A MECHANIC SYSTEM MODELING OF A NEW STORE INSTALLED IN FIGHTER AIRCRAFT

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Abstract *The installation of a new store in an aircraft introduces changes to its structural dynamics characteristics. Such new configuration can present undesirable instabilities in flight. One of the most dangerous instabilities that the aircraft may experience is flutter. It is a disastrous interaction among inertial, elastic and aerodynamic forces present in the modified aircraft configuration. Therefore, this phenomenon must be prevented.*
In the study of flutter, the knowledge of parameters such as natural frequencies, damping and shapes of some vibration modes of the aircraft-store/suspension assembly is of crucial importance. These parameters can be obtained from ground vibration tests.
This work presents a set of ground vibration test results of a new store intended to be installed in a fighter aircraft. The results are the natural frequencies, damping and mode shapes and are used to evaluate a three-degree-of-freedom model that will represent the mechanical system. The methods to obtain the inertia and stiffness parameters will be analyzed carefully in this paper.

1. INTRODUCTION

The structural dynamic characteristics of an aircraft are modified with the coupling of new stores. Sometimes the installation of new store configuration is necessary, like in military aircraft. The dynamic instabilities, as flutter, may occur due to the modification.

The flutter is a dynamic instability that can cause sudden, destructive vibration levels in an aircraft. Flutter is dependent upon aerodynamic, inertial and elastic forces. As an aircraft increasing the speed, the aerodynamic forces interact with and alter the structural vibration of the aircraft. Dowell et. al (1995) and Bismarck (1999), among the others, show how this interaction may induce flutter.

Traditionally, the information, such as natural frequencies, mode shapes and damping factors obtained from a ground vibration test (GVT), is used in order to feed the models used to predict the flutter speed, as Potter & Lind (2001) describe.

Cattarius (1999) shows a numeric methodology to examine fluid-structure interaction of a wing/pylon/store. He considered the wing as an elastic plate and pylon and store as rigid bodies. The store is connected to the pylon through an elastic joint exercising pitch and yaw degrees of freedom.

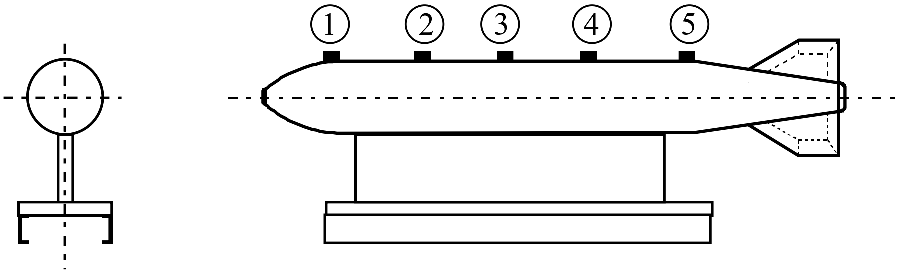

Figure 1 The store fixed on pylon clamped on the ground and the position of accelerometers on the stores

A comprehensive structural model for the aircraft wing combination is used by Frank & Librescu (1998). They have obtained the equation of motion of structures via Hamilton's Variational Principles and the application of generalized function theory to exactly consider the spanwise location and properties of attached stores.

Zeng (1997) have used the elementary Finite Elements in order to simplify the inertia and stiffness models of stores in a landing response analysis with commercial Finite Element Software.

This work presents a set of ground vibration test results of a new store intended to be installed in a fighter aircraft. The results are the natural frequencies, damping and mode shapes and are used to evaluate a three-degree-of-freedom model that will represent the mechanical system. The methods to obtain the inertia and stiffness parameters will be analysed carefully in this paper.

2. EXPERIMENTAL PROCEDURES

A preliminary modal analysis is necessary in order to model the wing-stores interaction. The Ground-Vibration-Test Experimental Procedures are described below to extract the data to make the modal analysis.

The pylon is clamped on the ground and the store is attached on it. Accelerometers are distributed over the surfaces of the store and the pylon, as shown in Figure 1. The accelerations are measured only the y and z directions.

