STATIC LOADS EVALUATION IN A FLEXIBLE AIRCRAFT USING HIGH FIDELITY FLUID-STRUCTURE ITERATION TOOL (E2-FSI)

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Abstract

This article presents a Fluid Structure Iteration method applied as a study case to a recent conventional transport aircraft with aspect ratio of 12. It evaluates the nonlinear structure effect on the static limit loads calculation. It uses the tool called E2-FSI, which stands for Nonlinear High-fidelity Static Fluid-structure Iteration, developed for high flexibility static aeroelastic evaluations. It uses Reynolds Average Navier Stokes Computational Fluid Dynamics combined with detailed Finite Elements Method in linear and nonlinear structural analyses. A discussion about the use and applicability of high fidelity static Fluid Structure Iteration for static loads calculation is presented as part of the conclusion, for both current and future conventional transport aircrafts.

1 Introduction

There is a considerable improvement in Fluid-structure Iteration (FSI) know-how applied to aeronautics using high fidelity computational tools. Different strategies and software combinations have been compared to test [2][3][5][7][13]. The overcame challenge was related to integrate or to couple structure and aerodynamic analyses.

Before coming to unsteady aeroelasticity and transient analysis using FSI, there are important challenges in static aeroelastic analyses. Next advances and novelties using static FSI are related to application and feature enabling for more realistic representation of flight.

In Static Loads technology there is a never-ending demand for loads reduction. New loads analysis methods for future aircrafts are also expected and under investigation [4][8]. One way to understand the necessary improvements in static loads analysis methods is to understand where the recent conventional aircrafts are in terms of flexibility and high flexibility effects.

This article presents a FSI method applied as a study case to a recent conventional transport aircraft with aspect ratio of 12. It evaluates the nonlinear structure effect on the static limit loads calculation.

More specifically, this study shows the limit static loads evaluation using static Fluid-structure Iteration with high fidelity tools in both aerodynamics and structures. Static pull-up maneuvers from 0.5g ($g=9.8m/s^2$) to 2.8g are presented for a selected Mach and Altitude condition.

2 E2-FSI

The called E2-FSI stands for Nonlinear High-fidelity Static Fluid-structure Iteration, it was developed for high flexibility static aeroelastic evaluations at Embraer [6].

E2-FSI manages the iterations between software CFD++ [9] and Nastran® [10], translating aerodynamic pressure coefficient to structural loads and transforming structural deflections into mesh update for computational aerodynamics. See Fig. 1. The CFD++ mesh is updated using morphing process without meshing again the geometry and far field.

It iterates until flight shape is converged. In this study case, convergence is obtained when there is less than 1.0% change in the deflections and rotations between iterations. For instance, when the wing reaches 3m (meters) deflection, 30mm (millimeters) difference between iteration was considered converged.

The E2-FSI tool is composed by Fortran and Shell Script routines. Fortran is used for calculations and Shell Script is used for sequencing the process, it is an evolution of previous multidisciplinary process created with a low fidelity aerodynamic solver [15].

