EFFECT OF CHANGES IN SOME DESIGN PARAMETERS ON THE DYNAMIC PROPERTIES OF AIRCRAFT

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Abstract

The aim of the study presented in the paper was to examine the impact of changes related to aircraft modernization, the dynamic properties of an aircraft on the basis of five cases studied experimentally. Which changes in the dynamics of an aircraft structure occurred as a result of modernization can be experimentally tested by resonance tests. For this purpose, resonance tests should be carried out before the aircraft modernization and after its completion. In order to mapping the conditions of free flight the objects were suspended flexibly. The electrodynamics actuators were used to induce vibrations, piezoelectric transducers were used for the measurement of vibrations. The size and phase of extortion forces and their application points were selected individually for each resonance in order to get the best separation of it. The first stage of the study was based on recordings the frequency - amplitude characteristics. The second stage of the study was the identification of individual frequencies and mode shapes of each resonance, which was implemented by choosing the size and the proportion of mutual phase shifts between the extortion forces. In the selection the criteria based on minimizing the phase difference of vibrations measured at several points of the structure were used. The final stage of this study was to register the frequency and shapes mode of the tested resonance and the resonance generalized masses and damping coefficients.

Keywords: *ground vibration test, modal analysis, aircraft structure dynamics*

1. Introduction

In its life cycle an aircraft is subjected to upgrades. The first of them has already place to improve the prototypes, the others when the need arise to replace the equipment, change the aircraft usage profile or during routine repairs.

From the dynamics of construction point of view the modernizations introduce the changes of masses and stiffness of aircraft structure. After the upgrade the aircraft structure parameters of resonances may change, that is to say its dynamic properties.

Which changes in the dynamics of an aircraft structure occurred as a result of modernization can be experimentally tested by resonance tests. For this purpose, resonance tests should be carried out before the aircraft modernization and after its completion.

Paper is devoted to study of such cases investigated by the author during the improvements of I-22 Iryda aircraft prototype [1] and excerpted from literature, results of research before and after the modernization of F-18 Hornet aircraft onboard equipment [2].

2. Aim of the work

The aim of the study is to examine the impact of changes related to modernization, the dynamic properties of an aircraft on the basis of five cases studied experimentally. The paper posed the following questions:

- what changes of the dynamic properties can be expected as a result of modernization and the structure change of the same aircraft?
- and what regularities and the phenomena are accompanying these changes?

3. Test procedures

In order to mapping the conditions of free flight the objects were suspended flexibly, so that their frequency of vibration on the suspension was significantly lower than the resonant frequency of vibration of the structure.

The electrodynamics actuators were used to induce vibrations, piezoelectric transducers were used for the measurement of vibrations.

The size and phase of extortion forces and their application points were selected individually for each resonance in order to get the best separation of it [3].

The first stage of the study was based on recordings the frequency - amplitude characteristics.

The second stage of the study was the identification of individual frequencies and mode shapes of each resonance, which was implemented by choosing the size and the proportion of mutual phase shifts between the extortion forces

In the selection the criteria based on minimizing the phase difference of vibrations measured at several points of the structure were used.

The final stage of this study was to register the frequency and shapes mode of the tested resonance and the resonance generalized masses and damping coefficients [3].

As a result of resonance tests the register (the map) of several resonances was obtained.
The similar procedures were used during the tests of the F-18 Hornet aircraft.

Fig. 1. The test apparatus

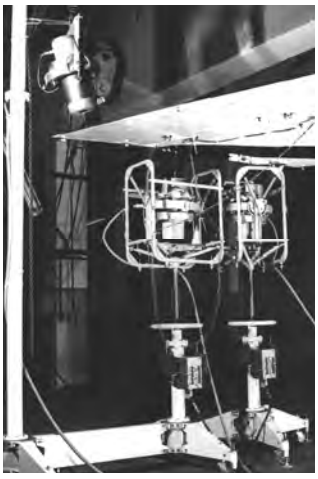

Fig. 2. Vibration actuators

4. Changes in dynamic properties resulting from the aircraft modification during the prototype improvement stage

In the process of testing and improvement of I-22 Iryda aircraft design, the several design changes were introduced. After the changes the structure resonance tests were performed, aimed to confirm the expected results.

The changes tested were the effects of the:

- stiffening of the pitot tubes booms at the wings tips,
- introduction of three ferrule vertical stabilizer,
- the introduction of mass equalizer,
- the introduction of spring locks on the wing flaps.