The store is excited by a dynamometric hammer, equipped with a load cell. The output of accelerometers and load cell are acquired simultaneously by a compact card with a 2500 Hz low pass filter. Measurements are taken from points 1, 3 and 5, (see Figure 1), when the point is the reference. The Frequency Response Function (FRF) with 5 samples is built immediately after the data acquisition. This procedure allowed us disregard bad data acquisition. The FRF of signals of five accelerometers on the stores are shown in Figure 2

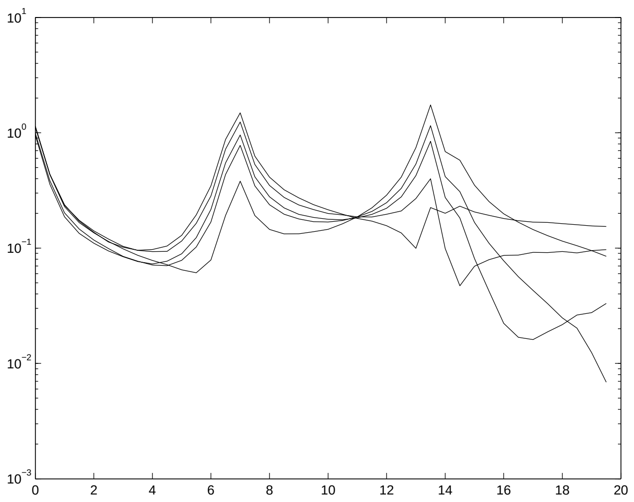

Figure 2 FRF of five accelerometers on the stores

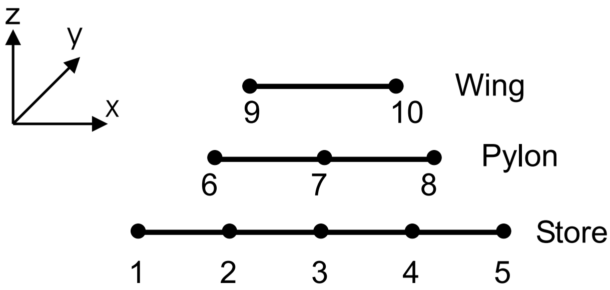

Figure 3 Geometry used to take the modal analysis

3. MODAL ANALYSIS

In order to extract the natural frequencies, the mode shapes and the damping coefficients, a commercial modal analysis software was used. The multi-degree-of-freedom analysis was performed with various FRF signals from all accelerometers. The complex Exponential Method was used.

The geometry used to representing the modes is shown in Figure 3). In this figure, the pylon and the stores are represented as rigid bodies.

The mode shapes considered on structural modeling are only the rigid body modes: pitch, yaw and rolling. The rigid body modes of the store and natural frequencies are plotted in

Figure 4).

