POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Executive Summary of the Thesis

Airframe design and optimisation of a H2-fuelled hybrid/electric 19-seat commuter

Laurea Magistrale in Aeronautical Engineering - Ingegneria Aeronautica

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1. Introduction

In recent years the necessity for the aerospace industry to go beyond near-zero emission flights requires the development of non-standard aircraft. One of this project, **Unifier19** by *Politecnico di Milano*, *Universidad Carlos III de Madrid*, *Pipistrel Vertical Solution* and *Technische Universiteit Delft* is being designed now. This thesis has the objective of providing a methodology to develop the preliminary structural sizing using mid-fidelity approach, GFEM analysis, to allow the capability of testing different airframe solutions.

Unifier19 is a project part of the EU founded *CleanSky2* policy characterized by an innovative configuration in terms of power source using fuel-cells running on liquid hydrogen and a non-standard aerodynamic configuration, presenting six *Distributed Electric Propellers* (DEP) in each wing and a main pushing propeller.

Figure 1: Unifier19.

2. Methodology

Given the innovative configuration of Unifier19, previous experience in structural design may not be applicable directly because the load and the stress may differ with respect to a standard aircraft, for this reason the necessity of developing a tool that enable the designer to test many different airframe solutions in a time saving way using mid-fidelity GFEM analysis. Structural design have been performed in different step with increasing fidelity, starting from an analytical beam model up to detailed GFEM analysis. In detail the design process reads:

1. *Input review:* a preliminary input review of data provided by Pipistrel is performed with the objective of fully understanding requirements, constraints and milestone that needed to be achieved during the project.

2. *Landing gear design:* one of the most important outcome from the input review is the necessity of defining a kinematics system for both nose and landing gear that impose strong constraint on the airframe design from the first project phase.
3. *Analytical beam model:* A first analytical beam model is created in MATLAB with the objective of testing all the load condition provided and find the sizing one for both wing and fuselage and to find the internal forces envelope that the structure have to withstand.
4. *Parametric GFEM development for wing and fuselage:* as function of the constraints highlighted in the input review, a fully autonomous script for the GFEM model creation is generated considering the inputs chosen by the user material selection, frames and string spacing and others.
5. *Static and buckling analysis for wing and fuselage:* other feature of the script developed is the application of a given load condition, boundary conditions and the execution of the analysis, producing as output the stress distributions in wing and fuselage.

3. Landing gear feasibility analysis

To fully understand the airframe constraints and allowable volumes, is necessary to define with a high level of fidelity the landing gear position both in extended and retracted position, because the retraction mechanism may interfere with other structural elements . The design of the landing gear is performed considering all the requirements that the landing gears must satisfy. Nose landing be fitted with a steering system that grant high maneuvering condition in runway operations. Main landing gear have the necessity to be fitted, in retracted position, in the fuselage without interference with the liquid hydrogen tank. The feature to achieve this goal is the development of a kinematic mechanism, driven by one degree of freedom, that couple the movement of the main leg with a rotation of the wheel, necessary to avoid interference with the hydrogen tank.
The landing gear analysis are performed from a kinematic point of view and do not consider the loads applied to the gears in taxing, take-off and landing operations.

4. Parametric GFEM script development

The tool developed in this thesis is composed by a series of scripts in `Python` and executed directly in *Abaqus CAE*. The script generated in different steps, the most relevant follows:

- *Input analysis:* the inputs are checked for any inconsistency
- *Geometrical partition, identification and material assignment:* accordingly with the constrains defined in both fuselage and wing structures, all the structural elements like frames, ribs and bulkheads are generated based on the inputs given by the user. Each element then is unequivocally identified and the material proprieties are assigned to each one.
- *Loads application and analysis:* the load are applied to the model for limit and ultimate condition and the analysis are executed providing as output the stress distribution to be analyzed by the user.

The main feature is that the parametrisation allow you not to change just the thickness but the entire internal architecture.

