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Stability and Response of a Forward Mounted Servo-Tab Driven by a Sub-Servo-Tab

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Background

The objective of this research is to determine the effectiveness, stability, and response of a rotor controlled by a servo-tab mounted in front of the leading edge of the rotor blade. This servo tab is itself is actuated by its own trailing edge servo tab. As a result an effective two step amplification of control power using the free stream is proposed to reduce the control power requirements to the point that small electric actuators could be used. Hydraulics and swashplates will be eliminated in favor of a lightweight on-blade system that allows for higher harmonic control and lower vibrations. A forward mounted servo tab is chosen because of the positive servo tab lift with increasing commanded rotor blade pitch. The servo tab and its mounting structure adds weight far forward on the rotor blade which has a stabilizing effect on pitch. Also the servo tab is free floating on its hinges and aerodynamically stable in order to “weathervane” into the local airflow and have less de-stabilizing effect on the rotor blade from an aerodynamic center standpoint despite its location in front of the rotor blade.

Approach

The design is shown in Figures 1 and 2 and utilizes a rotor blade 62 controlled by a leading-edge servo-tab 60, which is controlled by its own servo-tab 66.

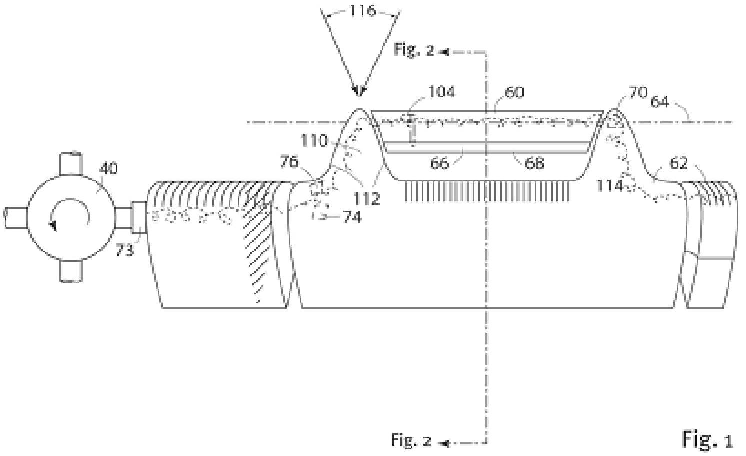

Figure 1 – Schematic Diagram of Leading-Edge Servo-Tab

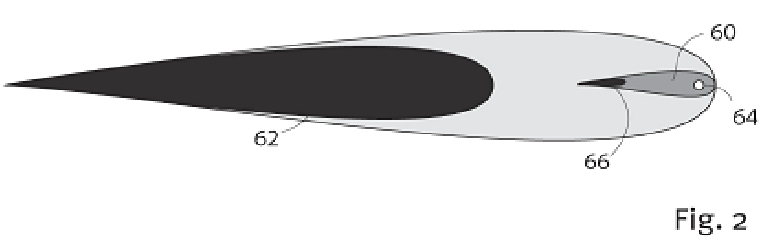

Figure 2 – Cross Sectional View of Leading-Edge Servo-Tab

In order to solve for the stability and response for the system, the equations of motion are derived using Lagrange’s energy method from the free-body-diagram. However, the equations of motion do not include the fact that there is a smaller servo-tab driving the leading-edge servo-tab. The schematic used for deriving the equations of motion has been simplified down for a general case with a leading-edge servo-tab with an applied moment and lift (servo-tab on the servo-tab) and with blade flapping neglected (a tip-path-plane analysis).

