Design strategy of the wing of the Next Generation Civil Tilt-Rotor Technology Demonstrator

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ABSTRACT
The T-WING project is a Clean Sky 2 research project aimed at designing, manufacturing, qualifying and flight testing the new wing of the Next-Generation Civil Tiltrotor Technology Demonstrator (NGCTR-TD. Requirements, design strategy, methodology and main steps followed to achieve the composite wing design are presented. The main driving requirements have been expressed in terms of structural, dynamic, aeroelastic and functional requirements and wing preliminary loads. Based on the above-mentioned requirements, the first design loop is performed by targeting an optimal wing structure able to withstand preliminary design loads, and simultaneously with stiffness and inertia distributions leading to a configuration free from flutter within the flight envelope. The outcome from the first design loop is then used to build a global FEM, to be used for a multi-objective optimization performed in ALTAIR OptiStruct environment.

1 INTRODUCTION
Horizon 2020 Clean Sky 2 FRC IADP NextGenCTR will be dedicated to the design, construction and flying of an innovative Civil Tiltrotor technology demonstrator [1-3]. NGCTR's demonstration activities, led by Leonardo Helicopters (LH), will aim to validate its architecture, technologies/systems and operational concepts, with significant improvement with respect to the current state-of-the-art tiltrotors. The NGCTR-TD is characterized by a different concept for the tilting mechanism with respect to the upcoming LH civil tiltrotor platform: a fixed engine installation with a split gearbox to provide the proprotor tilting mechanism, based on new capabilities in aerodynamic and structural analysis, design, and next-generation manufacturing and assembly principles. This will

also allow important operational cost reduction to address the competitiveness of the architecture and solutions adopted. T-WING consortium is working on the composite wing of the NGCTR-TD planned to be flying in 2023. The task undertaken by the consortium is aimed at designing, manufacturing, qualification and flight-testing of the wing and moveable surfaces of the NGCTR-TD, whose design is based on the requirements defined in cooperation with LH, the Work Area Leader. Once the wing will be manufactured and qualified, it will be assembled to all the other components of the NGCTR-TD. The last step of the development consists of a flight test campaign which will lead to the validation of the flight loads used for the preliminary design of the wing. Among the main technological advances of the NGCTR-TD with respect to current tilt rotors technologies, the following characterize the new vehicle: a new high efficient wing in helicopter mode by means of a rotating outboard flaperon and a large morphing surface that reduces the wing area beneath the rotors during hovering; a highly integrated composite wing structure; a compact structural wing box, since almost half of the wing chord-length is dedicated to the large moveable surfaces.

Figure 1 NGCTR

2 STATE OF ART

The tiltrotor represents the overcoming of the helicopter's limitations for a fast and reliable point to point connection or intercity flights and in order to improve public mobility and access to air transportation. Indeed, the tiltrotor combines the maximum cruising speed, range, endurance and payload of the airplane with the vertical lift capabilities of a helicopter. Although many tiltrotor concepts have been developed, few have actually flown, namely the NASA's XV-3 and XV-15, the Bell's military tiltrotors V22 and V280 and, finally, the AW609, currently subjected to certification process for use in the civil sphere.

3 REQUIREMENTS

Being the tilt-rotor able to operate as both a helicopter and an aircraft, the airworthiness specifications are both taken from CS-25 and CS-29 Airworthiness Requirements, and from brand-new requirements introduced specifically for tilt-rotors [4]. The wing box architecture and rib spacing of the NGCTR-TD comes out mainly from the fuel capacity requirement. The available internal space is maximized to host fuel bladders, hydraulics, electrical and avionics equipment, the control surface actuators and the driveshaft connecting the gearboxes of the tilting mechanism. Once the wing will be connected to the fuselage several flight mechanics requirements to be satisfied. Dynamic requirements concern the limitations on the natural frequencies of the wing to grant no coupling between wing modes and FCS/ rotors modes [5]. In addition, in the preliminary design of a tiltrotor with the lowest possible weight, the wing structural design, in terms of skin and wing box components thicknesses, has to cope with strength, buckling and stiffness requirements, the latter mainly dictated by fundamental aeroelastic requirements. Once preliminary sizing has been achieved, Finite Elements Models (FEM) and Digital Mock Up can be set up to verify compliance with all the remaining requirements, such as wing preliminary loads, accessibility, assembly & integration and to assess manufacturability.

