

Using Designing for Human Variability to Optimize Aircraft Seat Layout

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ABSTRACT

Integrating the seemingly divergent objectives of aircraft seat configuration is a difficult task. Aircraft manufacturers look to design seats to maximize customer satisfaction and in-flight safety, but these objectives can conflict with the profit motive of airline companies. In order to boost revenue by increasing the number of passengers per aircraft, airline companies may increase seat height and decrease seat pitch. This results in disaccommodation of a greater percentage of the passenger population and is a reason for rising customer dissatisfaction.

This paper describes an effort to bridge this gap by incorporating digital human models, layout optimization, and a profit-maximizing constraint into the aircraft seat design problem. A simplified aircraft seat design experiment is conceptualized and its results are extrapolated to an airline passenger population. The dependence of passengers' comfort ratings on seat height and seat pitch are analyzed, with the aim being to study how to maximize the design's profitability while not compromising comfort. This is a specific example of a general problem: modeling the design space of multi-objective problems involving designing for human variability. These multiple and often conflicting objectives can exist purely within the de-

sign (e.g., minimizing weight while maximizing strength) or can involve higher-level targets such as satisfying customers, passing regulatory requirements, and achieving profits (unfortunately these are not always congruent).

INTRODUCTION

DESIGNING FOR HUMAN VARIABILITY Seat design parameters (Figure 1) are heavily influenced by human anthropometry (body measures). Designers must incorporate an understanding of the variability of relevant body characteristics (e.g., knee height, hip breadth, etc.) of the target user population into their design. In order to do so effectively, anthropometric data must accurately represent the actual target population. For example, Ehrenman (2005) explains the importance of considering the effect of aging of the U.S. baby-boomer generation on the composition of airline passenger populations. Differences in the design and actual user populations result in disproportionate disaccommodation of sub-groups (e.g., small women, large men, older people, etc.). Since relevant anthropometry are not available for every possible target population, several approaches, including proportionality constants (Drillis and Contini, 1966), regression (Flannagan et al., 1998; Garneau and Parkinson, 2007; Nadadur and Parkinson, 2008), and principal components analy-

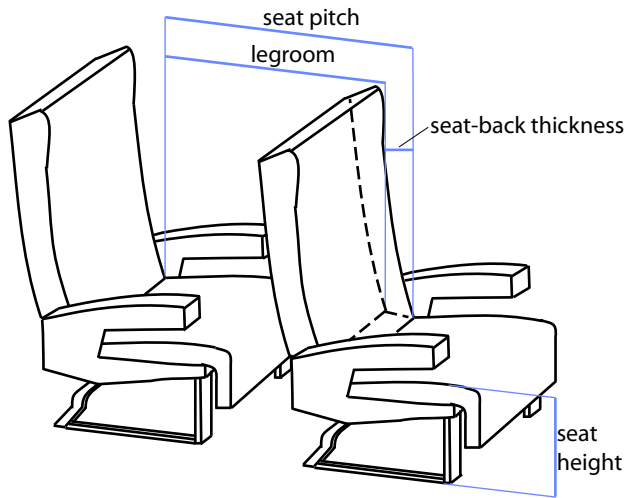


Figure 1: Some aircraft seat design parameters.

sis (PCA) (Parkinson and Reed, 2006a), have been used to obtain estimates of the relevant anthropometry for the target user population.

In addition to using proper anthropometric data, designers must utilize methods that are best-suited to accurately capture the relationships between passenger body characteristics and the seat design parameters. This allows for accurate analysis of the design's accommodation—a measure of the percentage of the target population for whom certain minimum comfort and safety criteria are satisfied by the design. Numerous tools may be used for this purpose, including: digital human modeling software (Human Solutions, 2007; UGS, 2007; Kaiser et al., 2003); boundary manikins (Bittner, 2000); and population models (Flannagan et al., 1998). A recent approach to designing for human variability (DfHV) uses virtual fitting trials and large numbers of manikins to provide more accurate design assessments (Garneau and Parkinson, 2007; Parkinson and Reed, 2006a; Parkinson et al., 2005; Parkinson and Reed, 2006b).

Virtual fitting trials require individual anthropometry for large populations of virtual users. One approach for obtaining these synthesized data, presented in Nadadur and Parkinson (2008), is used here. In an existing population database, multivariate regression is used to formulate relations between: a) the required anthropometry or other posture- and comfort- related parameters and b) basic body measures (predictors) such as stature and body mass index (BMI, a standardized ratio of weight to stature). The standard error of variance of each of these relations is retained and reintroduced into the corresponding regression equation as a stochastic component. The equations thus formulated can *estimate* the required anthropometry for the population with only information about the basic body measures as input.

This set of equations is then extrapolated to the target user population, for which stature and BMI data is usually either available or easily obtained. The required anthro-

pometry or posture- and comfort- related parameters for the target population are thus estimated using its stature and BMI data as input to the previously-developed regression relations. Note that the reason for using BMI, and not weight, as a predictor is the orthogonality that is usually observed between the former variable and stature. It is, therefore, possible to account for a significant portion of anthropometric variability using stature and BMI as predictors.

The uniqueness of this DfHV technique is its ability to retain the variability not correlated with the predictors—the standard error of variance—of each regression relation. The estimations thus generated do not replicate the actual body measures of the population. However, ensuring equivalence of the mean and standard deviation of the estimated and actual data makes for close correspondence of the results of statistical analyses of both sets of data.

Past work has already looked into the application of digital human modeling to designing aircraft interiors (Silva et al., 2007). The benefits of doing so include shortening design time, lowering design, fabrication, and certification costs, etc. In addition, a number of studies have explored the virtual design of seats through analyses of passenger comfort as a function of seat design parameters (Montmayeur et al., 2007). Methodologies have also been put forth, for example, to model the effect of these parameters on muscle fatigue and shear forces in tissues (Rasmussen et al., 2007; Rasmussen and de Zee, 2008), to develop finite element models for seating comfort analyses (Cheng et al., 2007), and to virtually simulate the impact of the characteristics of seats on occupant comfort (Pankoke and Siefert, 2007).

