Towards an adjustable aircraft seat pan creating comfort for small and tall persons

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Abstract When designing a comfortable aircraft seat a large variety of occupants must be considered. Also, variation of posture is seen as an important factor for creating comfort, and the question is how to translate that in a seat design. Past studies show that, for a comfortable position in an SUV and sedan seat, most of the pressure (50-60% of the total body weight) should be under the posterior one third of the contact area between seat and human, along with 20% in the middle and 10% in the anterior part. Other studies show that a large contact area between human and seat is preferable. It is not simple to design a seat facilitating variation of posture, creating an ideal pressure distribution and large contact area for a large variation in human sizes. For instance, having short lower legs increases the pressure in the front of the seat and having short or long upper legs might reduce the contact area. To overcome these problems in this project an aircraft seat pan was developed that was able to adjust both the height of the front of the seat pan and the length of the seat pan. The question was if this is technically feasible without adding too much weight. Therefore, a project was started to develop and design a mechanism that could be implemented into an aircraft seat. In this paper the background for the development of this seat is described and an evaluation was done technically to see if further technical improvements are needed and some people used the seat to have a first impression on the users' opinion. The first impressions are promising, but a lot has to be done also on the usability of the controls and further development is suggested.

Keywords: Aircraft seat, comfort, adjustable, technical feasibility

1 Introduction

There are many requirements for aircraft seats (Vink & Brauer, 2011). The seats should be lightweight, comfortable, reliable, maintenance costs should be low and seats should facilitate as many passengers as possible. Additionally, to increase revenue maximising the amount of seats in an airplane is a requirement as well. Airlines can in principle increase their profit margin by reducing maintenance costs. However, according to Brauer (2004), at a typical airline a 14% reduction in maintenance costs will result in only a 1 percentage point improvement in the airline's profit margin, while a passenger revenue increase of only 1% has the same result. To increase passenger revenue, we need to understand the flight selection behaviour of passengers. According to Brauer (2004) most passengers first select the most convenient route and departure time at the best price. In those cases in which the passenger is indifferent between equally convenient flights at a similar price, other aspects break the tie. These other aspects include comfort, service, the airline's reputation for on-time performance, and marketing programs such as frequent flyer programmes. For short distances on-time performance is more important and for long haul flights the comfort and service aspects play the most important roles. Under the foregoing flight selection paradigm, individual passengers never make a choice to pay more for more comfort. However, Vink et al. (2012) show that comfort has a high correlation with ‘fly again with the same airline’.

There are many complaints on leg room on the internet (Bouwens, 2018) in the current economy class seats, but also in the seats of 2011 (Vink et al., 2012). However, on average the seats of 2011 score better in comfort than the seats of airplanes 10-20 years ago (Vink et al., 2012). One of the challenges in designing an aircraft seat is that a large variation of people uses the seats. Molenbroek et al. (2017) showed that in measuring the anthropometrics relevant for seating of 346 persons that there is a large variation in buttock-popliteal depths (length of upper leg sitting between knee cavity and back of the buttock). The p5 female buttock-popliteal depth in 2014 was 449 mm while the p95 male had a depth of 558 mm. This was not significantly different from the recordings in 1986, which means that changes in time in these values probably go slow. So, ideally, the seat pan length should vary between 449 and 558 mm. The popliteal height sitting in the study of Molenbroek et al. (2017) varies between 406 and 544 mm for p5 female band p95 male in 2014 respectively, which could mean that about 14 cm difference in seatpan height is needed. However, in this case less dispersion is needed as longer persons can sit on a lower seat by stretching their legs. Also, 3d scans of subjects in an aircraft seat made by Hiemstra-van Mastrigt (2015) show a large variation in the form of the area touching the seat pan, especially in the area close to the knees (see fig. 1).

