Proceedings of the Thirteenth International Conference on
Engineering Computational Technology
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 13, Paper 1.2
Civil-Comp Press, Edinburgh, United Kingdom, 2026
ISSN: 2753-3239, doi: 10.4203/ccc.13.1.2

Sparse-Data Hybrid Modelling for Aircraft Fatigue Loads

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Abstract

The structural fatigue life of the doors' interfaces could be affected by the unsteady flow which might induce a buffeting phenomena on the doors. This work aims to capture such complex physics by using both flight test data and a computational model. Often the amount of sensors available in a FT is limited and consequently not sufficient to complete and validate completely the design. Because of that the required set of outputs is completed by employing a Finite Element Model. Because of the unsteady aerodynamics loads are unknown, this complementary approach is based on the idea of training the numerical model in order to match, in a least-square sense, the Finite Element Model (FEM) and the Flight Test (FT) Quantities of Interest (QoIs) at known instrumented locations. The results show a robust approach which might be instrumental for an accurate prediction of the doors' vibration loads.

Keywords: dynamic responses, optimization technique, Hybrid Data-Driven, surrogate model, fatigue life, sparse sensor placement.

1 Introduction

Main landing gear doors (MLGDs) cover the landing gear bays, figure 1, keeping the aerodynamic shape of the aircraft during flight. Before landing and after taking-off, an aircraft opens its main doors in order to allow the deployment and the retraction of the landing gears, respectively. During these phases, the nose landing gear creates flow separations, characterized by turbulent vortex motion, which are convected further downstream above the main landing gear region [1, 2]. An example of that is shown in figure 1. As a consequence of that, the induced aerodynamic unsteady loads, often called buffeting loads, could be significant and have a relevant contribution to the structural sizing of the MLGDs' attachments to the primary structure with a direct impact on their weight [3, 4]. In particular, it might there be some cases where an exhaustive fatigue life assessment, primarily based on the steady aerodynamic pressure and those loads due to the hydraulic activation, should include the vibrations' contribution. An example is shown in figure 2. Therefore, an accurate prediction of the unsteady loads, is instrumental to ensure optimized light and reliable aircraft structures.

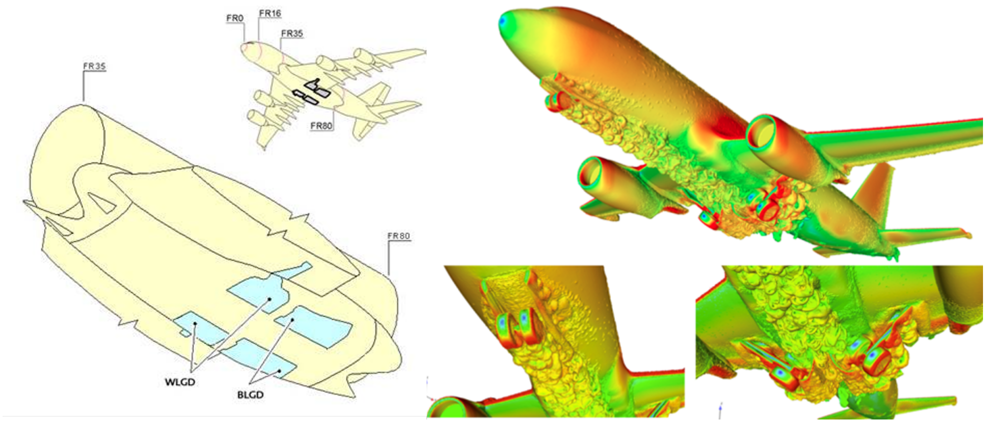

Figure 1: Aircraft's Main Landing Gear Doors (MLGDs): vortex motion in the nose and main landing gear region.

