed:

Wing Span	61 [m]	**Length**	14.7 [m]
Wing Area	106 [m^2]	**Height**	7.25 [m]
Aspect Ratio	25	**MTOW**	9588 [kg]
Taper ratio	0.4	**OEW**	3588 [kg]
t/c	0.20	**MFW**	5500 [kg]

Table 1 – Aircraft Characteristics

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The aircraft is equipped with two advanced common rail diesel engines; the fuel thanks are integrated in the wing structure. The two tail planes are connected to the wing by means of two booms.

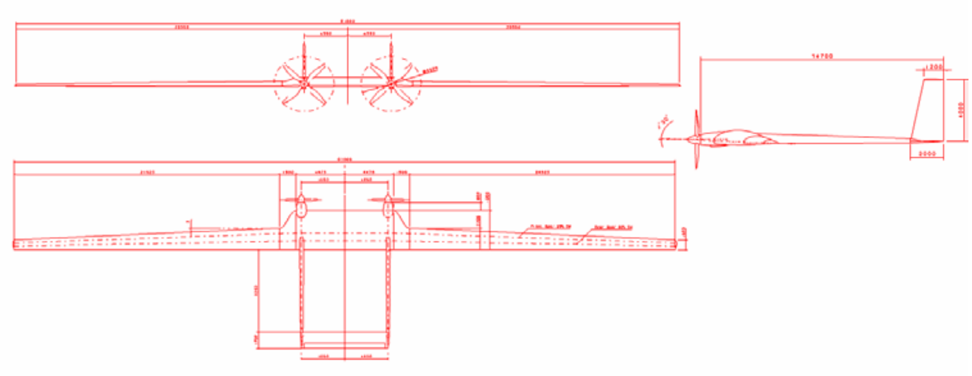

Figure 1 – Aircraft three view drawing

In order to reduce the friction drag coefficient, to obtain a high lift, a high efficiency and a natural laminar flow at appropriate Reynolds and Mach numbers required for the mission, a new wing airfoil has been developed in CIRA using a multi-objective genetic optimization algorithm. The airfoil is characterized by a high thickness (t=0.20) that allows to obtain a consistent weight reduction.

The front spar is located at 25% of the chord, the rear spar at 60%.

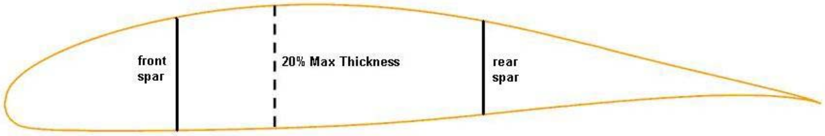

Figure 2 – Wing Box

In order to achieve the minimum weight all the structural components of the wing are in composite laminate and sandwich construction.

The caps of the spars are made out of **0° oriented carbon/epoxy laminate**, the webs of the spars are in **solid laminate with all ± 45° plies**. The panels of the skin are in **composite honeycomb core sandwich**.

For the laminates a common high-strength graphite/epoxy composite material (IM7/977-2 by ICI Fiberite) is used. The properties are listed in the table:

Moduli		**Allowables**	
E_1	148000 MPa	F_{tu1}	980 MPa
E_2	9310 MPa	F_{cu1}	593 MPa
G_{12}	5170 MPa	F_{su}	30 MPa

Table 2 – Material Properties

The allowable values are knocked down to take in account the effects of moisture absorption and impact damages. According to previous experiences on the composite materials, the applied knock down factors are 50-60%, then the design results quite conservative.

Design approach

The design approach can be so summarized:

1 Determination of the critical load condition assuming the aircraft as a rigid body.

2 Preliminary wing sizing with the MLIP procedure.

3 Evaluation of the new load condition considering the aircraft flexibility in the trim equation.

4 New wing sizing with the MLIP procedure.

5 Iteration of the steps 3 and 4 until the convergence is reached.

The design criteria are no strength failure no buckling failure at ultimate loads.

The laminate sizing criteria is the “first ply failure” according to which a laminate fails when almost a ply is broken.

The MLIP procedure

The procedure is based on an **in-house software** able to solve a **composed multi-box structure** subjected to shear, bending and torsion. It is characterized by three fundamental levels.

In the first level the structure is simulated with concentrated elements: caps, webs and skin panels. The caps are sized by the ultimate running bending moment, the webs by the running ultimate shear and the panels of the skin by the ultimate running shear and bending.

In the second level, using the internal loads determined in the previous step, the lay-up of the panels and the thickness of the honeycomb core are optimised by means of a structural sizing software.