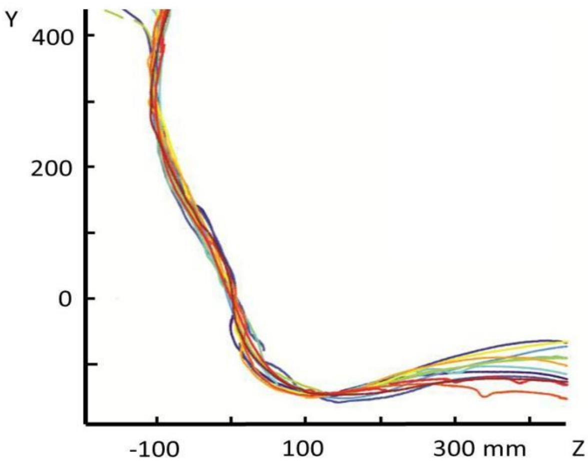

Fig.1. A cross-section of the contact area between seat and human in which the different 3d-scans are rotated and translated to create as much overap as possible between the different subjects (Hiemstra-van Mastrigt, 2015).

Supporting the area close to the knees is complex. First of all, there is the difference in sizes recorded by anthropometrics and 3d-scans. Secondly, there is the characteristic of the human body that influences the design of a seat close to the knee area. Vink & Lips (2016) studied the sensitivity of the back and buttocks with a view to choosing the best foam softness for different parts of the seat, and to define areas where a more flexible shell is needed. To this end, a special seat was made by Vink & Lips (2016) with 32 holes and a device with a round surface recording force was placed in the holes and pushed until the occupant stated that they were no longer comfortable. Sensitivity readings for 23 subjects were recorded (8 females and 15 males; 19-54 years old). Results from this sensitivity study are summarised in figure 2. Results indicated that the area of the human body in contact with the front of the seat pan is more sensitive – a conclusion that corresponds with the findings of Zenk et al. (2012), Mergl et al. (2005) and Hartung (2006), who state that the pressure in this area should be around 6% of the total pressure on the seat. Both increases and reductions in pressure result in more discomfort. Zenk et al. (2012) arrived at the ideal pressure distribution map for a BMW 7-series based on years of research with TU Munich and BMW (e.g. Hartung, 2006). A short-term test involving 84 subjects showed lower discomfort ratings in the ‘ideal distribution’. In a long-term test, eight participants drove three hours in their own preferred position and in a position derived from to the ideal pressure distribution. Results showed that the latter position produced significantly lower discomfort values. Results of a recent study by

Kilincsoy (2019) show that the ideal pressure distributions of both sedan and SUV passenger seats are close to these values. Companies designing seats can use these values to validate their seat designs. Both studies indicate that areas more posterior in the seat have greater pressure. The area around the tuberositas ischiadicus can bear up to 50-65% of the load and the load at the front of the seat should be around 6% of the total load.

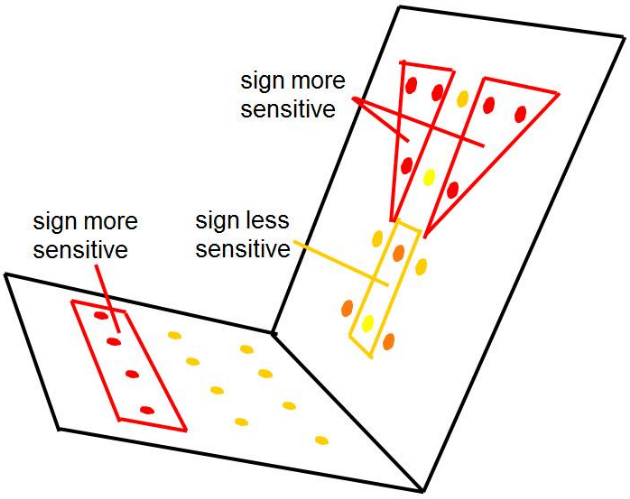

Fig.2. Areas with significantly different sensitivities (Vink & Lips, 2017).