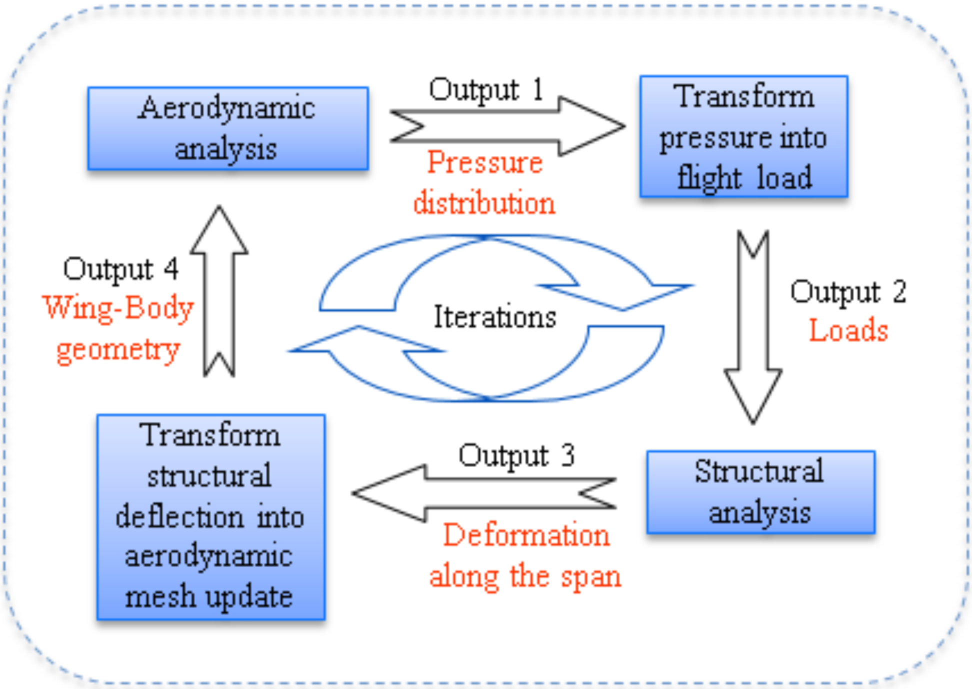

Fig. 1 – E2-FSI scheme.

3 Aircraft

Similar model of recent conventional transport aircraft was used as a study case for this investigation, see Fig. 2. The aircraft model has wing aspect ratio of 12 and dimensions of a regional transport aircraft.

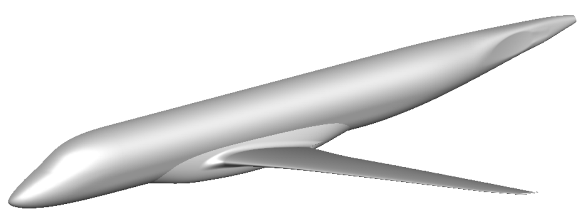

Fig. 2 – Wing-body conventional transport aircraft model.

4 CFD++

Wing-Body geometry was used for the computational fluid dynamics analysis on CFD++ [9]. The aerodynamic mesh is presented in Fig. 3 where the fuselage, wing and field symmetry plane meshes are presented. The wing surface mesh is deformable. It uses Reynolds Average Navier Stokes Computational Fluid Dynamics (RANS - CFD).

The Spalart - Allmaras turbulence models [14] was used, with curvature correction and quadratic constitutive relation. Solve to wall formulation was used.

The pressure distribution is post-processed to transform it into follower structural loads, which take into account the wing deformed shape.

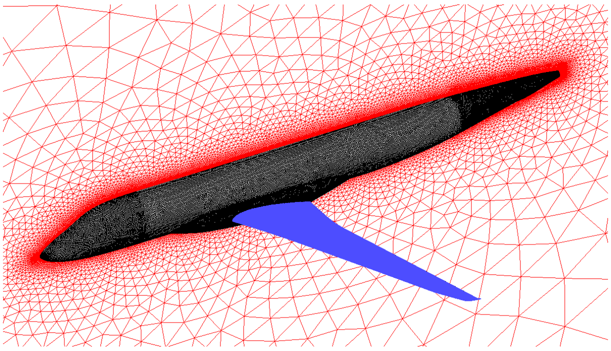

Fig. 3 - Wing-Body geometry mesh in CFD++.

5 Nastran®

A half-wing Finite Elements Method (FEM) model clamped at the root was used, see Fig. 4. The FEM model uses plates (for skin, spars and ribs) and bars (for stringers) to represent the structure in details. The inertial loads were not considered for this study in order to quantify only the aerodynamic effect. The solver Nastran® was used [12][11]. When the FSI uses static linear structural analysis, it is called E2-FSI Standard. In case FSI uses static geometric nonlinear analysis [1], it is called E2-FSI Featured.

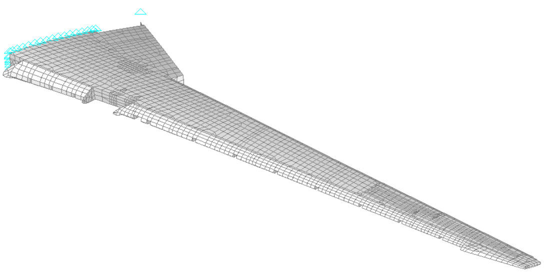

Fig. 4 – Wing clamped at the root.

6 Results

Mach 0.70 for 6 different load factors (NZ) are presented in Fig. 5 as a result of E2-FSI Standard. The airfoil in the tip of the wing was plotted for every iteration. The process was initially set to reach 0.5g flight and after 9 iterations it converged.

Then, the NZ was shifted to reach 1.0g flight, starting from the previous converged iteration. The same update of NZ and convergence were made for 1.5g, 2.0g, 2.5g and 2.8g. The selected RANS - CFD permitted the necessary high lift load factor simulations. In this case the overall process capability for forced fast convergence was not enabled then iterations needed were 9 in the beginning and 4 for the last load factor.

