DORNIER SEASTAR CD2 – FLUTTER FLIGHT TEST – ADVANCED METHODS FOR IMPULSE AND NOISE BASED OMA USING NYQUIST AND SVD

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ABSTRACT

This paper describes the development of advanced flutter flight test methods for on impulse based and noise based operational modal analysis (OMA) for the Dornier Seastar CD2.

The Dornier Seastar CD2 is an amphibious aircraft, with a wingspan of 17.7 m and featuring two PT6 engines in push-pull configuration. The aircraft has had its maiden flight in 1984 in its initial configuration with a max. take-off weight of 4.6 tons.

For several years, a new aircraft version is under development, with an increased 5.1 tons MTO, new avionics and new systems in general. AeroFEM accompanied the development of the new aircraft version with respect to all topics related to structural dynamics and aeroelasticity.

According to CS 23.629 (b) and related AMC/ACs, it must be demonstrated that the aircraft is free from flutter, control reversal and divergence. In case of a preceding rational flutter analysis, only the critical modes must be excited and detected in the final flutter flight test.

To fulfil this requirement, AeroFEM performed extended flutter analysis and whirl flutter analysis based on a global finite element model GFEM and using NX NASTRAN. A ground vibration test (GVT) has been carried out by DLR, which allowed AeroFEM to perform a GFEM to GVT correlation. In addition, a flutter analysis solely based on GVT data was performed.

Based on this rational analysis, two critical complex mode types were identified:

- A classical wing bending torsion coupling, in symmetric and antisymmetric form
- A complex horizontal tail bending torsion coupling, only occurring with multiple modal participations of additional higher frequency tail and control surface modes

This led to the challenging requirement that a relatively high number of modes - partially even closely spaced and similar in their appearance - had to be tracked during the flutter flight test.

The flutter flight test excitation was initially planned to be performed solely by means of stick raps and pedal kicks. In a later stage of the project, concerns have been raised, whether this excitation would be sufficient, and whether the legacy evaluation tools would fulfil above mode detection requirements.

To address these concerns, a virtual numerical flutter flight test has been performed based on transient impulses and using modified NASTRAN solution sequences. The obtained results emphasised the clear need of a new set of advanced evaluation methods to extract frequency, damping and especially mode shape of every critical mode.

In a first phase, the author thus developed a new set of software modules for signal processing, tailored to impulse based excitation in classical flutter flight testing. The software is based on a flexible main script and a set of function modules, developed in MATLAB: In a first step, raw sensor acceleration signals are preconditioned and filtered. The implementation of sensor

arithmetic yields specific “mode shape time signals”. Artificial damping is added to the time signals by exponential window functions, which helps to reduce side lobes when transforming the time signals to the frequency domain by FFT. For improved accuracy, and to even detect closely spaced modes, interactive Nyquist 2D and 3D plots are developed. Thereby, circle fit methods are used to detect eigenfrequencies and to determine damping. The corresponding mode shapes can then be animated using a simplified 3D aircraft model by means of operational deflection shapes.

For the flutter flight test, the aircraft was equipped with high quality acceleration sensors from PCB, and the data was recorded in a Curtiss-Wright data acquisition system. In a series of ground tests, the newly developed software showed very good results, matching to GVT results. In calm conditions, a single fist bump on the wing is sufficient excitation to detect many of the global aircraft modes!

However, during the first low speed flutter flight tests, it was observed that the signal to noise ratio SNR was very low, which especially held true for the tail, which is located downstream to the two propellers and other turbulence generating structures. In addition, high frequency random tail vibrations were observed, which needed to be investigated in further detail.

Thus, the author developed additional noise based methods using operational modal analysis (OMA) techniques. Thereby, the established mode shape time signals are investigated using power spectral densities PSD based on Welch’s method. In addition, for each frequency, a singular value decomposition (SVD) of the formed cross power spectral density matrix (CPSD) is performed. The resulting complex modal indicator function (CMIF) is used to detect eigenvalues, and the left singular vectors are used to extract the corresponding mode shapes.

The combination of impulse based and noise based signal processing methods proofed to be very successful even in difficult low SNR conditions. In summary, all critical modes could be measured, and the results are in very good agreement with the rational flutter analysis.

Thus, the flutter flight tests could be concluded successfully in November 2025.