An additional requirement for seats is that variation of posture should be stimulated. growing number of scientists in the field of musculoskeletal injuries are of the opinion that it is more important to vary posture (and avoid the static postures) than to design seating for the ideal posture (e.g. Lueder, 2004). It is not always easy to stimulate variations in posture. In office seats, variation is enabled via variations in tasks and having a movable seat pan and backrest (e.g. Ellegast et al. 2012). For many vehicles, however, this is not possible. Posture variation might be less important for short travel distances, but for larger distances it is certainly important in order to prevent discomfort and deep vein thrombosis. Hu et al. (2003) state that every two hours sitting time increases the risk of obesity by 5% and the risk of diabetes by 7% in female workers. The catchphrase du jour that 'sitting is the new smoking' is perhaps overstating it. However, there is a weight of literature showing that there are health risks attached to sitting in restricted postures. While alternating sitting with other activities is better for our health, small changes in the seat can also have positive effects.

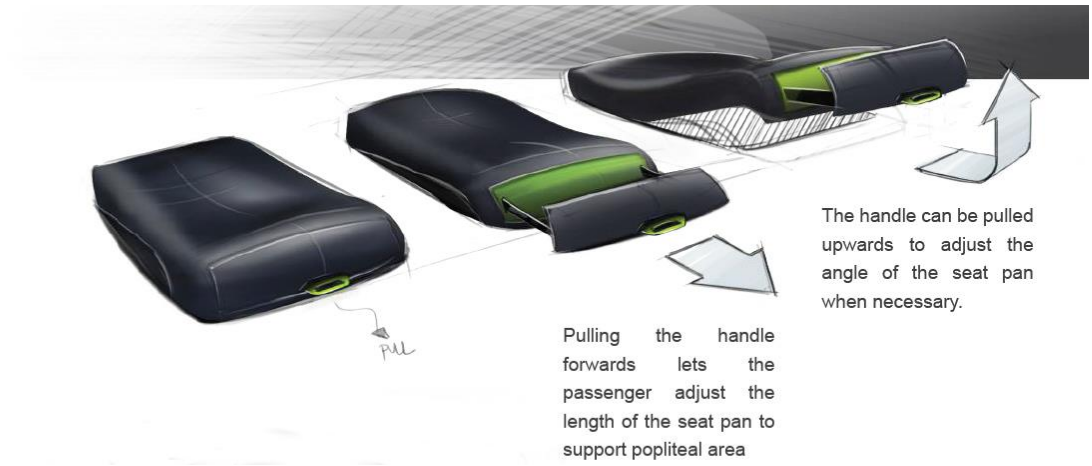

Fig.3. Rough design and working principle of the adjustable seat pan.

2 The design

So, it is not simple to design a seat facilitating variation of posture, creating an ideal pressure distribution and a large contact area for a large variation in human sizes. For instance, having short lower legs increases the pressure in the front of the seat and having short or long upper legs might reduce the contact area. To overcome these problems in this project an aircraft seat pan was developed that was able to adjust both the height of the front of the seat pan and the length of the seat pan. The question was if this is technically feasible without adding too much weight. Therefore, a project was started to develop and design a seat pan. After various brainstorms, idea sketches a decision was made on the design (see fig. 3). However, the technical feasibility and detailed design still had to be done. Detailed design was made of the frame, the frame adjustment system, the control mechanism, the locking mechanism, the bullnose and seating content (e.g. foam). A light weight and stiff carbon fibre composite seat frame forms the base of the seat, which is mounted from its rear end to the backrest mount. The seat pan can also articulate in combination with a suitable backrest adjustment mechanism if the seat structure allows for this function. A suspension fabric stretched over the frame forms the sitting plane. Therefore no additional weight is needed for components such as springs and attachment clips. A part of the mechanism is shown in figure 4 and 5.

