*Military Technical College,
Kobry El-Kobbah,
Cairo, Egypt*

*9th International Conference
On Aerospace Sciences &
Aviation Technology*

SOME ASPECTS OF AN EXPERIMENTAL INVESTIGATION ON COMPOSITE AEROBATIC AIRCRAFT STRUCTURE.

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ABSTRACT

There is a growing trend to employ composite materials in the development and construction of aircraft structures in keeping with the desire for lighter but stiffer structures. The A1 aerobat is an aircraft that has contributed extensively towards the field of research and has had a significant influence on education in aeronautical engineering. The present work deals specifically with the initial investigation of the dynamic characteristics of a Carbon Fibre Reinforced Plastic (CFRP) wing box. This wing box is designed and developed at Cranfield University, which is representing the wing box of the Cranfield A1 aerobatic aircraft.

The root of the wing box is attached to a large rigid concrete structure to serve as an ideal foundation simulating a root fixed boundary condition. The composite wing box is excited using random and sinusoidal excitation methods in the frequency range of 0 to 300 Hz. A total of five test locations are conducted in order to measure the response of the entire wing box.

Results obtained are in terms of eigenvalues and eigenvectors. These results are presented, discussed and the vibration experiment used to obtain these results discussed.

The primary objectives of these investigations are to study the dynamic characteristics of a real composite aircraft lifting structure by way of accomplishing a practical task and to provide a realistic mechanism for education in the field of aeronautical engineering.

KEY WORDS

Modal analysis, Structural dynamics, Aircraft composite structures, Composite materials

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INTRODUCTION

The Cranfield aerobatic aircraft [1] employed in this investigation is an excellent example of aircraft design, having potential for its application in education field. It is developed as student design project, which has resulted in an aerobatic aircraft that even today flies. Fig.1. shows the salient wing parameters of the whole of the aircraft.

The paper examines and evaluates the experimental vibration analysis of a wing box, which is representative of the complete wing constructed of composite rather than conventional metallic materials. Since the A1 aerobatic is currently undergoing significant modifications a study such as this is considered to yield a vital information to enhance the student understanding of the composite wing, should the metallic wing be replaced with modern materials.

Due to its inherent beneficial properties a composite wing box made from carbon fibre reinforced plastic is constructed for studying the post buckling behavior of the wing box [2]. This wing box is then adopted for vibration purposes and mounted with a 3 degrees angle of attack representing the level in-flight position. The wing box root is attached to a large rigid concrete structure to serve as an ideal foundation simulating a root fixed condition, representative of the wing-fuselage attachment on the actual aircraft.

External excitation is attained with an electromagnetic shaker. Vibration input is transmitted through a specially design sting to allow for the vertical displacement only. A total of eleven accelerometers are employed in five complementary tests to measure the response of the entire composite wing box. Due to the limitation of accelerometers the locations are carefully resolved and tests conducted such that the entire wing box could be truly represented. The structure is excited with both random and sinusoidal excitation using different types of transducers of known sensitivities [3].

Output from the transducers is linked to a Personal Computer (PC) with specially, Cranfield developed software. This software allowed the retrieval and presentation of the raw data, which is in the form of gain, phase, coherence and the input output responses at each accelerometer location.

It is felt that, a project such as this would enable the students to consolidate their theoretical knowledge with the real experimental functionality of practice. Furthermore, the experience gained via this practical approach is considerered to be of immense value since the student has a direct role in the setting up, retrieval and understanding of data. In addition, this process has successfully brought home some of the varied aspects related to experimental analysis e.g. accelerometer mounting, accelerometer locations, solution of practical problems related to spurious noise, screening and those practical difficulties.

EXPERIMENTAL COMPOSITE WING BOX

The airfoil section of the wing box at the root is NACA 23015 and at the tip NACA 23012. The details of the wing box employed are as per the refererence [2]. Suffice it to say that the A1 aerobatic metal wing is modeled as a composite wing box, constructed from (CFRP). Fig.2. shows the primary dimensions of the tested wing box, having a semi-span of 4050 mm from aircraft centre line, 812.8 mm root chord and 369 mm tip chord. As with any traditional wing torsion box it comprised of front and rear spars, a tip rib, seven intermediate ribs located along the semi-span of the wing box, stringers and top and bottom skins.

