Passive control of HALE aircraft wings with tuned mass dampers

Controle passive de asas de aeronaves HALE com tuned mass dampers

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ABSTRACT

In this paper we study the control of vibrations of a HALE aircraft wing using TMD devices. The structure was modeled using a commercial structural analysis software. The wing profile and material characteristics used were provided in available literature. Aerodynamic loads of random nature are simulated. When the first natural frequencies of the structure are close to the aerodynamic loads frequencies it can lead to unsafe flying conditions due to resonance. In addition, it can shorten the frame life due to material fatigue and further maintenance may be required. Processing suggests the presence of accelerations above the desired or anticipated by several international standards on the subject. To mitigate them, passive vibration absorber (TMD's, Tuned Mass Dampers) control is proposed for vertical and lateral vibrations.

Keywords: Hale aircraft, Vibrations, TMD's, Dynamic analysis.

RESUMO

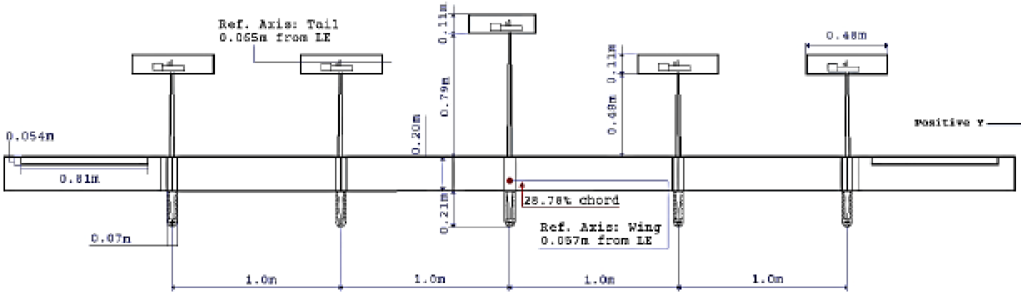
Neste artigo, estudamos o controle de vibrações de uma asa de aeronave HALE usando dispositivos TMD. A estrutura foi modelada usando um software comercial de análise estrutural. O perfil da asa e as características do material usados foram fornecidos na literatura disponível. Cargas aerodinâmicas de natureza aleatória são simuladas. Quando as primeiras frequências naturais da estrutura estão próximas das frequências de cargas aerodinâmicas, isso pode levar a condições de voo inseguras devido à ressonância. Além disso, pode reduzir a vida útil da estrutura devido à fadiga do material e pode ser necessária manutenção adicional. O processamento sugere a presença de acelerações acima do desejado ou antecipado por diversas normas internacionais sobre o assunto. Para mitigá-los, controle por absorvedor de vibração passivo (TMD's, Tuned Mass Dampers) é proposto para as vibrações verticais e laterais.

Palavras-chave: Aeronave HALE, Vibrações, TMD's, Análise dinâmica.

1 INTRODUCTION

HALE or (High Altitude Long Endurance) are light, resistant and economic aircraft. Its main feature is the utilization of very flexible wings to reach high altitudes and give greater autonomy to aircraft, such as VANTs (Tang and Dowell, 2001). As these wings are very flexible, their first frequency can be close to the frequency of aerodynamic loading, displacing and deforming the wings excessively, reducing the useful life of the material due to fatigue and even leading to flight instability. According to (Perroni, 2019), a wing can be considered as a cantilever beam, using classic beam deflection theory. As there are large deflections, it's necessary to use the exact expression of the curvature. The HALE that will be analyzed was developed by ITA (Brazilian Air Force Technological Institute of Aeronautics). Known as X-HALE, 6m half span length, consists of 5 booms with an engine propeller weighing 10.89kg. The distance between the booms is 1m and the others dimensions are showing in Fig. 1.

Figure 1. X-HALE dimensions of 6m wingspan.



Source: (Jones and Cesnik, 203)

It's possible to check all features about X-HALE in (Perroni, 2019).

