Modal Analysis of a Complete 18m-class Sailplane

J. A de Bruyn
M- Eng Student
School for Mechanical and Materials Engineering
Potchefstroom University for CHE
A.S. Jonker
Snr Lecturer
School for Mechanical and Materials Engineering
Potchefstroom University for CHE

Abstract

The Potchefstroom University (South Africa) is currently designing a new 18m-class sailplane, and it must be shown that this aircraft is free from flutter (self excitation of lifting areas) in the range of the designed speed. This flutter analysis requires that all the natural frequencies as well as the associated displacements of each mode susceptible to flutter, be calculated. Instead of first building the complete aircraft, it was decided to obtain these results from a complete FE (Finite Element)-model created in ANSYS. This paper will provide a brief background on the development, verification and solution of this model. The creation of this model included a simplified CAD-model which assisted the meshing process while the verification was done by two methods, firstly by means of independent FE-models and secondly by manufactured models. The final solution provided all the displacement associated with the different modes, and was extracted from ANSYS to serve as a grid over the lifting surfaces – which was successfully used for flutter predictions.

Introduction

Aeroelasticity is a term denoted for the study concerned with the interaction between the deformation of an elastic structure in an airstream and the aerodynamic forces (Reference 1). The aeroelastic phenomenon, where self excitations of certain lifting surfaces occur at different flight speeds, is called flutter. From this definition it can be seen that a flutter analysis has to do with both structural as well as aerodynamics modeling.

A flutter analysis consists of obtaining the natural frequencies and the associated displacements of the aircraft structure under investigation. This is then used in conjunction with a simple aerodynamic model in a flutter code to predict the flight speeds at which self excitation will start for the different modes. The lowest speed at which these excitations start, is denoted as the critical or flutter speed of the aircraft.

Normally a flutter analysis would be performed after the completion of an aircraft. In this case the natural frequencies as well as the associated displacements can be obtained by measuring the accelerations in a grid pattern over the lifting surfaces during forced vibration of the surface.

For this project however, it was decided to create a complete FE-model of the whole sailplane, and to use this model for the calculation of all the natural frequency and displacement data. The flutter analysis can thus be performed before the construction of the airframe commences. This would shorten the design and development cycle as it would, to a large extend, prevent costly modifications to a completed airframe should the analysis indicate flutter problems. This paper will not cover the flutter analysis but will focus on the development of the FEM model and extraction of the natural frequency and modal displacement data.

Procedure

The procedure that was used to complete this model consisted of the following main activities, namely the creation of the detailed CAD model (preparation), setting up of all the different real constant sets and meshing the model, verifying the model with several methods and finally extracting the modal data required by the aeroelastic code.

CAD model

In order to perform a FE-analysis on the complete sailplane, the whole CAD-model needed to be recreated. The existing model consisted of solids and was mainly created with splines. This model was then converted to a surface model and divided into smaller areas that each had either 3 or 4 straight-line boundaries. These smaller areas were created with the different lay-up schedules in mind. Figure 1 shows the cockpit region of this simplified model.

