Hinged wingtip modelling in NeoCASS based on Airbus AlbatrossONE

PIR – Project innovation et recherche
Bibliography report

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***Abstract*—This paper deals with the modelling of a new aircraft wing-design with NeoCASS software. Inspired by nature, Airbus has developed a remote-controlled demonstrator called AlbatrossONE, which is characterized by hinged wing tips. The advantage is reducing drag, stress and, at the same time, handling turbulence and gust effect in a more comfortable way. After an introduction on AlbatrossONE project, on the concept of ”semi aeroelastic hinge” (SAH) and on the main feature of NeoCASS software, the paper will report the analysis conducted via NeoCASS on a modelled aircraft equipped with folding wing tips. The main results will be analysed and compared with respect to the traditional wing configuration.**

I. Context

Folding wing tips are not a new design concept in aviation. In the past few years combat aircraft have been design in order to take up little space in the aircraft carriers for example. However, nowadays this design feature is getting more and more interesting due to other applications. The latest version Boeing 777 already includes this option in order to limit the space occupied on ground, in airports. The challenge now is to exploit this design to improve performance and to attain load alleviation, which can be translated or in lighter wings or in larger aspect ratio, in this case reducing the induced aerodynamic drag. As questioned in [1], this device allows the wingtip to rotate and such a mechanism can be even exploited during flights in order to improve performance. However, free wingtips aren't flawless: as highlighted in [2] zero stiffness hinges can lead to undesired effect during cruise for example. During leveled flight, aerodynamic performance can be worsened by constant deflection of the wingtip due to static loads or by oscillating phenomenona due to dynamics loads. Here comes the idea of a semi aeroelastic behaviour for this device, implemented with a kind of brake which frees the wingtip in case of need. As the research [1] stated, load alleviation can be attained by letting the wing tip fold and adjusting both the hinge orientation (described by a *flare angle* Λ) and the spring properties (e.g. stiffness). In fact a non-zero hinge angle introduces a local decrease in the angle of attack as the following formula explains:

$$\alpha_{wt} = -atan(tan\theta sin\Lambda) \tag{1}$$

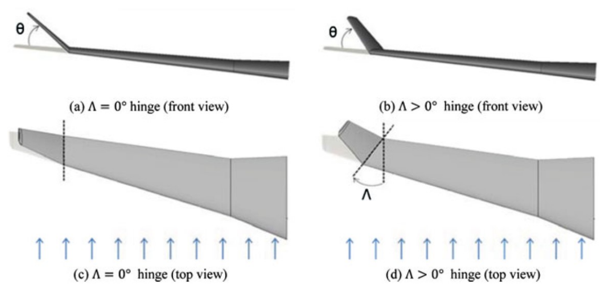

Fig. 1. hinge line folding wingtip [1]

A series of experiments about numerical modelling have been performed by [1] in order to find an optimum configuration both varying the flare angle ($0° \div 25°$), the weight (100kg or 943kg) and the torsional stiffness of the device, starting from a fixed one up to an almost free one. The model was build such that the wingspan was increased by 25% thanks to the folding device. The main presented results were the following:

- a reduction of 30% in the wing-root loads was obtained in the case of a low stiffness 25° hinge with respect to the fixed one;
- the loads were only 4.36% higher than in the baseline model without folding wing tips;
- flutter analysis showed how a low mass for the device in the case of 25° hinge was beneficial for all stiffness, while for the 0° hinge model flutter speed was vary high for all the values of mass and stiffness;
- the gust response proved load reductions for high swept hinge angles, low wingtip mass and stiffness.

