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EXPERIMENTAL AEROELASTIC ANALYSIS OF A TAPERED WING WITH EXTERNAL STORE CONSIDERING DIFFERENT PARAMETERS

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Abstract:

This paper aims to investigate aeroelastic stability of a wing subjected to external store using experimental method. The experimental tests have been performed in the wind tunnel with incompressible subsonic region. Aeroelastic model of the structure has been simulated using MSC PATRAN as a tapered wing. Boundary condition of the root of the wing as well as the store junction with the bottom of the wing, are clamped. The structure has been verified numerically using Nastran commercial FS, code. The effects of distance between the store and the clamped edge on the dynamic instability and the flutter velocity of the wing have been investigated. Moreover, effects of different parameters including aspect ratio, thickness of the plate and mass ratio have been studied and compared with numerical results. The experimental results show that the wing with lower aspect ratio, and higher thickness and mass ratio are reported to have higher value of flutter velocity.

Introduction:

Aeroelasticity is a field of aeronautics that deals with the interaction of vehicle structural components in terms of elastic and inertial characteristics, and aerodynamic loads. Aeroelasticity encompasses dynamic phenomena, such as buffet and flutter, and static phenomena, such as aileron reversal and wing divergence. Dynamic phenomena are highly undesirable and can result in a catastrophic instability if not eliminated during the design and development process. Aeroelastic instabilities, such as flutter, can jeopardize the ability of lifting surfaces, performance and survivability [Librescu, 2005]. The problems resulting from wing/store interaction in aviation, in particular military aviation have been a prominent topic in the aerodynamic community for decades. Many different approaches to understanding and solving these problems have been undertaken by researchers. But the complexity of the interplay of aerodynamics and structure has yet kept researchers from developing truly reliable concepts that can eliminate the unwanted and oftentimes dangerous effects of self-induced oscillations of configured wings. The stability problem of a rectangular wing subjected to external store has not received much attention experimentally and there has been a limited amount of published work dealing with the instability analysis of a wing with external store. Therefore the influence of different parameters on the aeroelastic behavior of wing with external store is necessary to be studied. Triplett et al. from McDonnell Aircraft Company, first, investigated analytically the possibility of adaptable wing/store flutter suppression using adjustable

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compensation in the feedback loop [Triplett 1973]. Honlinger under support from Messerschmitt-Bolkow-Blohm (MBB) installed forward vanes to external stores with the intention of using aerodynamic forces to suppress the onset of flutter [Honlinger 1975]. NASA Langley Research Center introduced the so-called decoupler pylon which mounted stores elastically to the wing, in contrast to the standard rigid connection. The idea was to decouple the store from the wing by using an elastic pylon and, with that, restore the performance capabilities of the wing [Reed 1979]. Simulations and wind-tunnel tests verified the potential of the method; it offered a practical alternative to previously pursued wing-based methods.Tang and Dowell designed and tested a delta wing/store model with freeplay in a periodic gust field in the Duke wind tunnel [Tang, 2006]. They discussed on the effects of the freeplay gap, the gust angle of attack and the initial conditions on the gust response. They showed that the quantitative correlations between the theory and experiment were reasonably good, but in the range of the dominant resonant frequency of this nonlinear system, i.e. at larger response amplitudes, the correlations were not good. Gern and Librescu analyzed the static aeroelastic response and flutter instability of straight/swept aircraft wings carrying external stores along their span and at their tip [Gern, 1998].The effect of thrust on the aeroelastic instability of a composite swept wing with two engines in subsonic compressible flow was investigated by Firouz-Abadi et al. [Firouz-Abadi, 2013]. Amoozgar et al. investigated the aeroelastic instability of a wing, modeled as an orthotropic composite beam with a concentrated mass subjected to the engine thrust, in an incompressible flow [Amoozgar, 2013].Dowell et al. in their latest edited monograph discussed the current theoretical, computational and experimental research conducted in nonlinear aeroelasticity [Dowell, 2004].

Method:

Statement of the problem:

A typical configuration of tapered wing subjected to an external store according to Figure1 is considered in this paper. Due to using the thin airfoil theory in the analysis, a thin plate is utilized to model the wing. The length of root of the wing is 30cm and considered fully clamped boundary condition. Other dimensions of the plate have arbitrary values in different cases.

