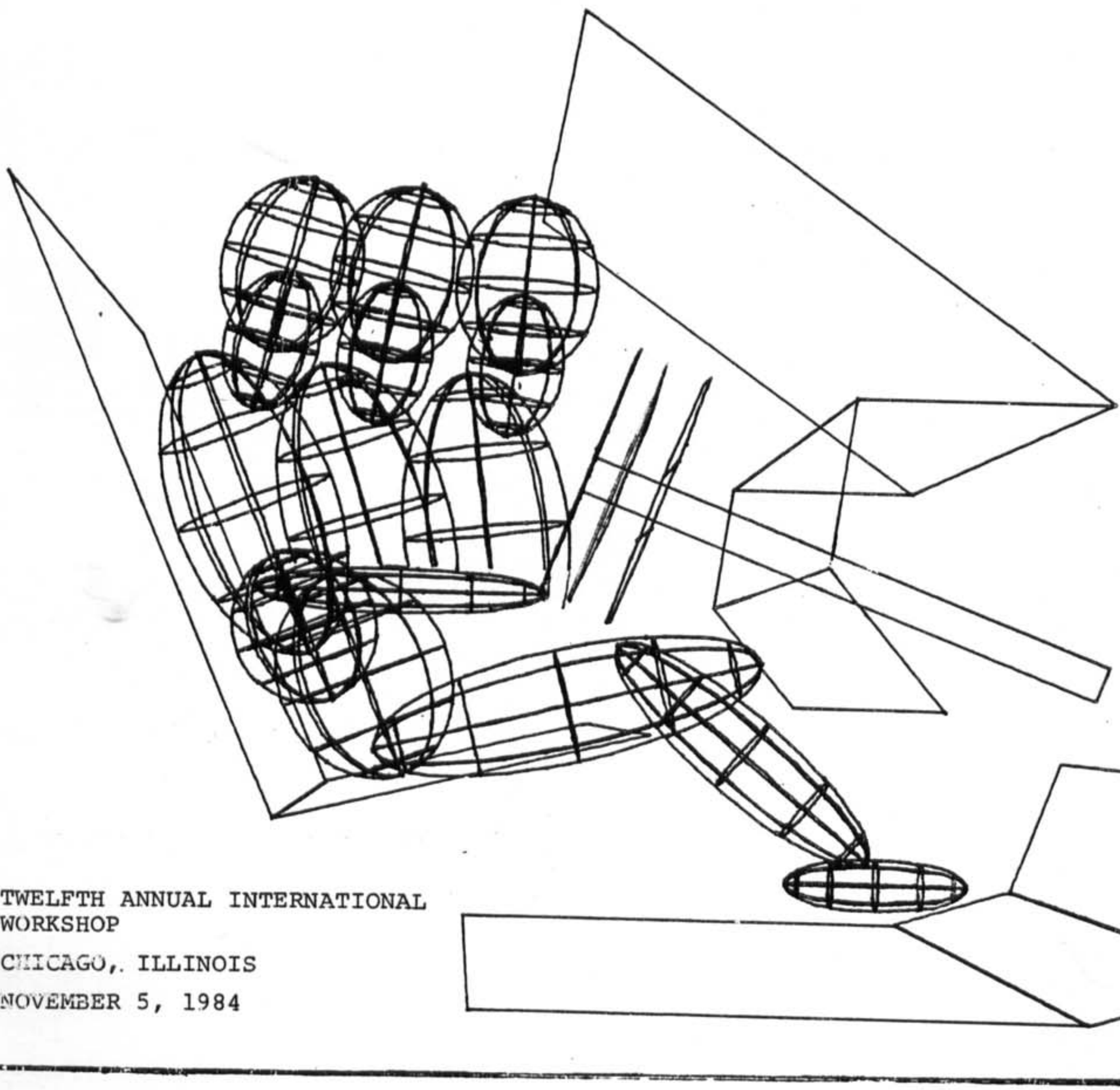
HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH



TWELFTH ANNUAL INTERNATIONAL WORKSHOP

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INTRODUCTION

The Twelfth Annual International Workshop on Human Subjects for Biomechanical Research, was held on November 5, 1984 in Chicago, Illinois. Attendance was about 45 for the eleven scheduled presentations and discussion.

