Lightweight design of a reclining aircraft seat considering manufacturability and crashworthiness

N. Trivers[a] C. Carrick[a] and I.Y. Kim[b]

[a]Department of Mechanical and Materials Engineering, Queen's University, Room 213 Jackson Hall, 35 Fifth field Company Ln, Kingston, ON K7L 2N8, Canada
[b]Department of Mechanical and Materials Engineering, Queen's University, Room 305 McLaughlin Hall, Kingston, ON K7L 3N6, Canada
E-mail: neil.trivers@queensu.ca; kimiy@queensu.ca

Abstract

Topology optimization [1] was used as the primary design tool to develop a clean-slate design for a business aircraft seat, subject to the limit loads and certification crash loads of the Canadian Aviation Regulations (CARs). A 2-stage approach was used to consider the static loads (limit loads) first for system-level design, and then the dynamic ultimate loads (crash loads) were used separately to tune the component-level design for crashworthiness. The work presented in this conference is the first stage topology optimization and the preliminary system-level design of the structure.

Keywords –

Topology Optimization, Aircraft seat, Aerospace, Certification.

1 Introduction

Aerospace seating structures are subject to strict certification physical testing including static qualification tests, and dynamic 16g crash tests. In order for a seat to be airworthiness certified, it must not fail under the 14g and 16g dynamic test conditions, and the occupant must not exceed certain load limits which pertain to their safety. The design cycle of a seat becomes significantly longer and more expensive if the seat does not pass the certification during the first test, and as a result many seats in industry end up largely over designed and unnecessarily heavy. As computational simulation and analysis tools rapidly advance, there is opportunity to model and predict structural performance and crashworthiness without construction of a physical prototype for sled testing. This work proposes a methodology and preliminary design to show that cost and weight can be reduced by using topology optimization along with explicit dynamic simulation.

The objectives of this work are to reduce the structural mass of the seat conceptual design when compared to a baseline design, and also to reduce the cost of the seat, while considering the manufacturability of the components very early in the design process.

2 Design Requirements

In the conceptual design stages the requirements of the presented design can be categorized as kinematic, or structural. The kinematic requirements of the seat dictate the range of motion the design must be able to accommodate. The seat pan and backrest must be able to recline to the full range of motion provided by the industry partner without any collisions between components.

The structural requirements of the seat are derived from the CARs and can be divided into 2 groups: static and dynamic. The static loads are outlined in Table 1 and are applied as inertial loads to the seat structure using a 50th percentile male anthropomorphic test device (ATD). For the static qualification tests, the seat must not experience failure within 3 seconds of when the loads are individually applied.

Table 1 Static ultimate load factors (CARs 525.561)

Direction	Load Factor
Forward	9.0g
Sideward	4.0g
upward	3.0g
Downward	6.0g
Aftward	1.5g

The dynamic requirements come from the emergency landing conditions specified in the CARs (Sec. 525.562) and are composed of 2 separate dynamic tests. A 14g deceleration applied in the downward direction and a 16g deceleration in the forward direction. The tests are performed using the 50th percentile male ATD and in order for the design to pass certification, the seat must remain attached to the aircraft floor, i.e. the main structural load paths of the seating structure must not experience catastrophic failure during dynamic testing.

In addition to the structural aspect of the dynamic tests, the ATD must not experience loads within the lumbar spine and femur that exceed 1,500 lbs and 2,250 lbs respectively. These loads are not considered in this early work, since the properties of the backrest and cushions are very influential on these values, and we are not considering detailed backrest or cushion design at this point. Head Injury Criterion (HIC) values must not exceed 1000 during the 14g or 16g crash tests. This usually occurs when the occupant experiences a head impact on structures inside the cabin.

3 Methodology

The planned design process and methodology used in this work is as follows:

1. Topology optimization of the structure using static loads (TO1)
2. System level design of assembly using results from TO1
3. Dynamic FEA modelling to determine loads experienced during crash cases
4. Topology optimization of the preliminary design using modified design space and crash loads (TO2)
5. Component level redesign of smaller features based on results from TO2
6. Dynamic FEA modelling of updated design for verification.

Topology optimization of the structure was performed first at the system-level, using the static loads in Table 1. The objective for this optimization is to minimize compliance, which is analogous to maximizing the stiffness of the structure. In order for the seat to best protect the occupant, a maximum stiffness design is used. It is common practice in industry to design the floor and fuselage frames for energy absorption during a crash, not the seat structure. The seat structure is designed to be as stiff as possible, to prevent the occupant from experiencing large displacements which could result in potentially fatal head impacts.

The design space for the preliminary optimization captures the kinematic requirements of the seat using rotational joints and separate designable domains, shown in Figure 1(a). The design space domains were developed with sufficient clearance between each other to allow for structures which do not interfere with the reclining motion of the seat. Results of the static load topology optimization are found in Figure 1(b). After topology optimization, the results were reinterpreted into a preliminary design.

The preliminary design will be modeled in a dynamic FEA simulation to predict the behavior of the structure during the crash loads (Figure 2). Forces from the seatbelts and the ATD contacting the seat will be extracted from this model, and used in the second topology optimization to refine the design of the seat.

4 Results

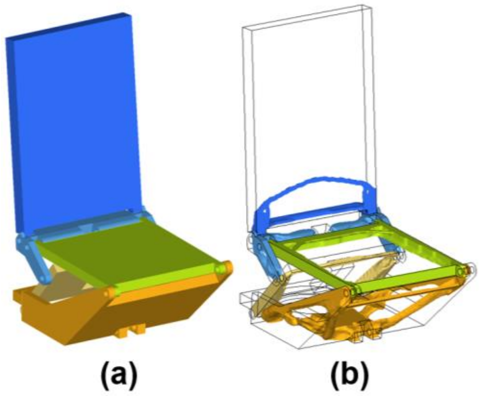

Figure 1: (a): Design space (b): TO1 result

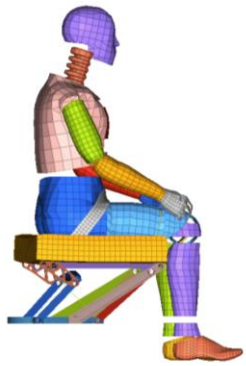

Figure 2: FEA model of the 50% Male ATD on the preliminary seat structure design

5 Conclusions and Next Steps

The mass of the preliminary design weighs 5.73 kg which is 23% lighter than the baseline design. A dynamic FEA model of the preliminary design will be used to determine the loads experienced by the seat structure during crash tests, and these loads will be used to perform a redesign at the component-level using topology optimization to maximize stiffness. Manufacturability will be evaluated to ensure the key manufacturability metrics associated with cost are reduced in comparison to the baseline design.

Acknowledgements

The authors would like to thank Philippe Erhel and Jerome Vigeant from Bombardier Aerospace for their continuous support and contributions towards this project.

References

[1] M. P. Bendsøe and O. Sigmund, *Topology optimization: theory, methods, and applications*, vol. 2nd Editio, no. 724. Springer, 2003.