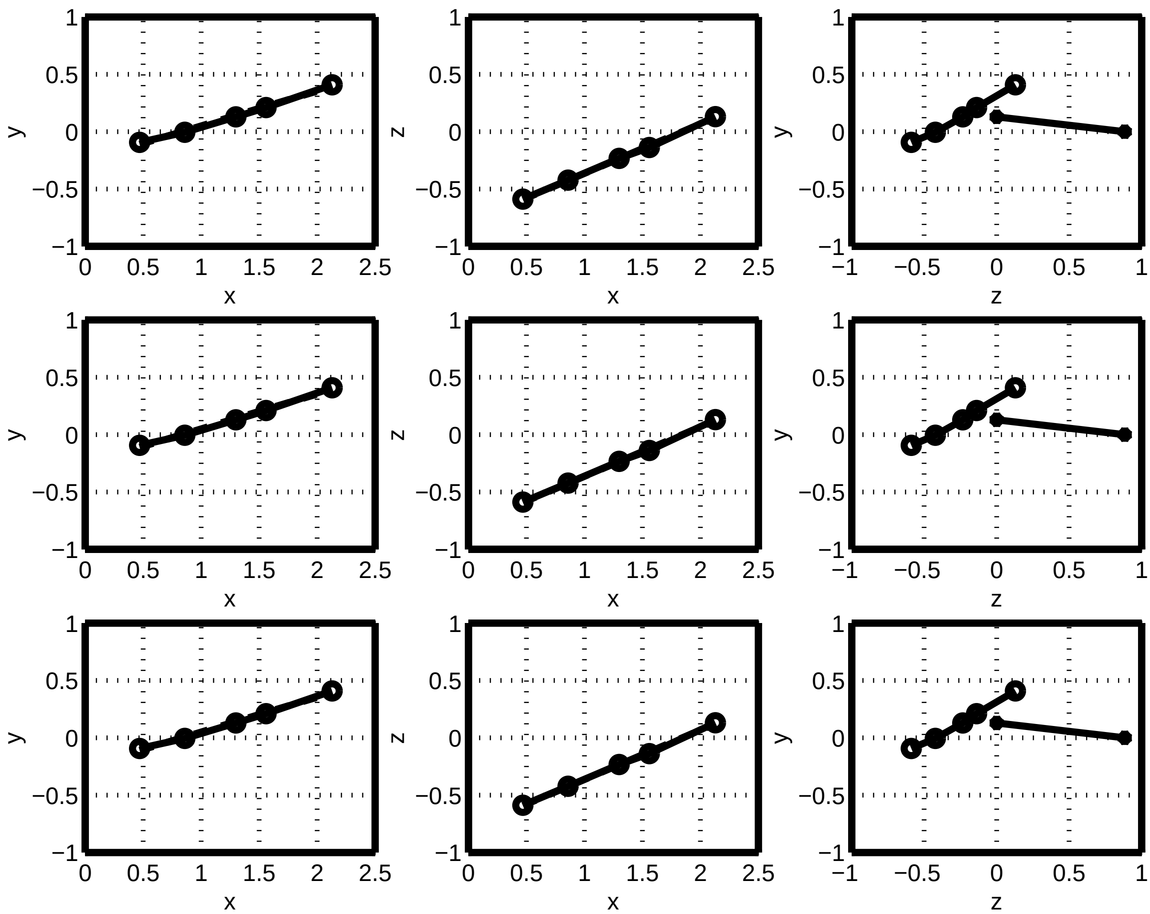

Figure 4 Three rigid body modes of stores extracted from modal analysis

4. MECHANICAL MODELING OF STRUCTURE

In the last section, it has mentioned that the stores and pylon are modeled as rigid bodies. The position of masses center of pylon and the store with out displacement are shown in Figure 5. The fixed reference frame is located on the elastic center of the wing. There are two joints. One joint, located on the elastic center of wing, allows only the pitch motion θ_x. The other joint J, located between the stores and the wing, allows the yaw and the rolling motion, θz e θz, respectively.

Considering the simplification cos(α)=1 and sin(α)=α for small displacements when α is a small angle, the displaments of pylon and stores mass centers, **d** are extracted from the cinematic scheme shown in Figure 5)

$$\mathbf{d} = \begin{Bmatrix} p_x \\ p_y \\ p_z \\ s_x \\ s_y \\ s_z \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} = \begin{bmatrix} 0 & -P_z & 0 \\ P_z & 0 & 0 \\ 0 & P_x & 0 \\ 0 & -S_z & 0 \\ S_z & 0 & S_x - J_x \\ 0 & S_x & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix} = \mathbf{Aq} \quad (1)$$

Where **q** is generalized coordinates and

$$\mathbf{A} = \begin{bmatrix} 0 & -P_z & 0 \\ P_z & 0 & 0 \\ 0 & P_x & 0 \\ 0 & -S_z & 0 \\ S_z & 0 & S_x - J_x \\ 0 & S_x & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (2)$$

In the equation the lowercase letter represent the displacement, the uppercase letter represent the coordinates. The subscript *x*, *y* and *z* represent the direction

In order to extract the equation of motion, the Lagragian approach is used. Then, the Kinetic energy and Strain Potential Energy is calculated as follow.

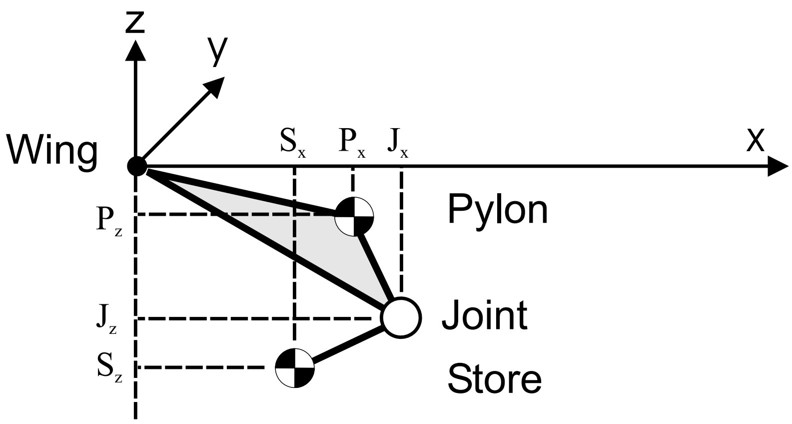

Figure 5 Model used to represent the dynamic of pylon-stores fixed on the wing

4.1 Kinetic Energy

The kinetic energy is defined as

$$T = \frac{1}{2}\int_V \dot{\mathbf{d}}^T \mathbf{M} \dot{\mathbf{d}}\, dV \tag{3}$$