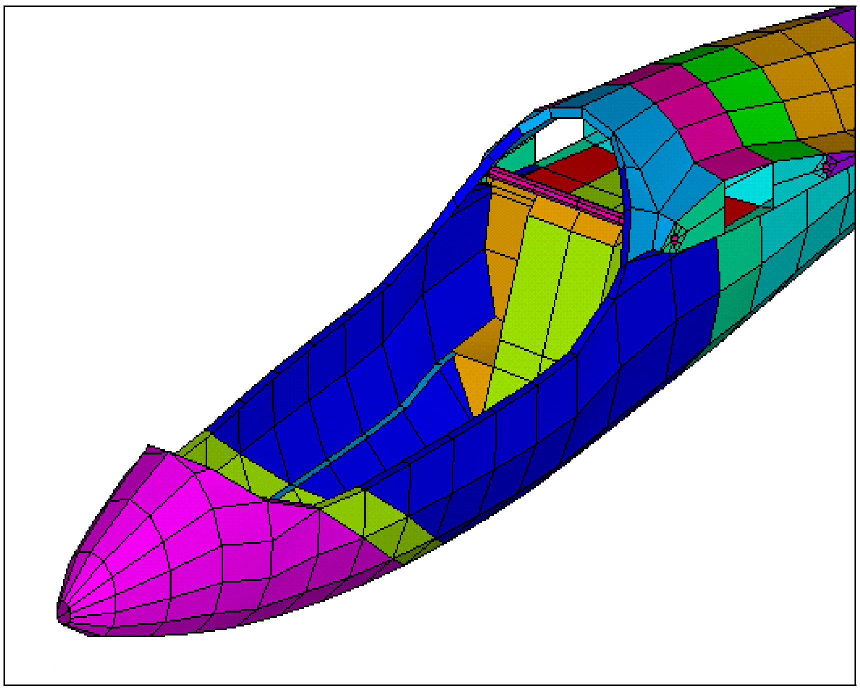

Figure 1. Simplified CAD-model

The model was then exported as an IGES file and successfully imported and glued in ANSYS. The different colors refer to the different real constant sets being defined for the areas.

Real Constant Sets and Meshing

The next step was to define all the real constant sets. The complete model consisted of nearly 200 real constant sets which were used to define the lay-up schedules for each of the SHELL99 elements in meshing the surfaces. These lay-up schedules refer to the choice of material, orientation and layer thicknesses and were the results of a static design-process for aerodynamical loads by other members of the design team. The main materials that were used were glass-, carbon- and Kevlar fibers. The complete model also used approximately 30 local coordinate systems to ensure the correct orientations of the fibers of the composite materials

The FE-model consisted mainly of SHELL99 elements, which were used on all the surfaces. Due to the simplified areas almost all of these areas were meshed by means of a mapped QUAD-mesh, with only a few that needed Triangle-meshes. For this analysis the ailerons and flaps were fixed to the wing by means of rigid elements (MPC184, with rigid BEAM options). Extra masses such as the airbrake-box and pilot were added by means of MASS 21 elements.

The final model used the complete fuselage as a sub-structured element (MATRIX50) with master degrees of freedom being set to ALL degrees of freedom at the connections with the wings and tailplane. Before this sub-structured element was created it needed to be verified. Figure 2 shows a close-up of the meshed region near the winglet while Figure 3 shows the sub-structured element representing the complete fuselage.

