A COMPUTER SIMULATION OF THE HYBRID II MANIKIN HEAD-NECK SYSTEM

Brian J. Doherty
Research Associate
Biomedical Engineering Dept.
Duke University
Durham, NC 27706
(919) 684-6185

Jacqueline G. Paver
Research Assistant Professor
Biomedical Engineering Dept.
Duke University
Durham, NC 27706
(919) 684-6185

ABSTRACT. The goal of this research was to develop data sets for computer models which accurately predict the head-neck kinematics and dynamics of existing dummies in crash environments. To accomplish this goal, a data set of the Hybrid II manikin head-neck system was developed for the AAMRL Head-Spine Model (HSM). The Part 572 Head-Neck Pendulum Compliance Test, of the Code of Federal Regulations, was simulated to validate this data set.

The HSM data set was made up of two elements: a rigid body, representing the head, and a beam element, representing the neck. The geometric and inertial properties were abstracted from the literature. The material properties were estimated. The model boundary conditions were defined by the constraints of the experimental design; the initial conditions were the specified pendulum impact velocity and acceleration-time history.

Part 572 specifies head rotation vs. time, chordal displacement of the head center of gravity vs. time, and peak head acceleration. By varying the material properties of the neck in a systematic manner, optimization of the model response with these specifications was possible. The final data set predicted head rotation and peak head acceleration data which complied with Part 572 specifications. The predicted peak chordal displacement was slightly lower than that specified by Part 572.

It is hoped that the ability to predict manikin head-neck responses will help in the understanding of the responses of humans in similar crash environments.

INTRODUCTION. In recent years, there has been an increasing awareness of the serious consequences that can occur with head and neck injuries and the effectiveness of biomechanical studies to reduce the likelihood of these injuries. Two sources of information about head and neck injury and prevention are: (1) analysis of mathematical models; and (2) experiments with human surrogates.

Mathematical modeling is an accepted technique of scientific research. Once validated by comparison with experimental results, mathematical models are useful, economical, and versatile engineering tools. They can, in lieu of direct experimentation with the actual physical systems, evaluate the effects of varying parameters on the responses of systems to a wide variety of input conditions. In particular, with validated data sets for the Hybrid II head-neck system, environments or tests, where the head and/or neck is in jeopardy, could be simulated.

The use of inanimate devices reduces the repeatability problems associated with animals and cadavers but raises questions as to biofidelity. Attempts to improve human surrogate biofidelity are well documented. When a new manikin design is incorporated into a crash test program, data bases are generated which describe their geometric and inertial properties and mechanical behavior. Compliance tests are developed and performance evaluations are conducted to ensure uniformity of results among different specimens and laboratories.

One goal of the AAMRL/BBM research program is to develop a durable, servicable, and biofidelic anthropomorphic dummy head-neck system with repeatable and reproducible biomechanical responses. Another goal is to develop data sets of computer models which accurately predict the head-neck kinematics and dynamics of existing dummies in crash environments. To accomplish these goals, it was desired to measure, analyze, and simulate the kinematic and dynamic responses of mechanical head-neck assemblies. As a preliminary effort, a data set of the Hybrid II manikin head-neck system was developed for the AAMRL Head-Spine Model (HSM). The Part 572 Head-Neck Pendulum Compliance Test, of the Code of Federal Regulations (1), was simulated to validate this data set.

The specific aims were:

(1) to abstract from the literature the geometric and inertial properties of the Hybrid II head-neck system and pendulum test apparatus and to review the existing specifications for Part 572 dummy compliance testing

(2) to analyze the relevant geometric and inertial properties and pendulum test performance standards to determine inputs for the HSM

(3) to compare simulations of the pendulum tests to experimental results to verify the assumptions used to define the head and neck structures and validate the HSM data set.

It is hoped that the ability to predict manikin head-neck responses will help in the understanding of the responses of humans in similar crash environments.

BACKGROUND--Theoretical. The mathematical model selected for this study was the HSM, an internal body structure model. Internal body structure models have been successfully implemented at AAMRL for military applications (e.g., the dynamic responses of head-spine subsystems to +Gz accelerations).

The HSM is a three-dimensional computer model which represents the human body by a collection of rigid bodies connected by deformable elements (2). The deformable elements can be beam elements, spring elements, hydrodynamic elements, or elastic surfaces. The rigid bodies generally represent bones (e.g., the head, vertebrae, pelvis, and ribs); the deformable elements represent soft tissues (e.g., viscera, ligaments, and intervertebral discs).

