

# ASSESSMENT OF UNSTEADY CFD FOR FLUTTER ANALYSIS OF TWIN-ENGINE COMMERCIAL AIRPLANES

*Alexandre Scalabrin\*, Devesh Kumar, Sascha Ruegamer, Eduardo Rodrigues*

*Boeing Commercial Airplanes,  
4000 Lakewood Blvd, 90808-1700, Long Beach, CA  
United States of America*

## ABSTRACT

### Motivation and Main Objectives

High-order unsteady computational fluid dynamics (CFD) methods have advanced significantly, and their application to flutter assessments in industrial settings is becoming more feasible. While unsteady CFD remains computationally expensive, it offers higher fidelity for flow phenomena that is not captured in traditional panel methods based on linearized potential theory, such as the Doublet Lattice Method (DLM). Accurate simulation of these flow conditions is increasingly relevant in the pursuit of more efficient airplanes. With lighter, more flexible and unconventional layouts, aeroelastic assessments are performed earlier in the design, before experimental data is available.

Traditional flutter practice relies on reduced order, frequency domain methods based on modal representation, in large part because they are computationally efficient. The panel methods used within this framework are often enhanced with adjustments from empirical or higher fidelity data. The linearized frequency-domain methods based on URANS CFD solution offer additional fidelity and physics representation while maintaining the modal approach and frequency domain convenience.

In this paper, NASA's FUN3D LFD (linearized frequency-domain) code is applied to a practical industrial case: a generic twin-engine airplane configuration representative of modern flexible transport aircraft. Results from FUN3D-LFD are compared to standard practices using DLM aerodynamics.

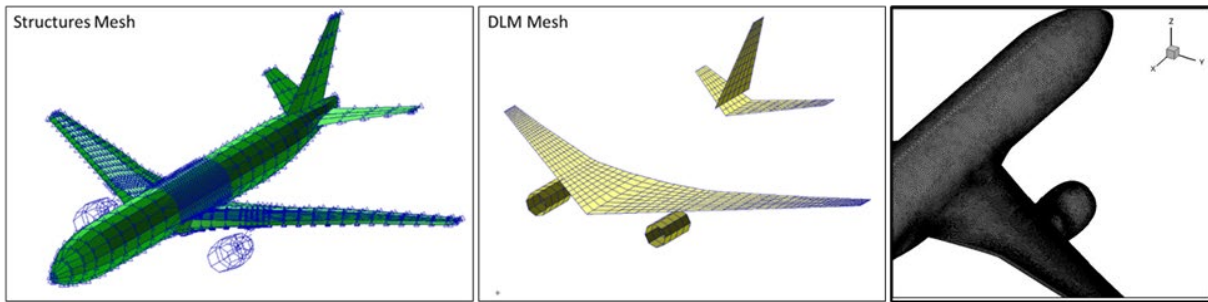
### Model, Analysis and Preliminary Results

In this study, a single condition at transonic Mach number is analysed, comparing results from FUN3D-LFD with standard DLM application. The comparisons start from the "end point", the flutter results, and work "backwards" investigating the underlying models used to build the flutter equation of motion. Initially, the flutter mode is considered; then, the contribution of relevant modes that define the flutter mechanism is investigated. The comparisons will include assessment of the Generalized Aerodynamic Force (GAF) matrix elements and pressure distributions. Preliminary results are shown in this abstract.

