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Assessment of Aircraft Pilot Seat Performances with Digital Human Models and Virtual Prototypes

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Abstract. In the aeronautic industry, some research is currently carried out to improve pilot seating and lying comfort, as well as cockpit ergonomics and accessibility. Pilots spend indeed a lot of time on their seat during a flight. If seats are uncomfortable and pilots are in a wrong posture, risks of injuries and fatigue increase a lot. But taking into account these comfort requirements for the pilot seat and the cockpit design is very challenging. In fact, the very strict aeronautics standards for certification may sometimes jeopardize initial design ambitions regarding comfort. The necessary innovations to address certification and comfort cannot rely on a classical trial-and-error approach on real prototypes with human volunteers. This way of working presents several disadvantages related to test repeatability and human subjectivity. From one real test to another, volunteers' morphology, posture and mood may change and sometimes do not represent the range of possible occupants. In addition, as tests happen late in the development process, at a time where there are limited possibilities to improve the seat and cockpit designs, or propose radically innovative solutions, it becomes very complicated for engineers to reach their initial objectives. To avoid these issues related to real tests, OEMs and suppliers are beginning to change their development process to adopt alternative ways to iterate earlier in the conception phase. In the scope of a project on pilot cabin development, done with Dassault Aviation, Safran and ESI Group, a tool dedicated to aircraft pilot seat virtual prototyping has been developed to integrate earlier in the industrial process comfort aspects and seat integration inside the cockpit. It has been adapted from ESI's Virtual Seat Solution already used in the automotive industry. This paper will describe an application of this virtual prototyping on industrial examples and how designers can virtually create a seat model right from the early design phases and start assessing its performances. Seating simulations of human models have been performed to evaluate static and postural comfort. Those simulations can be then extended to address, in a second step, other performances such as vibratory or thermal comfort, or static comfort for a different seat adjustment such as the reclined posture. Finally, these results have been compared to real measurements to give some insights into the predictivity of ESI Seat and Interior Solutions.

Keywords. Aircraft Pilot Seat, Virtual Prototyping, Digital Human Modeling, Static Comfort, Postural Comfort, Vibratory Comfort, Thermal Comfort, ESI's Virtual Seat Solution for Aero

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1. Introduction

Pilots spend a considerable amount of time on seats. This leads to disorders such as lower back pain and fatigue. And this is a matter of great concern because uncomfortable workspace for pilots leads to a reduction in alertness while flying the plane. Pilot comfort depends upon several factors such as seat dimensions and adjustments, the seating posture they make possible, the ability to reach easily every part of the control panel, the softness of the trim parts and other design parameters related to the seat and the cockpit [1]. As a consequence, aeronautic OEMs and suppliers want to have the ability to change easily seat and cockpit design to improve this comfort, while respecting safety standards and delivery time. However, seat comfort is usually tested late in the development process, at a time where it is not possible anymore to make a change which may impact the safety performance. To optimize time and costs developments while ensuring the right level for all types of performance, OEMs and suppliers want to iterate earlier on seat to avoid these kinds of issues.

In the scope of the SEFA IKKY [2] project, managed by CORAC French organization, and particularly in the work package focusing on cockpit layout, done with Dassault Aviation, Safran and ESI Group, virtual prototyping has been applied on a specific example to enable this integration of comfort considerations early in the development process. ESI-Group has adapted its automotive solution which is widely adopted by the automotive industry to the specificities aeronautics performance tests [3,4,5,6].

This paper will provide an example of how virtual prototyping can be applied during the early stage of seat conception to address first comfort requirements. Then, it will be used during the phase of detailed design to consider vibration response and thermal comfort as well. A variant of the pilot seat being manufactured, this paper will propose some correlations between real tests and simulation results to validate the software predictive capability at all stages of the seat development cycle.

2. Challenges of Aircraft Pilot Seat Performances Evaluation

Traditional seat development process is usually done after design freeze with a focus on safety. Some simulations are performed, but the seat model they use has been usually calibrated through tests on real prototypes. The outcome of those simulations is therefore limited. Furthermore, after seat design freeze, if issues are discovered on performance types other than safety, engineers and seat designers must take costly counter measures with associated delays or deliver their seat below the expected performance levels.

