A Comfortable Overlay for Economy Airline Seating

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***Abstract*—Economy airline seating has a widespread reputation for being cramped and uncomfortable. This research project was an effort to explore whether the comfort conditions could be improved. Solidworks was used to model the cushion and seating load to iteratively design a cushion that could be used to create a more comfortable sitting experience on commercial economy airline seats. It was found that an ideal cushion design had a lower Young's modulus and a contoured shaped to fit the buttocks. The simulations performed to date showed that the investigated cushion designs had not met a target peak pressure below 12kPa, which has previously found to be a threshold for higher comfort levels. Further research is required to investigate improved designs.**

***Keywords*—Airline Seating, comfort, cushion, pressure distribution, Solidworks.**

I. Introduction

How can an adjustable smart device overlay for airline seating be modelled to help increase the comfort for passengers within the current regulatory and carrier limitations?

Airline economy seating does not have a high reputation in terms of comfort. There is a pervasive view that it is cramped and not focused on the needs of the passengers [1]. This is a consistent theme across airlines and manufacturers and, as such, warrants investigation into the causes of this and how it could be improved. This research endeavours to improve comfort for economy seating in current airlines. The method pursued will be to design a commercially available product such as a cushion or overlay which the passengers can use to augment their commercial airline seating experience. Comfort is a multifaceted subject and covers many topics. To frame this subject within an engineering perspective there will be particular focus on measurable engineering phenomena such as pressure, force and friction. The factors that can be objectively measured and improved upon hold the most priority when framed from an engineering perspective so these factors will be focused on. On a more economical thread the product design has to stay within a reasonable cost as the design will have to be attractive to passengers as an investment in their comfort. It must also be durable enough to last several flights such as current products on the market for similar purposes.

The reasons for airlines' reputation for uncomfortable and cramped economy seating is varied. There are many criteria that an airline seat must achieve before it can be used for commercial purposes and the implementation of these may play into the lack of detail to comfort. Strict safety standards mandated by airline governing bodies must be adhered to [2]. These safety standards include force, motion and flammability criteria. Without these standards adhered to commercial airlines are forbidden to use those seats until they pass these safety tests. There are also no mandated comfort standards in terms of dimensions or any other factors and these are wholly decided by the manufacturers, airlines and their requisite governing bodies [3]. In addition the economics and profitability of the manufacturers and airlines are also a major consideration. Since airlines and manufacturers run under the world's largely capitalist system profit is essentially the highest consideration. As such capacity becomes a large driving factor for design and the profitability of these companies. With these factors combined the comfort of the passenger can slip down the list of priorities for airlines and seat manufacturers. Additionally there appears to be largely a race to the bottom for airlines in that economy customers are generally focused on price and only notice the conditions of the airline seating after the tickets are purchased and they are already committed to the flight. So airlines have little incentive to provide a significantly passenger experience to competitors and therefore the quality of economy seating drifts lower and lower.

Measuring comfort can be difficult since it is a very subjective matter with many factors involved. Not only are there psychological factors and individual preferences, additionally humans differ in their body shape and stature. Therefore a lot of subjective factors are prevalent when attempting to measure comfort. To simplify this problem there are some factors that can be objectively measured such as pressure, force and dimensioning for a majority of the flying population [4]. There is research to conclude that fluid flow in the body is a good indicator of overall comfort, if the flow is too restricted there is a strong correlation between chair design and discomfort. The current research indicates that at a pressure value greater than 12 kPa fluid flow in the body is restricted and long term comfort diminishes [5]. As such this value of 12 kPa has been targeted to provide a good measure as to how the design of the overlay performs. If an overlay or cushion can reduce the peak pressures to below this value then the design can be considered successful. Therefore essentially the design is an exercise in pressure and force redistribution, which matches well with framing the research in engineering terms.