The mathematical model is a matrix structural analysis program. The program integrates the equations of motion in time, either implicitly or explicitly. The analysis accommodates large displacements of the rigid bodies, nonlinear material properties, and viscous forces.

The data base defines the structure to be modeled. It consists of the geometric and inertial properties of the rigid bodies, the geometric, inertial, and material properties of the deformable elements, the connectivity data, boundary conditions, constraints, and global coordinate system definition. The initial conditions are defined in a separate subroutine called ICIF that is linked with the code prior to execution.

BACKGROUND--Experimental. The Hybrid II mechanical head-neck assembly was chosen as the specimen for this study. The Hybrid II was the first GM dummy design to have acceptable repeatability and good durability and serviceability (3). The Hybrid II head-neck assembly is a fairly simple system. The head is a hollow aluminum casting, with a rear cap to allow access to the instrumentation inside. The instrumentation consists of a mutually orthogonal array of three uniaxial accelerometers; this array is mounted at the head CG. Both pieces of the head are covered with a rubber skin. The neck is a right circular cylinder of butyl rubber. It is solid, except for a small hole through the middle. Metal plates are molded into each end to facilitate head-neck and neck-thorax attachment.

The head-neck pendulum test (see Figure 1) consists of a pendulum drop. At the bottom of the pendulum's swing, the arm impacts a block of honeycomb; this produces a near-square wave pendulum deceleration pulse. The head-neck system, which is mounted to the end of the pendulum, does not undergo any impact. The environmental test conditions, instrumentation requirements, and test procedures (including the pendulum geometric and inertial properties and strike plate deceleration pulse and impact velocity) are specified. For the Hybrid II dummy, the head rotation vs. time, chordal displacement of the head center of gravity vs. time, and maximum allowable head acceleration are also specified. Hybrid II test procedures and performance standards are described in the Code of Federal Regulations, Title 49, Part 572.

SIMULATING THE PART 572 HEAD-NECK PENDULUM TEST. An HSM data set, which represents the Hybrid II head-neck system, was developed. The Part 572 head-neck pendulum compliance test was simulated to validate this data set.

The HSM data set was made up of two elements (see Figure 2). A rigid body represented the head; a beam element represented the neck. The pendulum arm was not explicitly defined; the boundary conditions of the node at the base of the neck were made to reflect the presence of the pendulum.

The geometric and inertial properties of the rigid body were calculated by lumping the upper half of the neck with the head. Since the Part 572 specification requires that the head and neck properties be defined by the SAE Recommended Practice J963, in which the head and neck are lumped together differently, this data was inappropriate for this simulation. Instead, data from Hubbard and McLeod (4), where the geometric and inertial properties of the head are described separately from those of the neck, were utilized.

The coordinate system was defined so that the positive x axis was the A-P direction, the positive y axis was the L-R direction, and the positive z axis was the S-I direction. The pendulum arm was free to rotate about the y axis only. Since the response is measured only from the time of impact to the time the head returns to the pre-impact position, the end of the pendulum (i.e., the base point) does not rotate during the test. The motion of this point was modeled as a pure translation in the x direction; no translations in the y and z directions or rotations about the x or z axes were allowed for this point. All other points were allowed to translate and rotate in the x-z plane.

A near square-wave acceleration pulse (see Table 1) was the excitation for the model. This pulse complied with Part 572. The initial condition was the velocity of the base of the neck, which was calculated from the pendulum strike plate impact velocity specified in Part 572. These two quantities were not included in the data set itself; they were inputs to the subroutine ICIF. This subroutine is called by the model after it reads the data set.

The data set was tuned to make the HSM head-neck response comply with the Part 572 head-neck pendulum test performance standards. Part 572 specifies the response in three ways: head rotation vs. time, chordal displacement vs. time, and peak head acceleration. Since the geometric and inertial properties of the Hybrid II head and neck are well documented, these constants remained fixed; they were not used to tune the data set. The material properties of the neck, however, are not well documented. The values used initially for the bending, axial, and torsional stiffness and damping and the bending shear parameter were estimated from a material specification abstracted from a Sierra blueprint (5) and from static test data (6).

