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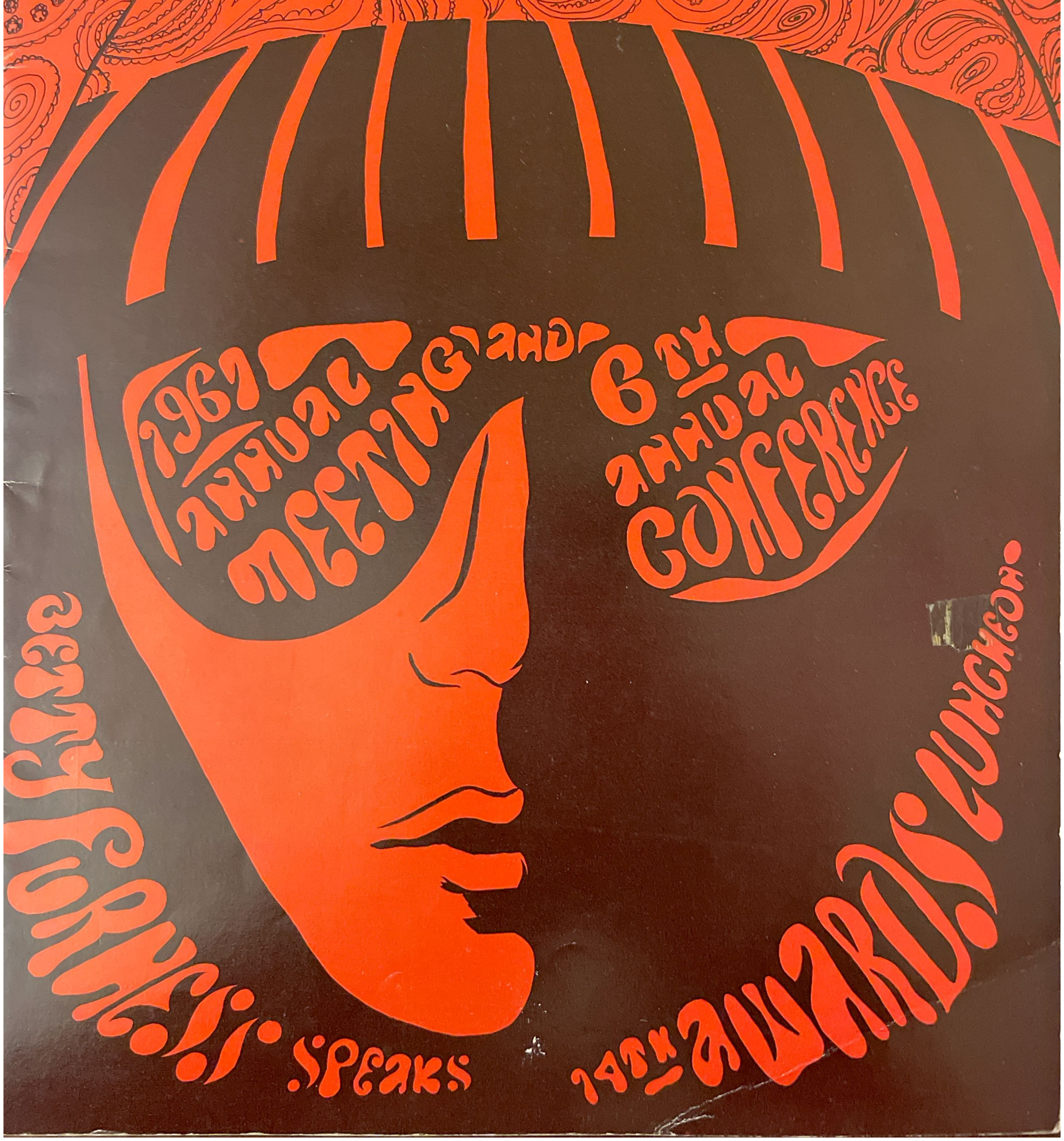

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Editorial Policy

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JOURNAL OF THE AMERICAN SOCIETY OF SAFETY ENGINEERS

COVER

An intensely impressionistic and possibly psychedelic interpretation of the Society's 6th Annual Conference and 14th Awards Luncheon. Leo Rotelli, artist.