This research will see benefits in a few areas, economically, physically and mentally. The benefits extend not just to the individual but perhaps also to the airlines and manufacturers themselves. From an individual perspective this allows for a more comfortable flight experience with a minimal cost outlay, without having to pay the relatively large costs for seating upgrades. The product can help stave off the risks of long term inactivity such as deep vein thrombosis. On another level this product may help encourage those who would otherwise not fly long distances to do so. The flow on affects of this are varied, such as more customers and, therefore, more revenue for airlines. As well as social reasons such as family and friends who otherwise would not meet each other physically given that opportunity. Of course the benefit for airlines and manufacturers is that this research assists them in creating perhaps a better comfort experience. If there are valid and easy to implement recommendations in this research then the manufacturers and airlines have been saved doing the research and development themselves.

II. Literature Review

Current research on this subject can be structured into four broad categories. These explore the current constraints and regulations on airline seating, the human factors of airline seating and sitting position more generally, current available products and designs which may aim to address a similar goal to this research as well as the materials and their properties needed to achieve the end goal. The literature is comprehensive in some parts but also slightly lacking in others, related topics were needed to get a better idea of how comfort is measured and how to implement this information.

A. Rules and Regulations

Airline seats have rules and regulations which must be adhered to, however these regulations mostly involve the safety specifications [2]. There are no regulations which specify minimum dimensions for comfort with these being agreed upon internally between the relevant airline manufacturer and its requisite governing body [3].In this particular research the focus will be on Boeing and the Federal Aviation Authority (FAA). Manufacturers must submit their designs for safety testing to the FAA for certification [6]. These tests cover safety standards for maximum forces, pressures and fire resistance [7]. This can take a long time and as such it appears the manufacturers, whether on purpose or not, push the priority of comfort behind the priorities of safety testing and carriers' capacity needs. Additionally the economics and efficiencies of flying see a large focus on reducing the weight of the seats, any small decrease per seat can see large gains economically [8].

The product itself will have to work within the dimensions of current airline seating standards (see table I) which can vary from carrier to carrier. Information for these dimensions can be quite hard to confirm so the product will also have to be flexible enough to fit within these parameters.

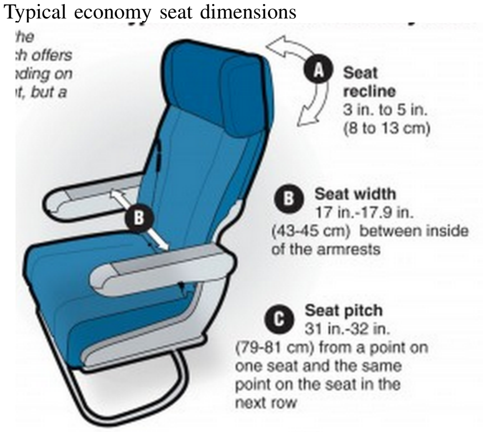
B. Ergonomics and Human Factors

The ergonomics of sitting for long periods has been studied for various purposes and there appears to be some consensus on what constitutes a relatively comfortable chair. Generally speaking a comfortable chair spreads the load of the body over as large a surface area as possible with high pressure points preferably focused on the bony protrusion on the bottom of the pelvic bone known as the ischial tuberosities [4]. Overall pressure on at any point should not exceed 12 kPa as this is the pressure that cuts off fluid flow and circulation in the body

TABLE I. Typical airline seating dimensions [9], [1]

Dimension	Description	Typical Distance
Pitch	Distance between the same point from one seat to the seat in front	76-81 cm
Width	Distance from armrest to armrest	43-46 cm
Depth	Distance from front of seat to back	42-50 cm
Angle/Rake	Angle of the seat relative to horizontal	Up to 15 degrees
Armrest height	Distance from top of cushion to top of armrest	Data Unavailable
Back height	Height of the back rest from the top of the seat height	Data Unavailable

Fig. 1. Typical economy seat dimensions



[5].This gives a good target to aim for as it is more absolute than data from questionnaires and surveys.