2 PASSIVE CONTROL – TMD (TUNED MASS DAMPERS)

The TMD's are known as vibration absorbers or passive vibration control. It means that TMDs don't need an external power supply to act. Its modeling can be carried out through the basic principles of physics by redistributing the vibration energy. Its implementation and maintenance costs are cheaper than active dampers usually used in aircraft. However, as a negative point, a single TMD can only be tuned with one specific frequency. If there is a large critical range of frequencies that one wants to obtain the same kind of control, it will be necessary to use several TMD's tuned to different frequencies, see, for example, Brasil and Silva (2015).

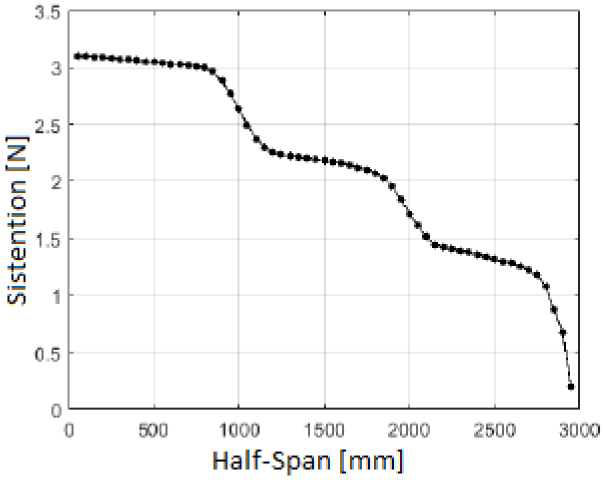
For this work, a TMD will be modeled resonant with a HALES's first wing vibration mode. Due to its large wingspan and low stiffness, it is expected that the fist mode is the transverse flexure mode.

3 AERODYNAMIC LOADS

According to (Perroni, 2019) the aerodynamic load can be applied in 3 different and equivalent ways on a wing. The force can be applied either to the pressure center or the aerodynamic center, approximately 25% of the wing string from the leading edge, or to the wing string itself. Here, the procedure chosen for the application of the loads will be in the aerodynamic center of the wing. A type of aircraft maneuver will be considered as a symmetrical "pull-up", which has a load factor of $n = 2.5$, thus being the most critical load.

In (Perroni, 2019) we have the aerodynamic lift load dispersed in point loads along the wing, every 50mm, as shown in Fig. 2.

Figure 2. Aerodynamic loading, load factor n = 2.5.



Source: (Perroni, 2019)

All point loads were added and distributed over the 3m of the half-wing. With that, a uniform load was applied along the beam with 42.13 N/m. To show the impact of the TMD, the load time history will be considered harmonic in resonance with the structure.

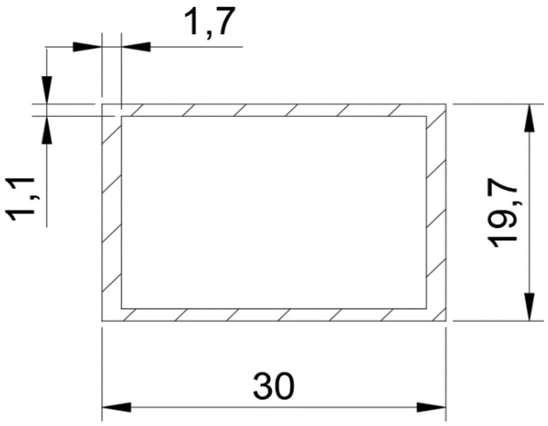
4 WING'S MODEL

The half-wing was modeled using the STRAP software, Fig. 3a. It was considered, as in (Perroni, 2019), a hollow rectangle with the dimensions shown in Fig. 3b. Aluminum Al2024-T351 used in aircraft structures was considered.

Figure 3a. Front view of the wing, fixe on the right end.

Source: Authors

Figure 3b. Wing cross section (mm).



Source: Authors

In the modal analysis, the structure's own mass and the mass of the 106.83 N booms located at 1 meter and 2 meters from the fixed base were considered. With that we have the following results for the first 9 modes of vibration described in Tab. 1.