Using human volunteers to test static or vibratory comfort is also inconvenient to ensure the right performance levels. The first issue is the repeatability. The seat static comfort performance is evaluated through the measurement of pressure distribution for a given occupant posture [7]. Ensuring that the same volunteer will adopt the same posture on different variants of the seat is a challenge. Therefore, it is difficult, with volunteers, to make a reliable comparison on comfort, between two design iterations of the same seat. A second issue related to those tests with volunteers, is the ability to recruit and keep available along the years, people representing the range of possible end-users from small female to large male.

Combining virtual seat prototypes and digital human models is one way to overcome the challenges previously described. Seat designers and engineers can create easily reliable seat models with data available during the early stages. They can anticipate potential comfort issues with human models of different anthropometries. With tools to quickly explore different seat design changes, it is also possible to make some choices very early in the development cycle. By addressing with the same seat model both safety and comfort, it is finally affordable to develop a seat ensuring comfort and prepare virtually its certification before producing any physical prototype.

3. Preliminary Comfort Performance Evaluation in Early Development Phase

In early development phase, designers and engineers may have very few information and available data to build a seat model. Indeed, all decisions have not been taken yet, and this is the purpose of the development process itself, to select the adequate materials and shape, which will lead to the best performances. In addition, people in charge of this initial concept phase are not necessarily used to simulation techniques and need support to make the best use of them.

3.1. Management of Missing Information at the Early Stage

The different seat components are made of selected materials, whose properties will influence significantly the seat performance. Consequently, in order to be predictive, the model needs to include a description of those properties. But as mentioned here before, the goal at this stage is to use simulation in order to choose the right material based on targeted performance levels. Therefore, at this stage only a first material assumption will be required (coming from a previous seat for instance), and simulation will be used to update those materials in order to reach the targeted performance, as for instance the occupant position. This is made possible with one of the tools developed in the frame of the project. Indeed, it includes first a material database with materials of different kinds (foams, textiles, metals, plastics) which are automatically assigned to the different seat parts based on the component they belong to (Figure 1). For example, if a part is recognized as being a cover, a textile material will be automatically assigned to it. Then, the user will give his targeted occupant position and the simulation will handle the optimization of the materials to reach this target. The output is here the choice of the materials to reach a prescribed performance.

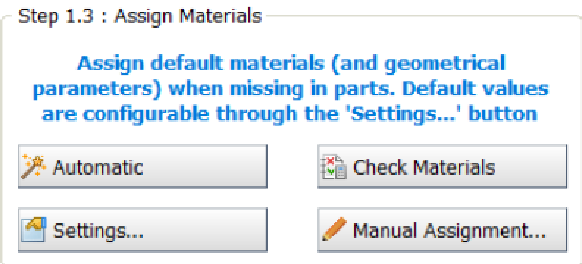


Figure 1. Material Assignment with ESI Interior Solution.

This automated material assignment is one step of a larger automated workflow, developed to guide people non-familiar with the building of seat models.

3.2. Human Models to Test Several Anthropometries

To ensure cockpit design will deliver a good level of static comfort while optimizing the living space, ESI has developed a finite element human models' database with anatomically precise features and deformable tissues. Several kinds of anthropometries from different populations and including elderly and overweighed people are embedded and can be scaled to match with real users (Figure 2). Those models have been developed based on real people and validated regarding their ability to predict pressure distribution and vibratory behavior [8][9][10].

Figure 2. Comfort Human Model Library embedded in ESI Interior Solution.

3.3. Occupant seating simulations for preliminary layout design choices

Regulations impose a precise seating position for pilots, ensuring that they will have the best visibility within the cockpit. This position is determined by the pilot's eyes position once seated. They should be at the Eye Reference Point (ERP) position, which is materialized by aircraft manufacturers with a marker in the cockpit. When seating, the pilot has to adjust the seat settings in order to make sure to have his eyes at the level of this marker. This being done, he will have adopted the optimum position to operate the aircraft.

