8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

EFFECTIVE PROBABILISTIC METHODS FOR UNCERTAINTIES IN AEROELASTICITY

F. Poirion

ONERA The French Aerospace Lab
BP 72, 92322 Cedex, Chatillon
poirion@onera.fr www.onera.fr

Key Words: *Aeroelasticity, Uncertainty, Random Delay, Almost Sure Stability, Probabilistic Methods.*

ABSTRACT

Uncertainty appears in many locations in aeroelasticity: structural parameters, wing geometry, control systems... Taking into account uncertainty during the design process of an aircraft is a mandatory stage in view of flutter certification. Because flutter calculations involve highly nonlinear equations, MCS methods are the more appropriate ones for introducing random uncertain parameters in the model and evaluating their impacts on the stability of the coupled system aircraft/aerodynamics.

Stability of the coupled system aircraft/aerodynamics is a key issue in civil airplane manufacturing. During the design stage of an airplane, many structural parameters are nor clearly fixed or known, but nevertheless the final project must comply to the various international certification regulations. One popular approach to deal with this problem is to model the parametric uncertainties through random variables. Then one has to study the stability of a random parameter dynamical system. Various steps, based on Monte Carlo simulation, have been developed at ONERA in order to construct an effective numerical procedure which can be utilized together with standard structural and aerodynamic codes by manufacturers. Basically two procedures were used: a direct simulation method which randomly draws the values of the uncertain parameters directly in the finite element model of the aircraft, and performs a complete flutter calculation at each step. It yields exact statistics in the sense that no reduction is performed on the random parameters. But, although this method is straightforward, it is not applicable at the present time for the large degrees of freedom models which are currently used.

A second approach has been developed based on a projected simulation method. It necessitates the construction of an unique basis of projection. Results have shown that the mean modal basis, which seems a priori to be a good candidate, is not rich enough to restitute the exact coupling behavior between the structure and the fluid. Moreover, this method is generally used in conjunction with a perturbation technique in order to represent the random parameter dependency of the generalized mass and stiffness matrices, valid solely for small uncertainties. We present an approach for extending the mean modal basis to a richer one. Moreover we show that polynomial chaos can be introduced in order to replace the perturbation technique with a representation capable of taking into account important uncertainties.

Contrary to structural parameter uncertainties, it not so easy to locate relevant aerodynamic parameters where uncertainty can be introduced. Should they model the discrepancy between different aerodynamic codes, the effect of simplification assumptions or more physical aspects such as the position of

the shock on an airfoil or the coefficient of pressure? Moreover the difficulty comes from the fact that solutions of the flutter equation do not depend in a functional way on those aerodynamic coefficients since aerodynamical forces are obtained through numerical integration of complex equations such as Euler or Navier Stokes equations. This problem can be clarified by considering the simple configuration of a two-dimensional airfoil. In that case, the proper aerodynamic parameter which has to be considered is the airfoil geometry. After having defined the flutter problem considered, a random field modeling airfoil geometric deformations will be constructed, then a Monte Carlo simulation method will be described and applied on a given airfoil. Results will show the effects of geometric defects on the coefficient of pressure and on the flutter equation solutions.

The use of active control technology significantly enhances aircraft stability and response, at reduced structural weight. In particular, high capacity aircraft are characterised by overlapping of rigid and flexible modes which induces severe interactions between the structure and controls. The effects of fly-by-wire controls on flutter must therefore be examined carefully. A particular aspect of this problem is the influence of time delays which cause unsynchronized application of the feedback control force and consequently can render the control ineffective and furthermore may destabilise the system. Fly-by-wire controls give rise to many sources of time delays which occur for instance during data acquisition, control law computation time, data transfer, etc. The numerical values of those delays can be determined once the sampling rates and number of computers are known. When redundant calculations are performed as it is the case for modern transport aircraft for which safety policy requires using several different data processor channels to calculate the same quantities in order to cater for failure of one of the computers, the time delay values vary during flight. Whereas a known and constant time delay can be compensated for — the study of delayed systems has received considerable attention in the control theory community — this is not true for unknown time-varying ones. Moreover the classical frequency domain approach using the Laplace transform can no longer be used and a direct analysis of the time domain response of the system has to be made in order to study the stability. Here we show that in this case flutter can be analysed by borrowing a numerical stochastic analysis tool developed for studying the stability of stochastic dynamical systems. This approach is based on the fact that a linear differential equation with random time delay can be seen in a certain functional space as an infinite-dimensional linear differential equation with stochastic multiplicative noise. Once discretized, this equation is approximated by a finite-dimensional linear system with a random matrix which describes the motion of a discrete dynamical system with multiplicative noise. The stability of its solution can then be studied using the stochastic Lyapounov exponent method. This method does not yield the usual flutter diagram showing the variation of the damping and frequency of each mode but instead gives a stability domain in terms of delay values and aircraft speeds.

REFERENCES

[1] R. Ghanem. “Ingredients for a general purpose stochastic finite elements implementation” *Comp. Methods Appl. Engrg.*, 168(**19**): pp. 19-34, 1999.

[2] F. Poirion. “Effective methods in stochastic non-linear dynamics: aeroservoelastic applications”. In R. Bouc & C. Soize eds.*Progress in Stochastic Structural Dynamics*, CNRS 152, ISBN 2-909669-16-5, 1999.

[3] F. Poirion. “On some stochastic methods applied to aeroservoelasticity” *Aerospace Science and Technology*, Vol. **4**, pp.201-214, 2000.