

Experimental Techniques of Measuring Vibratory Force for Aircraft Wings

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ABSTRACT

The authors measured the vibratory forces acting on an airfoil model by performing a ground vibration test (GVT). The airfoil model was manufactured using rapid prototyping. In the experiments, the airfoil model's structural response was also recorded and described. This paper detailedly introduces the entire experiment process and the obtained experimental data agreed well to the actual values.

INTRODUCTION

During flight, aircraft wings always subject to varying aerodynamic loadings and as a consequence, generate varying structural responses. The varying aerodynamic loadings and structural responses are coupled to create a complicated vibration effect known as structural coupling dynamics. This effect can significantly reduce the aircraft's service life. Even worse, sometimes the sustained vibration at natural frequencies of airfoils may lead to catastrophic structural failure. Due to the significance of the interaction between the aerodynamic forces and the aircraft's structural response, a science aeroelasticity was developed to study the mutual interaction among inertial, elastic, and aerodynamic forces acting on structural members exposed to an airstream, and the influence of this study on aircraft design [1].

The aerodynamic forces, which are extremely difficult to obtain from a flying aircraft, can usually be measured from experimental simulations. Conner, et al [2] created an experimental model which closely approximated a 3D aeroelastic typical section in 2D incompressible flow and

used that model to determine the system response of the aeroelastic section with control surface freeplay. Schewe, et al [3, 4] performed flutter and forced oscillation experiments in a transonic wind tunnel using an aeroelastic supercritical 2D airfoil model. From those experiments, it was found that very small control forces were sufficient to excite or suppress flutter oscillations of the airfoil system. Chen [5] performed an experimental study including wind tunnel tests to determine the flutter derivatives of section models under smooth and turbulent flows applying a neural-network-based method. Tang and Dowell [6] constructed an experimental high-aspect-ratio wing aeroelastic model with a slender body at the tip and measured its response due to flutter and limit-cycle oscillations in a wind tunnel test. Potter and Lind [7] developed a method to test an uncertainty model for modal analysis and robust flutter analysis using ground vibration testing data. Pickrel [8] demonstrated a method to improve and validate the structural dynamic model for ground vibration testing. The structural dynamic model was validated by comparing its predicted modes with experimental modes. Lee [9], Joshi [10], Sun [11], and Nakade [12] developed different experimental methods to measure the unsteady aerodynamic loadings and investigate the interaction between the loadings and the object's dynamic structural response.

In this paper, a physical downsizing airfoil was manufactured using rapid prototyping. This model is first used for a GVT test to obtain its natural frequencies, damping ratios, and mode shapes. Next, a wind tunnel test is performed on this airfoil model to determine its aerodynamic loadings at different air speeds. The experimental data are then validated by comparing to the actual values. The software LabView is employed to acquire the experimental data.

EXPERIMENT MODEL

A 3D wing model with dimensions fitting the wind tunnel test was designed using the commercial CAD package SolidEdge (Fig. 1). The CAD model was then manufactured in the rapid prototype laboratory in University of Louisville (Fig. 2). The airfoil shape of this model is NACA-65A004 and its dimensions are listed in Table 1.

In order to install accelerometers in to this model for vibration test, two rectangular cutouts were created at the side surfaces of both ends of the boom. The cables that connect the accelerometers and signal amplifier were fed through the interior of this model in order to eliminate aerodynamic influence. Thus, both the wing and boom are hollow, the thickness of the wing model is 1mm, and an 8.2 mm $\times$ 8.5 mm space is available inside the boom.

At the root of the wing, a plate is attached to fix the wing to the wind tunnel wall. In this plate, a helicoids hole is created to connect the model with the wind tunnel. The material of the wing model is DuraForm polyamide (PA), with Young's modulus 1600 MPa, Poisson's ratio 0.4, and density 590 kg/m³.

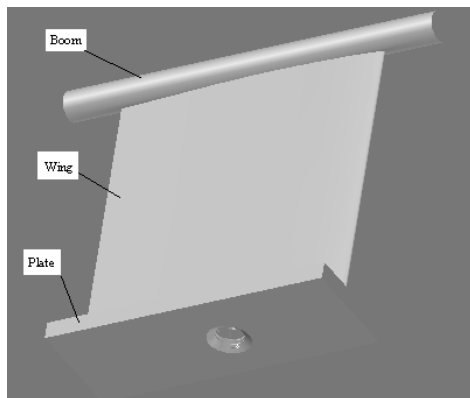


Figure 1. CAD wing model created in SolidEdge



Figure 2. Airfoil model manufactured using rapid prototyping

Table 1. Dimensions of wing model

Half Span	160.36 (mm)
Chord	161.01 (mm)
Diameter of boom	17.27 (mm)
Total length	225.00 (mm)
Total width	187.64 (mm)

GROUND VIBRATION TEST

EXPERIMENTAL SETUP

The purpose of the ground vibration test is to obtain the airfoil model's frequency response functions (FRFs) by measuring the excitation force and its behavior of response. Fig. 3 shows the flow chart of this test. In this test, a calibrated impact hammer (with a rubber tip) was used to excite the model and two accelerometers were employed to measure its responses (Fig. 4). In Fig. 4, a sensor was installed at the end of the impact hammer to measure the excitation force, and its sensitivity is 2.25 mv/N. During the test, the wing model was rigidly mounted by clamping it onto a steel tube (Fig. 2). Next, 22 test points were excited separately by the impact hammer and the model's responses were recorded by the accelerometers. These test points are either located at the leading and trailing edges, at accelerometer locations, or at the wing-to-boom joint, as shown in Fig. 5. The choosing of an amount of test points ensured that the obtained mode shapes were related to the entire wing model. In order to minimize the errors, 10 tests were repeated at every test point. The resolution of the data acquisition system is 0.5 Hz, the sampling time is 2 sec, and the sampling frequency is 5000 Hz.

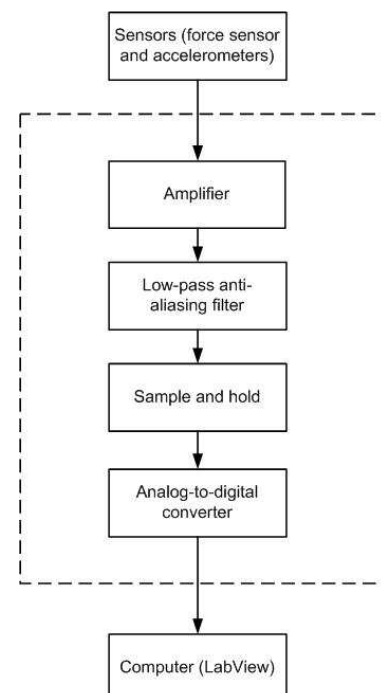


Figure 3. Flow chart of ground vibration test (GVT)