Table 1. Wing vibration modes

MODAL DATA: Eigenvalues (Units: ton, meter)				
Mode No.	*Eigenvalue (Omega**2)*	*Natural Frequency*	*Period*	*Max translation Node-DOF*
1	14.977	0.6159	1.62357	4-3
2	34.938	0.9407	1.06300	4-2
3	628.468	3.9899	0.25063	4-3
4	1459.875	6.0810	0.16445	4-2
5	5535.889	11.8417	0.08445	4-5
6	10161.767	16.0437	0.06233	4-4
7	299646.625	87.1214	0.01148	3-1

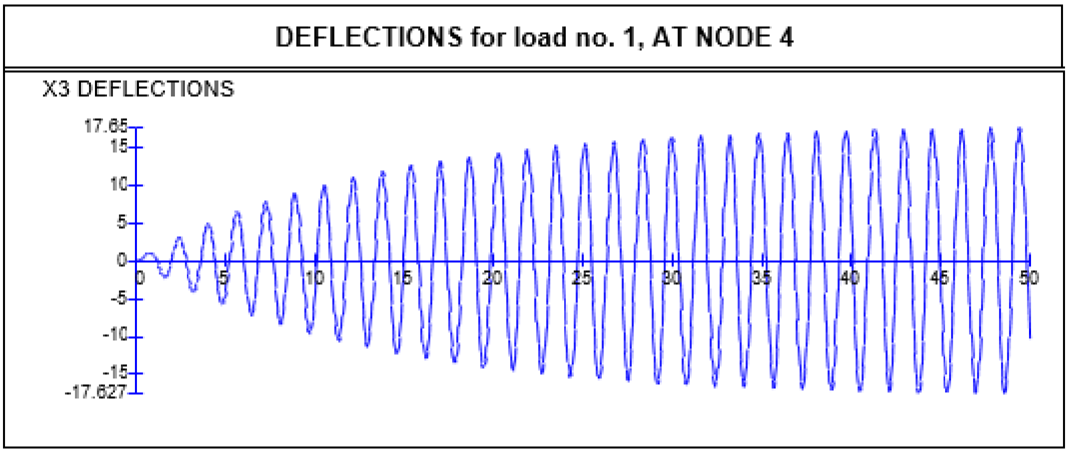
8	2060072.250	228.4343	0.00438	2-1
9	53373176.000	1162.7374	0.00086	4-1

Source: Authors

It is important to note that the X1 axis is the horizontal and longitudinal displacement of the wing, the X2 axis is the horizontal transverse of the wing and the X3 axis is the vertical of the wing.

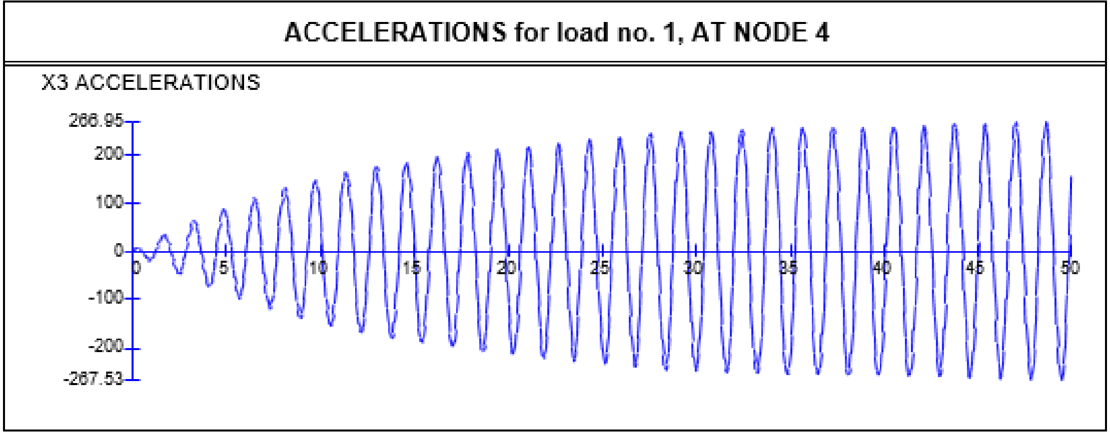
As previously mentioned, the frequency of the dynamic support load will be adopted to be the same as the first mode found, 0.616 Hz. It was considered a 2% damping in the structure to simulate the interaction between the wing profiles with the screws. With this loading, we have a structure in resonance with the loading. Results for displacement and acceleration over time at the wing tip on the X3 axis are shown in Figures 4 and 5.