4 DESIGN STRATEGY

Based on the above-mentioned requirements, the design strategy is composed of two main phases (Fig. 2). The first phase (top of Fig 2) consists in a multi-objective optimization (M-OO) [6], looped with aeroelastic analyses, mainly consisting of Matlab in-house codes (based on classical shear flow formulas in closed thin-walled sections and panel buckling formulas), that allow performing optimization runs in a very short time (compared with Finite Elements Analysis) with an acceptable degree of fidelity. The process aim is to find a set of feasible thickness and caps areas compliant with the strength and structural dynamics requirements, with the lowest possible mass:

- A first composite wing structure able to withstand preliminary design loads, and free from flutter within the flight envelope is obtained.
- The outcome from the previous step is then used to refine the model and compute more reliable flight loads and repeat aeroelastic analyses, returning further requirements to be fulfilled in terms of wing stiffness and inertia distributions.

The second phase (bottom of Fig 2) consists in the Finite Element modelling of the wing, to allow a multi-objective optimization within Altair OptiStruct environment. In particular the optimization is performed for the composite structures (skins and spars), in order to find the best solution - in terms of thickness - which minimizes the structural weight and is compliant with stiffness (flexural and torsional), strength & buckling requirements. The Finite Element model of the wing is made of mainly 2D and 1D Elements. The composites components subjected to the optimization are modelled with equivalent PSHELL. The optimization constraints are:

1. No buckling up to 80% of Limit Load on skin and spars;
2. Strength Margin of Safety > 0 at Ultimate Load on composite parts (max strain criterion);
3. Max allowed wing tip flexural displacements and torsion angle.

The algorithm is a gradient descent optimization. A total of no. 15 Loading conditions are considered: no. 12 load cases for strength and buckling plus no. 3 load cases for Flexural Out of Plane M_x, Torsional M_y and Flexural In Plane M_z.

The design variables of this optimization process are the thicknesses of the upper and lower skins and of the spars, all made of Carbon Fiber Reinforced Plastic. The outcome is a zonal optimization along the wingspan, as shown in figure 3. The optimized FEM will be used to compute new stiffness distributions and update structural aeroelastic stick beam model and repeat analyses. Moreover, this zonal optimization is the starting point of an engineered model and a detailed FEM, which will take into account also manufacturing constraints and it is beyond the scope of the present work.