E2-FSI Featured was evaluated at 2.5g condition in order to have the effect of geometric nonlinear structure analysis in the sizing pull-up maneuver. The converged deflection and rotation results comparison is plotted along the span in Fig. 6a and Fig. 6b. The nonlinear structure interacting with nonlinear aerodynamics converged to a less deformed geometry. E2-FSI Featured converged to an 8% less deflected and a 16% less rotated wing tip.

The smaller rotation for the nonlinear structure induces a more loaded wing in the outboard portion. The converged difference of 16% in airfoil rotation was considered significant, because it overcomes the effect of different aircraft design weights; existing loads process is more accurate; manufacturing process variability is lower and this difference is measurable in flight.

Fig. 7a and 7b present the Pressure Coefficient (Cp) along the wing chord for two positions along semi-span: 15.6% and 88.5%. Comparing E2-FSI Featured and Standard at 2.5g, there was a small difference in Cp for the inboard section and there was a bigger difference in the outboard section.

The E2-FSI Featured resulted in a less deformed geometry, then its Cp is higher in the outboard portion of the wing, this was how the lift is shifted outboard. There was an inboard portion of the wing with a small decrease on the Cp, but it has a much higher area (bigger chord) than the outboard portion, this was how the total lift is compensated. The E2-FSI Featured trimmed in a smaller angle of attack (0.08 degrees difference), this is why there is a lower Cp at root where there is almost no geometry change between Featured and Standard.

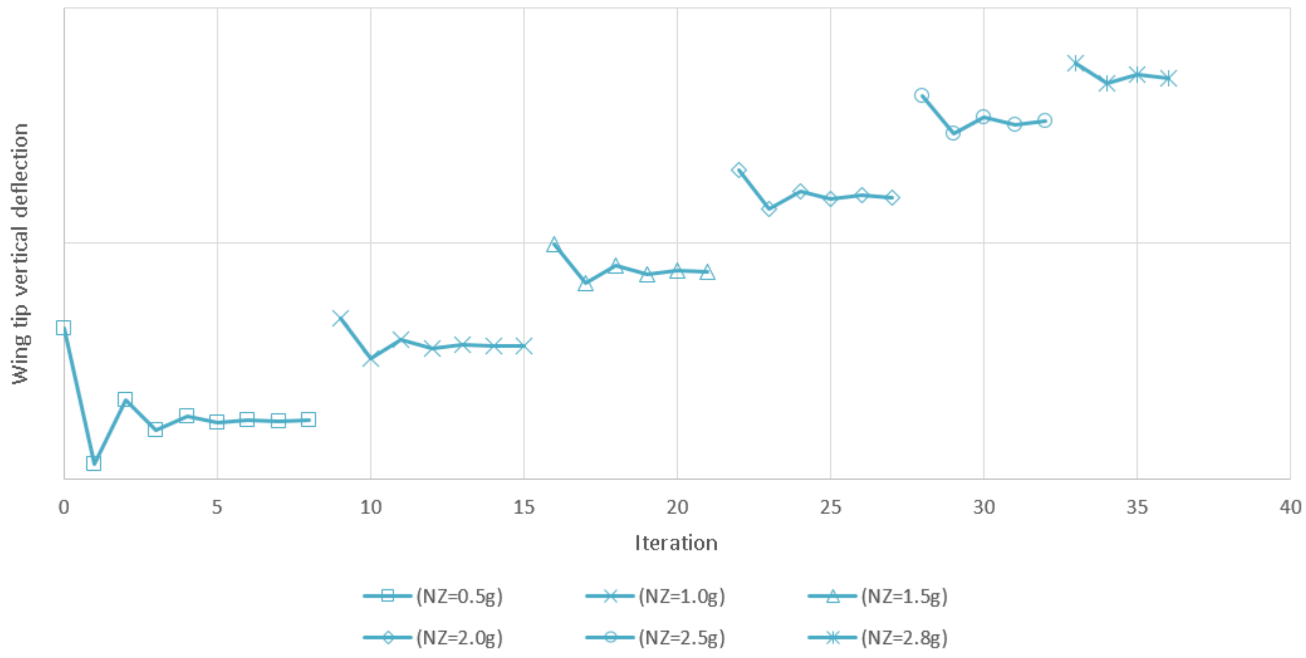

Fig. 5 – E2-FSI Standard simulation results along the iterations.