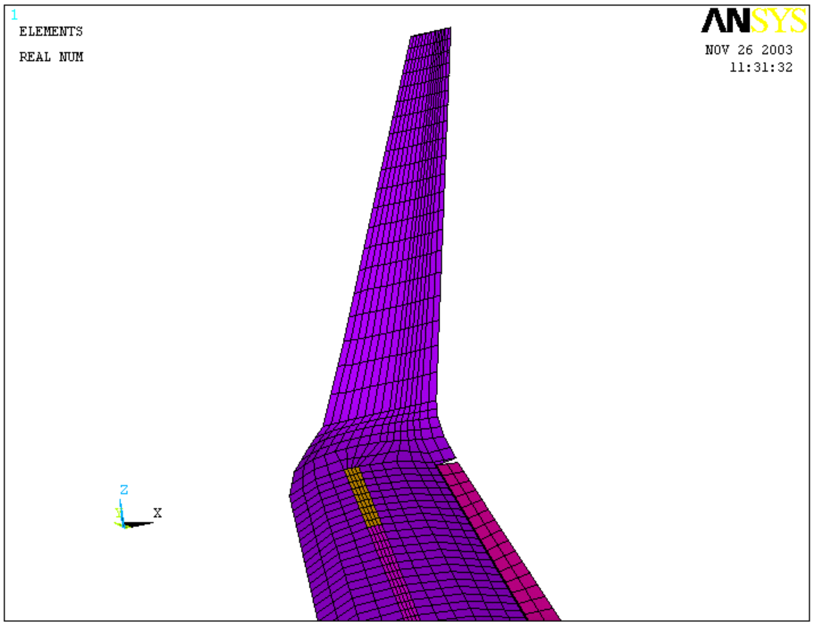

Figure 2. Winglet Mesh

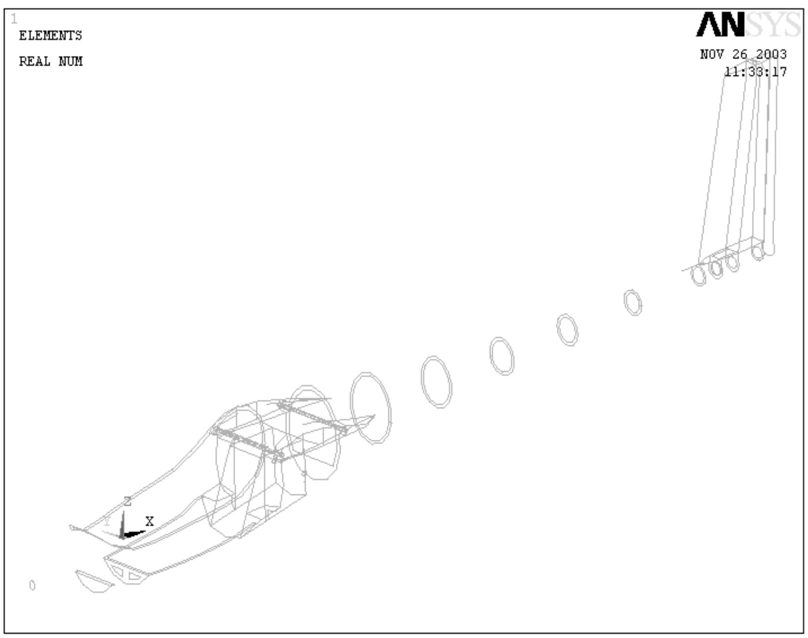

Figure 3. Fuselage Sub-structure

Verification

The verification process of the FE-model can be divided into two sections:

- Fuselage verification before creating a sub-structure; and
- Verification of the lifting surfaces with already manufactured components.

Before the fuselage could be created as a sub-structure, it was verified by means of 2 independent FE-models by different team members. One model was created using SI-units while the other was created using the imperial units system. The SI-unit model consisted of 16913 elements while the imperial model consisted of 7337 elements. Both models were loaded in such a way to determine their bending and torsional stiffness. Figures 4 and 5 show the different loads that were used to determine the verification of the fuselage. The deflection of the point as indicated in Figure 4 (DP) was used as reference. Comparing these two models gave the following results:

Table 1.

	Displacements [mm]	
	SI - Model	**IMP - Model**
Load Case 1 (Bending)	159.59	157.56
Load Case 2 (Torsion)	172.69	169.25