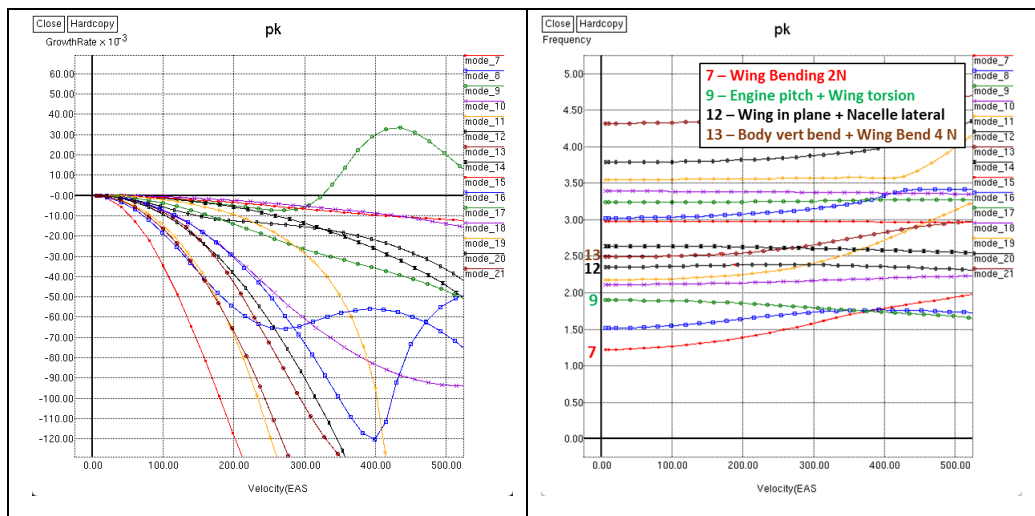
An aeroelastic model representative of a commercial airplane (CRM-FE) is used in the flutter analysis, as shown in Figure 1. The generalized coordinates (GCs) in the frequency domain are determined by the structural mode shapes, with 50 modes considered, including 6 rigid body modes.

Per the FUN3D-LFD process, structural mode shapes are projected on the aerodynamic surface, the static aeroelastic equilibrium for the condition is solved with the FUN3D-SFE module, followed by the frequency domain linearization solution (LFD module), which computes the generalized aerodynamic force (GAF) matrices. Flutter results based on FUN3D-LFD are shown in Figure 2. Analysis was performed for Mach 0.85 and flutter occurs for mode 9 around