Other research that is relevant to the problem of aircraft seat design and layout planning deals with integrating the principles of product design and marketing (Michalek et al., 2005). Such techniques would enable designers to satisfy the monetary constraints arising from the profit motive of companies while concurrently ensuring a certain level of user comfort. Also applicable to this problem are studies examining human behavior in different environments (Conradi and Alexander, 2007), which would enable designers to better account for the role played by psychological factors in deciding users' perceptions of comfort.

AIRCRAFT SEAT CONFIGURATION PROBLEM In a number of aircraft, seat designs and seat densities place excessive restrictions on the in-flight movement of passengers. This is especially true in the economy classes of aircraft. Such restrictions on passenger movement are not only among the main causes of passenger discomfort, but are also well-known health hazards. Medical conditions such as lower back pain, compressed spinal disks, and deep vein thrombosis (DVT) are all associated with sitting for extended periods of time (Hoschek and

1996; Holm et al., 1981). The risk of passenger discomfort and health issues increases with duration of the flight.

In order to minimize the occurrence of such injuries, some aviation authorities have specified guidelines to be adhered to when designing seats for civil aircraft. Research, commissioned by the European Joint Aviation Authorities (Joint Aviation Authorities, 2009) and funded by the United Kingdom's Civil Aviation Authority (U.K. Civil Aviation Authority, 2009), confirmed an increase in the average European body size. This prompted the Civil Aviation Authority to mandate appropriate seating configuration specifications. In addition to governmental guidelines, designers may use resources such as Woodson et al. (1992) and Moore et al. (1993), which provide more general design guidelines that take into account human factor considerations. Also available are the results of studies in seat cushion design (Anonymous, 1995; Beheshti et al., 2005).

Seating configurations so developed can provide adequate passenger comfort and safety. However, implementing these configurations may require a reduction in the number of passengers per aircraft, and may thereby adversely impact the profit margin of airline companies. In order to increase seat densities in aircraft (Lott, 2006), airline companies may resort to implementing seating configurations that conflict with designer specifications. This interaction could be better understood if aircraft seat designers were to utilize methodologies that incorporated airline companies' profit-maximization objective as a design criterion.

The focus of this paper is to showcase, using a simplified aircraft seating configuration problem, the techniques explored and detailed in Nadadur and Parkinson (2008). A relevant virtual user population will be synthesized, then the multi-objective design space will be explored. The problem examines the effect of two seat design parameters—seat height and seat pitch—on the “basic profit” of the design to passengers and airline companies. Penalties will then be introduced based on the percentage of dissatisfied passengers and the potential health risks posed by the design. A “net profit” of the seat design and layout configuration will thus be calculated. Maximizing the net profit is shown as a possible means of satisfying the requirements of the passengers as well as the airline companies. Note that the aim of this study is not to recommend optimal seating configurations, but to highlight the simplicity of the fundamental DfHV methodology and its adaptability to new problems.

METHODS

THE IMPORTANCE OF SEAT HEIGHT AND SEAT PITCH
Seat height (H) and seat pitch (P) are two of the aircraft seat design and layout configuration variables that are controlled by airline companies. Models of seats of the required height can be selected or, in some cases, ordered to be custom-made while procuring them from sup-

pliers. The number of rows of seats in an aircraft cabin can be adjusted to provide the required seat pitch.

Since seating preference varies within the passenger population, seat height may not be an accurate determinant of passenger comfort. However, passengers are advised to minimize pressure between their lower thighs and the surface of the seat in order to prevent the occurrence of DVT. In order for them to do so by placing their feet on the floor, passengers' knee heights must be greater than the seat height. The higher the number of passengers for whom seat height is greater than their knee height, the higher is the risk of occurrence of DVT. Airlines, however, have conflicting incentives here. Reducing seat height on an aircraft increases the amount of legroom necessary. This, in turn, increases seat pitch, reducing aircraft capacity and profit potential. However, higher seats can increase discomfort (which might affect customer loyalty) and increase the risk of DVT for some portion of the customer population (increasing liability and other problems).

Seat pitch is governed by two basic parameters: aircraft cabin length (L) and the number of rows of seats (N_s) in the cabin:

$$P = L/N_s. \quad (1)$$

Seat pitch, aircraft cabin length, and the number of seats per row (N_r) together determine the number of passengers (N_p) that can be transported in the aircraft:

$$N_p = (L/P) * N_r. \quad (2)$$

As seat pitch decreases, the aircraft's passenger capacity increases. Decreasing seat pitch is, therefore, a way to increase revenue from the aircraft. However, seat pitch, in conjunction with seat-back thickness (T), decides the leg room (R) available for each passenger:

$$R = P - T. \quad (3)$$

Assuming a constant seat-back thickness, too great a reduction in the seat pitch results in insufficient leg room per passenger and thus increases the risk of causing passenger dissatisfaction. The airline may get a negative reputation which may limit its growth potential and even cause a drop in existing passenger traffic.

Seat height and seat pitch are, therefore, variables that impact both passenger comfort and airline profitability, so much so that airlines and third-party sites (TripAdvisor LLC, 2009; Skytrax, 2009) now examine aircraft seat pitch while rating individual seat comfort potential.

DESIGNING FOR HUMAN VARIABILITY Garneau and Parkinson (2007) and Flannagan et al. (1998) showed how the results of a product study experiment conducted on a sample population could be extrapolated to a target user population. The DfHV methodology followed in the work was explained in the previous section. Regression