Designers must design a seat with settings adjustments which enable to have the actual eyes location on the cockpit ERP for several extreme anthropometries. ESI has therefore developed an automatic process to simulate the pilot seating and an automated adjustment of the seat settings to reach the ERP (Figure 3). This process is as simple as the workflow for the seat modelling described here before. Users must only choose the pilot anthropometry, define the cockpit ERP location, and then, the process is done in 3 main steps. The first one consists in seating human model and tightening belt. Then the cylinder located under the seat is adjusted to reach the vertical coordinate of ERP and finally the horizontal seat adjustment is done. The output of this simulation is not only the eyes position of the pilot for a given seat, but the adequate seat settings adjustments to reach the targeted ERP.

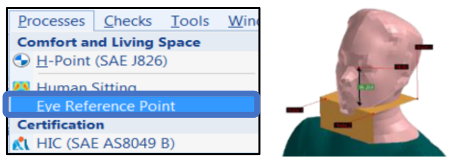


Figure 3. ERP process with ESI Interior Solution.

Fig a)

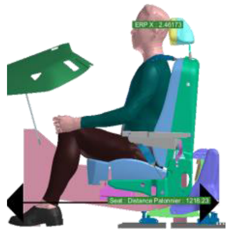


Fig b)

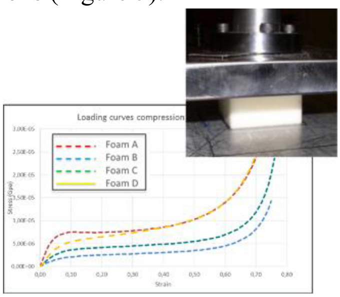
Figure 4. Simulation with the ERP process of ESI Interior Solution: before a) and after b) horizontal seat adjustments, applied on Safran Seat inside a Dassault Aviation Falcon Environment.

Thanks to these numerical tests, engineers have an idea of solutions they could incorporate in a future seat before any virtual and/or real prototype has been built (Figure 4). At this stage of development, engineers could explore virtually the seat integration inside the cockpit and can easily iterate.

4. Exhaustive Comfort Performance Evaluation during Detailed Design Phase

4.1. Seat Model

During detailed design phase, the main objective is to predict very accurately the performances of the seat. For this purpose, the virtual model of the seat is defined as close as possible to the future real production seat. Regarding comfort, foam properties have a major influence. Tensile and quasi-static compression tests must be carried out on samples of material to obtain stress as a function of strain for static comfort. Those data are directly applicable to the seat model. For vibrations responses, similar tests must be performed, and their results can be converted directly by the software into proper dataset for the simulation. Those properties are purely physical, and no numerical tuning is needed. Engineers have the possibility to fill their own material database into the software and assign a specific behavior to each seat part of the foam cushions (Figure 5).



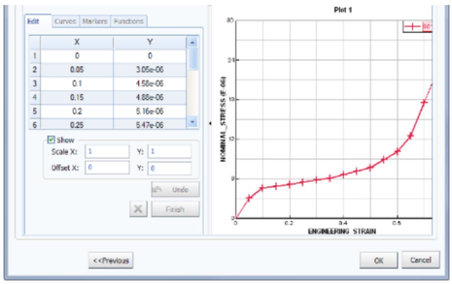


Figure 5. Material Mechanical Properties: As measured in test on the left, as pasted in the model on the right with ESI Interior Solution.

For the frame modelling, different strategies are adopted based on the performance to be simulated. For both certification and vibrations testing, the frame deformation must be considered. On the opposite, for static comfort, loads supported by the frame are not in a range where the frame is likely to deform. A semi-rigid modelling is used to save some simulation time. As a consequence, the model contains two alternative modellings for the frame which can be activated automatically based on the performance to be tested (Figure 6):

- Deformable Modeling: each frame part is deformable and all connections between all parts and the frame are precisely defined,
- Semi-Rigid Modeling: frame parts are modeled with large rigid bodies linked with kinematic joints.

Figure 6. Different foam materials assignment on the Safran seat cushions with ESI Interior Solution.

4.2. Static Performance

Safran has done several real tests with three volunteers to assess postural comfort. Digital human models have been generated by Safran engineers to match with volunteers. Real male volunteers correspond to small, medium and large statures [8][9].

