Multibody and Lumped-Mass Modeling and Sensitivity Analysisof Occupant-Seat-Underfloor-Skid System for an eVTOL Aircraft Crash Landing

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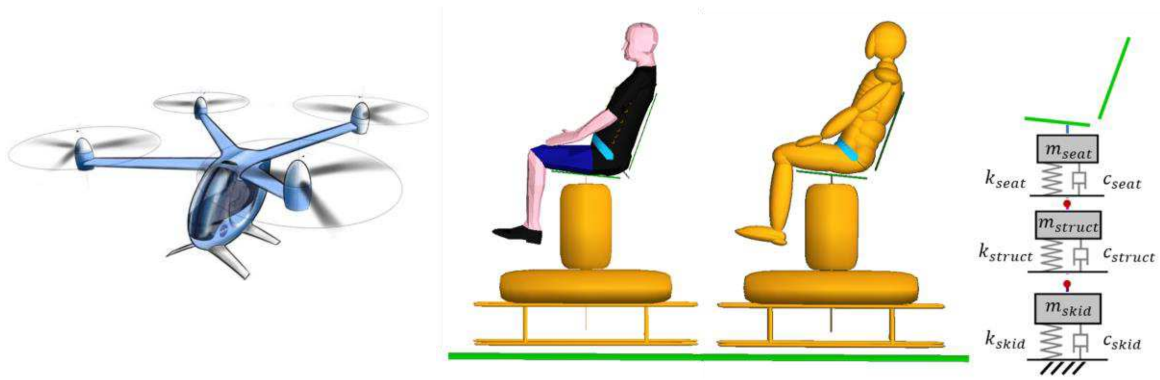
Abstract

The transportation industry has recently seen the dawn of eVTOL (electrical Vertical Take-Off and Landing) aircraft. NASA has outlined the potential of a few different concepts that can be employed for UrbanAir Mobility (UAM) operations, being the entrant a single passenger quadrotor (see Fig. 1a) that is piloted autonomously [1]. Although these aircraft are still not found in the skies, the industry readiness for launch far outpaces the implementation of compliant operational and safety regulations from the regulatory bodies. In such uncertain and competitive setting, having the capability of quickly comparing the effects on occupant safety from different design philosophies is of considerable benefit. Additionally, the concept of integrated occupant safety analysis, which has been under consideration by the airworthiness organizations, requires that the interaction effects of different systems to be accounted since theconceptual design level to take full advantage of them [2].

In this study, an investigation has been conducted on the structural parameters that influence the level of safety for the occupant, during the crash landing of an eVTOL aircraft, considering the single seater concept, the structure absorbing the impact energy consists basically of the seat system, the subfloor structure and the landing skid (shown in Fig. 1b). A representative multibody model of the vertical drop crash condition has been developed, characterizing the mass, stiffness and damping of the crushing structure using lumped masses with spring-dampers. Spring nonlinearities have been considered to account for component failure. The range of structural parameters is based on the limiting characteristics of current aircraft structures, like maximum energy absorption and typical construction materials, when accounting for the structural properties of theseat, the underfloor and the skid systems.



(a) Concept model of an eVTOL aircraft [1] (b) Structural and multibody models

Figure 1: Aircraft representation and modelling

The occupant is a multibody model of a 50^{th} percentile Hybrid-II ATD (anthropomorphic test device), which consists of 49 ellipsoidal bodies. A human multibody biomechanical model has also been considered in the study. The models are first validated versus experiment for two cases of rigid seat as well as collapsible seat configurations in vertical loading. The models are then subjected to vertical drop simulations with 5, 10 or 15 m/s of drop velocity. The structural parameters are varied to evaluate the corresponding lumbar load on the occupant, in order to assess any potential injury (Fig. 2). The level of safety has been considered from the biomechanical response of the occupant through its kinematics and the measurement of the maximum experienced lumbar load during the crash event.