The following proceedings contain the text of ten of the presentations. M. Walsh was unable to provide a copy of his paper for this printing. An abstract and notes of the discussion are included in the minutes. A paper by R.L.Stalnaker and C.A.Lin, "Application of the Mean Strain Criterion (MSC)" is included. Due to pressure of time, it was not presented at the Workshop.

Papers appearing in these proceedings are not to be considered as formal publications. Although references to these proceedings have appeared occasionally in the open literature, this recommendation has generally been observed by the research community.

On behalf of the participants and attendees of this Workshop, we would like to extend our thanks to the Stapp Conference Advisory Committee for their support of this activity, to SAE for administrative services and especially to Mr. David Foust who has served as secretary of this Workshop for many years.

The Workshop Committee

TWELFTH ANNUAL INTERNATIONAL WORKSHOP ON
HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH

MINUTES

The 12th Annual International Workshop on Human Subjects for Biomechanical Research was held on November 5, 1984, at the Chicago Marriott Hotel, Chicago, Illinois. The Workshop was co-chaired by J. Melvin, University of Michigan Transportation Research Institute, and R. Morgan, National Highway Traffic Safety Administration. Dr. Melvin reminded the approximately 50 attendees of the informal nature of the Workshop. Although Proceedings are distributed, the papers usually contain preliminary results and neither the Proceedings nor the papers should be referenced as publications.

There were no ad-hoc committee reports.

Technical Session

1. AIS and Probability of Death, R. L. Stalnaker and M.S. Ulman, Department of Mechanical Engineering, Ohio State University. Dr. Stalnaker reported "very preliminary" results on his recent efforts to correlate certain AIS codes with the likelihood of death. The project stemmed from attempts to recode injuries of laboratory test animals into the AIS system. He often found at autopsy that injuries with major AIS codes had minor effects on the animal's survival.

Working with National Accident Severity Study data on fatalities (within one month of the injury-producing event) and AIS codes, injuries are arbitrarily assigned one of 56 ranks between 100 and 600 (AIS 0 and 6 were excluded). The ranked data were then analyzed using log linear regression of each AIS level separately. Coefficients of variation (r^2) of about 0.6 were obtained for AIS 4 and 5. It was noted that multiple injuries at a given AIS level were more likely to cause death than a single injury at the next higher AIS level.

Dr. Stalnaker also applied the technique to Baker's Injury Severity Scale and to Somers' data (see paper in Proceedings). Rather similar results were obtained; much of the difference noted was attributable to different time periods being reported between injury and death.

Preliminary conclusions are that single injuries of AIS levels 1, 2, and 3 have virtually zero probability of death, AIS 4 has .09, AIS 5 has .25 and AIS 6 has 1.00. For ranking of three injuries (as in ISS) AIS 4 has .16 probability of death, AIS 5 has .64 and AIS 6 has 1.00.

Dr. Stalnaker is still analyzing animal data. His goal is to be able to assign a "probability of death" to particular AIS-coded injuries, so that AIS codes would be more "flexible" in reflecting lesions. He anticipated the method would be most useful to laboratory researchers, with some possible applications to accident investigation studies.

The presentation drew several comments and questions. Dr. R. Levine, Wayne State University, noted that advancements in medical treatment will change "probability of death" for many injuries. Dr. Stalnaker agreed, indicating that such changes could be included in each revision of the AIS handbook. Dr. J. States, University of Rochester, noted that some differences in the probability of death analysis between Baker's ISS work in 1969 and the NASS data from 1979-83 are due to advances in medical treatment. Dr. Stalnaker also noted that Baker's ranks are based on 1-3 lesions, whereas he is interested in single lesions so that he can assign a ranking to individual lesions from laboratory tests. Dr. Melvin commented that non-life threatening brain injury at lower AIS level can still affect the quality of life. Dr. Stalnaker agreed, but he believes that each AIS code should have the same relationship to a probability of death (i.e., AIS2 head and abdominal injuries would be equally likely to cause death).

