Uncertainty quantification in aircraft load calibration

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Abstract

For certification requirements, structural loads of aircraft have to be demonstrated with required margins. These structural loads can be predicted by calculations. Estimations of these loads can only be checked and confirmed with real flight measurements. But these measurements are subjected to uncertainties. So the loads have to be known with accuracy to reduce these margins to the minimum.

A current flight load determination relies on a method developed by NASA (ex-NACA) in 1954 [1]. Flight loads cannot be directly measured. The most common method consists in measuring the effects of the flight loads on the structure, which means measuring strains. These local strains are measured. The direct problem can be modelled by a response surface approximation:

$$F'^{flight} = (\mu_k)^T(\beta_k) \tag{1}$$

where F' is the load, μ_k is the measurement of the strain at location k and β_k is the parameter associated to the strain at location k representing the response of the structure. The structural response is thus characterized by the resolution of the inverse problem:

$$(\beta_k) = ([\mu_k]^T[\mu_k])^{-1}[\mu_k]^T(F'^{ground}) \tag{2}$$

The first step of the flight load determination is the identification of the model parameters β_k. The second step is its application in flight. The general objectives of the works on this topic are the determination, the quantification and the propagation of uncertainties through the load determination method. The paper is focused on the first step.

A ground load calibration allows characterizing the behaviour of the structure by determining the parameters β_k. Chosen loads are applied on the structure. Corresponding local strains are measured. However both the measured loads and the measured strains are affected by various sources of uncertainty.

This paper seeks to characterize the model uncertainty by taking into account the sources of uncertainty in the ground load calibration. These uncertainties are both on strains μ_k, which are the coordinates of the design points, and on loads F', which are the responses. Traditional approaches usually only take into account uncertainty on the responses.

Since the system representing the problem is highly over determined, a criterion has been first implemented to make a systematic and reliable selection of the relevant coefficients β_k and thus of the relevant strain measurements [2]. This criterion tests the significance of the coefficients β_k in the model. Non significant coefficients are deleted from the response surface which is recalculated. Results show a good fit between the currently used criteria and this new criterion.

The next step is the propagation of the uncertainties on both strains and loads in the ground load calibration. For this, a specific regression model has been implemented using the so-called "error in the equation" method [3].

References

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