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Musculoskeletal Simulation – (Dis)comfort Evaluation

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What exactly do the terms comfort and discomfort mean? While the obvious answer might be to characterize discomfort as simply negative comfort, ergonomists, based on investigations of human perception, tend to distinguish sharply between the two terms. Comfort is the *psychological* feel-good about the smell of a new car or the sound of a closing door, while discomfort is the *physiological* fatigue in a muscle or the irksome pressure of the seat on the thighs.

So, *comfort* is and probably will remain a difficult quality to capture. On the other hand, a scientifically based and quantitative *discomfort* evaluation has recently become available – at least for some of the factors causing discomfort. The new technology behind this progress is musculoskeletal simulation, or, more precisely, computer models of the human body as a mechanical system. Fatigue and perceived effort are linked to the muscle work, joint pain is linked to joint forces, and uncomfortable pressure on the tissue is linked to support forces between the body and the environment. All of these properties are mechanical and can be evaluated provided a sufficiently accurate model of the human body is available.

Why has it taken so long to begin performing discomfort evaluations by computer? As mechanical systems go, the human body is very complex. We have around 200 bones and a comparable number of muscles and joints, and many of the anatomical muscles cover large areas and must mechanically be divided into several parts. A reasonable mechanical model of the entire human body will comprise around 1000 independently activated muscles. Moreover, the body is both kinematically and statically indeterminate in the sense that we have more joints than strictly necessary to attain most common postures, and we have many more muscles than strictly necessary to balance most loading conditions. This means that there are an infinite number of solutions to just about any problem in musculoskeletal simulation. Yet the amazing central nervous system is capable of instantly picking good solutions for any skilled movement or loading position. Our inability to mimic this behavior by computer has prevented the use of musculoskeletal analysis and discomfort simulations in a time when just about any other property of a product can be investigated with impressive reliability.

This is now about to change, and the potential is enormous. Like any type of CAE technology, musculoskeletal simulation has a primary scope of applications, but it is only limited to products that have some sort of interplay with humans or animals. This is a vast number of technical products, and it is likely that this technology will lead to considerable improvements of product usability with an impact comparable to what finite element analysis has meant to structural design and vibration analysis. This is because the concept of comfort, or rather discomfort, is really much wider than you may think. It is also about the ease of use of a hand tool, the performance of a piece of sports equipment, the optimum exercise to strengthen a given muscle, or the design of a surgical implant.

The implementation of this technology is called the AnyBody Modeling System, and as the name implies, the system can be used to model any body, be it a specific human, a human representing a percentile of a population, an animal, or a robot. The system also allows for modeling of the environment in which the body is working, for instance a bicycle, a car seat, a hand tool, or even an airliner cockpit (see Figure 2). The idea is quite similar to other types of CAE software in the sense that it is a modeling system allowing the user to build a virtual model of the physical problem he or she wishes to investigate. Once the model is defined, it can be subjected to analysis for variations of the model parameters, and it is possible to quantitatively investigate what the height of a car door opening means to the effort of egress, or how the load on a surgical implant depends on its design and position in the body. The technology even allows for systematic parameter variation to optimize the ergonomic performance of the product.

Egress is a good example. The automotive industry is aware that the demographic development of the population is predicting a significant increase of elderly drivers in the not so distant future. Elderly persons typically have lower ratios of muscle strength to weight than younger persons, and furthermore they often have arthritic joint pain. Ingress and egress can be problematic, and assistive measures such as handles are being considered. Figure 3 illustrates four different possible locations of a handle on the window frame indicated by their distances in meters from the lower position. The purpose of the handle is to relieve the load on the legs during egress, but which handle position is best, and precisely how different are the positions? Does the improvement justify the additional cost of installing the handle?

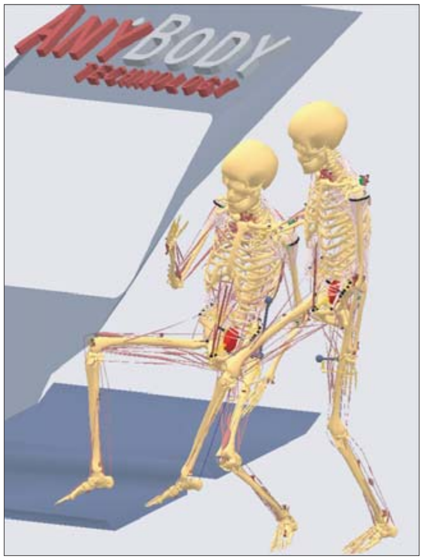

Figure 1. AnyBody technology.