2 Main Objectives

This work aims to estimates the time-domains buffeting loads in order to quantify and eventually, include their impact into the design. In particular, these dynamic loads should be superimposed to the steady aerodynamics for a proper estimation of the structural fatigue life of the doors' interfaces. Capturing such complex physics requires a multidisciplinary approach which involves the doors' structural dynamics and the unsteady aerodynamics. While the state-of-art of computational fluid-dynamics

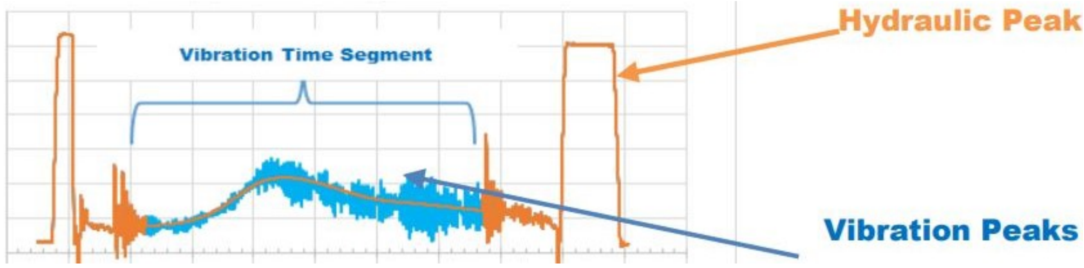

Figure 2: An example of Flight Test signal of a load at MLGD's interfaces.

(CFD) tools is able to provide accurate and reliable steady-loads, the predictiveness of such simulations, in case of flow unsteadinesses, presents still some limitations. In particular for complex geometrical patterns and in presence of compressible flow, i.e., Mach number higher than ~ 0.35, the computational cost increases exponentially the more finer meshes and smaller time-steps are required. As well, it has to be considered that the amount of sensors available in a FT is limited and consequently not sufficient to complete and validate completely the design. Our approach is based on the idea of training the numerical model in order to match, in a least-square sense, the Finite Element Model (FEM) and the Flight Test (FT) Quantities of Interest (QoIs) at known instrumented locations. In addition, the algorithm is enhanced by an automatic learning of the required loads cases in order to get a balance between computational efficiency and robustness (and reliability) of the results [5, 6].

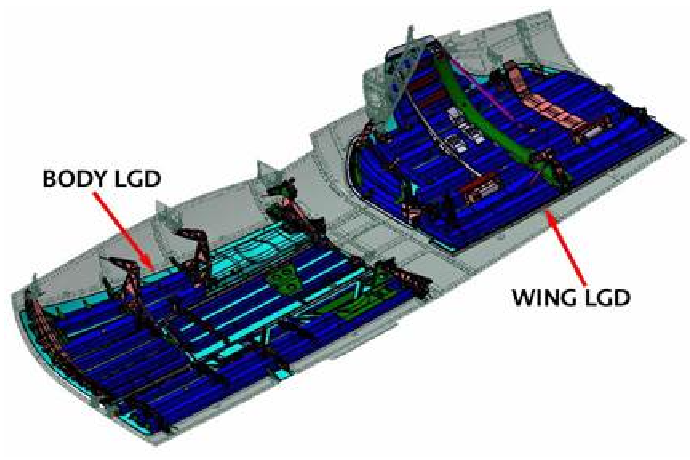

Figure 3: Details of Body and Wing Landing Gear Doors.