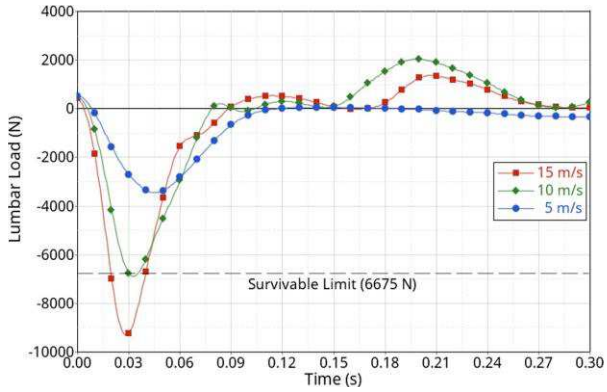
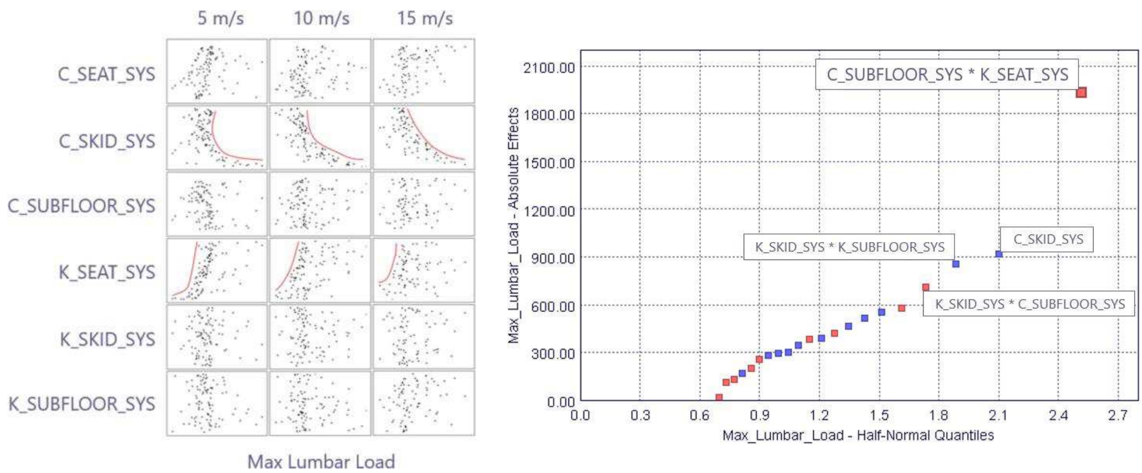


Figure 2: ATD lumbar load for different drop velocities in one structural configuration

A design of experiments (DOE) is generated using a uniform Latin hypercube algorithm to obtain 400 sparse designs. The DOE has been utilized with modeFrontier to study the sensitivity of the structural parameters on the level of safety for the occupant. The variation of the impact velocity has also been consideredin order to avoid conditional overfitting. The results obtained from this study highlight the interaction found between the considered parameters in order to maximize passenger safety.



(a) Scatter of results showing pareto curves

(b) Statistical analysis on the contribution of various effects

Figure 3: Analysis of the results

The analysis of the individual parameters considering the maximum lumbar load presents limiting performance pareto curves for the structural stiffness of the seat K_SEAT_SYS and energy absorption of the skid C_SKID_SYS (see Fig. 3a). The evaluation of the single and combined effects over the objective shows the predominance of interacting parameters over the individual ones, as shown in Fig. 3b. Thesefindings reaffirm the importance of the integrated occupant safety analysis in the perspective of the need to account for systems' interactions to obtain the highest safety performance. The application of such design methodology can decrease the potential for injury and promote a reduction of weight penalty due to redundant structure, which positively benefits the operation of such aircraft [3]. This is of special importance for eVTOL aircraft as the payload margins today are strict and limited by technologicaladvancements on energy and propulsion systems.

References

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