AEROSERVOELASTIC MODEL IN TIME DOMAIN AND A NOVEL APPROACH TO COUPLE THE FLIGHT MECHANICS-AEROSERVOELASTICITY

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ABSTRACT

The aeroservoelastic stability of a flexible aircraft (A/C) can be predicted by frequency-domain and time-domain methods, using the complete model realised merging the aeroelastic, the control laws (FCS) and the flight mechanics models. Concerning with the flight mechanics, if the first flexible modes appear at very low frequency, the conventional assumption of separate rigid-body motions from elastic vibrations becomes less appropriate. Therefore, it is necessary to realise a model based on coupled flight mechanics and aeroelasticity.

The frequency-domain approach is usually used in aeroservoelasticity and the applied flight mechanics data is linearized to a specific flight condition and A/C attitude. The time-domain approach may improve the accuracy of the analysis and may give the possibility to investigate the effects due to non-linearities of the aeroservoelastic system.

The novel approach to couple the flight mechanics and aeroelasticity presented in this paper is a state-space time-domain model that includes the inertial (M) and the aerodynamic (L) coupling terms between the flexible modes (Q) on rigid modes (R) as well as the rigid modes on flexible ones, obtained for unitary displacements and rotations (named MQR/MRQ and LQR/LRQ). In the common aeroservoelastic frequency methods, generally these forces/moments, that are multiplied to proper state vector and depends on linearized rigid A/C conditions (quasi-steady small perturbations assumptions), remain unchanged in the analysed frequency range; instead, by this approach defined in the time-domain, the state variables may depend on the time-behaviour of the rigid A/C and the aeroservoelasticity may be computed simulating also the A/C manoeuvre.

Using the MATLAB/SIMULINK® tools, the rigid A/C has been then defined by an external flight mechanics model that is able to couple the rigid A/C data with the aeroelastic flexible model. The mutual effect of the elastic-rigid modes due to an input to the control surfaces by FCS, is introduced as additional forces and moments into the state-space of the flight mechanics that performs the calculation at each time step of the correct rigid behaviour of the flexible A/C.

The following Figure 1 illustrates the overall block scheme of the SIMULINK® showing how all models and inputs/outputs are connected and implemented.

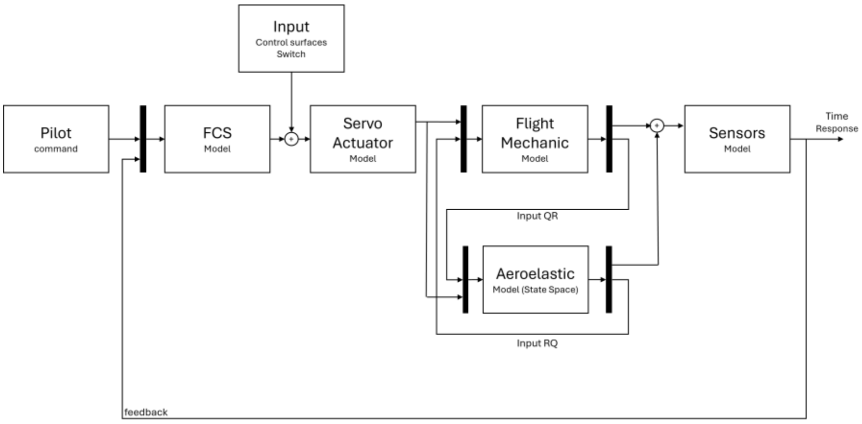

Figure 1 – Aeroservoelastic Model – Overall Block Scheme

Since this novel approach is based on time-domain simulations, it is also possible to investigate the effects of non-linearities of the system, due to mechanical free-plays and frictions as well as due to the high perturbations of the rigid A/C model; in this last case, instead of the linearized state-space model, the non-linear equations of the flight mechanics based on the aerodynamic derivatives coming, for example, from an aerodynamic data bank might be applied. Once that equations are validated, a further future application of this approach might be, for example, the calculation of the structural loads simulating a non-linear manoeuvre and considering, into the computations, the aeroservoelastic effects.

This paper presents both the description and the results of this innovative methodology developed in the framework of Clean Aviation Hybrid-Electric Regional Aircraft (HERA) project applied to the aeroservoelastic models of a generic regional transport A/C and of a proprietary unmanned A/C. As an example of the results, the following figure shows the Frequency Response Function (FRF) on the Bode’s diagram (magnitude and phase), related to a FCS structural sensor, comparing the cases with and without elastic-rigid coupling terms. As expected and clearly visible on the figure, the main impact of the coupling terms occurs at low-frequency, in the range associated to the rigid-body modes (up to about 3 Hz); the orange curves represent the aircraft sensor FRF that includes the contribution of the elastic-rigid coupling terms, while the blue ones correspond to the decoupled case.