BUILDING ARTICLE

SPECIAL TREAT

TECHNICAL SECTION

The use of explosives in space vehicles is not science fiction but contemporary fact. This article emphasizes the human as well as the safety factor in the proper handling of these deadly devices.

The authors, members of the Transportation Research Department at Cornell University's Aeronautical Laboratory, discuss the validity of digital computer simulation of an automobile occupant during a frontal, head-on collision. Their progress report covers one phase of a long-range program of development of simulation techniques for study of occupant/vehicle and vehicle/obstacle collision responses.

DEPARTMENTS

Notice

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Computer Simulation of the Crash Victim- A Validation Study

RAYMOND McHENRY

KENNETH NAAB

RAYMOND McHENRY is Head, Engineering Mechanics Section, Transportation Research Dept., Cornell Aeronautical Laboratory, Inc., Buffalo, New York (since 1961). He holds a BS degree in engineering physics from the University of Maine, and is a master of automotive engineering from Chrysler Institute. A member of the Industrial Mathematics Society and a Registered Professional Engineer in Connecticut, he also has several years of extensive experience in structure and design.

KENNETH NAAB is an Aeronautical Engineer, also affiliated with the Transportation Research Dept. at Cornell. A graduate of Purdue University with a BS in aeronautical engineering, he has been with Cornell since 1964. He is doing graduate work in mechanical engineering at the State University of New York, and his background includes experience in aircraft stability, control, and performance.

THIS RESEARCH PROGRAM WAS PERFORMED to examine the validity of a digital computer simulator of an automobile occupant during a frontal, head-on collision. The simulation is an analytical tool for use in the exploration of the effects of several types of restraint systems on occupant responses in a confined compartment, where injury-producing contact forces occur. The effects on occupant responses produced by the positions, orientations, and load-deflection properties of contacted interior surfaces are also simulated. This progress report covers one phase of a Cornell Aeronautical Laboratory long-range program of development of simulation techniques for study of occupant/vehicle and vehicle/obstacle collision responses.

The overall problem of improving the crashworthiness of automobiles is so complex that various aspects have been isolated for concentrated study. For example, controlled collisions of actual automobiles are essential to define the acceleration environment within the passenger compartment and to investigate the various modes of structural collapse. However, the development of human tolerance data, improved interiors, and restraint system designs by this means alone is not feasible. Therefore, additional experiments are conducted with cadavers and anthropomorphic dummies in a variety of sled tests, and mild impacts are sometimes investigated with living subjects to permit comparison.

Although excellent experimental work has been done on the dynamics of automobile crash victims, a particular difficulty is that research stems from the system complexities and nonlinearities which preclude extrapolations and cloud interpretations of test results. Variations in equipment and procedures prevent a direct correlation of the results obtained by different investigators. Also, there is a lack of agreement on the procedures and equipment that are required for a realistic and repeatable physical simulation.

In analytical approaches to the automobile crash-injury problem, the human body has been represented by a wide range of mathematical models. At one extreme, a linearized equation for a single rigid mass has been used. At the other extreme, the presently reported mathematical model includes nonlinear equations for an articulated assembly of rigid mass segments with ten degrees of freedom within a confined compartment (Figure 1).

Each technique of automobile collision simulation, whether physical or analytical, has its own limitations and difficulties. In view of the overall complexity of crash-victim responses, both experimental and analytical simulation techniques are required in a comprehensive research program.