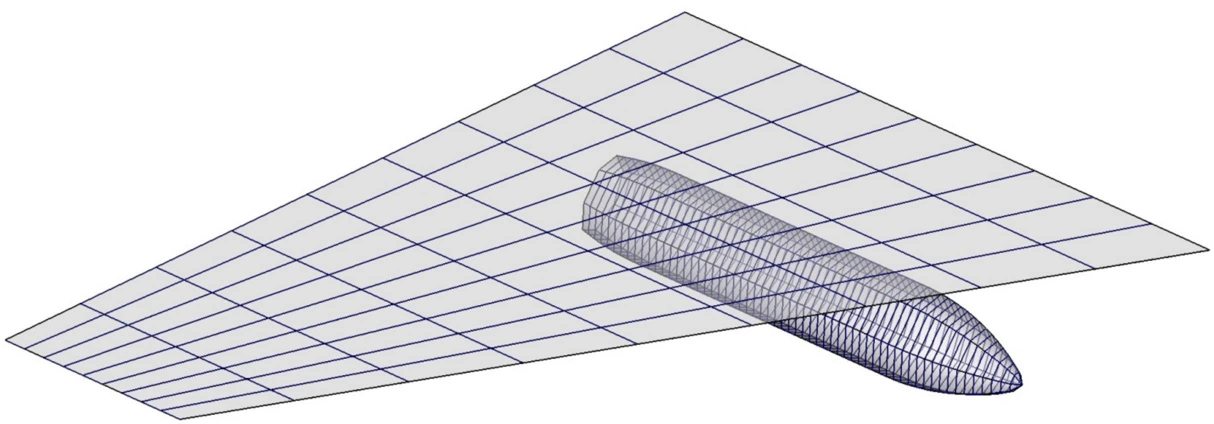

Figure 1: *Schematic view of the wing with external store*

The plate is made of steel and its material properties are listed in table 1. Since the flutter test is a destructive test and it is possible that plate experiences failure in the tunnel and makes problem for fan; thus, using a material with higher flexibility, such as steel, is in preference than brittle material.

Table 1*: material properties of steel*

Density(kg/m^3)	Poisson ratio	Young modulus(Gpa)	Thickness(mm)
7800	0.3	210	1

In the numerical simulation using Patran code, the plate is meshed using shell element with four nodes and store is considered as a beam model in structural simulation. The external store has a maximum diameter of 5cm and length equal to of 20cm. The position of the store is along the wing with 5cm distance from the bottom of the wing (Figure 1) and is jointed to the wing by two rigid links. Dubllet Latice Method (DLM) theory is used for incompressible flow in low subsonic region. Plate and store are meshed as flat plate lifting surface and slender body in aerodynamic simulation, respectively. In addition, in aero-structure coupling, surface spline and beam spline are used for plate and store. Governing equations of the aeroelastic model are solved by the PK method in software analysis.

Experimental modeling

The experimental wing/store configurations are the same as those of the theoretical model. Steel thin plate is used as a wing model. Wing/store model is shown in Figure 2. Junction between wing and store is supplied by two rigid links that shown in Figure 3. As it has been shown in Figure 4, store is made of three parts. Also, the middle part is made of aluminum because the junctions between wing and store are located in this part. The forward and the aft part are made of composite materials because these parts do not carry any structural loads.

Figure 2: *Wing/store model*

Figure 3: *Junction between store and wing*

End part *Middle part* *Front part*

Figure 4: *Different parts of stores*

Three accelerometers are installed on the wing for modal analysis of win/store model that shown in Figure 5. Modal analysis is done to obtain natural frequency because of correlation between experimental and finite element (FE) model. Also, natural frequency is needed for non-dimensional Flutter Speed.

Figure 5: *Installing accelerometers on the wing/store model*

The first four natural frequencies of the wing/store model obtained using a standard code in finite element method, i.e. NASTRAN, are shown in table 2. Also, the corresponding experimental results are shown in table 2 that reveal a good accuracy in the modeling. These results are for a specific state of store location on the wing (0.4 span location of store).