Table 1. Pilot morphology: Real Volunteers & virtual human models from ESI Interior Solution.

	Small		Medium		Large	
Properties	Size (cm)	Weight (kg)	Size (cm)	Weight (kg)	Size (cm)	Weight (kg)
Real Tests	161	51	192	82	194	118
Virtual Model	157	51	180	82	191	118

The first simulation step consists in seating the human model. Contacts between occupant and seat are then defined automatically. Then the automatic ERP process adjusts the seat position on longitudinal and vertical axis. Once the seat has been correctly positioned, pressure maps and pressure distributions from simulation and real tests have been compared.

Numerical pressure maps are very close to real maps (Figure 7). Average pressures and pressure distributions are also near experimental results (0,54 N/cm² for simulation tests and 0,50 N/cm² for real tests. Moreover, overpressure areas have the same locations. These areas are below ischium tuberosities and on lateral zones where the foam is stiffer. However, demarcation line with the forward foam is not present on virtual simulation because it wasn't included in the CAD file. Moreover, real test reports did not contain any precise information on each occupant posture. This could affect results.

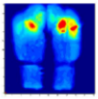
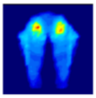
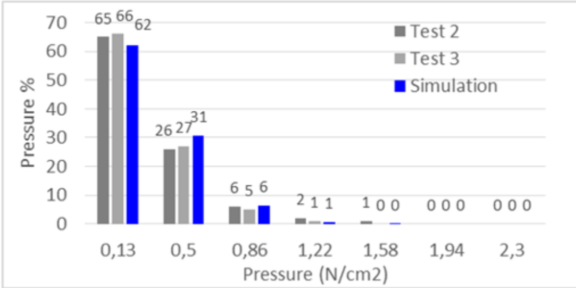
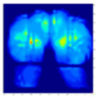
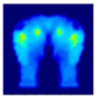
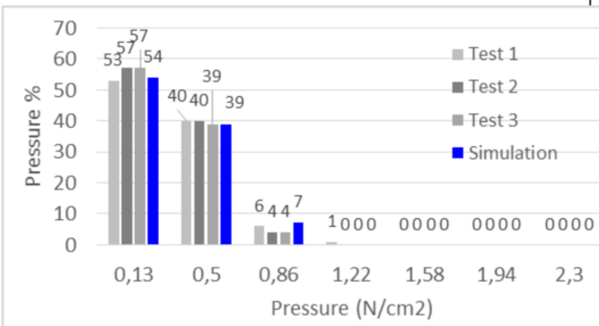
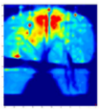
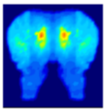
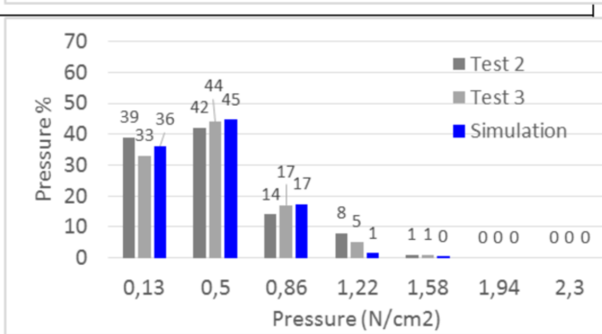
	Real Tests	Simulation Tests	Pressure Distributions
Small	 Average Pressure 0.50 N/cm²	 Average Pressure 0.50 N/cm²	
Medium	 Average Pressure 0.50 N/cm²	 Average Pressure 0.54 N/cm²	
Large	 Average Pressure 0.65 N/cm²	 Average Pressure 0.64 N/cm²	

Figure 7. Static seating pressure map comparison between real tests and virtual tests done with ESI Interior solution.

4.3. Dynamic Comfort Performance

To ensure vibratory seat performance, seat coupled with human system transfer function has been measured. In these tests, the same human volunteers as for postural studies have been positioned on the seat. Regarding simulations, the previous seating simulations are extended to replicate seat excitations based on confidential experimental data and monitor how much those vibrations are absorbed or increased by the seat at the level of the occupant. Occupant comfort only depends on low frequencies around peak of resonance [11].