The response of the model did not comply with Part 572 using these initial values; it was necessary to increase the amplitude and decrease the period of the response. The material properties of the neck were varied in a systematic manner to optimize the model response with Part 572 specifications. It was discovered that an increase in the bending stiffness decreased both the amplitude and the period of the head rotation (see Figure 3) and chordal displacement (see Figure 4). Increasing the bending stiffness also decreased the peak head acceleration (see Table 2). An increase in the bending damping from 1E-7 to 1E-4 dyne-sec/cm had no effect on the predicted performance of the Hybrid II head-neck assembly. An increase to 1E-2 dyne-sec/cm, however, lowered the amplitude and increased the period of the head rotation (see Figure 5) and chordal displacement (see Figure 6). Increasing the bending damping also decreased the peak head acceleration (see Table 2). An increase in the bending shear parameter increased the amplitude and delayed the head rotation (see Figure 7), increased both the amplitude and period of the chordal displacement (see Figure 8), and increased the peak head acceleration (see Table 2). Changes in the axial and torsional stiffness and damping over several orders of magnitude had no effect on the predicted performance of the head-neck assembly. The final data set predicted head rotation and peak head acceleration data which complied with Part 572 specifications. The predicted peak chordal displacement was slightly lower than that specified by Part 572.

SUMMARY AND RECOMMENDATIONS. A data set of the Hybrid II manikin head-neck system was developed for the HSM. The Part 572 Head-Neck Pendulum Compliance Test, of the Code of Federal Regulations, was simulated to validate this data set. The fit was adequate. The following are recommendations for future studies:

(1) Continue tuning the proposed Hybrid II data set by additional validation studies. For example, Hyge tests could be used to derive values for the neck axial stiffness and damping. Other test modes could be utilized to derive values for the neck torsional stiffness and damping.

(2) Develop and validate data sets of other mechanical head-neck systems.