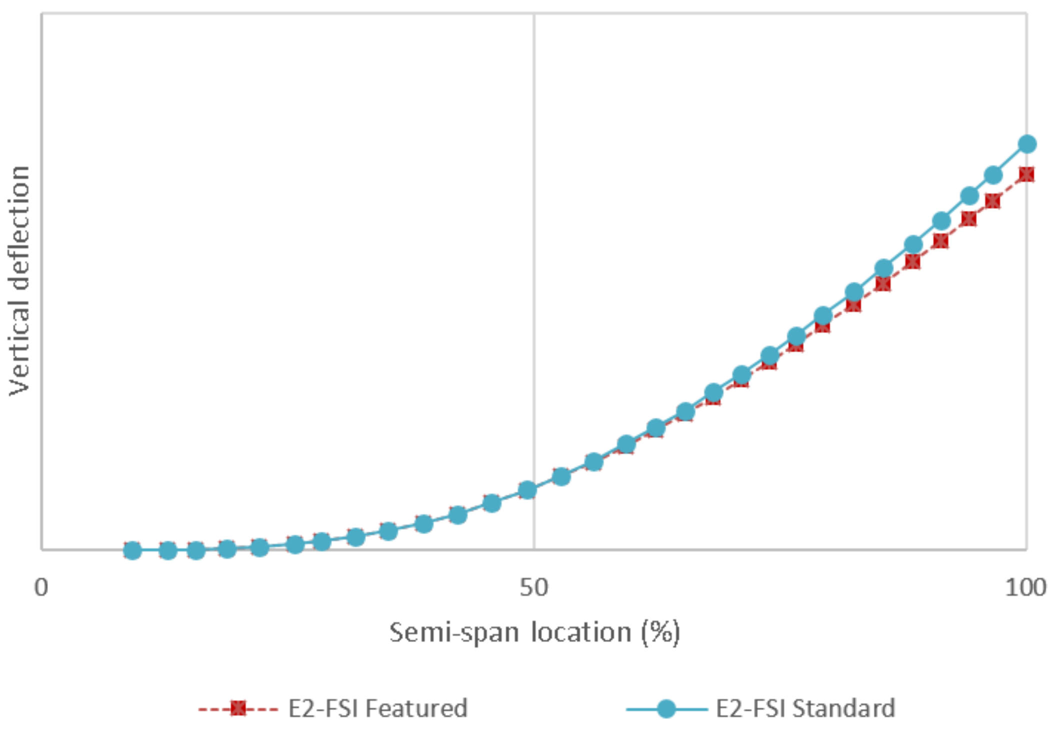

Fig. 6a – Effect of the geometrical nonlinear structure on the FSI converged geometry result. Deflection along semi-span.