Other important considerations are the addition of well positioned footrests, backrests and armrests [10], [11] which allow for further weight redistribution and body adjustment. They have been shown to increase comfort considerably given the placement of them is optimised for the sitter. The limitations with these is that it becomes difficult to place these various rests in a positions which satisfies the 95th percentile [11].

This also leads into the theory of dynamic sitting which suggests that for long periods of time a single sitting position cannot be ideal and the sitter must change position to allow for good circulation and redistribute muscle strain [12]. These changes should generally occur every fifteen minutes or so however able bodied human beings will generally do this unconsciously due to the encouragement of the body producing aches and pains. For the wheelchair bound it has been shown that dynamic cushions, which change shape themselves to encourage dynamic seating, can be beneficial to encourage fluid flow within the body [12].

C. Current Designs

There are currently some products that claim to assist with comfort on long haul flights as well as a few scattered patents [13], [14]. The bulk of these appear to be low quality and have varying claims in their effectiveness. Patents by their nature do not claim huge benefits but rather just outline ideas and the current designs available do not appear to be backed by

Fig. 2. A dynamic cushion [18]

TABLE II. ADVANTAGES AND DISADVANTAGES OF CERTAIN MATERIAL TYPES

Material	Advantages	Disadvantages
Foam	Light Cheap Good heat transfer properties	Limitations in compression Quality and durability variable
Gel	Comfortable Malleable Recommended by health proffesionals	Leakages can occur Heavier Viscosity can be disconcerting
Air	Light Constant density Cell design	Costs are high Can be unstable to sit on Can be punctured

evidence for their claims. So it seems there may be a niche to create a product that is more evidence based.

There are some studies on related topics which have may have applicable ideas to the current task. There are some papers involving car seats [15], [16] which offer good evidence into comfort. They also provide valuable information on computer modelling of seats and how to measure human interactions with them. Another related topic which has proven to be useful has been the industry of wheelchairs and the infirm. Care must be taken with this data since experiments have shown to have differing results depending on whether the test subjects were in fact disabled or not [17]. Keeping this in mind however the products take greater care to provide comfort and less damage to the body. The theory of dynamic seating is perhaps a useful one, it states, as previously noted, that no static position will remain comfortable, instead the person sitting will naturally (assuming they are able bodied) move and shift position due to encouragement from natural aches and pains [10]. This helps the body circulate better and prevents problems seen in the disabled such as bed sores [12]. Using this theory there are various dynamic cushions (see figure 2) on the market designed for use for people with disabilities [18]. They generally consist of a cushion consisting of separated air pockets which slowly inflate and deflate allowing for better circulation within the body and allowing for pressure differentials to propagate about the body rather than stay in one area. They tend to retail in the high hundreds of dollars to the low thousands. This may be a useful avenue to pursue, if costs can be compressed enough perhaps a commercial version for the general public may be viable.

D. Materials

The materials used for our design are the options of three broad categories. Each with specific advantages and disadvantages. Table II shows a summary of each material.

1) Polyurethane Foam: Polyurethane foam has the strongest advantages of the options. The properties which make it desirable are it's cost, weight and compressibility. It generally follows the stress strain rule (see equation 1). There also some disadvantages however.

TABLE III. TYPICAL PROPERTIES OF POLYURETHANE FOAM

Mechanical Properties	Metric
Young's Modulus	0.000138 - 3.45 GPa
Poisson's Ratio	0.300 - 0.750

$$\sigma_x = E\varepsilon_x \tag{1}$$

The density is important for polyurethane foam specification. It is an important indicator of foam performance with regard to comfort, support and durability. It is also an indicator of the relative economics of the foam [19]. High-density foams can be produced to be very soft. Low-density foams can be very firm. High-density foam products generally offer great deal of support, but they may actually be fairly soft foams (Volume I, Number 2, May 1991). Studies have shown that the most comfortable seating with a foam cushion is a medium density polyurethane with compression no greater than two to three centimetres [11]. Foam, in contrast to the other options, is compressible and suffers from reaching a point of incompressibility. If this point is reached seating will feel much more uncomfortable [5] as the foam has no where to disperse sideways. There are possible ways to get around this limitation, such as slicing the foam into upright square prisms. This however can affect durability.