Figure 4. Displacement in X3 (mm)



Source: Authors

Figure 5. Acceleration in X3 (mm/s²)



Source: Authors

It is evident in figures 4 and 5 the necessity to use TMD to mitigate the results presented.

5 WING’S MODEL WITH TMD

As a TMD consists of a spring mass system, a cantilever beam fixed in a desired point of the wing will be modeled, with equivalent stiffness and a point mass at its tip. The equivalent stiffness at the free end of the beam is given in Eq. 1:

$$k = \frac{3EI}{L^3} \qquad (1)$$

where “E” is the modulus of elasticity of the material, “I” the moment of inertia and “L” the length of the beam.

With that, a beam of the same material used in the wing will be proposed, with a square section of 4x4 mm. The TMD will have a mass of 3% of the mass of HALE's half-wing. Such mass is chosen in order not to overload the structure. With that, we have a mass fixed at its end of 1.129 kg. For the TMD to be in resonance with the loading, we have the following Eq. 2:

$$k = \omega^2 m \qquad (2)$$

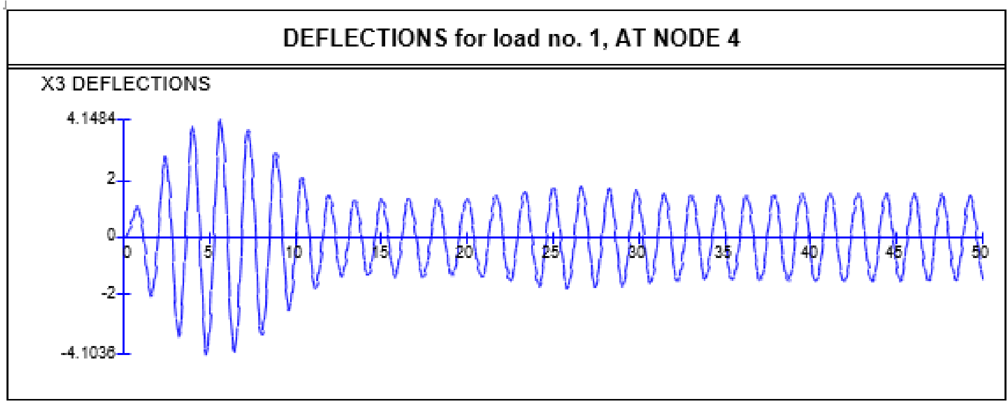
where “ω” is the frequency in rad / s and “m” is the mass of the TMD. With this it is possible to calculate the length L = 65.15 cm, with that, the TMD is in resonance with the loading.

Three placements for TMD’s were analyzed. Two meters from the fixed base of the wing, parallel to the wing axis. At the tip of the wing, parallel to the wing axis, and 3 TMD’s distributed every meter of the wing, always parallel to the wing axis. For the third case, it is necessary to recalculate the TMD’s using 1/3 of the mass for each TMD. This gives us a new L length equal 93.96 cm for a mass of 0.376 kg.

6 RESULTS

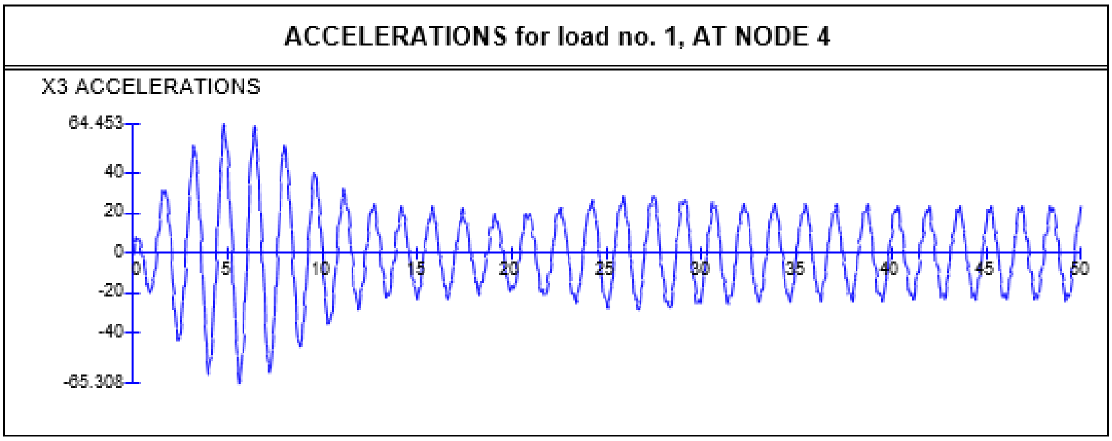
Considering a 2% damping for the TMD’s, we have the following results in Fig. 6 to Fig. 11 of displacement and acceleration at the wing tip for the solutions proposed.