The numerical model presents results which are in the range of the experimental scattering (Figure 8). The movement observed at the peak of resonance is a movement mainly vertical with a slight flexion of the pelvis around the sagittal axis. The natural frequency for the foam material is always around this value.

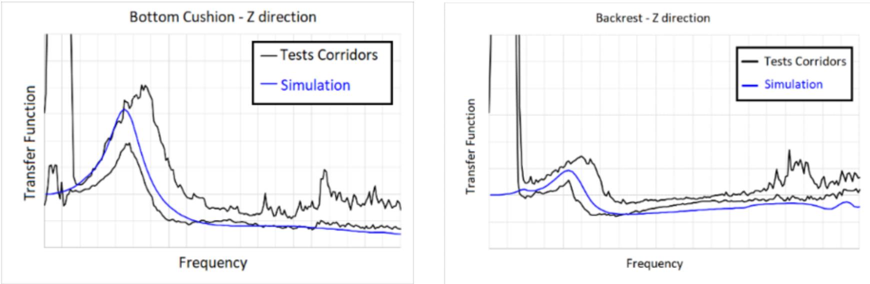


Figure 8. Examples of vibratory response and correlation between simulation done with ESI Interior Solution and experiment.

4.4. Thermal Comfort Performance

To evaluate thermal comfort performance the seat model has been updated, by adding some thermal material properties to the mechanical properties already defined before. Two main parameters are fulfilled: the conductivity and the specific heat capacity. Both can be set as constant or temperature dependent. Conductivity can also be made dependent on the level of compression reached by the material after an occupant is seated. Pilot seats are also covered with sheepskin including wool. The main function of sheepskin cover is to keep pilots cool in the summer and warm in the winter – whatever the temperature in a cockpit is, sheepskin covers remain of almost the same temperature and keep a pilot dry. Sheepskin is also a perfect seat cover for aircraft seats since it is totally flame resistant and self-extinguishing. Sheepskin and wool cover were modelled as a porous material retaining air flows. Its width is 10 mm. Such covers were placed both on the backrest and on the cushion.

At the level of contact interfaces if two interfaces are in contact, the heat is transferred without loss and, the more the two interfaces are distant, the less heat is transferred. The loss of heat by convection with air is modelled through a uniform and constant coefficient applied on all external surfaces of the seat [6]. Regarding human models, mathematical models predicting human thermal behavior are included and rely on the computation of the body thermal balance. The human body can be considered as a combination of two thermoregulation systems: one active and one passive system. The active system model mimics the behavior of the central nervous system which manages the temperature regulation, and the passive system simulates the heat and mass transfers within the body but also with the body environment. In addition to the simulation of the thermoregulation and the calculation of the temperature distribution, the human models can provide comfort scores [6]. The aim of defining such scores is to have an objective criterion to support the design of seat heating and cooling system or global thermal management of the cockpit. The thermal comfort criterion which has been developed is partially based on the work of Zhang [12]. Based on experimental data, Zhang has established a direct relationship between objective values (skin temperature, skin temperature variation…) and the subjective feeling of comfort/discomfort [5] [6].

After calculations, engineers can have access to temperature distribution on seat and occupant, sensation and comfort scores, and can explore several seat variants to diminish the thermal loads on pilots, which have a direct influence on dehydration, fatigue and alertness (Figure 9).

Figure 9. Temperature Distribution on Safran Seat done with ESI Interior Solution.

5. Conclusion

In order to deliver a seat prototype meeting standard and performances requirements, Safran & Dassault Aviation have decided to adopt virtual prototypes. Indeed, usual traditional seat development process doesn't allow to test seat comfort very early in the development process and a large margin to correct defaults.

This study showed the benefits of using Virtual Seat Prototyping and digital human models to anticipate pilot seat integration inside a cockpit. Thanks to dedicated workflows, Safran & Dassault Aviation engineers and designers could start to explore new designs with few data and almost no finite elements background and compare results coming from simulations with real tests, validating software predictivity for static comfort and vibration response evaluation. They were able to iterate on existing seat designs for future seat development projects.

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