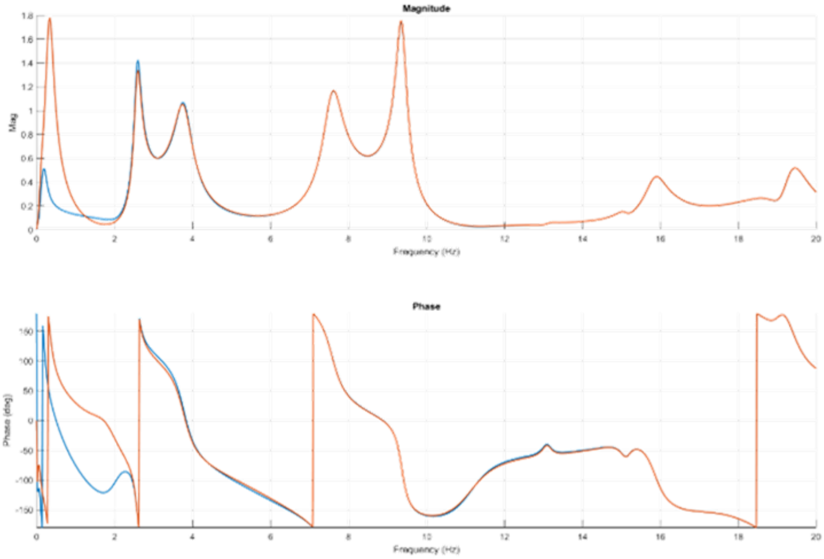

Figure 2 – Effects of the Rigid-Elastic Coupling Terms – A/C FCS Sensor

Looking at previous Figure 1, it can be seen that the servo-actuator block has been separated from FCS control laws. In the linear aeroservoelastic model that block is represented by a series of n-order Transfer Functions (TF) in the Laplace's domain (s). This approach, which permits the creation of simpler and lighter models, is useful when it is needed to perform a lot of aeroservoelastic analyses, but it is not applicable when it is required to investigate the effects due to non-linearities such as frictions, free-plays, saturations, etc. In the SIMULINK® aeroservoelastic model developed for HERA framework a set of full non-linear Electro-Mechanical Actuators (EMA) has been integrated, in order to more realistically simulate the behaviour of each actuator component, as electrical motors, bearings, gearbox, brakes etc., which are basically non-linear.

In the following figures they are shown the time response (Figure 3) and the related FRF (Bode's diagram of Figure 4) of a structural FCS sensor applying the linear (blue) and the full non-linear actuators block.

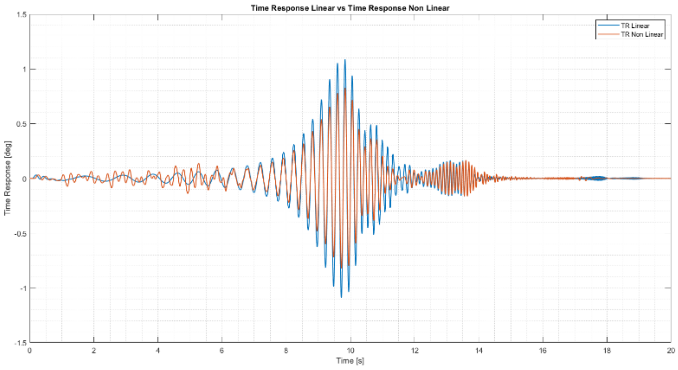

Figure 3 – Non-Linear Actuator Investigation – A/C FCS Sensor (Time Response)

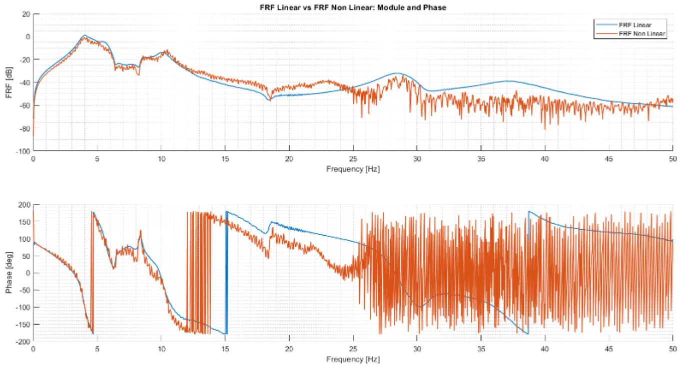

Figure 4 – Non-Linear Actuator Investigation – A/C FCS Sensor (FRF)

In some frequency ranges the magnitude of the non-linear curve (orange), characterized by the ripples typical of the non-linear systems, is slightly higher than the linear one. The phase dispersion is also typical of non-linear elements. From the computational cost point of view, non-linear analyses are much longer (1 hour vs 1 minute), but may be necessary in cases where the non-linearity impacts of the actuator on aeroservoelasticiy has to be investigated.

A further application of this approach might be the mathematical modelling of the free-plays associated to the command line located downstream of the actuators.