Another important property of foam as compared to other options is that foam does not have a strictly linear compressibility pattern. Initially foam has a linear compression curve but then there is a point of incompressibility where the properties change sharply. Ideally this point of incompressibility should not be reached to achieve maximum comfort values.

2) Gel: Gel seat cushion are generally recommended by Health professionals and are used extensively by wheelchair users [12]. The development of the gel seat cushion is fuelled by the need for a comfortable and healthy seating option for car, office and the infirm. They ensure maximum comfort for a long period of time. The extra-wide design fits any body type and offers full protection from direct pressure. The ideal is for long road trips, flights, picnics, ball games, and camping. They are ideally placed against the backrest. Support comes from the lumbar or lower back region, effectively eliminating lower back pain (Brooks K, 2013). The general design is of separate pockets with highly viscous gel in each with the skin made of a tough rubber. This is generally regarded as giving the best comfort however there are some disadvantages. These are the heaviest of all cushions and can be prone to leaking [20]. Hence their use in applications which do not require lots of travelling. As such this material may not be suitable for the needs of the project.

3) Air: Air-inflated seat cushion consist of cells allowing air to flow between each of them and inflation holes. Inner parts of the cushion are connected. There are air outlets and passages for air to flow between cells. When a driver moves onto the cushion, the shape of the cushion will change accordingly. With air flowing between cells, the air-inflated cells act as shock absorbers with damping characteristics depending on cell pressure, cell size and air transfer rate between cells [21]. This design is generally the one which can easily incorporate dynamic seating [18]. Air suffers some of the downsides of gel cushions but does manage to stay light, this however introduces issues with stability, where the cushion can easily shift and collapse under uneven pressure [20]. The advantage of both gel and air cushioning is that when compressed the outer skin allows the fluid inside to disperse horizontally and should theoretically create a more comfortable impression [5]. These are however not insurmountable problems for foam to overcome.

E. Other Considerations

1) Thermal Conductivity: The total thermal conductivity is the sum of the conductivities of both the gas and solid phase plus the thermal conductivity due to convection and radiation. The thermal conductivity is very low for polymer foams because the amount of solid in the foam is very small. The thermal conductivity has a minimum at a certain density. At low densities the radiative component is more dominant since the cell size is larger, and so is the convective component. At high densities the number of cell walls and the thickness of them is higher so the radiative component is less important, but the heat transfer through the solid phase becomes more dominant [22].

2) Cushion Covering: The selection of an appropriate cushion cover can influence seating for example a smooth surface cover, compared with a towelling-type or wool-pile cover, may ease sideways transfers for those who are weak or with a degenerative neurological condition. Maintenance or loss of body heat may also influence the selection of cover materials. Where less body heat is generated for example in the frail elderly a wool-pile or towelling cover may be preferable whereas in young active wheelchair users similar covers may promote heat and moisture build-up. For the incontinent individual ease of cleaning the cover is crucial and where the cover can be detached from the cushion a covered zip is required. As with the care of the cushion itself the individual, their family and/or carer require to be informed regarding the care of the cushion cover. This education needs to cover how to detach, launder and reapply the cover taking account of instructions that may be printed on the cover or cushion for example location of the front or top surface of the cushion or cover [23].

III. Methodology

Solidworks simulations were used as the preferred method for iterative design of the cushion. Finite element analysis was used to determine the maximum stress felt by the human lower torso simulation on a variety of cushions shapes with varying material properties.The analysis done was a static FEA model as there are assumed to be negligible dynamic forces when a person is sitting down. The material properties and cushion shape were iterated to attempt to design a model that minimised peak pressures on the surface of the buttocks to below 13 kPa.