Table 2: *Natural frequency*

Natural frequency (HZ)	Mode 1	Mode 2	Mode 3	Mode 4
FEM	1.98	6.76	11.7	14.09
EXP	2.01	6.8	11.83	14.16

Wind tunnel test

In order to evaluate the flutter, created model was installed in the wind tunnel and has been tested. Wind tunnel that we used in the experimental test is the open-circuit tunnel. Figure 6 shows the blow-down of the subsonic wind tunnel, with six axial-flow fans at exit section and 80×100cm^2 in the cross-sectional size of the test section. The change in speed of the wind tunnel is done by two ways. It can be adjusted by changing the suction fan rotation of the wind tunnel or by injectors before diffuser section. It must be noted that the installation of the model into the test chamber is similar to modal analysis. The velocity is increased gradually and consequently the related flow velocity corresponding to flutter occurrence is recorded as flutter velocity. The flutter occurrence time can be easily observed without any special device in tunnel. Installing model into the tunnel is shown in Figure 7.

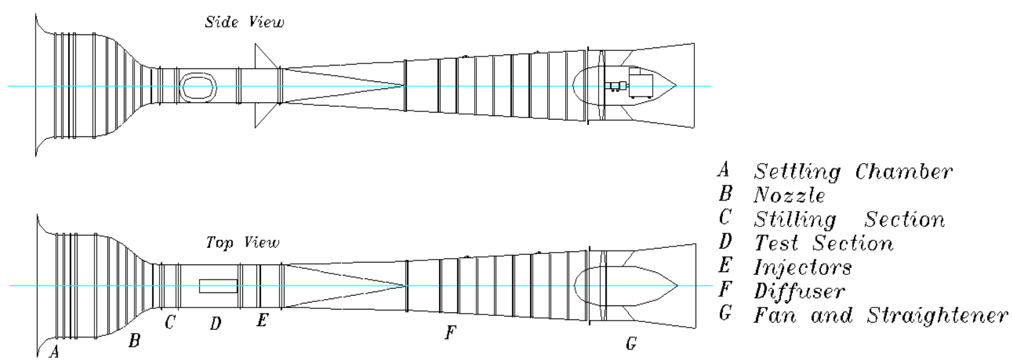

Figure 6: *Subsonic wind tunnel*

Figure 7: *Installing model into the tunnel*

Results

A comprehensive experimental aeroelastic analysis was performed on the flat plate with different geometries. The results obtained from the experimental test were compared with those of the FE simulation in Nastran commercial FS, code. The results demonstrate a very good agreement between experimental and numerical analyses. In order to compare the results in the best and obvious way, all the values of flutter velocity have been plotted as non-dimensional versus different parameters. All numerical results are presented regarding to non-dimensional value of location of the store. This non-dimensional value is ratio of distance of store from clamped edge to length of the span. The non-dimensional value of flutter velocity is $U/b\omega$ where U, b and ω are flutter velocity, wing span and first torsional frequency respectively. Figure 8 shows the effect of thickness on the flutter velocity. It is observed while the store has a constant mass, by increasing the thickness from 0.5mm to 1mm the non-dimensional flutter velocity increases. Hence, dynamic instability occurs in higher velocity. Figure 9 depicts the effect of aspect ratio for a flat plate with 1mm thickness. It is apparent that increasing the aspect ratio leads to reduce the non-dimensional value of flutter velocity. Figure 10 investigates the effect of the mass ratio (μ) (which is defined as the store mass divided to the wing mass) on the flutter velocity. It can be concluded that as the value of (μ) increases, the non-dimensional value of flutter velocity increases. Furthermore, for different values of (μ), the velocity of the flutter increases with increasing the distance of the store and clamped edge. This process continues with higher slope, if the value of μ increases.