Furthermore, in the simulation of a semi aeroelastic wingtip [2] it was proved that the system response to a discrete gust was positive: the behaviour was statically stable with a max fold angle of 25° and dynamically stable thanks to an aerodynamic damping contribution from the flapping motion. As the bending moment across the hinge drops to zero, bending moments at the wing-root were decreased.
The same research [2] simulated studies on an aircraft loosely based on A320 family, extending the span from 36m to 45m

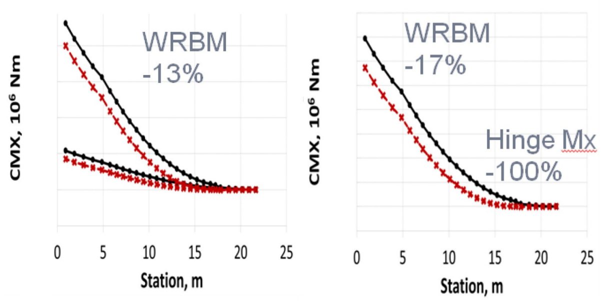

Fig. 2. Wing-root bending moment for up/down gust (right) and 2.5g maneuver (left), red for free hinge and black for fixed hinge [2]

with the aim of studying loads and flutter both for a fixed and a free hinged wingtip. Again, as shown in figure (2), the results were in favour of the free hinge, in the gust case wing-root bending moment was reduced by 13% while in a 2.5g maneuver by 17%. However flutter speed showed to be higher with the fixed hinge, as already had been found by [1]. In a second model a heavier (2.5 times) wingtip was considered, again the free wingtip was characterized by a strong flutter coupling due to the the flapping mode coupling with the first wing bending mode. This is a dangerous risk that can be avoided by adding mass to the wing tip and by tuning the flare angle to 15° (instead of 25°). hence it was proved that free hinge could induce flutter, but that it could be stabilised by careful shrewdness.

Later studies [3] dealt with aeroelastic flight dynamics coupling due to the installation of a semi aeroelastic hinge and proved that the baseline model had the same handling qualities and dynamics response as the free-hinge one.

Further simulations [4], [5] tried to find a solution to the oscillating deflections of the wingtip which spoils cruise aerodynamic performance. The concept of a non linear hinge spring was introduced in order to enable the folding mechanism when aerodynamics loads were greater than a threshold value. In this simulation a 100Kg wingtip model with a 25° hinge and a spring stiffness of 1Nm/rad were considered. When the loads generated a wing moment grater than a defined value M_{max} the wingtip was allowed to fold, such an idea was realised by applying on the hinge restoring moments ($M_{NL} = -K_\theta \theta$) through a piecewise linear spring whose stiffness varied as follows:

$$\begin{cases} K_\theta = 1.E12 Nm/rad \ if \ K_\theta \theta \leq M_{max} \\ K_\theta = 1.E0 Nm/rad \ if \ K_\theta \theta > M_{max} \end{cases} \tag{2}$$

Even a hinge moment provided by a linear damping element was considered:

$$M_{damp} = -D_\theta \dot{\theta} \tag{3}$$

The gust response was analysed at 25.000ft at M=0.6, different gust length and speed were considered along with different values for hinge damping factor and threshold value. The results highlighted that a good load alleviation was obtained when both the threshold and damping values were low, as the wingtip was allowed to fold soon and quickly. Higher values showed a delayed and less effective response, due the less time available to counteract the perturbation. Even the damping factor proved itself to be positive, it reduced the inertial loads of the wingtip, but a good compromise was sought in order not to decrease the load relief ability (related to a fast response). The investigation on gust response was analysed again in [5] where the wingtip was released as an increment of 1° in the angle of attack was detected.

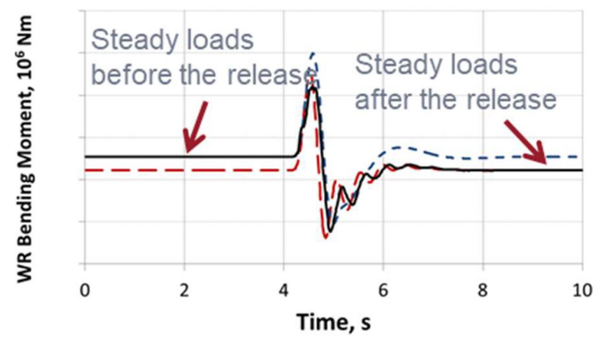

Fig. 3. Wing root bending moment for release and gust excitation (red = free hinge, blue = fixed hinge, black = SAH) [5]

The semi aeroelastic wingtip was the most effective compared to the fixed and a free ones, reducing gust peak and 1g loads, as shown in figure (3).