Figure 6. Displacement in X3 with TMD at 2m from the fixed base (mm)



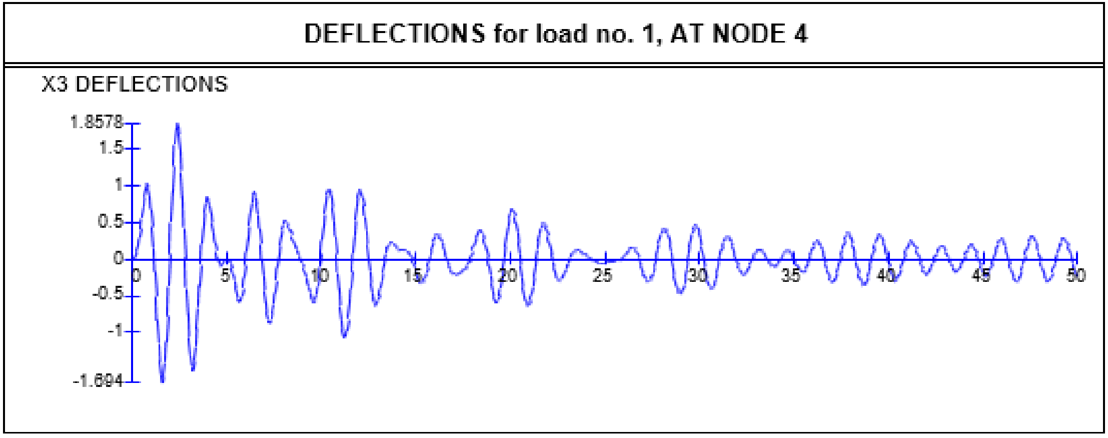
Source: Authors

Figure 7. Acceleration in X3 with TMD at 2m from the fixed base (mm/s²)



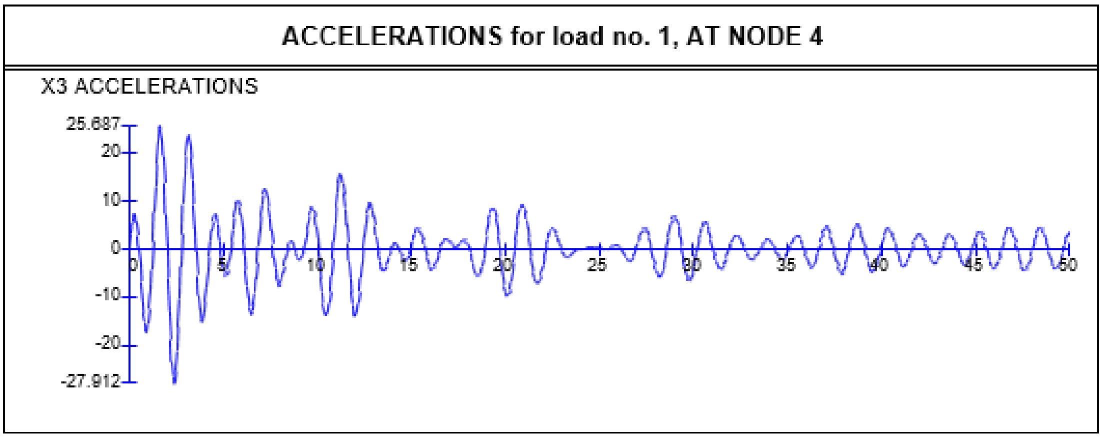
Source: Authors

Figure 8. Displacement in X3 with TMD at the tip of the wing (mm)