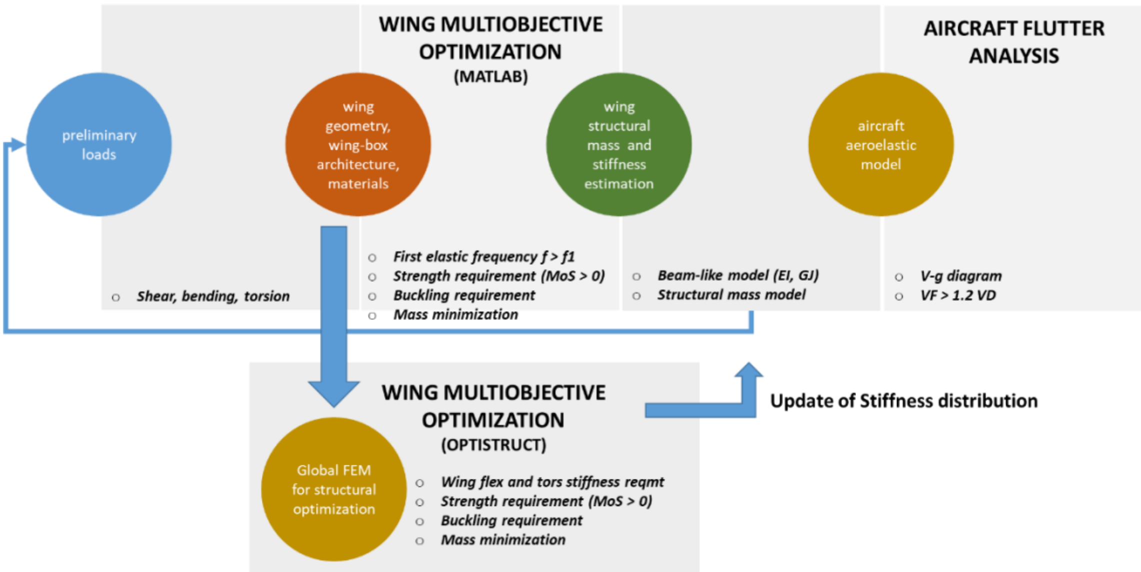

Figure 2. Design strategy flowchart

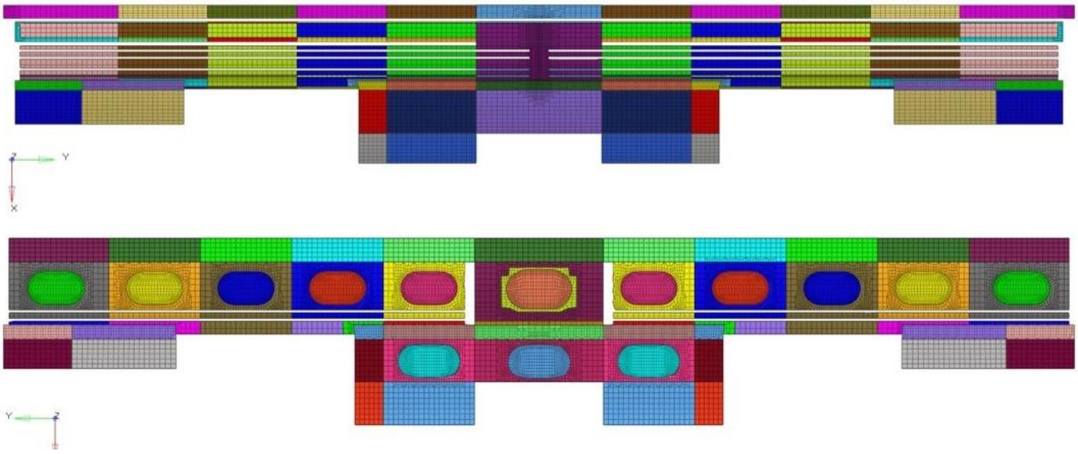

Figure 3. Design strategy flowchart

5 CONCLUDING REMARKS

In this paper the main steps followed to achieve the composite wing preliminary sizing of the NGCTR-TD tiltrotor have been presented. In particular the design strategy, aimed at finding a first optimal solution on terms of composite components thickness, is based on a two-level optimization: the first one performed with engineering models (not FEM), and the latter within OPTISTRUCT FEA environment.

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REFERENCES

[1] CLEAN SKY 2 Joint Undertaking Third Amended Bi-Annual Work Plan and Budget 2018-2019, Annex to decision CS-GB-2019-04-09 Decision Third Amended and Budget 2018-19.

[2] Smith, D. E.; Wilkerson, J.; Montoro, G. J.; Coy, J.; and Zuk, J.: Technology Development for Runway Independent Aircraft. Proceedings of the American Helicopter Society 59th Annual Forum, Phoenix, AZ

[3] Larry A. Young, William W. Chung; Alfonso Paris; Dan Salvano; Ray Young; Huina Gao; Ken Wright; David Miller; Victor Cheng: A Study of Civil Tiltrotor Aircraft in NextGen Airspace

[4] Johnson, W.; Yamauchi, G.K.; and Watts, M.E.: Design and Technology Requirements for Civil Heavy Lift Rotorcraft. American Helicopter Society Vertical Lift Aircraft Design Conference, San Francisco, CA.

[5] Jiri Cecrdle: Whirl Flutter of Turboprop Aircraft Structures. Cambridge, UK, Woodhead Publishing

[6] Deb, K.: Multi-objective optimization using evolutionary algorithms. John Wiley & Sons