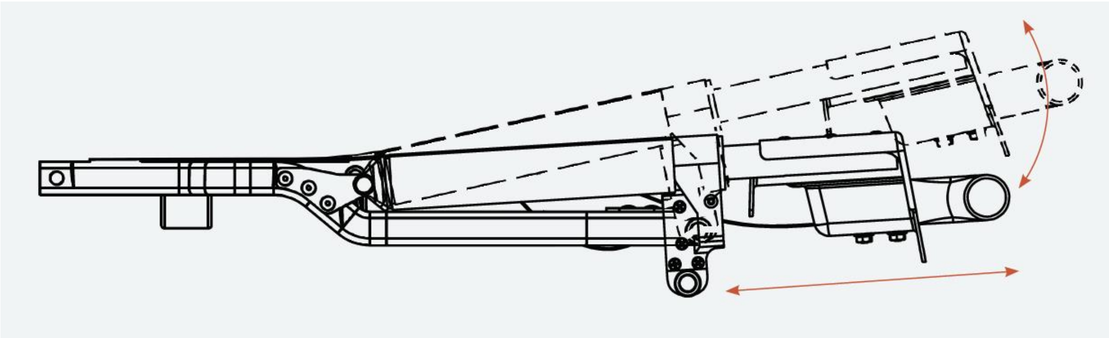

Fig.4. Elements of the structure of the adjustable seat pan.

Fig.5. The basic structure of the seat pan developed in this project.

Fig.6. One of the two protypes that can operate the way the envisioned product should work and tested at the AIX trade fair.

3 Evaluation

Two working prototypes were made (see fig. 6) and presented at the AIX in Hamburg. Visitors at the EXPO were asked to take a seat and adjust the seat pan in length and height and impressions from the visitors were noted. Additionally, the technical side is evaluated as well and a list of further ti study technical aspects was made. Apart from the aircraft seat certification, several tests still have to be done, like the strengthof the various parts, the maintainability and how many cycles it will hold. Also, due to the short time frame of the project (6 months), design developments of several parts with the longest lead time had to be frozen in order to start production. For example, the most important part included the carbon fibre seat pan frame to which other parts had to be attached. This part took a long time to develop, but also took quite some time to produce as it was produced in the Aeroworks facility in Thailand. So when other parts or subassemblies were already manufactured and assembled, the overall assembly process had to wait until the main seat frame arrived from Thailand. Other parts, such as the telescopic mechanisms were purchased and tested. However, by the time all the parts had arrived, several design flaws had been detected and it was be too late to re-order or re-manufacture the parts that caused functional problems. Nevertheless, the system worked and people were able to sit on it and the system looks promising despite the technical work that still has to be done.

During the testing of the seat at the AIX in Hamburg, several design concerns were confirmed by participants of the test. For example, having a handle in the middle of the seat may not work well for women who happen to wear a long dress or skirt. Many participants had trouble understanding how the raising and lowering mechanism functioned. As pulling the handle would disengage the locking mechanism, the user would have to tense their body to lift up their legs prior to raising the nose of the seat pan. In observing participants trying to figure out how the seat worked unnatural behaviour was seen according to the observers. Participants for instance overstrained the handle mechanism which resulted in several components of the prototype to fall apart. It was easy to fix, but in indicates that the adjustment and handle mechanism is far from optimal. Feedback provided by every participant with various body dimensions showed that individual adjustment per body type and the ability of supporting the popliteal area proves to be a highly pleasant and was experienced as comfortable. Everyone (appr 20 participants) who had the chance to sit in the seat believed it to be a valuable addition to current economy class seats. Other feedback gained from industry experts revealed that simple icons or use cues that would clarify how the handle should work would result in less confusion.

4 Conclusion

Variation in anthropometry and sensitivity of the human legs and buttock ask for a special aircraft seat design. In this project an attempt was made to design a mechanism making many people fit in a seat in a comfortable way and making variation of the posture possible. After half a year of working, a promising direction for a solution was made. End users see and feel the benefits. However, in the technology improvements have to made and also the control needs further improvement.

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