2. <u>Mass Distribution Data of Part 572 Dummy and Recommendations for a Standard Data Set for CVS</u>, J. Wismans, Research Institute for Road Vehicles (IW-TNO), Delft, the Netherlands. Dr. Wismans reported on partially completed work to create a single standard anthropometric test dummy data set for the Part 572 dummy which could be used with all of the principal Crash Victim Simulator (CVS) models. The work is being performed for the Analytical Human Simulation Task Force of the SAE's Human Biomechanics and Simulation Subcommittee.

Two phases are planned. Phase I, mass distributions for the Part 572 dummy, is complete and details are included in the Proceedings. Mass, moments of inertial, centers of gravity and link lengths have been specified for the various dummy segments, based on three different data sets published by Fleck, Hubbard and Hasselman. Among the three data sets, there were moderate deviations in masses, less than 20% variation in moments of inertia, less than one cm difference in CG, and generally less than 10 mm difference in joint locations. Three popular CVS models (Calspan, MVMA-2D, and MADYMO) were analyzed for differences in data set requirements. A standard description of 13 dummy segments is proposed to assure consistent origins for segment coordinate systems, a standard reference standing position, and recommended standard mass distribution characteristics. See Proceedings for details.

In Phase II, which is not complete, standardized external geometry, joint properties, and body stiffness characteristics will be developed. The external geometry task is expected to be "fairly simple." Establishing joint properties will be difficult and will probably not include combined rotations. Body stiffness properties are complex because both force and penetration algorithms are involved.

During the question period, Dr. Wismans noted that no similar work is currently planned for the Hybrid III dummy because most simulations are performed using the Part 572.

3. <u>Comparison of Mannequin v. Human Response for +Z Vector Direction</u>, W. Muzzy, U.S. Naval Biodynamics Laboratory. The effects on humans of Z-direction acceleration is being studied as part of the Navy Advanced Concept Ejection Seat program. The Navy is using a 95th percentile male ATD with Hybrid III head and neck in development tests for seat specifications. The Biodynamics Laboratory is studying human response using volunteers and has conducted several tests to compare human and dummy responses. Test conditions were similar (torso horizontal, head offset above the torso surface with Frankfort plane vertical, acceleration range 3-12 g's, accelerometers in similar locations).

Results show that the dummy is stiffer at the 12g test level, and that response is very sensitive to initial head orientation. Human response has tended to be one of two types. In longer necked individuals (Type I), the head always rotates up, flexing the neck. Type II response is initial extension, followed by flexion. The dummy always exhibited Type I response but with less than 1/2 the amount of human head rotation. Also, humans reach maximum body slump at 8g, but the dummy showed increasing slump with increasing acceleration up to 20g.

Dr. States asked if Type I or Type II response in humans is predictable. Mr. Muzzy noted that response could usually be predicted based on neck length and detailed anthropometry. With one exception (an ex-boxer), neck musculature did not modify head-neck response.

4. <u>Comparability of Sled Tests and Pendulum Tests</u>, N. Ranga, Automated Science Group, Washington, D.C. Mr. Ranga is collaborating with R. Morgan and J. Marcus of NHTSA, using the Lobdell model to compare simulated frontal impacts with pendulum and sled data. The Lobdell model has two masses (sternum and spine), with a spring representing skin and a spring and damper between the masses to represent thoracic stiffness and damping. Comparisons were made of spinal and sternal acceleration, relative velocities of masses, and chest compression. The following test simulations were conducted: pendulums of 52 and 100 pounds, each at velocities of 15, 20, 25 and 30 mph; sled with no offset between sled and model, square acceleration pulse of 20g, velocities of 10, 15, 20 and 25 mph; similar sled conditions except sled is offset 5, 10, 15, and 20 inches and adjusted to strike model either before or after the acceleration pulse.

Results for the four response parameters were as follows. Maximum chest compression and maximum spinal acceleration for the model are similar if sled velocity is 5 mph less than pendulum velocity. Maximum sternal acceleration and maximum relative velocity between spine and sternum are similar if sled velocity equals pendulum velocity.