3 Methods

The structural dynamics of the MLGDs is captured by means of a detailed Finite Element Model (FEM), which considers the body of the component and its connections to the aircraft. The doors are allowed to rotate around the hinge line, defined by the interfaces' alignment, and their operational position is driven by actuators. The unsteady pressure field applied on the doors' surfaces is unknown, however thanks to an extensive FT campaign, the unsteady reaction forces of some interfaces and actuators can be retrieved. Then, by analyzing the FT outcomes at these instrumented positions one can select the relevant flight points, and consequently the correspondent boundary conditions and the actuator mechanical properties can be considered in the modelization. Because, also, accelerometers' data are available, for these selected doors' conditions, one can check the congruence of the first normal modes between the FEM and the FT points. A fatigue study to confirm the robustness of the design, in particular in buffeting conditions where the vibrations' magnitude can change greatly from one location to another, requires internal loads, stresses and deformations in several structural sites, i.e., several dozens of QoIs are often needed from the FE model. In contrast to that, in general the amount of sensors available in a FT is limited and consequently one has a relevant but still not sufficient set of retrievable experimental data to complete and validate the design. Our semi-empirical approach is based on the idea of training the numerical model in order to match, in a least-square sense, the FEM results and the FT test data at the known instrumented locations. The numerical model is run under a certain number of parametric load conditions and then the scale factors, one for each load case, are the results of a multi-cases optimization process. The load cases include a vertical and a lateral gust, whose aerodynamic is modelled via the Double Lattice Method (DLM), in combination with nodal pressures on those doors' locations where the DLM panels are unable to capture the underlying aerodynamics due to the double-blended geometrical profile of the doors. A correct definition of the pressure cases is key when the DLM panels fail: the higher the number of cases the more refined the analysis is but also the more expensive and difficult the optimization process is. Our algorithm is able, by means of an on-line learning process, to automatically select a proper number of cases to balance the trade-off between robustness and efficiency. Once, throughout the semi-empirical optimization process, a set of quasi-optimum scale factors is obtained, one can retrieve from the model the desired QoIs at any other not-instrumented location.

4 Results and Findings

Figures 4 and 5 show respectively that the experimental data are well-fitted both in frequency and time domains. The results indicate a robust semi-empirical method because the agreement shown in Figures 4 and 5 is obtained simultaneously in all the parameters included in the optimization procedure without any nonsense results, i.e., some parameters whose outputs are meaningless or in strong disagreement with the

FT data. In addition, the quality of the overall results is maintained when different flight test points are considered, i.e., a different set of FT parameters: velocity, angle of attack α and angle of sideslip β.

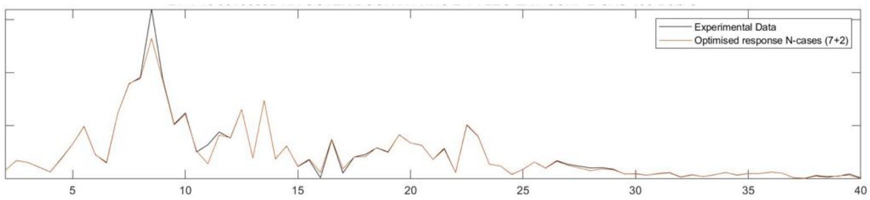

Figure 4: An example of matching of FE and FT results in frequency domain.

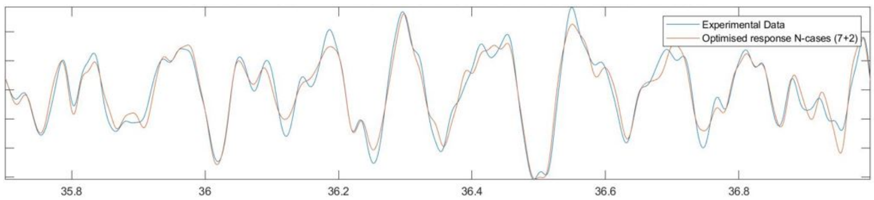

Figure 5: An example of matching of FE and FT results in time domain.

5 Conclusions

An accurate prediction of buffeting loads can be instrumental to ensure optimized light and reliable aircraft structures. In the case of MLGDs, when excited by a turbulent vortex motion, a correct estimation of the fatigue life has to consider also the vibrations' loads because they might be significant. The magnitude of the vibrations has to be combined with the statistics of usage in order to determine how significant they are. This work proposes a semi-empirical approach in order to estimate the time-histories vibration loads. The preliminary results, presented in section 4, indicates that the proposed method can be a feasible way when QoIs at not-instrumented FT locations are required. These are obtained by training the FE model to match, in the least-square sense, the data at those locations where experimental loads are known (section 3). The optimization considers a relevant number of FT parameters and several FT points, which differ in terms of velocity and FT parameters. The quality of the results is congruent throughout all the considered parameters and cases. Due to the complex geometry of the doors' surface, DLM can fail in representing properly the aerodynamics conditions and then an additional number of local pressure cases, on the curved surfaces, has to be defined and considered. This instrumental selection is done automatically by employing an on-line learning approach.

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