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Assessment of dynamic effects on aircraft design loads: The landing impact case

Michael Bronstein [a,*], Esther Feldman [a], Riccardo Vescovini [b], Chiara Bisagni [b]

[a] Israel Aircraft Industries, Tel Aviv, Israel
[b] Politecnico di Milano, Department of Aerospace Science and Technology, Milano, Italy

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ABSTRACT

This paper addresses the potential benefits due to a fully dynamic approach to determine the design loads of a mid-size business jet. The study is conducted by considering the fuselage midsection of the DAEDALOS aircraft model with landing impact conditions. The comparison is presented in terms of stress levels between the novel dynamic approach and the standard design practice based on the use of equivalent static loads. The results illustrate that a slight reduction of the load levels can be achieved, but careful modeling of the damping level is needed. Guidelines for an improved load definition are discussed, and suggestions for future research activities are provided.

1. Introduction

The DAEDALOS project aimed to develop new methods to reduce the uncertainty and the conservatism of today's design and certification procedures. Among the objectives of the project, an in-depth investigation was carried out to account for dynamic effects in the context of the design loads evaluation. The present effort focuses on dynamic landing, a loading condition usually relevant for the fuselage design.

Early studies on dynamic landing are found in the works of Biot and Bisplinghoff [1] and Williams and Jones [2]. They assume that the landing gear reactions are independent from the elastic properties of the structure. Once the reactions are computed, they are applied to the elastic aircraft, which is represented by means of simple analytical models. Pioneering work on effects due to coupling between landing gear and structure is due to McPherson et al. [3] and Cook and Milwitzky [4], where the structure is modeled with a two-degree of freedom model. More recently, extensive use of the finite elements has been done to model the response of an elastic aircraft. An example is found in Luber et al. [5], where dynamic loads due to landing impact on the main wheels are computed and then the attachment loads of the landing gear are used as input for the excitation of the aircraft structure. In Ref. [6], the simulation tool developed by EADS is briefly reviewed. In this case, the landing gear nonlinear behavior is considered, together with its interaction with the flexible structure. The simulation is performed using MSC Adams and MSC Nastran. A similar strategy is proposed in [7] for aircraft tailless configurations. The effects on the landing impact due to the pitching motion and the response of the nose gear were accounted for by Chester [8].

Despite the improvements due to modern simulation techniques, common design practice still relies on the use of equivalent-static approach to establish the stress distribution in response to dynamic loading conditions, such as those due to a landing impact.

The main advantage of the standard design practice can be found in its simplicity and time effectiveness. Indeed, the evaluation of the aircraft internal forces and the subsequent evaluation of the stress distribution can be performed by direct application of a predefined set of static loads on the finite element model of the structure. However, the procedure suffers from its inability to account for the propagation along the fuselage of the loading forces-mainly related to the frequency content of the input load and the characteristic frequencies of the fuselage structure-and damping, i.e. the capability of the structure itself to damp the loading waves amplitudes, starting from the zone close to the load introduction point and propagating away from it.

In particular, the underlying assumption is that the model does not absorb any energy by the stringer/frame/skin constructions and the load acting at a certain location is propagated along the fuselage without attenuation arising from structural damping.

Up-to-date, very few studies have been directed towards the assessment of the potential reduction of the section forces propagating to the rest of the aircraft, accounting for the effects of energy dissipation near the load introduction location, and the

* Corresponding author.
E-mail address: mbronste@iai.co.il (M. Bronstein).

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transfer of energy from local impact locations to other parts of the fuselage.

It follows that the final design can be affected by the approximation due to this approach, with an impact on the final weight of the configuration.

Contrarily, an improved fully dynamic approach could be adopted if more refined finite element models are used since the early phases of the design process. In this case, the transient dynamic analysis is performed directly using a shell model, with no need to transfer the relevant loads from the stick to the shell model in the form of static loads. In this context, the structural response, which can be performed in the time or in the frequency domain, is determined for different loading conditions by adopting numerical models with a larger number of degrees of freedom. Therefore, the stress distribution of the various portions of the structure can be directly monitored at the various timeframes of the load history. The increase of the overall analysis time is noticeable and, for this reason, classical design procedures have usually discarded a fully dynamic design procedure.

Nowadays, thanks to the improved computational resources available, the assessment of the benefits due to a fully dynamic approach is compatible with the time needed to complete the overall sizing process, and a fully dynamic procedure can be adopted during the aircraft design phase.

