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Computer Aided Analysis of Deformation and Pressure Distribution at the Driver/Seatpan Interface

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Summary
Analysis of deformation and pressure distribution at the driver/seat interface is valuable for ergonomic analysis and improving the comfort of car seat designs. This paper presents human body surface modelling using a shadow scanning technique, car seat modelling and non-linear finite element analysis of deformation and pressure distribution at the driver/seat interface. In order to avoid the difficulties in the calculation of direct 3D force loading a technique of determining reaction forces from the displacement between the human body and the car seat was used. The results of deformation and pressure distributions at the driver/seat interface are presented which were found to be qualitatively comparable with experimentally derived measurements although peak pressures were 2-4 times greater. The reasons for this difference are presented. This project was supported by the Brite-Euram project No. BE5549.

1 Introduction
Analysis of deformation and pressure distribution at the driver/seat interface is valuable for ergonomic analysis and improving car seat design. The Finite Element Analysis method was employed in this investigation to resolve this three dimensional non-linear contact problem. The data for human body surface modelling obtained from LASS (Loughborough Anthropometric Shadow Scanner)\cite{3} was transferred into the surface modelling package DUCT. A variety of human body posture models were generated using DUCT command files and series of car seats were modelled by integrating the component parts of the seats. A model of a driver sitting on a car seat was produced in DUCT and was transferred through IGES files into the PATRAN finite element analysis package. The contact areas of the buttocks on the seat-pan and the back on the back-rest were considered. To simplify the calculation it was assumed that the human body surface was a rigid solid and the car seat was
a deformable solid. The non-linear material parameters of the car seat were optimised. The human body weight described as the force loaded on the human body surface was optimised by loading the displacement onto the human body so as to avoid the problem in the calculation of direct 3D force loading. The deformation and pressure distribution at the driver/seat interface were obtained. The results were comparable with experimentally derived measurements. The situation in which both the human body and the car seat are deformable solids needs to be further investigated.

2 Computer driver and car seat modelling

The measurement of human body size and surface shape has drawn considerable interest in textile manufacturing, medicine, biological sciences, human factors and industrial design. Various types of optical and opto-electronic techniques have been developed since 1970. LASS[3] is a fully automated system which is capable of measuring accurately, quickly, and comprehensively, the size, as well as the shape, of the human body. The data for the human head, torso and leg obtained from LASS were transferred into the DUCT surface modeller, through a C interface program. Some reduction and modification of the data was made in DUCT, and the body parts were integrated into a whole human model. Some human postures, such as stand and sit, were generated by changing the angles of the cross section at the articulations of the trunk, ankle, knee, hip, wrist and neck. Over 100 car seat surface models were generated from the component parts of the seats, pan with and without side supports, back-rest with and without side support and head-rest and integrated head-rest. The sitting driver was then put onto the car seat (Figure 1).

3 Finite element modelling

In real life both the driver and the car seat are deformable solids, but in order to simplify the problem, it was assumed, as a first order approximation, that the driver was rigid and the seat was deformable. Further simplification was made by only considering static analysis. Various types of contact problem can be investigated using finite element analysis, such as Hertz contact over parts of surfaces where only small relative sliding takes place, two deformable bodies in contact with large relative motions, and rigid body surface contact causing solid deformations where large relative motions between the components occur. The finite element displacement method, in which a large system of equations is solved to obtain the displacements at all node points of structure, is the most widely used. Strains are obtained at the element level as derivatives of displacements and stresses are obtained by multiplying a small matrix of material constants by the strains. The model of the driver sitting on the seat
was transferred from DUCT into PATRAN through IGES files. In order to save computer space, the two contact areas of the buttocks contacting the seatpan and the back contacting the seat back-rest were chosen for calculation. Also considering rough symmetry of the driver and car seat about the vertical plane, only half model was used for finite element analysis (Figure 2) [1,2]. The driver body surface was meshed by 381 triangular surface elements. The seat was meshed by 1,200 hexahedron solids. The top surface of the seat was meshed by 200 quadrilateral surface elements. The complete model contained 1,836 nodes and 1,781 elements (Figure 3). The seat was modelled as hyperelastic, compressible foam. Hyperelastic models are used to describe the behaviour of materials that exhibit elastic response up to large strains, such as rubber, solid propellant and other elastomeric materials. These materials are described in terms of a “strain energy potential”, \( U \), which defines the strain energy stored in the material per unit of volume in the initial configuration as a function of the strain at that point in the material. The form of the Ogden strain energy potential used is

\[
U = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i} (\lambda_i^{\alpha_i} + \lambda_i^{\alpha_i} + \lambda_i^{\alpha_i} - 3) + \sum_{i=1}^{N} \frac{1}{D_i} (U_i - 1)^{2i}
\]

where \( \lambda_i = J^{1/3} \lambda_i \) is the principal stretch ratio, \( N, \alpha_i, \mu_i, \) and \( D_i \) are material parameters, which may be functions of temperature. For this model, the initial shear modulus and bulk modulus
are given by

\[ \mu_0 = \sum_{i=1}^{N} \mu_i \quad K_0 = \frac{1}{D_1} \]

Under compressible and Ogden material conditions for the car seat-pan, material parameters \( \mu \) and \( \alpha \) needed to be determined. The parameters \( \mu \) and \( \alpha \) were optimized by a series of comparison calculation and the optimisation values were founded as \( \mu = 100 \) and \( \alpha = 150 \).

The driver was modelled as a rigid surface and the contact surface of the seat was modelled as an elastic slip soft contact surface. The driver’s rigid surface was only allowed to move towards the seat along the vertical axis, \(-Z\). The bottom surface of the seat was fixed and not allowed to move or rotate in any direction. The loading simulates the driver sitting condition in which a compression load, driver body weight, is applied and adjusted such that there is only a uniform \(-Z\) axial displacement of the rigid body surface. Therefore, in the analysis, the driver body surface is loaded by uniform compressive displacements rather than by uniform compressive force, so as to avoid the problem of the calculation of direct 3D force loading. The resultant forces corresponding to the compressive displacements can thus be determined.

4 Discussion and Conclusions

The deformation of the car seat under compressive displacement can be obtained by removing the driver body surface (Figure 4). The relationship of the resultant force corresponding to the compressive displacement was calculated (Figure 5). First order pressure distribution at the original top surface of the seat was obtained (Figure 6). Experimentally derived pressure distributions were obtained with real people and seats. The finite element analysis predicted pressure distributions that were qualitatively comparable to the experimental distribution; although the peak pressures were approximately 2-4 times greater [2]. This difference is mainly due to 1) the assumption of the human body as a rigid solid. In reality, the body weight borne by the seat pan is transferred through the small rigid bony protuberances (the ischial tuberosities), the rest of the thigh and buttocks being deformable fat and muscle tissue. The investigation of the contact problem in which both human body and car seat are deformable solids needs to be investigated in the future. 2) the difference of the human buttock shape between the FE model and the real human body. As the buttocks were generated by rotating the middle cross section of the buttock when the man stands up, there is some difference in shape between standing and sitting buttocks. The surface modelling of the real shape of the human buttocks in a sitting posture should be improved. The pressure distribution and deformation vary with the shape of the human buttocks and the flesh
properties, the shape of the seat and its material properties and the chosen driving posture.

This preliminary investigation shows that it may be possible to use the finite element analysis method to analyse the deformation and pressure distribution at the driver/seat interface.

![Deformation of the car seat](image1)

![Force/displacement relationship](image2)

![Pressure distribution prediction on left half seat](image3)

**References**