The actual wing having a span of 10 m and is made of Aluminum. Other salient wing features are given in Fig.1. The composite wing box dimensions are different from the actual wing mainly due to manufacturing and logistic reasons. Hence the wing box as employed in this investigation is the primary torsion box structure with the aileron hinge brackets protruding at the trailing edge.

EXPERIMENTAL SET UP

Experimental set up used for excitation of the wing box as illustrated in Fig.3. shows the power amplifier, signal generator and filter unit connected to the shaker. These implements provide the input needed to excite the wing structure. Standard Bruel & Kjaer equipment is used extensively. An electromagnetic exciter Goodmans vibrator model 309 is used to shake the composite wing box. The location of the exciter is placed at the tip of the wing box at the intersection of the tip rib and the middle stringer of the bottom section through a sting as suggested by [4] is shown in Fig.3. A force transducer type 8200 is also connected to the sting and a mounting block. The load cell is being glued directly onto the lower surface of the wing box with standard quick setting car body filler. An inexpensive and effective method of attachment such as this is used extensively in industry. The sting allows only the vibratory input to be limited to the vertical plane. Fig.3. also shows the location of the reference accelerometer, which is directly opposite to the force transducer at the top surface of the wing box.

Fig 2 shows a total of eleven accelerometers type 4374 including the reference accelerometer are calibrated and used in five complementary tests to measure the response of the entire wing box. Thus a total of 46 possible locations at which the output from the vibratory experiment could be retrieved. The accelerometers are attached at the intersection of each rib with the stringers and spars over the composite wing box with the aid of Bostick blue-tac . An inexpensive and effective means of a temporary attachment secure enough for the duration of the test. The electrical leads of the accelerometers to the junction/splitter box are securely tapped on the wing box so as to avoid any drumming of the leads.

Equipment used for retrieval of this output data as shown in Fig.3 illustrates the accelerometers connected to a signal conditioning unit. From here the data is transmitted via a specially designed unit to a PC interface which acts as multichannel filter plus switched gain amplifier, and finally to a dedicated PC. Specially designed windows based software as developed at Cranfield, which greatly assists in the analysis of the results is employed.

The wing box is excited in the frequency range of 0 to 300 Hz, with both sinusoidal and random excitation. For the random excitation cases data is acquired for a period of five minutes in each test.

DISCUSSION OF RESULTS

In view of the fact that there are a total of 46 separate locations for the five sets of tests conducted, therefore, a considerable amount of data is acquired. However, the paper shows a typical sample of the results obtained which is representative of the whole array of acquired data.

Only results for the tip location are illustrated and discussed because this location is associated with maximum deflections. Fig.4 and 5 show the gain, Phase and coherence for the reference accelerometer (Acll 6) and the tip accelerometer (Acll 22) respectively. Location of these accelerometers are shown and identified in Fig.2. These are typical of the results obtained, and it will be noted from the gain plots indicating that there are some distinct visible peaks. The gain is defined as the ratio of the output to the input response. On closer inspection of the gain plot, it is possible to identify each resonance frequency by peaks in the response. Also there is no discernible displacement of the structure below 10 Hz. The peak, resonant locations on the gain plot can be corroborated with the phase diagram, which illustrates clearly the change in phase at the resonant condition. Further confirmation could also be obtained by the inspection of the Coherence plot, which amounts to a drop off at the resonant condition.

Similar results are obtained for all the other locations mentioned above. These results are collated and hence the main resonance frequencies obtained. Six resonant conditions as identified are given in Table 1.

Table 1 Eigenvalues for the composite wing box.

Mode Number	Resonance Frequency (Hz)
1	19.7350
2	73.8500
3	142.415
4	158.081
5	232.430
6	254.720

The mode shapes for these six frequencies are further shown in Figs. 6-11. From these shapes it is apparent that the fundamental mode, at 19.735 Hz, is representative of the first bending mode as shown in Fig.6. The second mode is at

73.85 Hz, which represents the second bending mode shown in Fig.7. Evidently, there is a large frequency separation between these two frequencies.

Similarly there is a large separation between the second and third frequencies. The third mode shape occurs at 142.415 Hz followed closely by another mode shape at 158.081 Hz. The third mode is the third bending mode as seen from Fig.8. The fourth mode at 158.081 Hz, illustrates a coupled bending-torsion mode, see Fig.9. This is further confirms that the frequencies of the third and fourth modes are quite close. The fifth mode, at 232.43 Hz, is the fourth bending mode as shown in Fig.10. Finally the sixth mode, at 254.72 Hz is represents the tip bending and torsion mode as shown in Fig.11.