In the third level, a finite element model of the wing is generated using the lay-ups and core thicknesses obtained in the previous step. In this case the internal FEA loads are used in order to update lay-ups and thicknesses. The iterations between the finite element software and the structural sizing software continue until the convergence is reached.

At the end, the structure with the minimum weight is obtained; for this structure, all the margins of safety result positive.

First load condition: rigid aircraft

The external loads (shear, bending and torsion) on the wing are evaluated according to **Gust Pratt formula at $V=V_c$**.

For this condition, the MLIP procedure furnishes an optimized finite element model from which it is possible to extract all the characteristics of the structure for the aeroelastic analysis.

New load condition: elastic aircraft

The first weight of the wing (rigid aircraft) has turned out higher than the estimated one in a preliminary design phase. Moreover the HALE is an high aspect ratio aircraft with high flexibility, so the trimmed conditions must be evaluated to take into account the effects of the elastic deformations on the loads distribution.

For these reasons, two load conditions are evaluated: the Manoeuvring at Limit Load Factor and the Continuous Turbulence both to Maximum Zero Fuel Weight (MZFW) [2]. At each new load variation (due to wing elasticity) the structural proprieties are updated.

In order to evaluate the external loads the aircraft is elastically trimmed at $n_z = 1$ and excited by the Von Karman PSD.

The dynamic loads, correlated at the maximum wing root bending, are added at the static trimmed condition.

During the dynamic analyses the stresses of some structural members are estimated using influence matrices that correlate the inner loads at the external ones.

The two successive diagrams show the distribution of the stiffness (bending and torsional) and internal stress (axial and shear) along the spanwise:

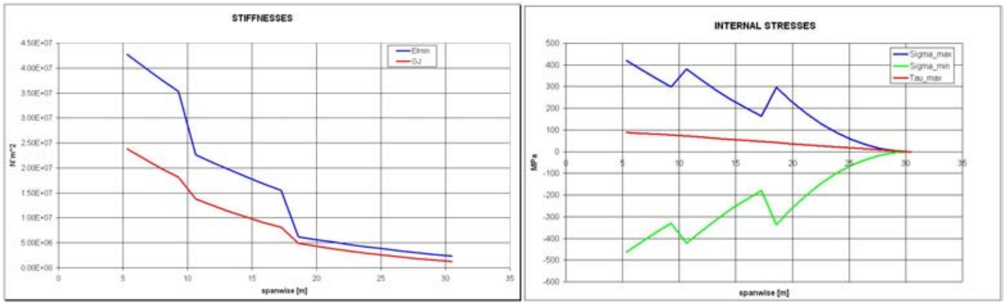

Figure 3 – Stiffness and stress distribution

Finally, the aeroelastic model and the results of the flutter analysis are shown:

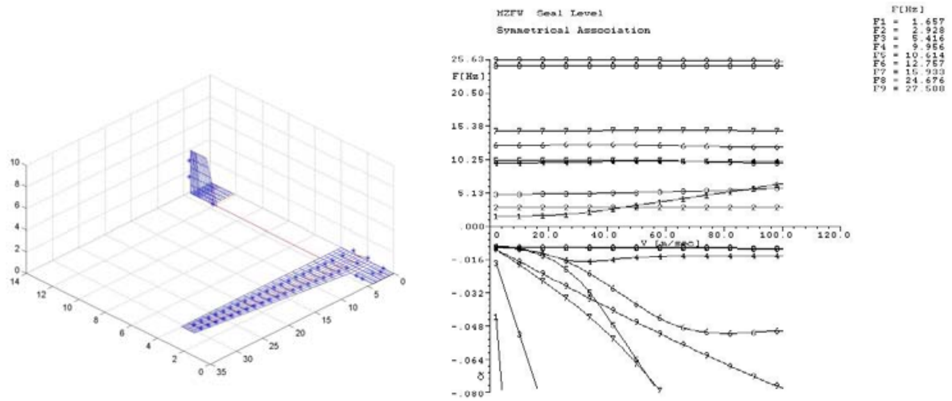

Figure 4 – Flutter analysis results

Conclusions

Using advanced composite materials and fabrication technologies can allow to design a wing with a low weight (less than 9 kg/m^2):

ITEM	**Weight (kg)**
Front spar	121
Rear Spar	94
Wing Box Skin	138
Trailing Edge	20
Leading Edge	93
TOTAL	**467**
ESTIMATED	**600**

Table 3 – Half wing weights

This structural weights makes hope well for the future developments of the aircraft, if compared with the weights obtained by similar UAV research programs [3,4,5]. The time spent from the definition of the mission requirements, aircraft configuration, aerodynamic and weight requirements up to the structural sizing, has been of three months.

Acknowledgments

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Reference

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