The goal of the present work is to assess the possible advantages due to the adoption of a dynamic approach in the sizing process of a typical business jet. The benefits due to a dynamic design strategy are investigated with regard to the structural weight. Part of the study is directed towards the evaluation of the effects due to the damping properties on the reduction of the design loads. The investigation culminates into a novel proposal to reduce the conservativeness of static design loads, providing guidelines for an improved sizing for the next generation of aircrafts.

2. Aircraft model description

The aircraft model here considered was developed within the DAEDALOS project on the basis of the experience of the industrial partners involved in the project. The aircraft configuration is considered as representative of a mid-size business jet, powered by two turbofan engines mounted in the aft fuselage. A sketch of the model and its relevant dimensions are provided in Fig. 1. The wingspan is 15.38 m and the overall length is equal to 15.65 m; the wing reference area is 32.38 m^2. The structural configuration is characterized by a two-spar box structure for the wing, a fuselage with a multi-frame configuration, a sandwich horizontal tail and a vertical tail with a three-spar configuration.

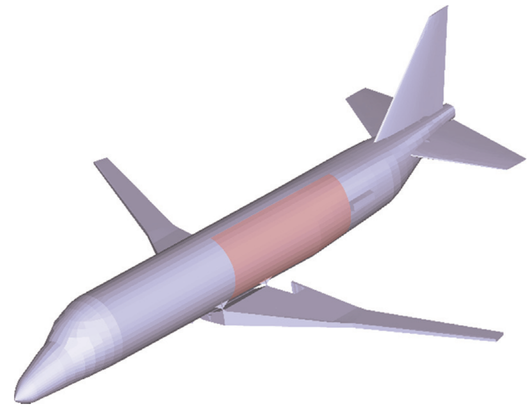

Fig. 2. Fuselage section selected for the study.

2.1. Structural section

The assessment of the potential benefits due to an improved dynamic approach is conducted on the design of the mid fuselage section. This portion of structure is the one experiencing the highest load levels in response to the fuselage bending after an impact loading. A sketch of the portion of structure is highlighted in Fig. 2. As observed, the model is reduced to half of the structure due to symmetry of the loading conditions resulting from the landing.

This section extends from a distance of 5582 mm from the fuselage nose, up to 9905 mm. The overall length of the barrel here considered is then 4323 mm.

The comparison between the standard procedure and the improved one is conducted by comparison of the stress levels in terms of components σ_y, where y denotes the direction along the fuselage axis. To this aim, the stress level is monitored for all the elements of the selected section.

2.2. Landing gear

The stress distribution due to a landing impact is influenced by the load introduction in correspondence of the landing gear attachment. The DAEDALOS aircraft model is characterized by a trailing link landing gear, with the presence of an energy absorbing element (shock absorber) mounted between the rigid upper trunnion part and a moving element or trailing link. The main advantage of this configuration relies in the good balance between an adequate value of stroke and a compact gear design. A sketch of the landing gear is reported in Fig. 3(a).

The shock absorber is assumed to be of the oleo-pneumatic type. This type of damper absorbs energy by pushing a chamber of oil against a chamber of gas and then compressing the gas and the oil. Energy is dissipated by the oil being forced through one or

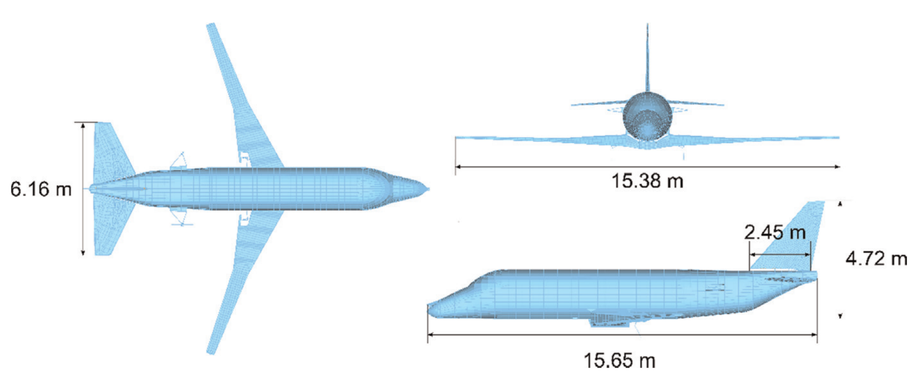

Fig. 1. DAEDALOS aircraft model.