Control of helicopter ground resonance by means of passive non-linear energy sink

Baptiste Bergeot, Sergio Bellizzi, Bruno Cochelin

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B. Bergeot[a], **S. Bellizzi**[b], **B. Cochelin**[c]

LMA, CNRS UPR7051, Aix-Marseille Univ., Centrale Marseille, F-13402 Marseille Cedex 20, France

[a]baptiste.bergeot@centrale-marseille.fr

[b]bellizzi@lma.cnrs-mrs.fr

[c]bruno.cochelin@centrale-marseille.fr

Extended Abstract

Problem Statement. Helicopter Ground Resonance (HGR) [1, 2] is a dynamic instability involving the coupling of the blades motion in the rotational plane (i.e. the lag motion) and the motion of the fuselage. HGR can be very violent and can lead to the total destruction of the aircraft. The present work is a preliminary study of the capacity of a passive nonlinear absorber (or Nonlinear Energy Sink (NES)) to control an HGR.

Framework. In the domain of passive control vibration, it has been shown that the use of a NES can provide very interesting results. Under certain conditions an irreversible energy transfert from the primary system to the NES can occur. This phenomenon is called Targeted Energy Transfert (TET). In their seminal paper [3], Gendelman *et al.* analyze TET in term of resonance capture and nonlinear modes. More recent works show that the use of NES is also an interesting way to control dynamic instabilities. For instance, Lee *et al.* [4] show that a NES coupled to a wing in subsonic flow can partially or even completely suppress flutter instability by TET from the wing to the NES.

The simpler helicopter model that can describe HGR is well known. It involves only lag motion of the four blades and one direction of the fuselage motion. Linear stability of this model shows that HGR is due to a frequency coalescence between a lag mode and the fuselage mode and predicts the range of rotors speeds Ω for which this frequency coalescence occurs. In this work a NES is coupled to the fuselage in an ungrounded configuration (see Fig. 1). The differential equations which govern the time evolution of the fuselage displacement $y(t)$, the NES displacement $h(t)$ and the blades lagging angles $\delta_i(t)$ (with $i \in [1,4]$) can be easily derived using Lagrange's equations. These equations of motion are:

$$\left\{\begin{array}{ll} (M+4m_\delta)\,\ddot{y} + c_y\dot{y} + k_y y + \mu(\dot{y}-\dot{h}) + \alpha(y-h)^3 & \\ +m_\delta \displaystyle\sum_{i=1}^{4}\left\{L\ddot{\delta}_i\cos(\psi_i+\delta_i) - L\left(\Omega+\dot{\delta}_i\right)^2\sin(\psi_i+\delta_i)\right\} = 0 & \text{(1a)}\\ m_h\ddot{h} + \mu(\dot{h}-\dot{y}) + \alpha(h-y)^3 = 0. & \text{(1b)}\\ m_\delta L^2\ddot{\delta}_i + c_\delta\dot{\delta}_i + k_\delta\delta_i + m_\delta L\ddot{y}\cos(\psi_i+\delta_i) = 0 & \text{(1c)}\\ \text{with} \quad \psi_i = \Omega t - 2\pi\dfrac{i-1}{N}, & \end{array}\right.$$

where $N = 4$ is number of blades, M is the mass of the fuselage, m_δ is the mass of one blade, m_h is the mass of the NES ($M > m_h$), c_y, c_δ and μ are damping coefficients, k_y and k_δ are linear stiffness coefficients and α is the cubic stiffness coefficient of the NES.

Results. Numerical parametric investigation of the system of equations (1) is performed. It consists to determine the possible regimes in the parameter space. We show that it is possible to partially or even completely suppress HGR by passively transferring energy from the fuselage to the NES. As in [4], three responses for the fuselage motion are highlighted: *strongly modulated response (SMR)*, *partial suppression* and *complete suppression* of the HGR. An example of SMR is depicted in Fig. 2.

We are currently working on the design of the NES. The aim is to know if the NES parameters leading to a good control of the HGR are compatible with industrial applications.

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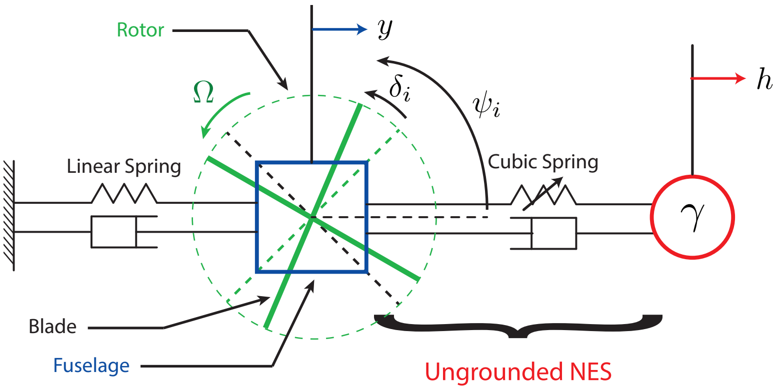
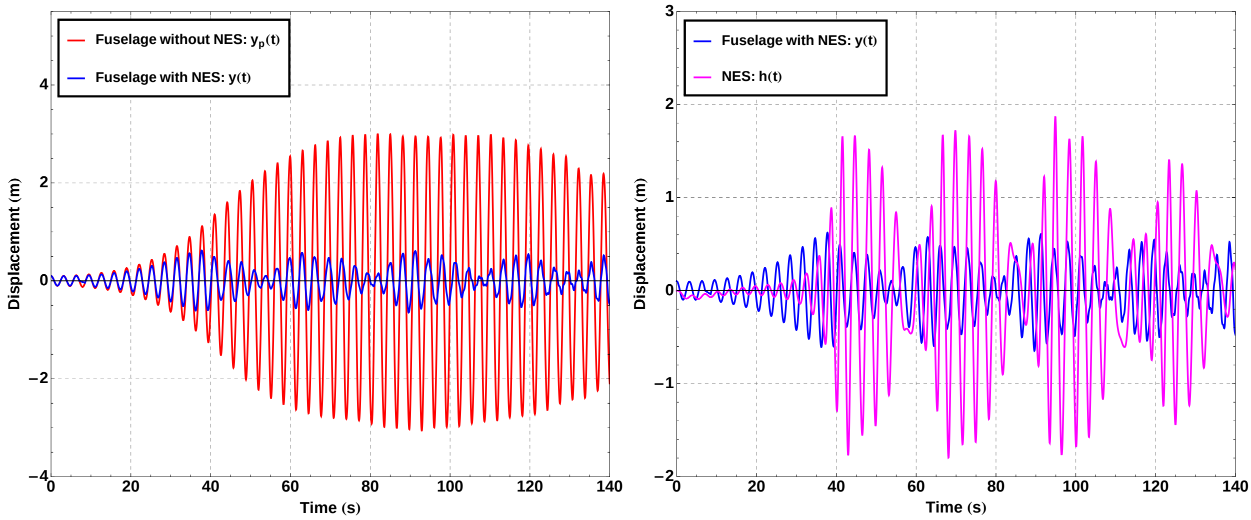


Figure 1: Schematic representation of the studied system.



(a) (b)

Figure 2: (a) Comparison between the fuselage motion without NES $y_p(t)$ (red line) and the fuselage motion with NES $y(t)$ (blue line). (b) Comparison between the NES motion $h(t)$ (magenta line) and the fuselage motion with NES $y(t)$ (blue line).

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