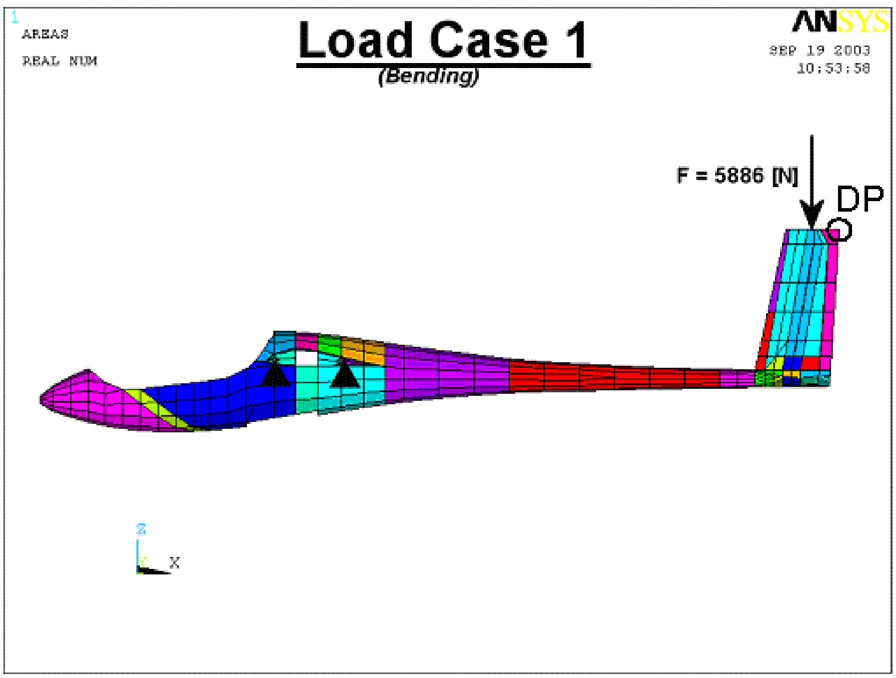

Figure 4. Verification, LC 1

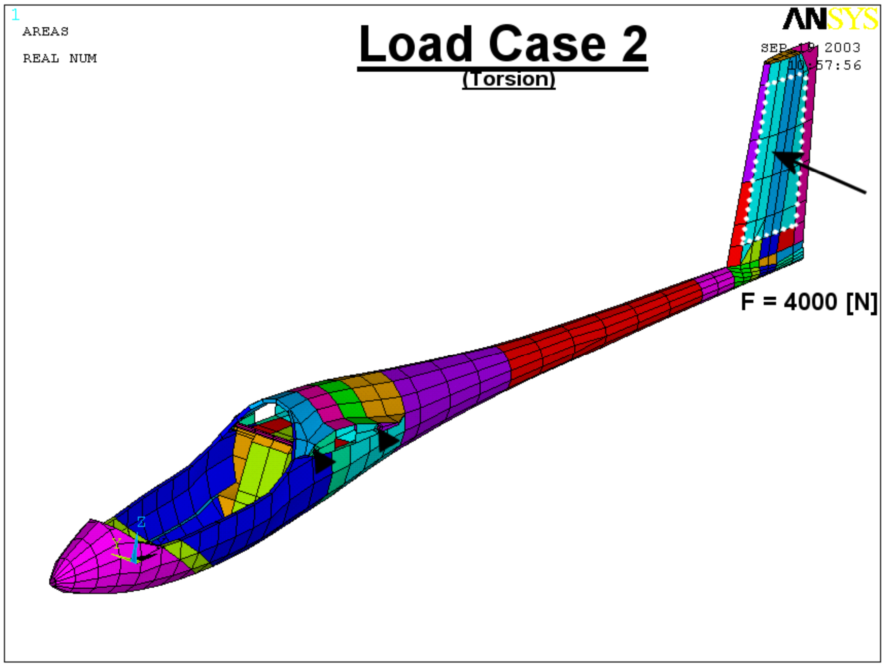

Figure 5. Verification, LC 2

With this comparison it was accepted that the FE-model of the fuselage was a true representation of the real model, and that the slight difference between the results was due to the large difference in the number of elements used.

The next verification method made use of a manufactured component. For this purpose the tailplane was manufactured and subjected to a simplified bending load (whiffle tree loading) as described in Figure 6 and 7. This bending load was also chosen due the fact that the bending displacements was among the easiest to measure. The following table gives the comparative results:

Table 2.

	Tip Deflection (mm)
Actual Model	84.5
ANSYS Model	83.6 [3.293"]

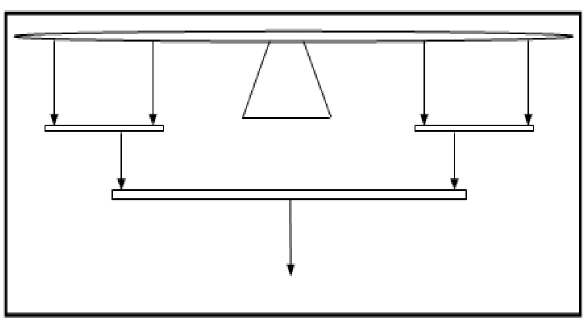

Figure 6. Tailplane load application

Figure 7. Tailplane being loaded

The final step before the complete modal analysis could be performed was to update the masses of the FE-model to match those of real or similar components. The FE-model of the tailplane was updated to match the manufactured component while the wings, flaps and ailerons were updated to the mass of a very similar sailplane.