1.8 Hz.



**Figure 1:** CRM-FE model – structural (left), DLM mesh (center), and part of the CFD mesh (right).

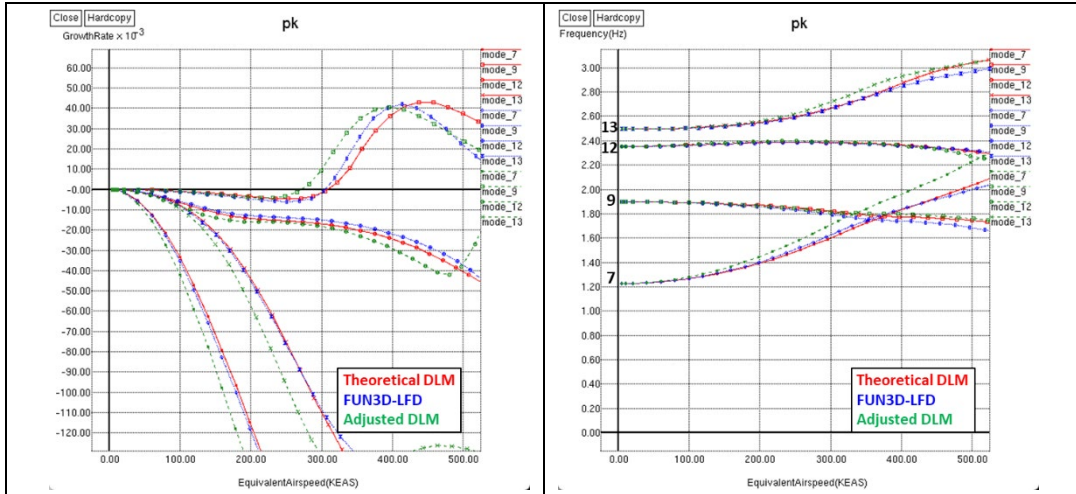


**Figure 2:** Flutter result (vg and vf plots) for FUN3D-LFD aerodynamic model – Mach 0.85.

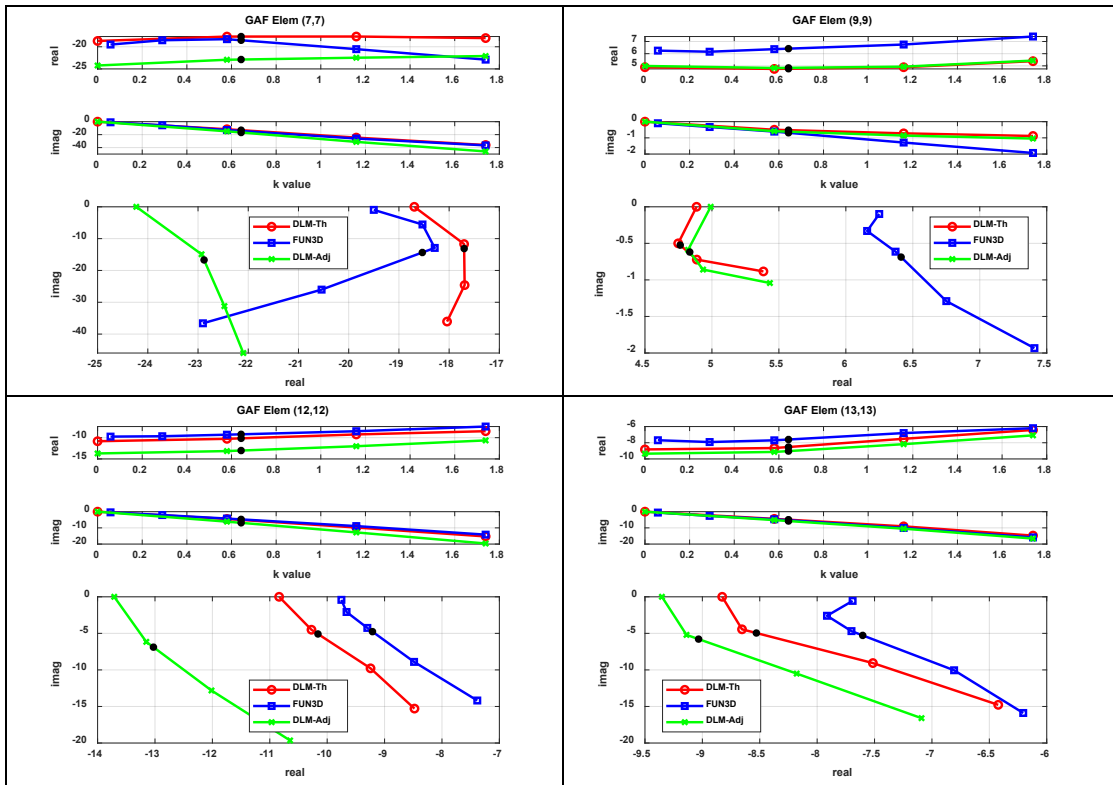
An examination of the flutter results shows that the GCs that contribute the most are modes 7 and 9, with smaller contributions from modes 12 and 13. Mode 7 is predominantly a symmetric wing bending, mode 9 primarily engine vertical bending (pitch), mode 12 a second symmetric wing bending with some engine lateral motion, and mode 13 primarily fuselage vertical bending with wing bending and engine lateral bending.

Flutter analyses for the same condition were performed with the traditional Doublet Lattice Method, purely theoretical and with correction factors. Results for these three cases are shown in Figure 3, with the four relevant modes included. Flutter speed for the unsteady CFD case is between the two DLM approaches. From the frequency plot it is observed that the biggest difference occurs for mode 7, for which the FUN3D-LFD frequency is slightly higher than the DLM theoretical and lower than the DLM adjusted.

The variation of the diagonal terms of the GAF elements with reduced frequency are shown in Figure 4 for the relevant modes. The black dot indicates the reduced frequency for the flutter mode. In general, the imaginary part at the flutter reduced frequency is similar for all cases. The real part shows variations. Like the frequency plot, for mode 7 the FUN3D-LFD real part is slightly higher than the DLM theoretical and lower than the DLM adjusted, at least around the flutter reduced frequency.



**Figure 3:** Flutter results (vg and vf plots) for all three aerodynamic models; only relevant aeroelastic modes (7, 9, 12, 13) shown.



**Figure 4:** GAF Matrix for elements with key contribution to the flutter mode.

Additional results planned for the final version of the paper will include comparison of pressures ( $C_p$ 's) for the unsteady complex flutter mode, due to perturbations of each of the relevant structural modes, and for the rigid body pitch rotation mode.