Related work to load alleviation was presented by [6] and [7]. In this case main attention was concentrated on the concept of an active wingtip extension, hence giving a new insight into this topic. The device was designed such to have a trailing edge control surface, with an extension set by running an optimisation problem. Even if this simulation gave a different nuance to the problems submitted before, the results were again satisfying, the active control on the surface proved to lead loads reduction both in gust and maneuver cases. Besides much theoretical work, even a concrete application of it must be taken into consideration.

Presented in June 2019, the Airbus AlbatrossONE [8] embodies the innovative idea of the semi aeroelastic hinge wingtip. This small scale remote-controlled aircraft is based on the A321 and has already been tested in flight in Filton (UK) both in the fixed and free hinge configuration. The demonstrator is not dynamically scaled, the purpose of the project is just to provide a qualitative but concrete application of the SAH device in order to test previous theoretical work [1], [2], [4], [5]. Besides, another objective of the demonstrator is proving that the wing aspect ratio of an Airbus-like aircraft can be approximately doubled without any worsening on loads and handling qualities. Different wingspan for the demonstrator have been conceived:

- A 2.6m wing span with no wing tips, equivalent to a 35m wing span;
- A 3.2m wing span equivalent to a 45m wing span, one with fixed wing tips, and one with the wing tips free to

rotate about their hinges;
- A 3.7m wing span equivalent to a 52m wing span, one with fixed wing tips, and one with the wing tips free to rotate about their hinges.

The main technical characteristics of AlbatrossONE, as reported by [9], are the wings made in carbon fibre reinforced plastic, the fuselage in fiber glass supported by plywood frames, electric fan motors and a cruise speed of 25m/s. Again, the demonstrator doesn't reproduce a real aircraft behavior, but it has been considered representative in a qualitative sense. Flight test results were satisfactory, the wingtips were stable, the pilots had no problem in handling the aircraft with free wingtips and bending moments measured in different parts on the wingspan showed a decreasing trend for free hinge case [9], thus providing load alleviation.

II. Problem statement

The purpose of this paper is presenting a model inspired by the AlbatrossONE and to reproduce qualitatively its performance via NeoCASS (Next generation Conceptual Aero Structural Sizing) a suite of Matlab modules that merges state of the art computational, analytical and semi-empirical methods to deal with all the aspects of the aero-structural analysis of a design layout at conceptual design stage [10]. As presented in [11]–[13] NeoCASS is made up of different modules:

- WB (weight and balance), which estimates masses and their location;
- GUESS (Generic Unknowns Estimator in Structural Sizing), which gives an analytical sizing of the airframe, generates both a structural stick model (by means of semi-monocoque method) and a FE mesh;
- SMARTCAD (Simplified Models for Aeroelasticity in Conceptual Aircraft Design), which solves different aero-structural problems (trimmed solution, modal analysis, flutter computation, steady and unsteady aerodynamic analysis and static aeroelastic analysis), exploiting both a beam model and Vortex/Doublet Lattice Method.
- MDO, which ameliorates initial sizing and meets aeroelastic constraints

The geometrical representation of the aircraft is stored in a .xml file and the geometry database is developed in an ad-hoc module called ACbuilder, a graphic environment where the user can interact with the model.Aware of the potential of NeoCASS, it is possible to imagine how to model a folding wingtip in order to analyse the advantages of such a configuration and to reproduce the results reported by AlbatrossONE.

III. Future work

Next steps will be addressed to modelling an Airbus A321 into NeoCASS, adding the wingtip device, running the simulation and at the end comparing the results, in terms of loads and performances, of the aircraft configurations. Since NeoCASS mass estimation methods implemented in Weight and Balance module are tuned for typical transport aircraft, the work won't deal to reproduce the scaled demonstrator AlbatrossONE and it will look for qualitatively satisfying results. It is thus expected that the hinge wingtip configuration lead to load alleviation, as previous work presented in this brief bibliography report.

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