The CAL mathematical model of the frontal collision case constitutes a research tool that can be manipulated quickly, easily, and at low cost to extrapolate experimental results

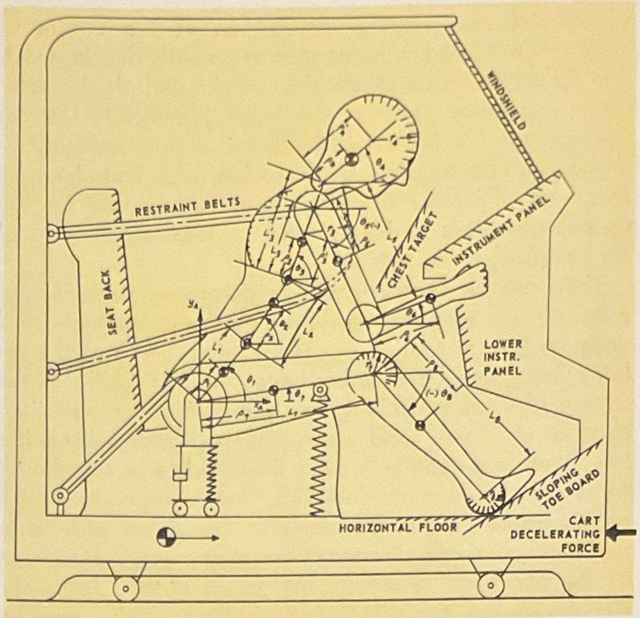

FIGURE 1

MATHEMATICAL MODEL OF HUMAN BODY AND RESTRAINT SYSTEM ON TEST CAR (11 DEGREES OF FREEDOM)

to other impact conditions, system configurations, passenger sizes and weights, and conditions of occupant muscular tension that may arise from anticipation of a crash. The advantages of this approach are: the capability of establishing optimum characteristics for crash injury countermeasures through the relatively rapid and inexpensive exploratory variation of idealized parameters; the ability to repeat identical impact conditions while changing a single system parameter; and the comprehensive output information which clarifies the dynamic interactions that occur within the complex, nonlinear system and thereby provides insight for developing system improvements.

Research Differences—Aerospace/Automotive

This research involves mathematical modeling of the human body in a manner that is significantly different from that of related aerospace research. Results obtained from the extensive related aerospace research have only a limited application to the automobile case, dut to several basic differences. For this reason, the aerospace work has not appreciably diminished the need for research related specifically to the automobile case.

For example, a highly restrictive restraint system and protective headgear can be specified in an aerospace vehicle, and the directions and speeds of impact are controlled within specified limits. Also, in aerospace vehicles the ranges of passenger size, weight, and physical conditions are limited.

In the case of automobiles, the voluntary use of crash helmets and highly restrictive restraint systems is not a widespread practice. Standardization of the design of compartment interiors is not seen as an early development, and the ranges of passenger size, weight, and physical condition encompass those of the entire population. The variety of possible impact conditions is almost limitless, although certain statistics are available regarding the relative rates of incidence and the relative severities for the various directions of impact and contact regions around the periphery of the vehicle.

Therefore, in comparison with aerospace vehicles, the automobile is seen to constitute a much more complicated problem for attenuation of crash injuries. Much of the related aerospace research has been concerned with the response of viscera within a tightly restrained or even "encapsulated" torso, and aerospace mathematical models have therefore dealt with every limited visceral, spinal, and torso deformation considerations. The corresponding automobile research must be primarily concerned with large and highly variable changes in the position and orientation of the occupant, even with the use of existing restraints. For this reason, contacts with the vehicle interior, particularly those of the unprotected head, must receive concentrated attention, as well as the various kinds of restraint devices and the conditions associated with crashes.

The ultimate objective of research is a valid analytical simulation of the responses of a living subject in an actual automobile. In view of the overall system complexity, it appears that this objective can best be accomplished through the mechanism of specialized simulation programs for particular areas of interest—programs in which analytical detail and sophistication would be incorporated only in relation to a particular aspect of occupant-interior interaction. The remainder would be left in the simplest adequate form.

This general approach is based on a consideration of both the economics of obtaining the time-history solutions and the requirements for parameter data. For example, it would appear to be both unnecessary and inefficient to incorporate a sophisticated and detailed treatment of foot-floor interactions in a parameter study that is concerned with steering wheel-column-chest interactions.

This initial validation study may therefore be viewed as an examination of the adequacy of a variety of analytical representations that were deliberately simplified. The existing simplifications reflect both the exploratory nature of this initial attempt at simulating contact forces and the associated uncertainty of the economic feasibility of time-history solutions. The extent and the magnitudes of discontinues in the nonlinear differential equations, even in the simplified case, made the machine time for time-history solutions uncertain.