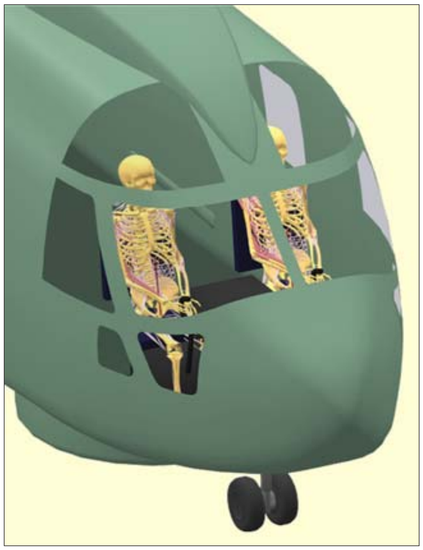

Figure 2. Airliner cockpit.

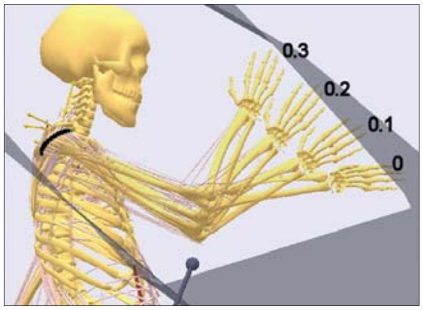

Figure 3. Four possible locations of a handle on a window frame, distances indicated in meters from the lowest position.

A musculoskeletal analysis of the egress movement (Figure 4) reveals that a high position of the handle leads to approximately 20% less muscular effort than a low position. However the difference in terms of a possibly pain-inducing knee force is much higher. It turns out that the lower handle positions lead to a significant peak in knee joint force in the middle of the movement.

The AnyBody Modeling System originated as a research project at Aalborg University, Denmark, and it was spun off

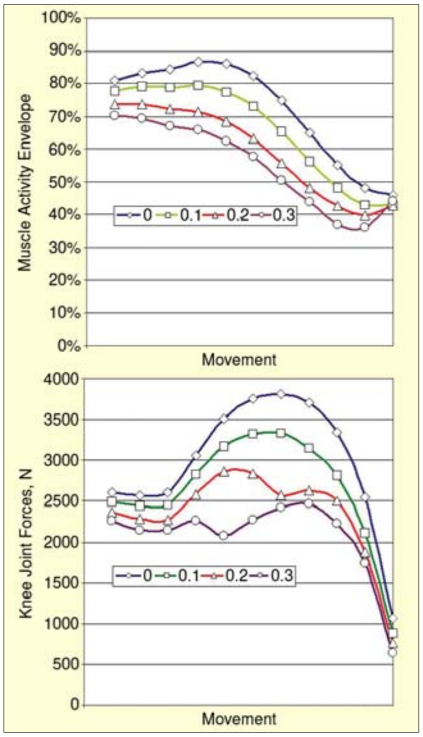

Figure 4. Musculoskeletal analysis of the egress movement.

as a company with the purpose of development and distribution of the software and know-how in 2002. The software is currently in version 1.3 with version 2.0 expected in the first quarter of 2005. As the version numbers indicate, this technology is still young and somewhat immature compared to more established CAE tools. Models are defined using a scripting language that gives full control of the mechanical system and allows for easy exchange of the models. It is also fairly technical due to the intrinsic complexity of the mechanics. Fortunately, the more complex part of any model (namely the human body) is available for import from a public domain library, the so-called model repository. Scientists from several different countries have contributed to this repository, and the amount of body parts continues to grow. Arms, legs, pelvis, abdomen, lower spine and shoulders are already available, and models of the foot, neck and mandible are under development by scientists.

The body models are freely available from the homepage of the research project and free demo licenses of the software can be downloaded from AnyBody Technology's homepage. For further information, please visit The AnyBody Research Project at www.anybody.aau.dk and AnyBody Technology at www.anybodytech.com.

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