Analysis, Results & Discussion

With the completion and verification of the model, a modal analysis was performed for one of the many configurations. This analysis made use of the Block Lanczos (Reference 2) method and was used to extract the first 20 modes of the complete structure. Literature indicated that modes shapes associated with flutter problems were expected to fall within the first 20 mode shapes. (Reference 3). The model was solved with no displacements being specified to any entity which forced the first 6 modes to represent the translational and rotational modes. All modes were extracted over the entire spectrum and were normalized to mass.

The following table gives the results from the modal analysis as well as the associated mode descriptions. These values were evaluated against results from not only similar sailplanes but also other complete composite aircraft and corresponded very well to the overall trend of these planes. With this information known, the next step would be to perform the flutter prediction.

Table 3.

Mode Number	*Hz*	*Description*
7	3.0986	1st wing bending (SYMM)
8	4.4646	Wing backward bending
9	4.697	1st wing bending (A-SYMM), fin bending (SYMM)
10	5.4134	1st wing bending (A-SYMM), fin torsion
11	6.1976	Fin torsion
13	8.9244	2nd wing bending (SYMM)
14	10.942	1st wing bending (A-SYMM), fin bending (A-SYMM)
17	15.013	1st stabiliser bending
19	17.564	Wing torsion, stabiliser bending
20	18.593	3rd wing bending (SYMM)

The following Figure shows some of the mode shapes. The displacement scaling was set to 6 in order to have a better view of the mode shape.