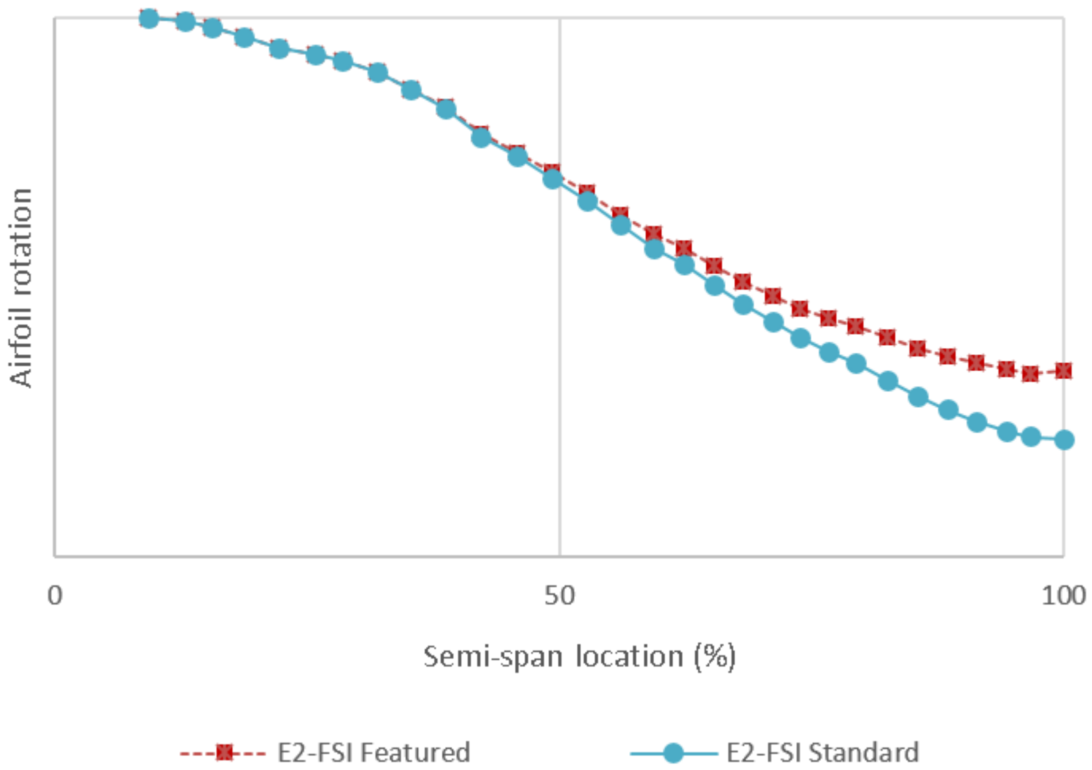

Fig. 6b – Effect of the geometrical nonlinear structure on the FSI converged geometry result. Rotation along the semi-span.

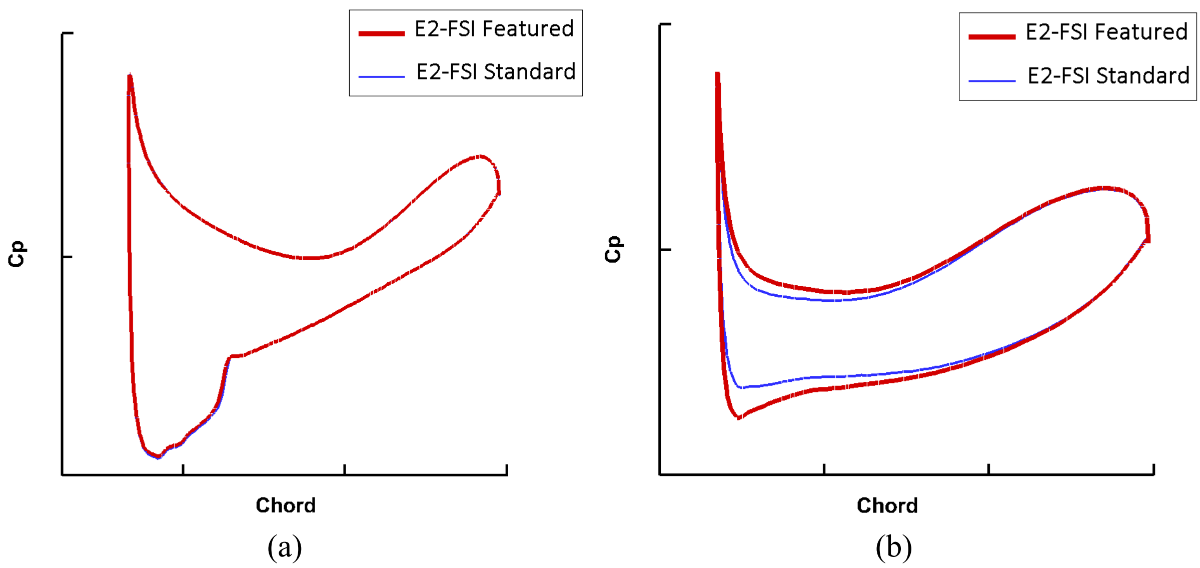

Fig. 7 – Pressure coefficient comparison at 2.5g static pull-up maneuver. a) 15.6% span location. b) 88.5% span location.