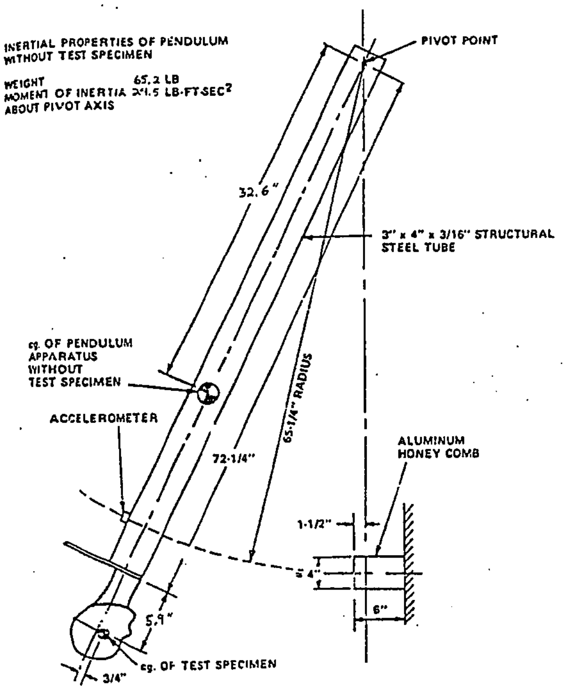

FIGURE 1: PENDULUM TEST APPARATUS

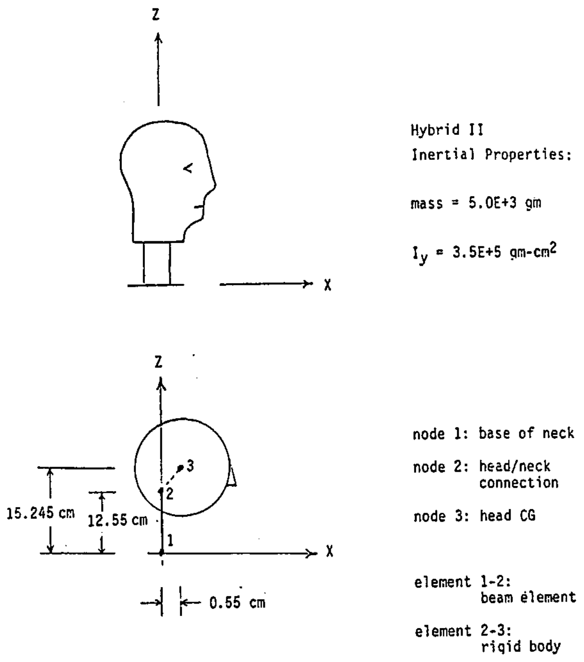

FIGURE 2: HSM DATA SET DEVELOPMENT

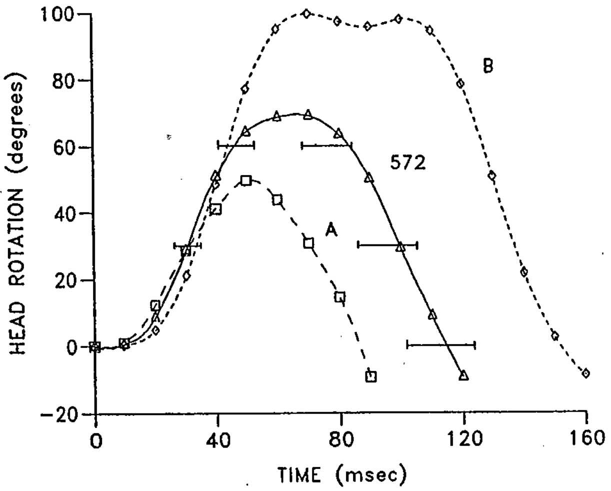

FIGURE 3: EFFECT OF BENDING STIFFNESS VARIATIONS ON PREDICTED HEAD ROTATION

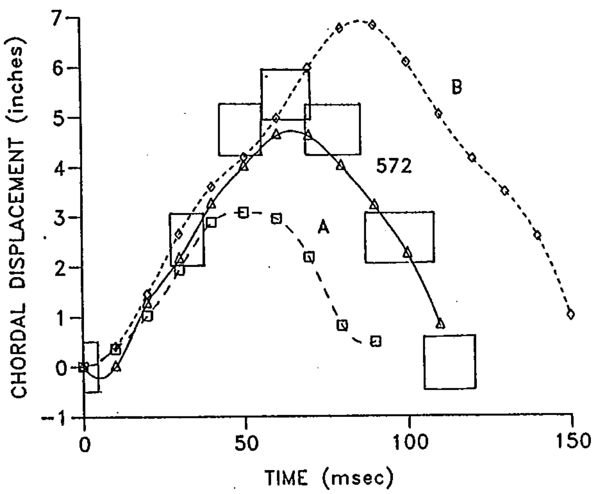

FIGURE 4: EFFECT OF BENDING STIFFNESS VARIATIONS ON PREDICTED CHORDAL DISPLACEMENT

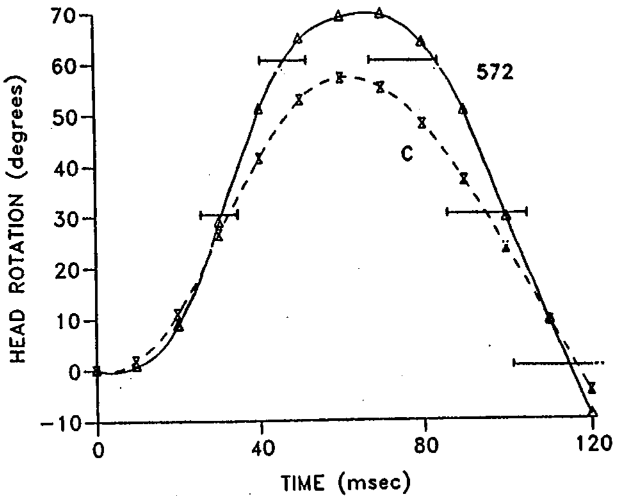

FIGURE 5: EFFECT OF BENDING DAMPING VARIATIONS ON PREDICTED HEAD ROTATION

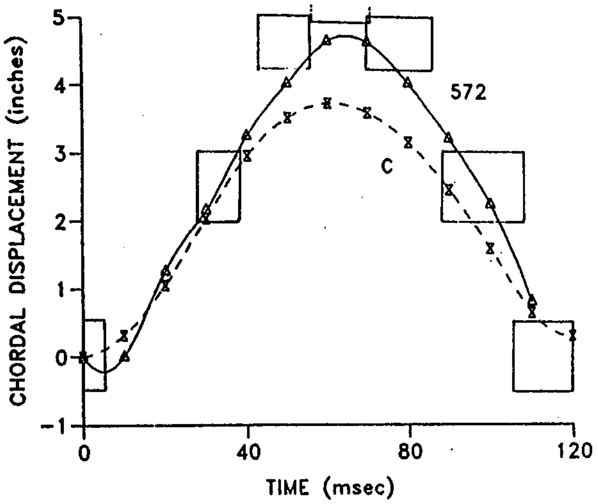

FIGURE 6: EFFECT OF BENDING DAMPING VARIATIONS ON PREDICTED CHORDAL DISPLACEMENT

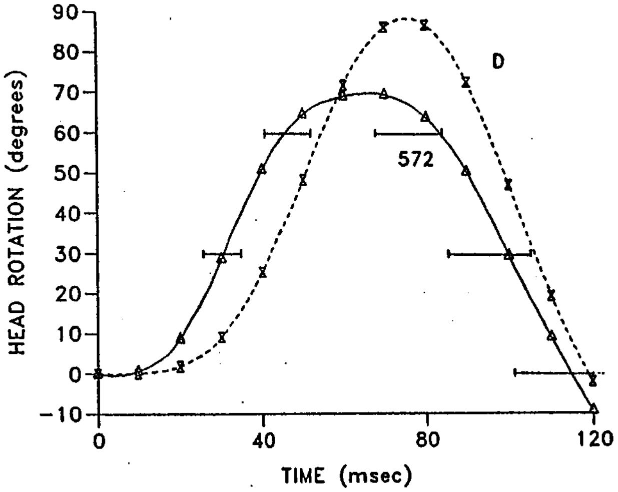

FIGURE 7: EFFECT OF BENDING SHEAR PARAMETER VARIATIONS ON PREDICTED HEAD ROTATION

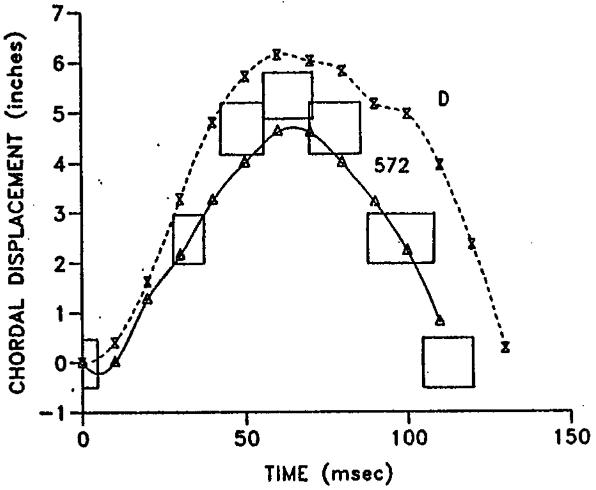

FIGURE 8: EFFECT OF BENDING SHEAR PARAMETER VARIATIONS ON PREDICTED CHORDAL DISPLACEMENT

TABLE 1: ACCELERATION PULSE DATA

TIME (sec)	ACCELERATION (g's)	ACCELERATION-TIME SLOPE (g's/sec)
0.0	0	0.
0.0025	-5	-8.
0.0175	-26	-4.
0.005	-26	0.
0.012	-22	0.
0.020	-22	0.
0.02933	-22	2.
0.0335	-5	4.
0.03475	0	2.667
0.036	0	0.
0.063	0	0.
0.068	0	0.
0.073	0	0.
0.08	0	0.
0.085	0	0.
0.09	0	0.
0.1	0	0.

TABLE 2: VARIATIONS IN BENDING STIFFNESS, DAMPING, AND SHEAR PARAMETER AND PEAK HEAD ACCELERATION RESPONSE