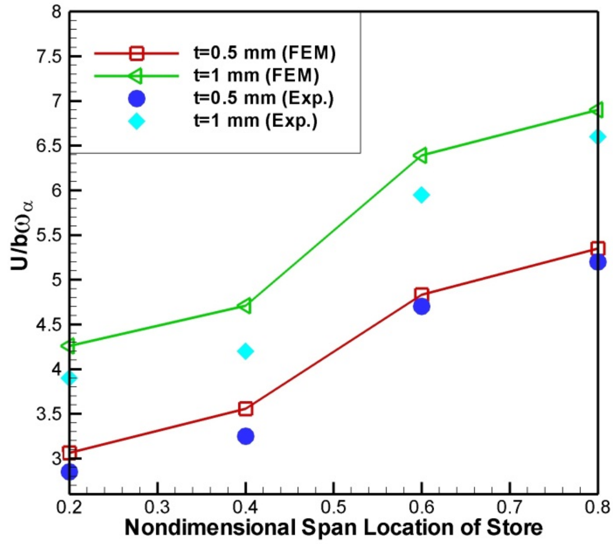

Figure 8*: The effect of thickness on the non-dimensional values of flutter velocity*

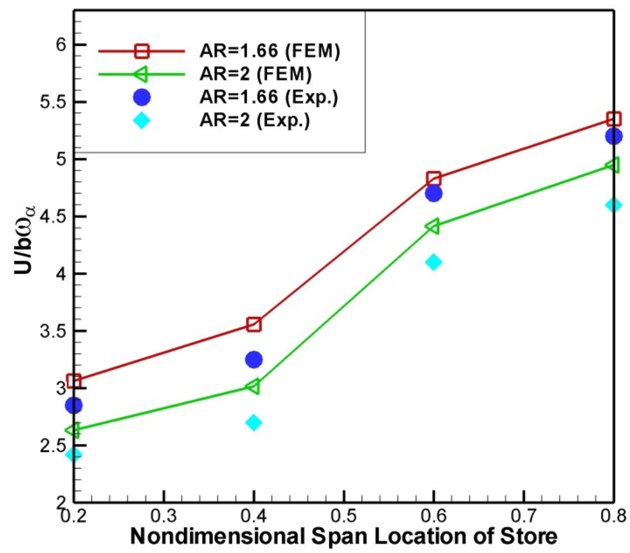

Figure 9: *The effect of aspect ratio on the non-dimensional values of flutter velocity*

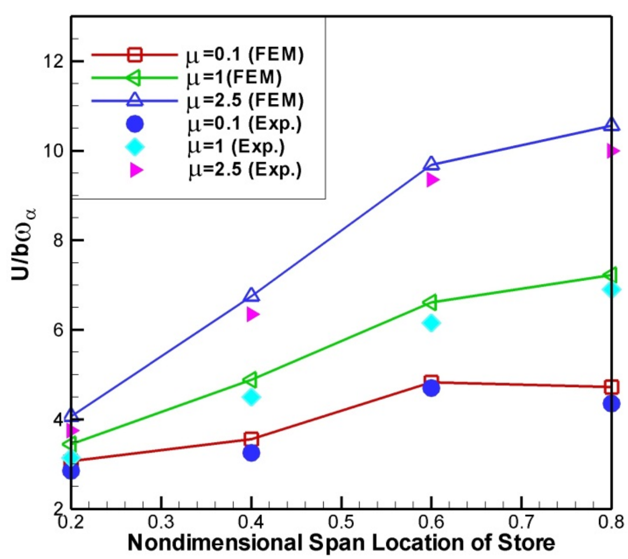

Figure 10*: The effect of mass ratio on the non-dimensional values of flutter velocity*

Conclusion

An experimental flat plate model was developed and used to study the aeroelastic instability of a wing subjected to external store. The effects of parameters including thickness, aspect ratio and mass ratio as well as the distance of the store from root of wing on the stability and frequency boundaries of the structure were studied. It was shown that adding the store to the system has a significant effect on the aeroelastic stability which in different cases leads to reduce or increase in the flutter velocity. Furthermore, by increasing the distance between the store and the root of wing, non-dimensional value of flutter velocity increases. Also, it can be concluded that increasing the thickness leads to obtain a stable system. Higher aspect ratios lead to lower non-dimensional values of flutter velocity. On the other hand, the non-dimensional value of flutter velocity increases by increasing of the mass ratio. The numerical results obtained by Nastran commercial code verify accuracy of the experimental results.

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