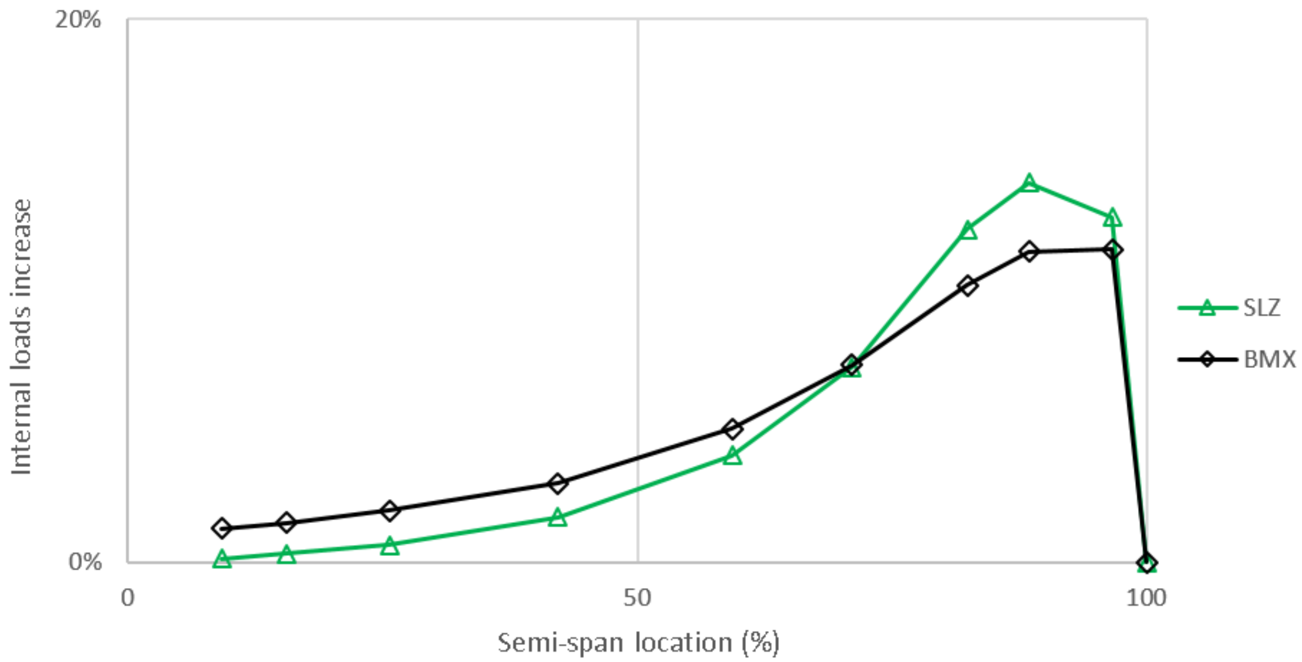

Fig. 8 – Internal loads increase for geometrical nonlinear structure analysis on FSI.

Then, the internal loads along the wing structure span were investigated for 2.5g load factor. Bending Moment (BMX) and the Shear Load (SLZ) were integrated at reference points along the span in order to quantify the internal loads difference between those two results at 2.5g. Fig. 8 presents the percentage of increase in the internal loads along the semi-span for the nonlinear structural analysis when compared to the linear structural analysis, both converged in the FSI. The SLZ difference at root (9% of the semi-span) was 0.1% indicating equivalent wing total lift for Standard and Featured runs. Although, the BMX at the root was 1.2% higher for the Featured, because of the more loaded outboard portion of the wing generating more moment. From 60% to 100% semi-span location there was a considerable percent increase in the internal loads: the bigger difference was 14% for SLZ and 11.5% for the BMX.

This scenario of different internal loads distribution for the Featured FSI, which is expected to better represent the flight, indicates a different stain distribution in the wing so that structure safety margins are effected.

3 Conclusions

The tool E2-FSI was presented as means of structure high flexibility effect study on limit load factor static maneuvers. The E2-FSI enabled the geometrical and follower force nonlinearities integrated in the aerodynamics and structure iteration cycle. The overall multidisciplinary iterative analyses were high fidelity and nonlinear.

There was a difference in converged wing geometries during a pull-up static maneuver of 2.5g load factor when linear and nonlinear structural analyses were compared. The converged geometry difference (16% on the tip) induced a different pressure coefficient distribution on the wing. The lift was shifted to the wing tip direction. Then, the internal shear loads were the same in the root but higher in the outboard portion (14%). The bending moment was a little higher in the root (1.2%) but in the outboard portion there was a significant increase (11.5%).

The effect of highly flexible wing structure was quantified for a conventional recent regional transport aircraft with aspect ratio of 12. The load was presented higher when nonlinear structural analysis is used. Then, consistent loads and stress analyses are demanded for existing high aspect ratio aircrafts with normal flexibility. There is an expected reduction is stress due to nonlinear structural analysis but this paper shows an expected increase in the loads due to the same structural nonlinearity. This is why the use of conventional process (linear structure) for loads evaluation and nonlinear structural stress analysis will result in false perception of safe margin.

The geometric nonlinear structure is already changing the loads on current conventional aircrafts. As the span and flexibility increases, for future aircrafts, the effect on loads will become more important. High fidelity FSI may play a big role on aeronautical industry mid-term future loads process, not exactly by replacing it but generating specific effects information in order to improve and feed the existing processes.

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