CONCLUSIONS

The vibration experiments are amply successful, yielding six resonant frequencies and associated eigenvectors. These results are representative of the composite wing box constructed from CFRP material with cantilevered boundary condition and provide useful initial data. This study has also demonstrated a useful teaching and learning tool which allows the application of taught material. The experimental results obtained can be used for comparison with calculated results from Finite Element analysis.

ACKNOWLEDGMENT

The author would like to express his gratitude to the Flight System and Measurements Laboratory group at Cranfield Aerospace for their kind assistance and advice during this experimental work. Thanks are also due to their having extended the facility to loan the equipment used in this study.

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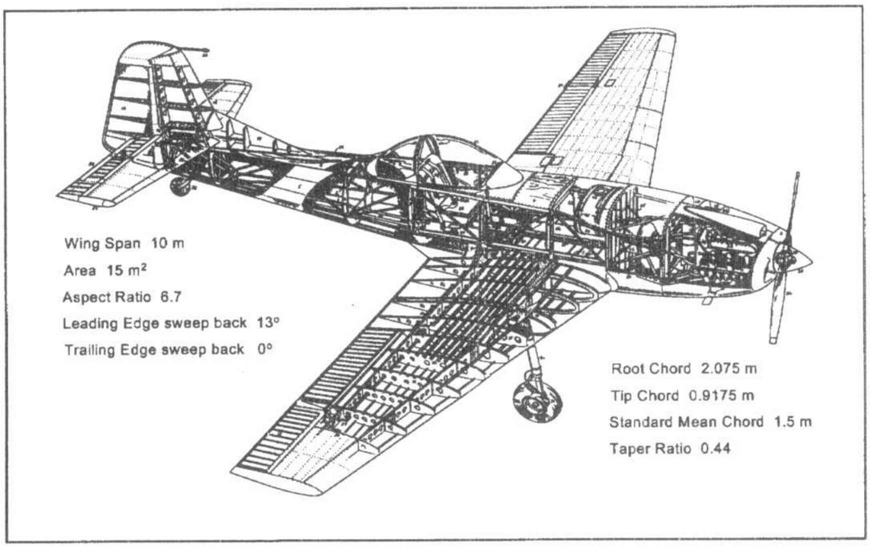

Figure 1 Cranfield A1 Aerobat with salient wing parameters.