or, in Coordinates generalized terms:

$$T = \frac{1}{2}\int_V \dot{\mathbf{q}}^T \mathbf{A}^T \mathbf{M} \mathbf{A} \dot{\mathbf{q}} dV \tag{4}$$

Where **I** is the matrix carrying the inertial terms

$$\mathbf{I} = \begin{bmatrix} m_p & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & m_p & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & m_p & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & m_s & 0 & 0 & 0 & 0 & 0 \\ \vdots & & & & m_s & 0 & 0 & 0 & 0 \\ & & & & & m_s & 0 & 0 & 0 \\ & & & & & & Ixx_p & 0 & 0 \\ & & & & & & & Iyy_p & 0 \\ Sym & & & & \cdots & & & & Izz_s \end{bmatrix} \tag{5}$$

The **M** is known as mass matrix

$$\mathbf{M} = \mathbf{A}^T \mathbf{I} \mathbf{A} \tag{6}$$

4.2 Strain Potential Energy

The strain energy is defined as

$$U = \frac{1}{2}\int_V \mathbf{d}^T\mathbf{C}\mathbf{d}dV = \frac{1}{2}\int_V \mathbf{q}^T\mathbf{A}^T\mathbf{C}\mathbf{A}\mathbf{q}dV \qquad (7)$$

The $\mathbf{C}$ matrix is related to the material properties of Pylon and stores and does not need to be known. The term

$$\mathbf{K} = \frac{1}{2}\int_V \mathbf{A}^T\mathbf{C}\mathbf{A}dV \qquad (8)$$

is known as stiffness matrix

4.3 Equation of motion

The equation of motion, derived from the Lagrange Equation, is

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{\mathbf{q}}}\right] + \frac{\partial L}{\partial \mathbf{q}} = \mathbf{F} \qquad (9)$$

Where the Lagragian term L is

$$L = T - U \qquad (10)$$

Then the equation of motion is written as

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{F} \qquad (11)$$

4.4 Stiffness Matrix

Using the three mode shape normalized with respect to the mass matrix M, we can take the modal transformation

$$\mathbf{\Phi}^T\mathbf{M}\mathbf{\Phi} = \mathbf{I} \qquad (12)$$

$$\mathbf{\Phi}^T\mathbf{K}\mathbf{\Phi} = \left[{}^{\backslash}K_{\backslash}\right] \qquad (13)$$

Thus, the mechanical system is decoupled and it is possible to calculated the modal stiffness as follows

$$K_{ii} = (2\pi f_i)^2 \qquad (14)$$

Where f_i is the natural frequency of i-th mode.

In same way we take the inverse modal transformation and calculate the real stiffness matrix **K** of the substructure (store and pylon) to be cople on the aircraft model.

$$\mathbf{K} = \mathbf{M\Phi\Phi^T}\left[{}^{\backslash}K_{\backslash}\right]\mathbf{\Phi\Phi^T M} \tag{15}$$

5. NUMERICAL RESULTS

Using the natural frequencies found in modal analysis, and the Mass matix calculated as in Eq(6),

$$\mathbf{M} = \begin{bmatrix} 274,4810 & 0 & 259,5502 \\ 0 & 301.0951 & 0 \\ 259,5502 & 0 & 382,7242 \end{bmatrix} \tag{16}$$

it is possible to calculate the modal stiffness matrix Kii as in Eq(14) and the stiffness matrix **K** of stores-pylon model as Eq(15).

$$\mathbf{K} = 10^6 * \begin{bmatrix} 1,2316 & 0 & 1,6857 \\ 0 & 2.4307 & 0 \\ 1,6857 & 0 & 2,7093 \end{bmatrix} \tag{17}$$

6. BIBLIOGRAPHY

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