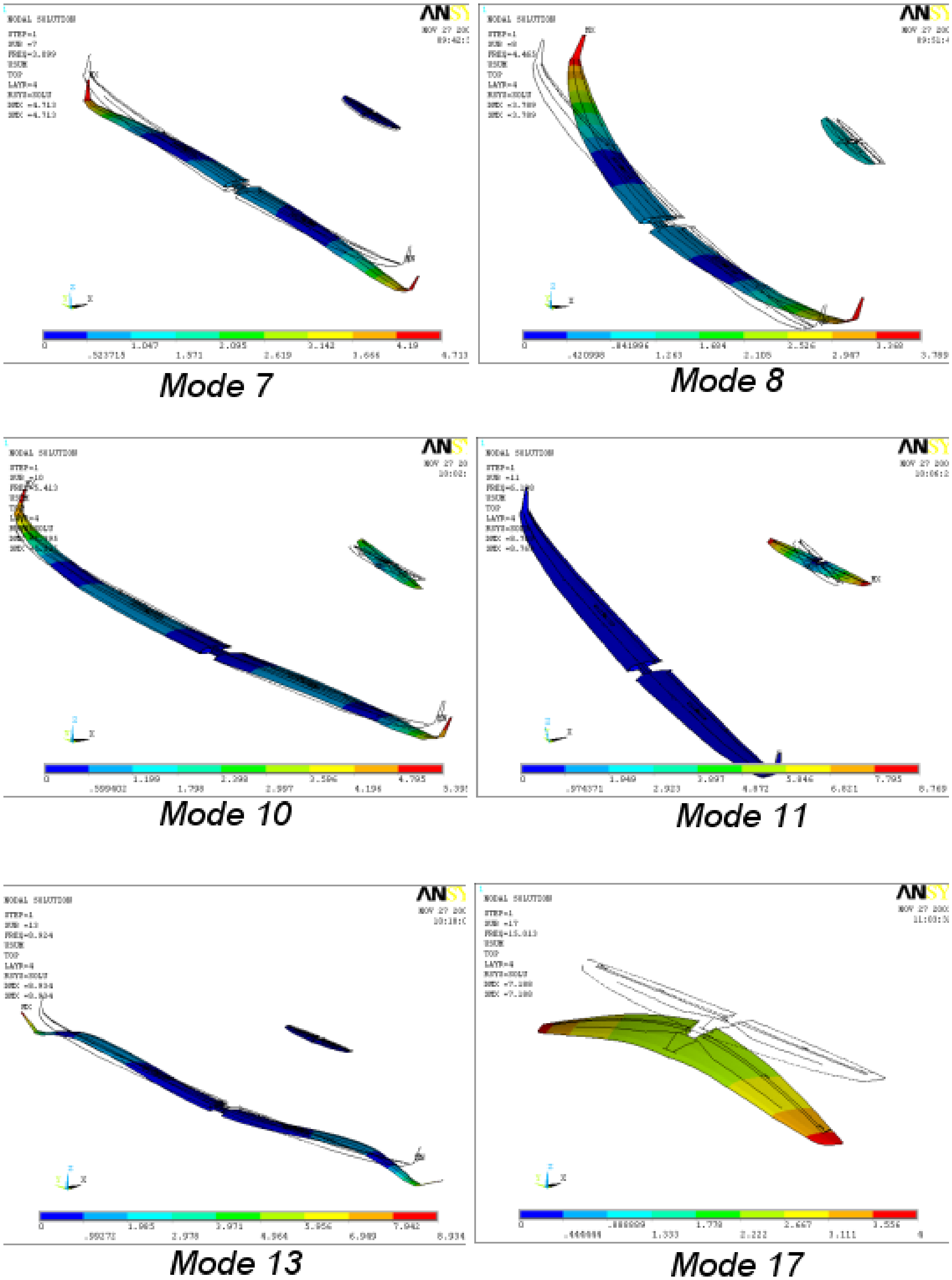

Figure 8. Displacements of modes

With the modal data calculated, the z-displacements of the nodes corresponding to the points as in Figure 9 were used as input for flutter calculations.

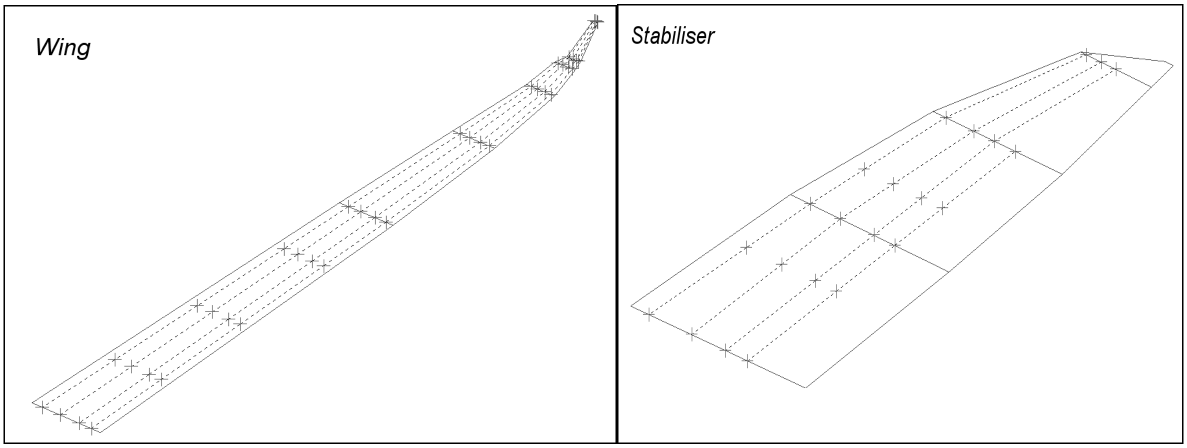

Figure 9. Modal data extraction points

By creating a component in ANSYS which consisted of the selected nodes, the configuration could easily be changed, where after the new data could be extracted into the flutter code by means of the text-file output option.

Conclusion

This paper gave a brief summary of the process that was followed to create a complete FE-model of an 18m-sailplane. The accuracy of the model was verified against other independently set up models as well as completed structural components. The model was used for the extraction of modal displacement data associated with its natural frequencies. This data was then used to calculate the flutter characteristics of the complete aircraft.

The use of a FE model made it possible to determine the flutter characteristic during the design phase, thus reducing costly modifications to a completed aircraft if the analysis was performed the traditional way. This study would also serve as a validation for a complete GVT (ground vibration test) once the aircraft is completed.

References

1) E. H. Dowell, E. F. Crawley, A Modern Course in Aeroelasticity, Lower Academic Publishers, 1995, ISBN 0-7923-2788-8.

2) ANSYS 7.1 Documentation

3) M. Hollmann, Modern Aerodynamic Flutter Analysis, 1997, Monterey, California.