The stiffening of the pitot tube booms at the wing tips had a significant effect on the resonances with „wings twisting" modes.

Test results before and after modernization are shown in Tab. 1.

Tab. 1. Changes in the wing dynamic properties the after modernization of Pitot tube booms

Item	Vibration mode	f1[Hz] before modernisation	f2 [Hz] after modernisation	f2 f1
1	I symmetric and anti symmetric wing twisting	29	38	1.31
2	II symmetric and anti symmetric wing twisting	51	57	1.12

Before the modernization in the resonances of the frequency f = 29Hz the boom vibrations dominated, therefore, one has decided about their modernization. After the modernization the frequency of resonances in which the pitot tube booms were vibrating in phase with the twisting wings increased by 31%. Similarly, the resonances in which the booms were vibrating in the counter phase to the twisting wing, increased their frequency from 51 Hz to 57 Hz.

Introduction of the three ferrule horizontal stabilizer became the reason for disappearance of the 2-node bending resonance mode of the horizontal stabilizer (commonly called „the gob").

After modernization of the horizontal stabilizer the frequency of the resonances increased by approximately 20%.

Tab. 2. Changes in elevator dynamic properties after the introduction of third mounting ferrule

Item	Vibration mode	f1[Hz] before modernisation	f2[Hz] after modernisation	f2 f1
1	Symmetric elevator deflection	22.3	27.1	1.22
2	Anti-symmetric elevator deflection	35.7	43.2	1.21
3	2-node fuselage bending with vertical stabilizer bending	22.3	24.1	1.08

The introduction of the mass equalizer had on the target the reduction of control stick forces in the longitudinal channel. During the aircraft maneuver the inertial force of the equalizer is deducted from the force on the control system, while the correction force is proportional to the load coefficient.

On account of the mass equalizer introduction the new additional resonance occurred in the elevator control system. The new resonance frequency of 41 Hz had a vibration mode of „mass equalizer movement contrary to the control system movement".

Tab. 3. Changes in dynamic properties of the mass control system

Item	Vibration mode	f [Hz]
1	In-phase control stick and elevator deflection	2
2	Contra-phase control stick and elevator deflection	24.5
3	Mass equalizer deflection in contra-phase to the elevator deflection	41

The introduction of spring suspension locks on the flaps had on the target the elimination of backlashes and the associated vibrations within the flap system and their mechanisms.

The introduction of spring suspension locks increased the frequency of resonance with „flap extension" mode from the value of 34Hz to 48Hz.

Fig. 3. I-22 Iryda aircraft during the resonance tests

5. Changes in dynamic properties resulting from the modernization of aircraft equipment

Aircraft are exploited in the period of several years or even several decades. During this time they undergo repairs and upgrades to the different levels. Modernization usually affect the exchange of equipment - new generations of electronics and armament or changes to the aircraft application or destination.

An example might be the modernization of equipment of the F-18 Hornet aircraft [2].

The resonance tests of this aircraft were performed before and after its modernization.

Test results are presented in the Tab. 4.

Modernization has caused a 20 percent reduction in resonance frequency of 2-nodal vertical and 2-nodal horizontal fuselage bending modes. About 15 percent decreased the resonant frequency of a 1-nodal wings twisting mode.

Tab. 4. Results of the resonance tests of the F-18 Hornet aircraft before and after the modernization

Item	F-18 Hornet aircraft before and after the modifications	f1[Hz]	f2 [Hz]	f2 f1
1	2-node vertical wing bending	5.94	6.02	1.01
2	Horizontal fuselage bending	8.22	6.64	0.81
3	Vertical fuselage bending	9.57	7.76	0.81
4	3-node wing bending	8.78	8.33	0.95
5	1-node wing twisting	13.81	11.8	0.85
6	2-node wing twisting	12.29	12.13	0.99
7	Horizontal stabilizer A bending	13.59	13.45	1.01
8	4-node wing bending	16.11	17.00	1.06

6. Summary and conclusions

The study investigated the effect of changes related to modernization of the aircraft on its dynamic properties. The author had the results of his own investigations of I-22 Iryda aircraft and the test results of the F-18 Hornet aircraft.

In all presented cases the resonance tests were performed before and after aircraft modernization.

In those tested cases a few percent, several percent and even thirty percent changes of resonance frequency occurred. The increases of the frequency usually accompanied the upgrades aimed at improving the prototype design solutions, the decreases in the frequency were the result of modernization which in effect increased the mass of the aircraft fuselage.

Changes made during the aircraft modernization create a new image of its dynamics.

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