LABEL	STIFFNESS (dyne/cm)	DAMPING (dyne-sec/cm)	SHEAR PARAMETER	PEAK HEAD ACCELERATION (g's)
572	7.7 E+8	1E-7 to 1E-4	0	23.53
A	15.4 E+8	1E-7	0	21.34
B	3.85E+8	1E-7	0	26.50
C	7.7 E+8	1E-2	0	20.63
D	7.7 E+8	1E-7	5	27.21

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BIOGRAPHIES

Brian J. Doherty is a Research Associate at Duke University. He received the B.S.E. degree from the University of Pennsylvania in Bioengineering in 1984. As an undergraduate, he worked in the Head Injury Laboratory at the Hospital of the University of Pennsylvania, where he studied strain detection within a physical model of the head. Recently, he received the M.S. degree in Biomedical Engineering from Duke University, where he performed Modal Analysis of the human head.

Jacqueline G. Paver is a Research Assistant Professor at Duke University. She received the B.S. degree in Engineering from Harvey Mudd College in 1977 and the M.S. and Ph.D. degrees in Biomedical Engineering from Duke University in 1980 and 1985, respectively. Since 1977, she has worked on a variety of theoretical and experimental projects dealing with the biomechanics of human trauma. Her primary research interest is in the biomechanics of head and neck injury and protection.