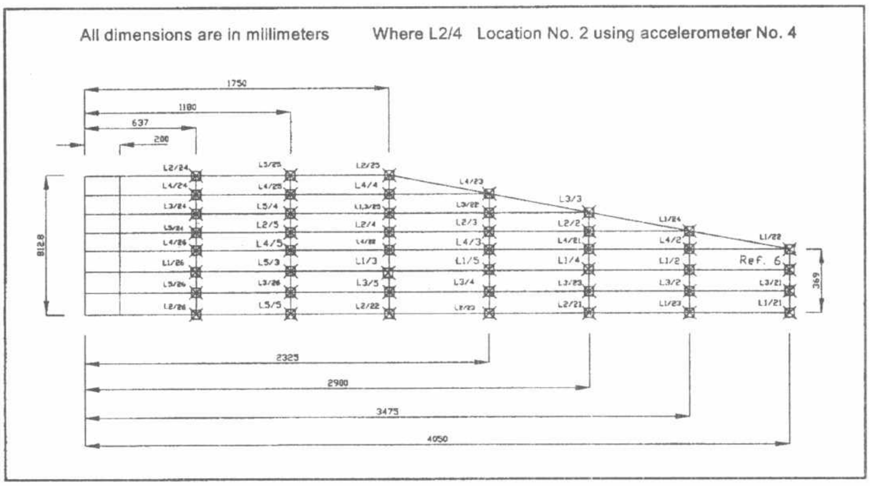

Figure 2 Plane view of the composite wing box

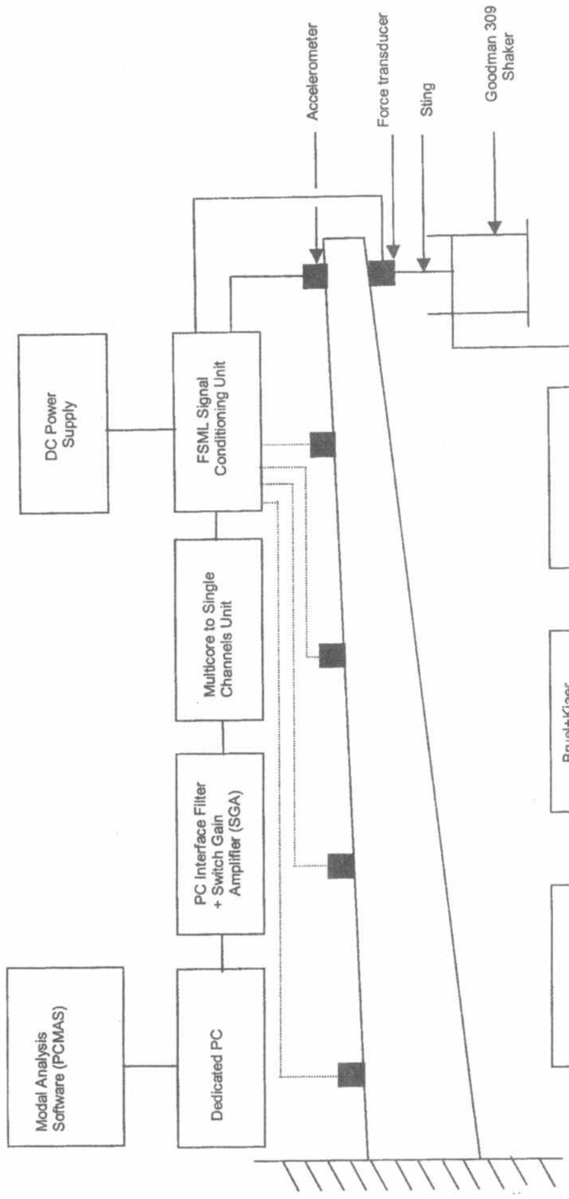

Figure 3 Schematic of the experimental used equipment

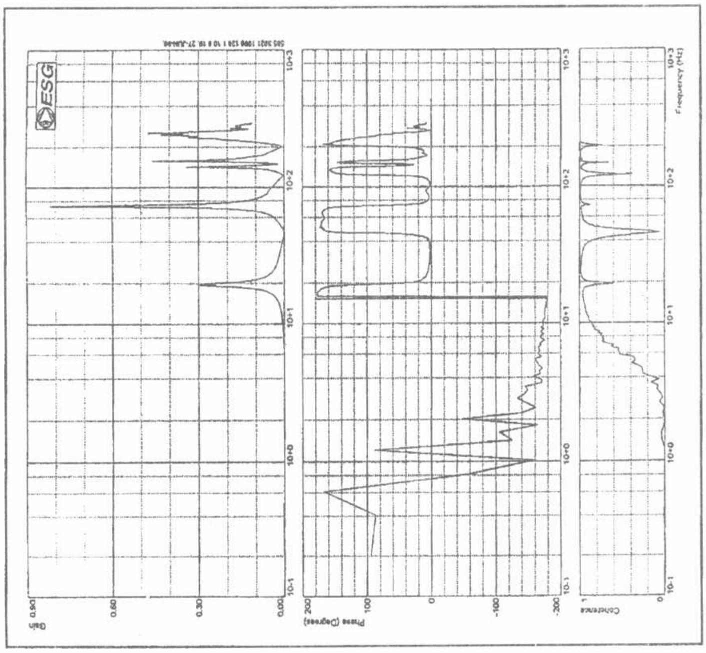

Figure 4 Gain, Phase and Coherence plots for reference accelerometer (Accl. 6).

