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Aeroelastic analysis of turboprop commuter aircraft with tip-tanks

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This paper deals with aeroelastic (flutter) analysis of an aircraft with unconventional wing structure, which is specific by the installation of wing-tip tanks. The subjected aircraft is twin wing-mounted tractor turboprop commuter aircraft for 19 passengers, with a wingspan of 9.6 m and a maximal take-off weight of 7000 kg. The paper is focused on the assessment of specific flutter issue, originating from the unconventional wing configuration. Further, another flutter issues related to elevator flutter and rudder flutter are described.

Aircraft are required to have a reliability certificate including the flutter stability. Flutter analysis must include all mass configurations in terms of fuel or payload, which are applicable at an aircraft operation. These configurations are given from the typical flight profiles. Installation of tip-tanks significantly increases the number of applicable mass configurations. During the flight, the fuel is transmitted from the tip-tanks to the main tank, when enough space becomes available. The amount of fuel in the tip-tanks decreases while the fuel in the main tank increases; however, it must also take into account the fuel consumption because the fuel pumping process takes some time, during which the aircraft is burning fuel. Installation of tip-tanks causes significant variability in characteristics of the wing bending and torsional modes. Fuel load in the tip-tank represent large moment of inertia, even placed at the wing-tip, and therefore, frequencies of wing torsional modes rapidly increase as the wing-tip fuel load decrease. At the same time, frequencies of the wing bending modes are increasing as well; however, the rate of change is considerably lower. As a consequence, the crossing of frequencies of some bending and torsional modes inherently appears with the negative outcome to the wing bending - torsional flutter. This flutter is very sensitive to the wing modal characteristics.

Wing bending – torsional flutter: For the subjected aircraft, the major contributing modes of the mentioned bending - torsional flutter type were 1st symmetric wing torsion and 2nd symmetric wing bending. In addition, Symmetric engine pitch vibration mode was also contributing to this flutter. Considering the maximal flight distance flight profile, frequency of the 1st symmetric wing torsion rapidly increased as long as the tip-tank fuel was decreasing (i.e., during fuel transmission) and remained at the same level for the zero tip-tank fuel. Contrary to that, frequency of the 2nd symmetric wing bending mode increased as long as the wing fuel was decreasing, and remain roughly at the same level during the fuel transmission process. Considering the early-stage computational model, based on the structural parameters, which were set according to the virtual model, there was the frequency crossing of 1st symmetric wing torsion and 2nd symmetric wing bending modes with the consequence in the significant drop in the flutter speed. The lowest flutter speed values were under the certification velocity ($1.2{*}V_D$) for some mass configurations and for some flight altitudes. Such a case would not be acceptable with respect to the certification rules. After the ground vibration test (GVT) of the aircraft prototype, computational model was updated according to the results of GVT. Such a model, with the relation to the real prototype structure is considered as more reliable. Considering the updated model, the frequency crossing was eliminated as the frequency of the 1st symmetric wing torsion mode significantly increased. Consequently, flutter speeds got higher and well above the certification threshold. Also, flutter frequencies increased. The certification problem of bending - torsional flutter was therefore eliminated.

Elevator flutter: Elevator of the subjected aircraft was specific due to its large static unbalance (centre of gravity aft a hinge axis). In general, static unbalance makes a structure vulnerable to control surface flutter. In addition, static unbalance has usually negative effect on a dynamic balance with respect to common modes of a surface. Therefore, static unbalance is not generally recommended, but it is acceptable, provided no flutter appearance within the certification envelope is properly justified. Elevator unbalance was adopted from the previous specification of the subjected aircraft. Although, the unbalanced elevator has been already in operation, flutter study was required anyway, at least due to the increase in certification speed of the subjected aircraft compare to the previous specification. Several types of elevator flutter or elevator tab flutter (both symmetric and antisymmetric) were found; each of them was caused by a specific combination of elevator and tailplane modes. Finally, flutter study evidenced no flutter inside the envelope of required stability considering the nominal state and considering the reasonable variation of structural parameters. Thus, unbalanced elevator might have been applied on the subjected aircraft.

Rudder flutter: Vertical tail and rudder of the subjected aircraft was, compare to the previous specification of the aircraft, modified. Modification included increase in span, and increase in rudder horn balance surface in terms of both span and chord. Consequently, rudder mass-balance weights were modified as well. Removable weights to adjust the rudder balance were placed at the leading edge of the horn balance. There was found rudder flutter instability with the combination of rudder flapping and rudder torsional mode. Also, rudder tab flapping mode was contributing to this flutter issue. The key factor was increase in the mass moment of inertia of the upper rudder part due to the increase in mass-balance weight arm. Considering the nominal (statically balanced) rudder, flutter speed was very close to the margin of the required stability, but still above the certification threshold. However, any unbalance of rudder would push the flutter speed below the threshold. Moreover, rudder over-balance by increasing the removable weight placed at the horn balance leading edge had almost no effect on the flutter speed. Therefore, the study of rudder dynamic balance with respect to node lines of appropriate modes was performed. The study evidenced small dynamic effect of the horn balance weight with respect to the flutter major mode. After that, optional placement for the mass-balance weight, which was dynamically effective, was determined. The removable mass-balance weight was moved to this new, rudder bottom-part, position. Over-balance using the new weight placement had significantly stabilising effect. Therefore, the problem of rudder flutter was eliminated.

References

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