

Design Optimization of Airline Seats

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ABSTRACT

This paper investigates the opportunity to optimize the parameters of an airline seat for maximum comfort within the confined space available in coach class. A computational model is subjected to a systematic variation of its parameters leading to identification of optimal movement patterns between the seat pan and backrest in terms of discomfort from muscle fatigue and shear forces.

The paper concludes that such patterns exist but other factors may have to be included before the results are brought to practical use in airline seat design.

INTRODUCTION

The majority of airline passengers fly coach class and endure considerable discomfort during long-haul flights. Thus, coach class discomfort is an important competitive parameter, and a systematic minimization of discomfort is in the joint interest of passengers and airlines.

Passengers on long-haul flights typically desire to sleep and are prevented from doing so by at least two sources of recurring discomfort: (i) inability to maintain a stable position without constant muscle activation and (ii) pressure on the soft tissues under the buttocks. The latter phenomenon is investigated intensively by experimental methods (e.g. [1]) but the traditional pressure mats used for experimental investigation are only able to measure normal pressure, i.e. not shear. Computational finite element models (e.g. [2]) have also been used, but their accuracy depends on accurate boundary conditions, i.e. the forces flowing into the system. This is not trivial information to obtain for a human body, whose internal forces are subject to very complex joint mechanisms and voluntary muscle forces controlled by the central nervous system.

Rasmussen et al. [3] used a computational model to compute the net forces acting between the human body and the chair and the necessary muscle activity level to maintain the posture. These results can be fed into a

finite element model to compute actual pressure distributions, but they can also be used independently to assess the comfort of the seated person. In terms of the latter, it was stipulated [3] that shear forces are particularly problematic in terms of discomfort, indicating that the net shear force along with the necessary muscle activity can be used to assess the discomfort of the seated individual.

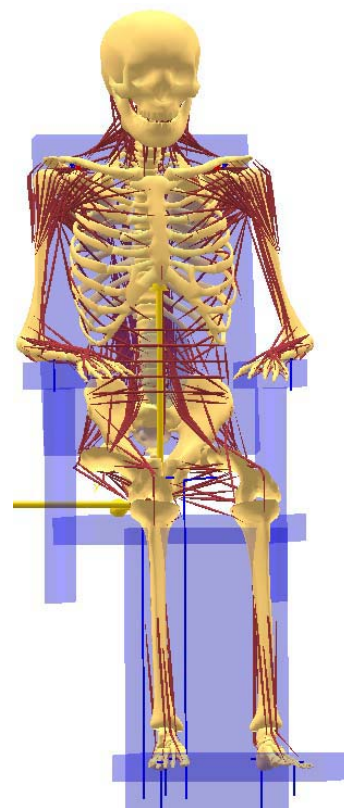


Figure 1. The generic seated human model.

Relevant parameters for the computation are the adjustments of the seat pan and backrest along with the coefficient of friction of the cushion fabric. Typical coach class seats have inclinable backrests while the seat pans are static and horizontal. The backrest inclination is

limited to approximately 20 degrees because of the space limitation. Armrests are available in coach class but they are of limited value because they are not adjustable in height and hence fit only a small fraction of the population, and because one armrest is usually shared between two adjacent passengers.

Rasmussen et al. [3] concluded that it is difficult to combine the desirable muscle relaxation with limitation of the shear forces, because the backrest support necessary to relax in the inclined posture inevitably requires shear forces between the seat pan and buttocks. This paper investigates the parameters more systematically and reveals that certain combinations of seat pan and backrest inclinations do in fact offer good compromises between the two sources of discomfort.

METHODS

The computational methods of the present investigation are similar to those of [3] and will only be repeated briefly here for completeness.

A musculoskeletal model of a seated human [3] has been developed in the AnyBody Modeling System. It is computer software designed for constructing complex models of the human body and for determining the environment's influence on the body. The mathematical and mechanical methods of the system were described in detail in [4]. In short, the system is based on inverse dynamics. It presumes that muscles are recruited according to a minimum fatigue criterion and is capable of simulating the force in every muscle and reactions in every joint and external support condition for prescribed movements and external loads. This full-body model comprises approximately 650 individually activated muscles, but it turns out that the muscles above waist height have little influence on the result, so in the interest of limitation of computational cost the investigations in this paper are based on a reduced muscle configuration covering only the lower extremities and the pelvic, abdominal and lumbar spinal regions as shown in Figure 6 and Figure 8.

The model is set up to be controlled kinematically by the adjustments of the seat pan and backrest such that the human body part of the model automatically attains a posture conforming to the seat pan and backrest inclinations.

The human body and the chair are connected by multiple contact points along the spine, on the pelvis including the ischial tuberosities, sacrum, thighs and feet (Figure 2). The contact points can transfer compression but not tension. The multiple contact points create a statically indeterminate support situation, which is resolved by means of the muscle recruitment. In other words, it is assumed that the body elects to use the available support such that it serves the general criterion of the muscle recruitment, namely minimization of muscle activity. This is of course only a valid assumption if the seat is actually designed to provide the support

points that have been assumed in the model. The model emulates Coulomb friction conditions at each support point correctly in the sense that friction forces are limited by the product of friction coefficient and normal force. The friction coefficient in turn is a user parameter defined as input to the model.

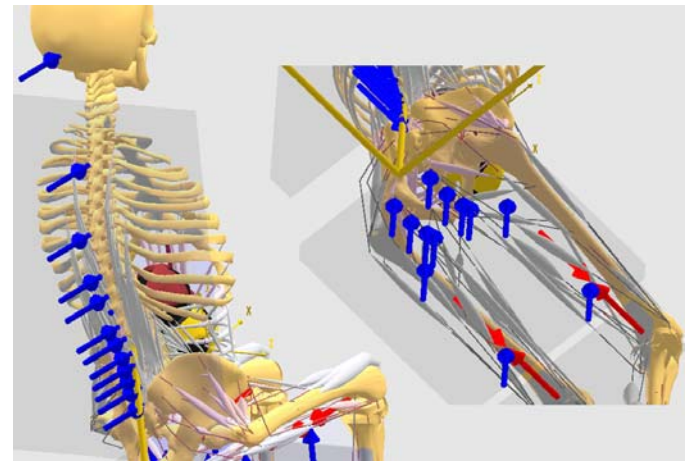


Figure 2. Possible support points on the head, spine, pelvis and thighs. In addition the model has contact points under the feet.

Systematic variations of backrest inclination between 0 and 20 degrees and of seat pan backward inclination between 0 and 30 degrees were performed for two different values of the friction coefficient: $\mu = 0.2$ corresponding to a slippery surface such as leather or vinyl and $\mu = 0.5$ roughly corresponding to a woven fabric such as wool or cotton. For each μ value the seat pan and backrest angles were varied in 10 steps each, creating a total of 100 combinations. For each combination, the necessary muscle activity to maintain the posture and the total shear force between the seat pan and the buttocks are computed. Each such parameter study comprising 100 combinations takes roughly 5 minutes to complete on a 1.6 GHz laptop personal computer.

RESULTS

FRICITION COEFFICIENT $\mu = 0.2$.

At $\mu = 0.2$ the muscle activity declines with simultaneous backrest and seat pan inclination (Figure 3). This is not very surprising in view of most passengers' preference to incline the backrest for sleep. Please notice, however, that the slippery seat surface means that the positive effect of backrest inclination on muscle activity almost vanishes when the seat pan is maintained horizontal.