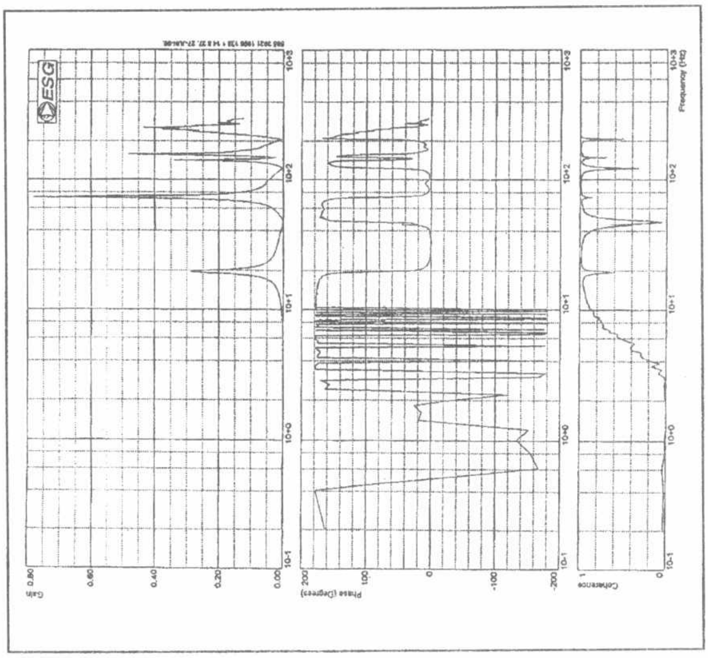

Figure 5 Gain, Phase and Coherence plots at tip station (Accl. 22).

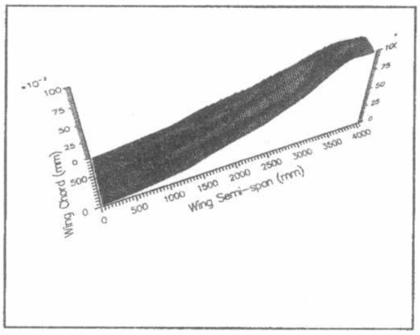

Figure 6 1st bending mode, 19.735 Hz

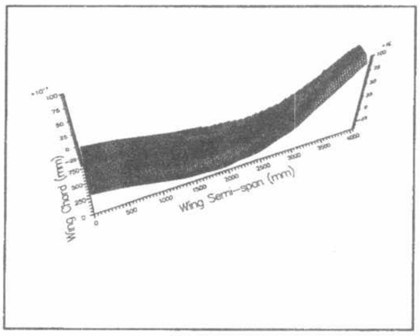

Figure 7 2nd bending mode, 73.85 Hz

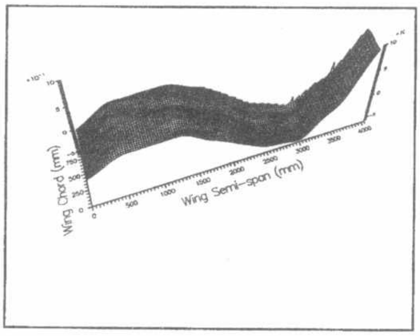

Figure 8 3rd bending mode, 142.415 Hz

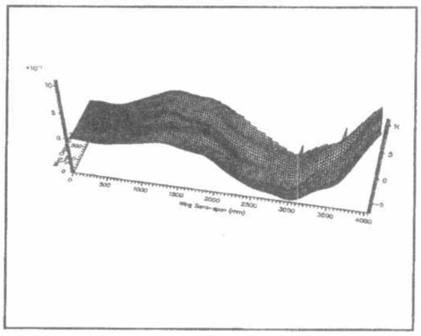

Figure 9 Coupled bending-torsion mode, 158.081 Hz

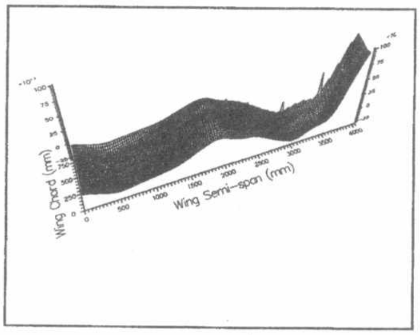

Figure 10 4th bending mode, 232.43 Hz

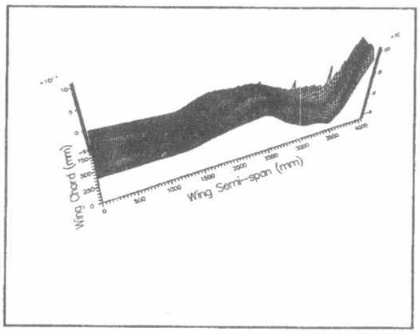

Figure 11 Tip bending-torsion mode, 254.72 Hz