PhD position offer

Aeroelastic modeling of a high aspect ratio composite wing optimised for the solar HALE UAV concept

The purpose of this thesis is to develop a non-linear aeroelastic model dedicated to the predesign phases of a very high aspect ratio and flexible wing designed with composite materials, using a coupled numerical and experimental methodology. The approach is multidisciplinary and aims at optimizing aerodynamic and structural performances, more specifically for the fixed wings of solar HALE (High Altitude Long Endurance) UAV concept.

Establishment:
French Air Force Academy Research Center (https://crea.ecole-air-espace.fr/)
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Gross salary/month: (co-funding from French Air Force Academy and French government defence agency DGA-AID[1])
Start date: October 2021
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Context and objectives

HALE fixed-wing solar UAVs, such as NASA's Helios prototype (Figure 1), are among the innovative concepts for applications in the field of observation and telecommunications [1,2]. The design of such a solar UAV remains a major challenge for aircraft designers. Because such drones require a very good aerodynamic efficiency and a large surface area for solar panels to be fitted, most of the designs feature really large span wings, which are necessarily very flexible, sensitive to external loads and subject to large displacements. Despite the use of carbon/epoxy composite materials to minimize the weight and maximize the resistance of the wing, these wings are particularly vulnerable to fluid/structure interactions such as torsional divergence and flutter. The aeroelastic performance of this type of wing remains a scientific and technological challenge on which research efforts must be carried out to improve its modelling and simulation [3]. Therefore, it is necessary to determine the dynamic characteristics of these highly flexible structures taking into account their non-linear behaviour (large rotations and displacements), coupling with aircraft flight dynamics. Loads that result mainly from in-flight manoeuvres and gusts or turbulence in the air also remain complex to assess and model. But this is essential to identify those that are critical for the design of the structure.

[1] https://www.defense.gouv.fr/aid/appels-a-projets/appel-a-projets-theses-aid-classiques

HP01 High-Altitude Configuration August 2001 HP03-2 on Takeoff June 2003

Figure 1 : **Helios Prototype Aircraft – NASA**

Research activities at CREA on solar HALE UAVs started with work on multidisciplinary optimization based on low and medium fidelity models. Recently, Bertrand Kirsch's PhD thesis [4] has led to the development of a computational code for the simulation of an anisotropic composite flexible wing (called GEBTAero [5]), allowing to determine the critical speeds of instabilities (divergence and/or flutter), but also to highlight aeroelastic instabilities in wind tunnels on anisotropic composite plates. The model developed is a solution based on the geometrically exact beam theory coupled with a two-dimensional unsteady finite state aerodynamic model implemented into an open-source solver. To date, the model does not take into account non-linear aerodynamics, such as airfoil stall during the oscillations of the wing resulting in the limit cycles clearly observed in wind tunnel tests. Moreover, in 2003, the analysis of the NASA Helios UAV accident [6] showed that the aeroelastic modes on this type of UAV had to be simulated taking into account the UAV's motions and gust effects. The objective of the thesis is thus to extend the capacities of the model with the addition of flight dynamics and a non-linear aerodynamic model, in a tightly coupled manner. This kind of full aeroelastic model, being able to simulate the response of the structure to a gust for example, is required for pre-design phases of such wings.

Work program

The thesis program is based on the modeling tool developed in [4,5]. The code is based on a strong coupling of an anisotropic beam theory, in large displacement and large rotation, to a two-dimensional analytical unsteady aerodynamic model. It has multiple features ranging from static modal analysis of a wing represented by beam elements to simulation of time dependent behaviour, as well as prediction of flutter and divergence speeds.

First, the flight dynamics of the UAV will be modeled in order to take into account the coupling of the rigid modes of the aircraft with the aeroelastic modes of the wing. Then, a non-linear aerodynamic model will be implemented to improve the existing aerodynamic modeling in order to simulate the flight of a real HALE UAV subjected to a gust for example. The effects of non-linearities coming from aerodynamics or structures will be studied in order to simulate and analyse limit cycles and thus improve the prediction of the aeroelastic behaviour of the composite plates already tested in the wind tunnel [4]. Non-intrusive experimental techniques will be developed by using high speed cameras and video processing for tracking techniques ensuring the 3D metrology of the wing kinematics for both very small vibrations and large deflections. The experimental approach[2] will constitute an originality of the thesis and the results obtained, as validation test cases, will also be of proven interest to scientists in the field.

Lastly, new modeling features will be developed to contain the computational cost while being modular and to facilitate its implementation within a multidisciplinary optimization platform, such as openMDAO. The final objective is the implementation of new means for validating the complete aeroelastic modeling, and its application to produce optimal single-wing solutions using aeroelastic tailoring for example as initiated in [4,5,7].

2 This part of the work will be done in collaboration with QUARTZ – ISAE-SUPMECA laboratory. https://www.isae-supmeca.fr/recherche/vibroacoustique-et-structure/

Profile requirements: Candidates must hold a Master 2 research and/or an engineering degree in structural mechanics and/or fluid mechanics. The candidate must have a pronounced taste for interdisciplinary approaches, computer programming and for the development of numerical simulation tools with open source approaches. Knowledge in aerodynamics and/or flight mechanics will be appreciated.

References

1. CESTINO Enrico, Design of solar high altitude long endurance aircraft for multi payload & operations. *Aerospace science and technology*, 2006, vol. 10, no 6, p. 541-550.
2. MONTAGNIER, Olivier, Drones solaires : la quête du vol perpétuel, dans Les drones aériens : passé, présent et avenir. Approche globale, sous la direction de S. Mazoyer, J. de Lespinois, E. Goffi, G. Boutherin, C. Pajon, Paris, *La Documentation française*, pp. 491-501, 2013. ISBN : 978-2-11-009376-9
3. CESNIK, Carlos ES, SENATORE, Patrick J., SU, Weihua, *et al.* X-HALE: A very flexible unmanned aerial vehicle for nonlinear aeroelastic tests. *AIAA journal*, 2012, vol. 50, no 12, p. 2820-2833.
4. KIRSCH Bertrand, Apport de l'anisotropie des matériaux composites aux performances aéroélastiques des ailes à grand allongement de drones HALE, Thèse de l'Université d'Aix Marseille, 2019.
5. KIRSCH Bertrand, MONTAGNIER Olivier, BÉNARD Emmanuel, FAURE Thierry, Tightly coupled aeroelastic model implementation dedicated to fast aeroelastic tailoring optimization of high aspect ratio composite wing, *Journal of Fluids and Structures*, in press, 2020.
6. NOLL, Thomas E., BROWN John M., PEREZ-DAVIS Marla E., ISHMAEL Stephen D., TIFFANY Geary C. & GAIER Matthew, Investigation of the Helios Prototype Aircraft Mishap - Volume I, NASA, 2004.
7. KIRSCH Bertrand, MONTAGNIER Olivier, BÉNARD Emmanuel, FAURE Thierry, Numerical and experimental study of aeroelastic tailoring effect using flexible composite laminates for HAPS application, in International Forum on Aeroelasticity and Structural Dynamics (IFASD), Savannah, June 10, 2019.