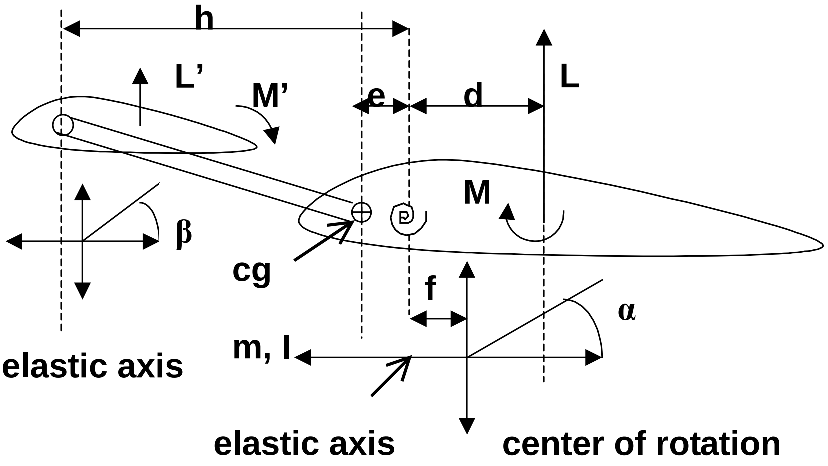

Figure 3 – Free Body Diagram of a Leading-Edge Servo-Tab

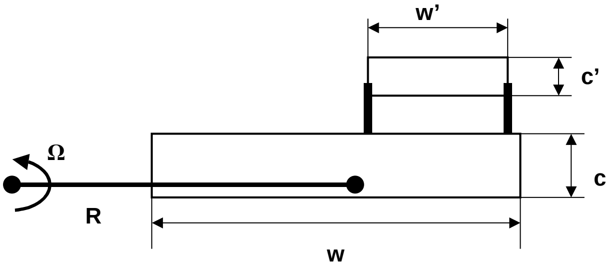

Figure 4 – Top view of Free Body Diagram of a Leading-Edge Servo-Tab

Using Lagrange's energy method, the equations of motion for the first simplified case are for the concept on any size vehicle:

$$\begin{gathered}\begin{bmatrix}1+r^2\mu & 0\\ 0 & \mu\end{bmatrix}\begin{Bmatrix}\ddot{\alpha}\\ \ddot{\beta}\end{Bmatrix}+\\ k\gamma\begin{bmatrix}(1-\varepsilon)^2 & -\varepsilon(1-\varepsilon)\\ -\varepsilon(1-\varepsilon) & \varepsilon^2\end{bmatrix}\begin{Bmatrix}\dot{\alpha}\\ \dot{\beta}\end{Bmatrix}+\\ \begin{bmatrix}\omega_\alpha^2+\kappa+1 & -\kappa-\gamma(1-\varepsilon)\\ -\kappa & \kappa+\mu+\gamma\varepsilon\end{bmatrix}\begin{Bmatrix}\alpha\\ \beta\end{Bmatrix}=\gamma\begin{Bmatrix}\theta\\ \phi\end{Bmatrix}\end{gathered}$$

As a preliminary study, where the centrifugal effects are included, data were acquired from Kaman Aerospace's Seasprite helicopter which has a trailing-edge servo-tab. The first step is to correlate the data to see if the system would be stable; and if not stable, then change the parameters to obtain a range of stable regions. In order to determine stability ranges, it is helpful to create root locus plots for each iteration to determine the ranges of stability

The next step of the process is to determine the forcing response for the system. In order to solve for a forcing response, the general solution for α and β are in the form of simple harmonics. Then the magnitude and phase of the response are plotted to give ranges of values for which the response would remain stable.

As one of the design studied, it is important to determine whether it made sense to increase the “free floating” characteristic of the servo tab by neutralizing the “tennis racquet” effect using “Chinese weights” or other mechanisms. To remove the “tennis racquet” effect, the stiffness of the servo-flap and the ratio of moment of inertia in the stiffness matrix is set to zero. Then an eigenvalue analysis is performed to determine whether the parameters from Kaman Aerospace would result in a stable free-floating case.

Key Results

For the system to be stable, the real part of all the eigenvalues for the system has to be negative. Using the torsional stiffness value provided by Kaman Aerospace, the solution is unstable for a leading-edge servo-tab. However, plotting the roots at different varying torsional stiffness values, there is a small region in which the solution is stable.

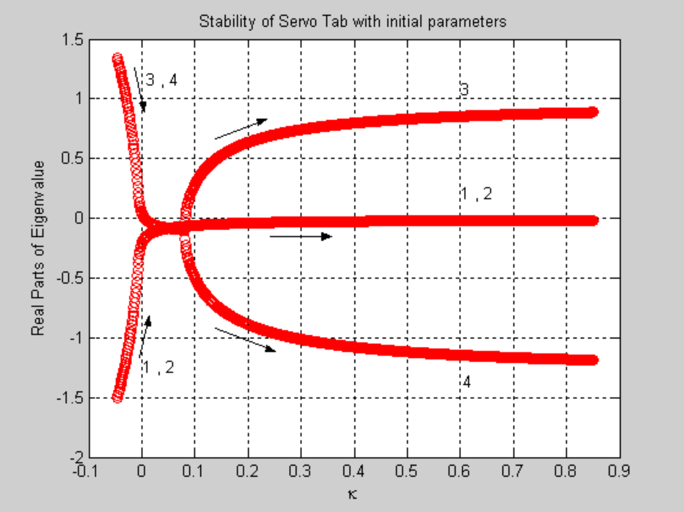

Figure 5 – Stability plot of eigenvalues from initial data obtained from Kaman Helicopter

The next simulation is to find other parameters (the pitch offset from the hinge axis of the blade to the hinge axis of the servo-tab, h from Figure 3, and the aerodynamic center of the servo-tab, d’ from Figure 3) that will provide with a wider range of stability. By changing these parameters, the range of stability increases.