Mr. Ranga was asked to comment on the effect of different pendulum masses. He noted that increased mass caused increased acceleration, but the model response varied. The 100-pound mass caused responses that were more similar to sled test responses.

5. Side Impact Injury Studies. S. Rouhana, Biomedical Sciences Department, General Motors Research Laboratories. Dr. Rouhana is experimenting with an animal model in lateral impacts to develop a viscous tolerance criterion. He is examining the interrelationships of impact velocity and abdominal compression. The protocol involves suspending a deeply anesthetized New Zealand white rabbit in a sling in front of a high-speed impactor. The impact occurs laterally, centered on the distal tip of the last rib, and covers the area between the ninth rib and the lower margin of the kidney. Abdominal compression is preset in a range of 10-50% and impact velocity varies between 15 and 30 mph. The animal is euthanized 15 minutes after the impact and a necropsy performed.

Results from 117 tests were summarized. There were no liver lacerations after low velocity, low compression impacts, but many occurred during high velocity, high compression tests. Kidney injuries were seen only on the near side, and few splenic or gastrointestional injuries were observed.

Dr. Rouhana has reached three principal conclusions. First, compression alone is not predictive; probability of injury is based on the product of velocity and compression (true for right- or left-sided impacts). Second, a Viscous Tolerance Criterion (VTC), equal to velocity times compression, has both an experimental and a theoretical basis. Third, using Probit analysis, VTC correlates well with probability of injury for AIS levels ≥ 3.

Questions were related to the impactor shape and impact locations. A flat faced impactor was used and the impact area was chosen to contact only the abdomen, excluding pelvic contact.

6. Analysis of Cadaver Injury Data Using Weibull Distribution Function. H. Mellander, Volvo Car Corporation. Dr. Mellander summarized a paper presented at the 1984 IRCOBI Conference. A copy of this very technical paper is included with the Proceedings. The work involves a new method for analyzing occurrence/non-occurrence data (such as fractures) where the response is known but the transition point is imprecise. Such data are "censored" (skewed) such that statistical analysis using normal distribution techniques may be unreliable. Dr. Mellander proposes using a Maximum Likelihood method to fit the three-parameter Weibull Distribution to biomechanical data expressed as a cumulative frequency. An iterative computerized method calculates maximum likelihood by solving for the best-fit sample mean and standard deviation from the data. Several applications of the method were described, particularly analysis of cranial fractures vs HIC number. Of the analysis methods contrasted (Mertz-Weber "overlap range," maximum likelihood from normal distribution and maximum likelihood from Weibull Distribution), the Weibull Distribution seemed to give the best fit.

Dr. Mellander is encouraging comments from other researchers who may analyze data sets using this technique. He plans to revise and enlarge the paper, make the computer program available to accident research groups as an aid in planning experimental programs, and develop confidence levels for this type of analysis.

Questions centered on the applications of the Weibull Distribution to various data sets. NHTSA was not able to run Volvo's program, but their version gave similar results for similar data sets [see following paper]. Dr. Rouhana noted that Probit analysis seems to be a special case of the Weibull method; Dr. Mellander responded that the Weibull Distribution should be used if there is skewness in the data, but that Probit is also useful if the data are first subjected to a log transform. To other questions, Dr. Mellander noted that HIC does not really seem to be correlated to skull fracture. Also, his analysis method cannot be used to predict injury.

7. Use of the Weibull Distribution in the Analysis of Injury Severity v. Exposure, R. Morgan, NHTSA. Using a Weibull Distribution program written by NHTSA, Mr. Morgan conducted a study similar in concept to that of Volvo. Starting with a cumulative frequency distribution, the NHTSA program used probability of fracture (fracture or no fracture), calculated a maximum likelihood function, and solved for the Weibull Distribution.

Mr. Morgan analyzed four different data sets. First was a replication of Volvo's HIC vs skull fracture analysis; very similar results were obtained. Second, side impact data were analyzed at AIS levels ≥3, ≥4 and ≥5. In each case, the Weibull Distribution was contrasted with other statistical analysis methods. The maximum likelihood values diverged increasingly from normal-distribution based statistics as AIS level increased. Mr. Morgan believed the Weibull analysis superior at each AIS level studied. Third, thoracic injury data were analyzed and contrasted with a regression analysis. The Weibull Distribution gave a smooth function at all AIS levels, again proving superior to the other method. Fourth, after some data were "corrected" to give the effect of changing input data, it was possible to complete another analysis in a few minutes.