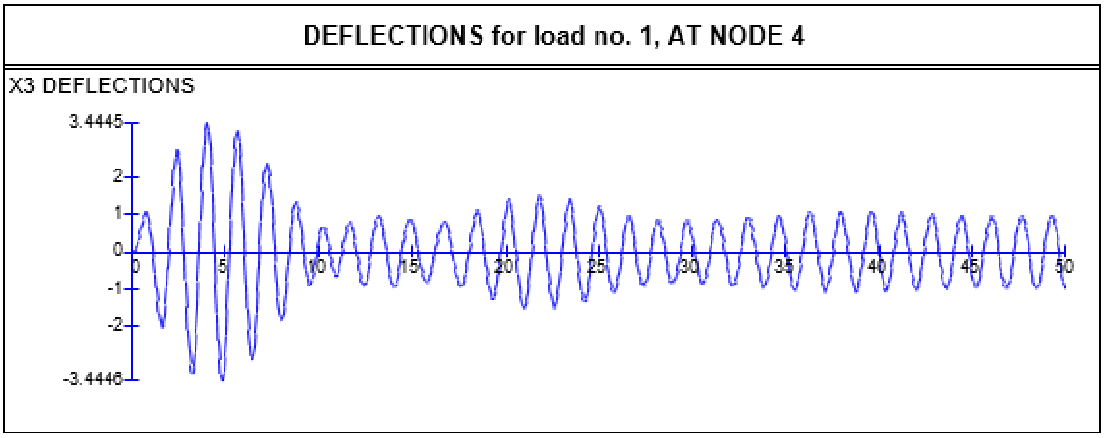
Source: Authors

Figure 9. Acceleration in X3 with TMD at the tip of the wing (mm/s²)



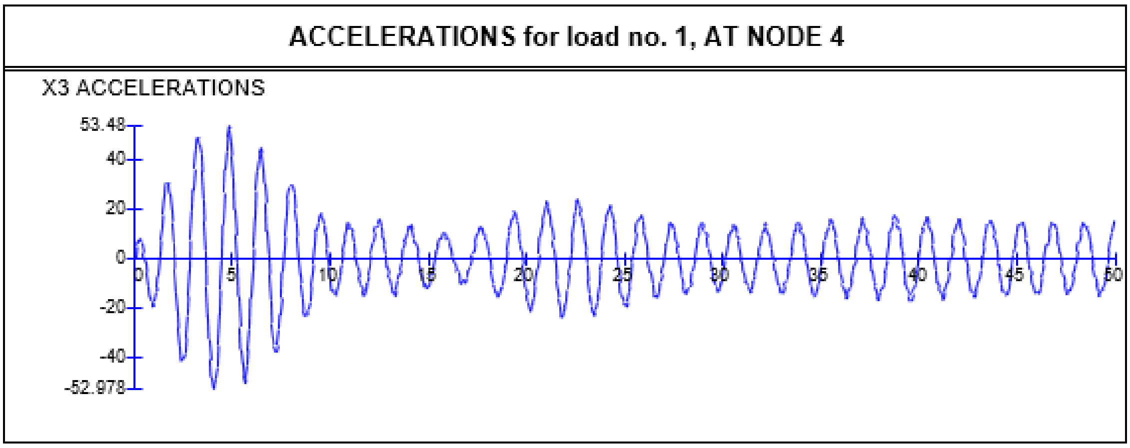
Source: Authors

Figure 10. Displacement in X3 with 3 TMD (mm)



Source: Authors

Figure 10. Acceleration in X3 with 3 TMD (mm/s²)



Source: Authors

7 CONCLUSIONS

From the presented simulations, it is evident that TMD's have mitigated the effects of resonance loading. Among the three proposed positions, a single TMD positioned on the tip of the wing obtained the best result, followed by the use of 3 TMD's and finally, with a TMD positioned at 2 m from the clamped base. This passive method of vibration control can make it possible to develop wings with longer wingspans without losing the stability of the wings in flight.

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Peço que por gentileza que após o pagamento envie para o mesmo email que estava conversando com o editor comprovante e artigo em formato Word.