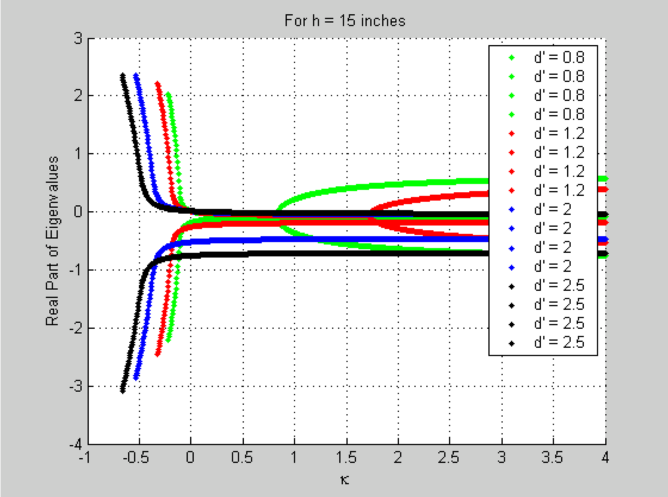

Figure 6 – First simulation with h = 15 inches evaluated at the range of stable d’ values

The forcing response analysis is done after verifying that the leading-edge servo-tab is stable. For the forced response, the magnitude and phase are plotted at varied forcing frequencies. Since the torsional stiffness for the Seasprite is unstable for the leading-edge model, the forcing response is solved at the critical torsional stiffness value.

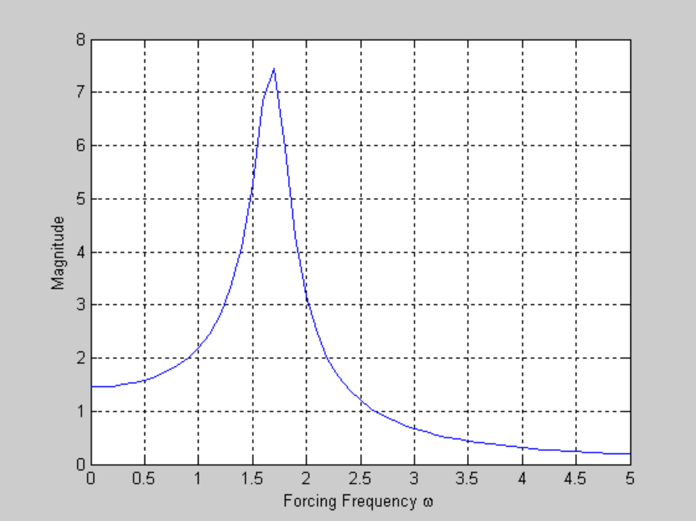

Figure 7 - Magnitude plot for the system at varying forcing frequency values at critical κ value

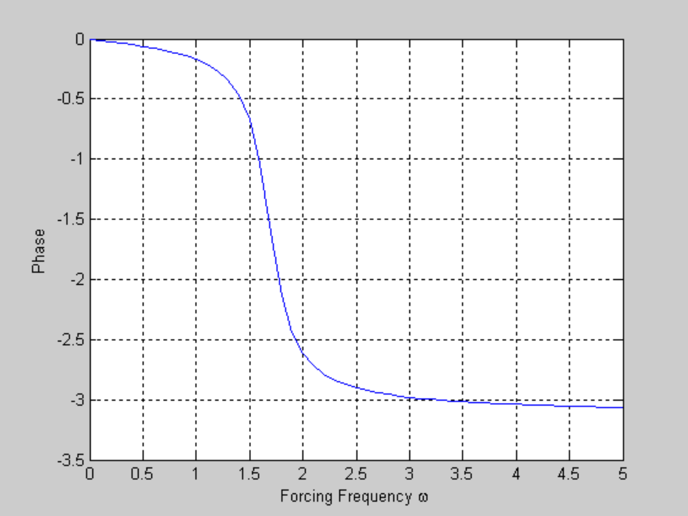

Figure 8 – Phase plot for the system at varying forcing frequency values at critical κ value

Conclusions

The initial stability and response analysis shows that the leading-edge servo-tab design seems to be an effective design. From the stability analysis, there are wide ranges of design values that result in stable solutions. However, when performing an analysis with the "tennis racquet" effect on the servo tab neutralized, the initial analysis shows that the system is unstable when the stiffness and the ratio of moment of inertia are removed from the stiffness matrix. Therefore it seems that excluding the "tennis racquet" effect (i.e. adding Chinese weights) would limit the range of acceptable design parameters for the torsional stiffness value. As a result the design will not require and in fact it is undesireable to have Chinese counter weights or use other techniques to try to neutralize the "tennis racquet" effect of the forward mounted servo tab.

For the forcing analysis, the phase and amplitude of the response is consistent even after changing the design parameter. The only noticeable difference is the amplitude. The data obtained from the preliminary study will be correlated with the data provided by Kaman Aerospace.