The model buttocks was kept as a simple model with few surfaces and the shape was based on pressure profiles of buttocks from similar studies [4], [16] . The simple model allowed for simpler contact points and easier iteration on the cushion design. A uniform force was distributed on the top surface which was the the equivalent of an 80kg human being (see figure 3).

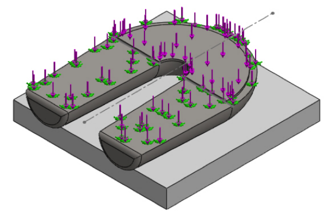


Fig. 3. Simulation with forces and restraints

The first designs of the cushion remained a simple rectangular prism which eliminated variables in the contour of the cushion. The cushion was constrained on the bottom surface and the buttocks was constrain to translate vertically only. This way the static analysis could focus on the ideal material properties to achieve the desired target peak pressure. Two material properties were varied, Young's modulus and Poisson's ratio, these had the largest affect on the pressure distribution.

After the iterative material property design process was completed on the flat cushion iterative design then proceeded contouring the cushion to better fit the simulated buttocks. The contours on the cushion were based on results from previous studies and trial and error design. The contoured cushions were tested using the optimal material properties determined in the first part of the methodology. The best of these designs can be seen in figure

IV. Results

V. Discussion/Analysis

The results of the flat cushion were telling in that Young's modulus was the main driver in pressure redistribution. With Young's modulus set at the upper range of typical polyurethane foam material properties, that is 3 GPa, there was evidence of much higher peak pressure values. As the modulus was gradually set lower the peak pressures decreased to a point that did not allow for peak pressures to reduce below the given target, but at the least get to a closer value. The other main factor that was varied in the simulation was Poisson's ratio. The varying of this material property had a much less pronounced role in reducing peak pressures within the confines of the range in table III.

A. Limitations

With the simulations being restricted to linear analysis we are in effect ignoring the non linearity characteristics of polyurethane foam. Foam has a compression profile of linearity up to a point but the the compression behaviour changes drastically.

The simulations never seemed to reach the point of compressing further than the bottom restraint so the assumption is that the model stayed within the range of linearity in compression of foam. However a more thorough analysis would test the same properties through a non linear simulation as this particular property may in fact be desirable for better comfort.

Modelling the human body is a complex process. The body contains many variable solids, liquids and gases, each with their own material properties. On top of this the human body is not completely static and is constantly moving, circulating, breathing, whether voluntarily or not. The current simulations simplify the human buttocks down to a single solid, with uniform properties, with a single force pushing down uniformly. A more thorough investigation would begin to simulate the buttocks more completely s has been done in some studies [24]. Alternatively commercially available human Solidworks models are may also be used to acquire more thorough results.

VI. Conclusion

Knowing that a peak pressure greater than 12kPa greatly increases discomfort in a sitting position Solidworks simulations were used to design a cushion that would reduce those peak pressures below this threshold. It was found that, of the material properties of the cushion, a lower Young's modulus allowed for lower peak pressures.

References

[1] SKYTRAX Online, "Economy Class and Premium Economy Class Airline Seat Reviews — SKYTRAX," 2014. [Online]. Available: http://www.airlinequality.com/Product/Yseats-entry.htm

[2] Cornell University Law School, "14 CFR 25.785 - Seats, berths, safety belts, and harnesses. — LII / Legal Information Institute," 1990. [Online]. Available: https://www.law.cornell.edu/cfr/text/14/25.785

[3] Civil Avaition Safety Authority, "Seating information." [Online]. Available: http://www.casa.gov.au/scripts/nc.dll?WCMS:STANDARD::pc=PC_91475

[4] Herman Miller, Inc., "The Art and Science of Pressure Distribution," 2013.

[5] M. Nigel and G. Adam, "Seat cushion design case study," 2002. [Online]. Available: http://www.foamstudies.bham.ac.uk/cushions/index.html

[6] Federal Aviation Authority, "Technical standard orders (tso) authorization," 2015. [Online]. Available: https://www.faa.gov/aircraft/air_cert/production_approvals/tsoa/

[7] T. Housel, "Flexible polyurethane foam," *Handbook of polymer foams*, pp. 85–122, 2004.