5. Wing structure

The first step of the wing analysis is the definition of the internal forces envelope in a beam model approach with the objective of identify the most critical condition and have a quantitative understanding of the forces that need to be transmitted by the airframe. In this step the reaction force are computed and used to be the sizing factor for the wing-fuselage connection.
For different types of standard alloy have been chosen for the wing structure design considering the material proprieties and the necessity of each wing component considering the load condition expected. By analyzing the wing shape and constraint, in particular driven by the DEP presence, the wing FEM model is generated and the sectional proprieties are assigned. The analysis are executed for static and ultimate load and the wing thicknesses are defined following an euristic approach in which the stresses are checked and the thicknesses are changed accordingly.

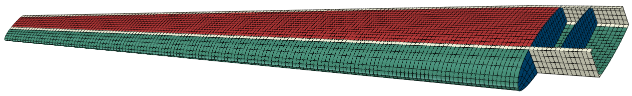

Figure 2: Wing structure

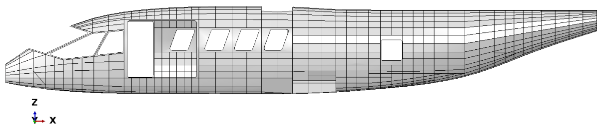

Figure 3: Fuselage architecture.

6. Fuselage structure

As done for the wing first step of the fuselage structure design is the definition of a beam model in order to find which are the most critical load conditions for fuselage bending moment and shear force and those are the condition that will be tested in GFEM analysis. For consistency with the wing design the materials used in the fuselage design are two types of standard alloy. The main aspect for the fuselage design is the definition of the constraints that the airframe has to fulfill, the most relevant are the cutouts, like doors, windows and landing gear bays, which fix the position of frames an stringers and the internal subsystem which need to be fixed using strong frames, these systems are liquid hydrogen tank, fuel cells, batteries and many others. Once the constraints are defined the parametric script is developed and the model is generated following a similar procedure made for the wing, the analysis are computed and an euristic approach is used for the overall sizing.

7. Wing-fuselage junction mechanism

One important parameter for the structural design is the definition, in the preliminary project phase, of critical systems like the wing and fuselage connection mechanism. This component have a huge impact on both wing and fuselage design because it impose the position of a strong element to carry the load.

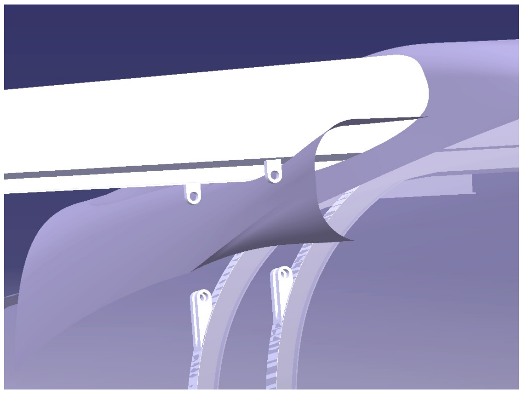

Figure 4: Wing fuselage connection lug concept.

The connection mechanism connects wing front and rear spars with two main fuselage frames though two lugs and pin junction. The sizing of this component is done first of all with an analytical methodology proposed in literature, then the concept is checked using finite elements modelling and edited in order to have a fail safe design.

8. Conclusions

The outcome of this research is to be intended at two levels: first of all a proven automated methodology is developed and tested to develop the preliminary airframe design for wing and fuselage. These scripts can be applicable to different planes having different configurations because rely only on the inputs defined by the user and the external aircraft loft. Main strength of this approach is the possibility of performing sensitivity analysis on the materials or the structural elements spacing highlighting and understanding what are the most important parameters for an efficient strucrtual design. Secondly, from an engineering point of view, a preliminary sizing for Unifier19 is provided considering static and buckle conditions. The structural result obtained in this work are based on an euristic optimization procedure, therefore the sizing produced is intended to be used as a baseline for a proper optimization procedure to be developed in the next project phases. Further development on the project will include the consideration of composite materials to furthermore optimize the overall structure and reduce the total weight.

References

[1] T. H. G. Megson. *Aircraft Structurs for engineering students*. Elsevier, 2007.

[2] M. C. Y. Niu. *Airframe Structural Design*. Conmilit Press LTD., 1988.

[3] M. C. Y. Niu. *Composite Airframe Structures*. Conmilit Press LTD., 1992.