Mr. Morgan concluded that the Weibull method leads to smoother transitions in the cumulative distribution function, whereas Probit analysis has much sharper transitions. He noted that the NHTSA program was available, but that confidence limits have not yet been established.

In answer to questions, Mr. Morgan noted that confidence limits are more difficult to establish with the Weibull Distribution. However, when confidence bands are established, he thinks they would help a researcher distinguish between "good" and "bad" data.

8. Impact Studies on Pressurized Cadavers, M. Walsh, Calspan. Under contract to NHTSA, Calspan is investigating methods of simulating normal vascular pressure in cadavers for more humanlike response in impact tests. Dr. Walsh reported on thoracic and brain pressurization techniques. He has had some success in pressurizing the entire thoracic and abdominal area using fluid with dye. It is then possible to measure impact pressures as a function of chest deflection. Results show peak pressure is reached before peak compression. The pressurization technique is most effective when fluid volumes are minimized and pressurization is limited to only the areas needed for the test.

The brain is pressurized through the carotid arteries. Pressures may be measured from both sides of the brain, but this requires pressurization through both carotid arteries. Results of left lateral skull impacts show a phased response with initial pressure decreasing on the left side and increasing on the right. Lesions are often found at the top of the brain, in the precentral gyrus and in speech and motor centers. More contre-coup than coup lesions were seen in this left lateral impact study.

Dr. Walsh fielded a number of questions about the Calspan technique, and made the following points. Fluid volume required for abdominal/thoracic pressurization is 1000-1500 ml; for both sides of brain-100-200ml. Pressures of 100-120mm Hg are achieved. The dye is useful because a sudden skin color change indicates the fluid is being injected into a vein rather than an artery, the dye stains the vessels well, and dyed fluid gives excellent perfusion when the proper artery is used. India Ink has limited applications at Calspan because it goes out of solution in all but brain tests. Responding to a comment that UMTRI has India Ink to mark rupture sites other than brain, Dr. Walsh noted that UMTRI starts perfusion with a high-pressure pulse. Calspan cannot use that method, and he also thinks the impact levels in Calspan tests may cause less damage. Calspan test velocities are similar but the impact area is larger.

9. Driver Interaction with Steering System, P. Begeman, Wayne State University. Observers have noted that steering wheel rims are often severely deformed in fatal crashes, but seldom show much bending in crash tests with dummies. Dr. Begeman is assessing the thoracic and abdominal biofidelity of dummies and cadavers. A series of tests was conducted using the WHAM sled. Comparisons were run at two speeds, 37 and 42 kph and the test buck consisted of a non-collapsible column, hard seat, knee restraint and no lap/torso restraint. Pressure recording tape was used on steering wheel and hub and a triaxial accelerometer was mounted at T1 on the test subject. Test subjects were four cadavers, two Part 572 dummies, and three Hybrid III dummies.

Results showed substantial differences between dummies and cadavers. The dummy thorax reached maximum compression (bottomed out) at about 37 kph and did not deform the steering wheel past the level of the hub. At 42 kph, the cadaver chest bottomed out and the steering wheel was "turned inside out." All cadavers sustained significant numbers of rib fractures, but no abdominal or soft tissue damage. Cadaver column and hub loads were no more than half those of the dummies; rim loads were also less.

Simulations were also performed, using a Lobdell thorax model. Using cadaver parameters, Dr. Begeman found it necessary to modify the model's damping coefficient to achieve the observed bottoming effect.

Dr. Begeman concluded that current test dummies cannot simulate steering wheel deformations seen in the field, dummy chests have different energy-absorbing characteristics than cadaver (and presumably human) chests, and the Lobdell model is a good simulator if a bottoming effect is included.