[8] RECARO, "Light Weight Alloys in Seat Design," 2010. [Online]. Available: http://www.fire.tc.faa.gov/2010Conference/files/Magnesium_Use_In_Aircraft/StachelSeatDesigns/StachelSeatDesignPres.pdf

[9] R. S. Goonetilleke and S. Feizhou, "A methodology to determine the optimum seat depth," *International Journal of Industrial Ergonomics*, vol. 27, no. 4, pp. 207–217, 2001.

[10] M. Graf, U. Guggenbuhl, and H. Krueger, "Investigations on the effects of seat shape and slope on posture, comfort and back muscle activity," *International Journal of Industrial Ergonomics*, vol. 12, no. 1-2, pp. 91–103, 1993.

[11] C. G. Drury and B. G. Coury, "A methodology for chair evaluation." *Applied ergonomics*, vol. 13, no. 3, pp. 195–202, 1982.

[12] L. Stockton and S. Rithalia, "Is dynamic seating a modality worth considering in the prevention of pressure ulcers?" *Journal of Tissue Viability*, vol. 17, no. 1, pp. 15–21, feb 2008. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0268000907000042

[13] R. Duncan, "Inflatable aircraft seat cushion," dec 9 2003, uS Patent 6,659,552. [Online]. Available: https://www.google.com/patents/US6659552

[14] O. Treacy, "Inflatable seat cushion," jan 10 1967, uS Patent 3,296,635. [Online]. Available: https://www.google.com/patents/US3296635

[15] M. M. Verver, R. de Lange, J. van Hoof, and J. S. H. M. Wismans, "Aspects of seat modelling for seating comfort analysis." *Applied ergonomics*, vol. 36, no. 1, pp. 33–42, jan 2005. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0003687004001267

[16] M. Grujicic, B. Pandurangan, G. Arakere, W. C. Bell, T. He, and X. Xie, "Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants," *Materials and Design*, vol. 30, no. 10, pp. 4273–4285, 2009. [Online]. Available: http://dx.doi.org/10.1016/j.matdes.2009.04.028

[17] D. a. Hobson, "Comparative effects of posture on pressure and shear at the body-seat interface." *Journal of rehabilitation research and development*, vol. 29, no. 4, pp. 21–31, 1992.

[18] Bartram Associates Ltd, "Bartram Associates Ltd - Tri-pos Alternating Air Cushion," 2015. [Online]. Available: http://www.bartrams.net/productdetails.php?category_id=117\\&product_id=1070

[19] Polyurethane Foam Association, "Information on Flexible Polyurethane Foam," 1991. [Online]. Available: http://pfa.org/intouch/new_pdf/hr_IntouchV1.2.pdf

[20] S. Arthanat and W. Strobel, "Wheelchair ergonomics : Implications for vocational participation," vol. 24, pp. 97–109, 2006.

[21] Z. Xinglei and Y. Jianguo, "A computer simulation study of seating comfort of air-inflated seat cushion," in *2010 2nd International Conference on Future Computer and Communication*, vol. 1. IEEE, 2010, pp. V1–675–V1–680. [Online]. Available: http://ieeexplore.ieee.org/articleDetails.jsp?arnumber=5497344

[22] K. Sivertsen, "Polymer foams," 2007.

[23] Tissue Viability Society, "Seating and Pressure Ulcers," 2013. [Online]. Available: http://tvs.org.uk/wp-content/uploads/2013/05/TVSseatingandpressureulcerguidelines.pdf

[24] Q. Shu, Y. Cui, and Y. Qi, "Study of building virtual human body model based on SolidWorks," *2009 IEEE 10th International Conference on Computer-Aided Industrial Design & Conceptual Design*, no. 3, pp. 1366–1369, 2009. [Online]. Available: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5375090