A number of questions were posed, especially on details of the procedure. Dr. Begeman offered that chest deflection was measured by film analysis of relative movement between a target at T8 and the fixed-length column, and rim force was calculated as difference between hub load and total column load. The only spinal acceleration data was from the T1 mount. The Lobdell modeling was based on data from one cadaver.

A spring was used to represent the dummy torso in the model because current dummies have spring-like torsos. Dr. Begeman did not have a complete explanation for the good fit of the Lobdell model, given the results that 40% of the force was absorbed in the wheel rim but force-deflection results were derived from total column load. Test results showed that the cadaver tests matched field observations only at the 42 kph level. He did not consider the effect of holding the steering wheel rim on the amount of rim deformation.

Steering Wheel-Abdominal Impact, G. Nusholz, University of Michigan Transportation Research Institute. A series of abdominal impact tests with cadaver subjects was reported. The test device was a large-mass pendulum, to which was attached a steering wheel. The wheel plane was adjustable and the device was arranged so that the lower rim contacted the abdomen between sternum and umbilicus. Measurements included dynamic wheel rim deformation (via stringpots attached to the rim) and acceleration from rigid mounts on ribs and/or sternum and/or spine. UMTRI developed an abdominal pressurization method for the test series, which features pulsed pressure to perfuse followed by adjustment to the lower pressure desired for the test.

Cadavers showed severe damage to the liver and also damage to the pancreas, stomach and duodenum. Mr. Nusholtz noted some difficulty in measuring force-deflection: deflection was measured using both the stringpots and photo targets; force was measured easily at the hub, but with difficulty at the rim-to-abdomen contact point. Only the initial portion of the force-deflection curve is attributable to abdominal contact, since the torso rapidly engages the entire wheel rim and causes a large hub force with little abdominal force.

Questions related to cadaver positioning and the effects of time after death on pressurization effectiveness. UMTRI is trying to standardize cadaver positioning in a configuration representative of actual crash conditions. Each cadaver is X-rayed just before the test. The wheel rim contact point is placed consistently at 4-1/2 inches below substernale and the cadaver "posture" is adjusted around that point. Repressurization is most effective if it can be accomplished up to 5 hours after death. After 1-2 days the liver can be pressurized only by repeated pulses. Except under ideal storage conditions, an unembalmed cadaver cannot be well pressurized after one to two weeks post-death.

11. Viscous Tolerance Criteria for Chest Impact, I. Lau, Biomedical Science Department, General Motors Research Laboratories. Dr. Lau reviewed Lobdell's model of the thorax [described earlier in these minutes] and noted that no tolerance criteria exist for the viscous response properties of the chest. Tolerance criteria exist for the inertial component (maximum acceleration of 60g for 3 msec.) and have been proposed for the elastic component (32% compression for non-skeletal injury, 40% or 75mm compression for skeletal injury. However, the viscous component becomes important in high-speed (>5m/sec) impacts.

Dr. Lau reviewed the derivation of a Viscous Tolerance Criterion [details in Proceedings] and noted experimental results showing that different injury mechanisms acted on the lungs for different impact velocities. He also presented his analysis to select the optimal viscous criterion (V*C). V*C is based on velocity-compression interactions: as chest compression increases, its sensitivity to velocity increases. Dr. Lau suggests that three thoracic tolerance criteria are needed: inertial, elastic and viscous. However, he has no specific criterion number to propose as yet because human-size data do not now exist.

In the question period, Dr. Lau indicated that a series of simulations varying velocity and compression could be matched to known injuries to develop injury assessments at peak velocity/compression points. Responding to a comment about very high velocities, Dr. Lau characterized those as blast phenomena which do not pertain to automotive situations and are not related to his proposed V*C. Finally, Dr. Lau stated that the V*C index is purposely dimensional (for velocities) and non-dimensional (% compression) so that the index may be expressed in velocity dimensions. He does not plan to use non-dimensional velocities at this time.

At the completion of the Technical Session, the Chairman announced the arrangements for the 13th Annual Workshop. It will be held in Washington D.C. (Crystal City) on Saturday, October 12, 1985, following the Stapp Car Crash Conference.

David R. Foust
Secretary