Time for the Computer

The computer time requirement of initial runs of the existing simulation program was found to be approximately four to five times that of the simulation described in Reference 1. While not exorbitant (approximately $35 to $40 for a 200 millisecond time-history), the running costs made it desirable to seek a basic validation within the limitations imposed by the relatively simple analytic geometry and solution logic. More detailed and sophisticated treatments could be developed later and validated in specialized programs for areas of particular interest.

The General Motors sled facility at Wayne State University was found to be ideally suited for the initial basic validation study, since it featured instrumented, padded, simple "targets" representing the contacted regions of the automobile interior (Reference 2).

The specific objective of the program was to obtain detailed parameter and response data from fully instrumented sled tests in order to examine the basic validity of the developed mathematical model, with analytical refinements incorporated only as required to achieve an adequate degree of correlation. The selected test subject was an anthropometric dummy, since it is not feasible to use living subjects to validate the simulation of injury-producing contact forces. Some of the detailed body parameters of living subjects and cadavers are also difficult to measure, and it was desirable to avoid the use of estimates of "typical" parameter data in this initial validation study.

A series of fifteen instrumented sled tests was performed with an anthropometric dummy unrestrained, restrained

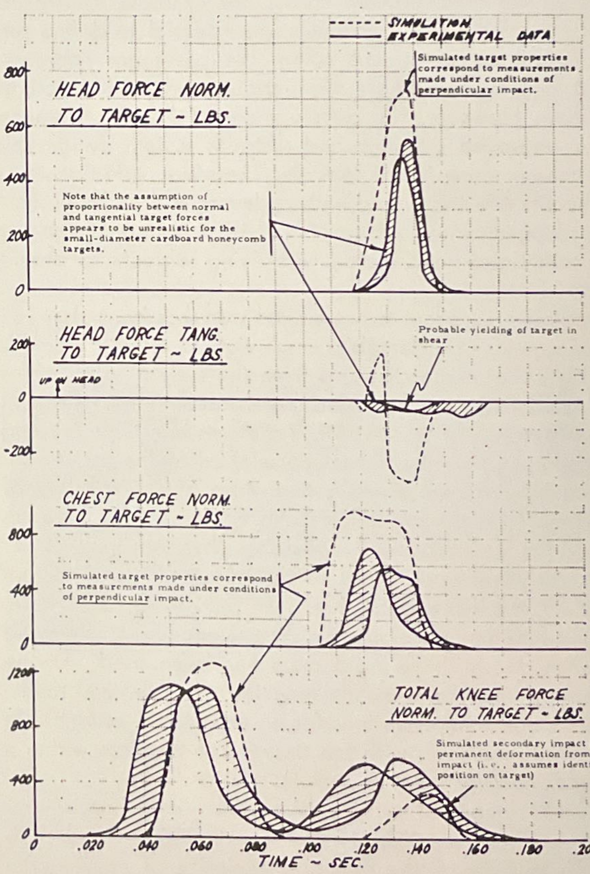

FIGURE 2

NO RESTRAINT

CART VELOCITY 10 MPH

by a lap belt, and restrained by a lap belt and an isolated shoulder strap at two levels of severity. The series included repeat runs of all but one of the experimental responses. Dynamic load-deflection properties of system components were measured in a separate series of component tests. Detailed measurements were also made of properties of the anthropometric dummy.

It was originally planned to schedule the tests associated with each condition of restraint separately, so that comparisons of analytical and experimental responses could be completed prior to proceeding with tests of another restraint condition. In this manner, it would have been convenient to perform reruns of experiments as required and to incorporate analytical refinements as required for the particular case before proceeding with the test program. However, a prolonged series of delays in the original test schedule, combined with limitations on the overall schedule and budget available for this research, resulted in the use of "first-shot" measurements of component characteristics and results from sled tests for all conditions of restraint.

Therefore, many of the discrepancies found between theory and experiment are of a sort that would normally have been corrected either in repeated runs of experiments

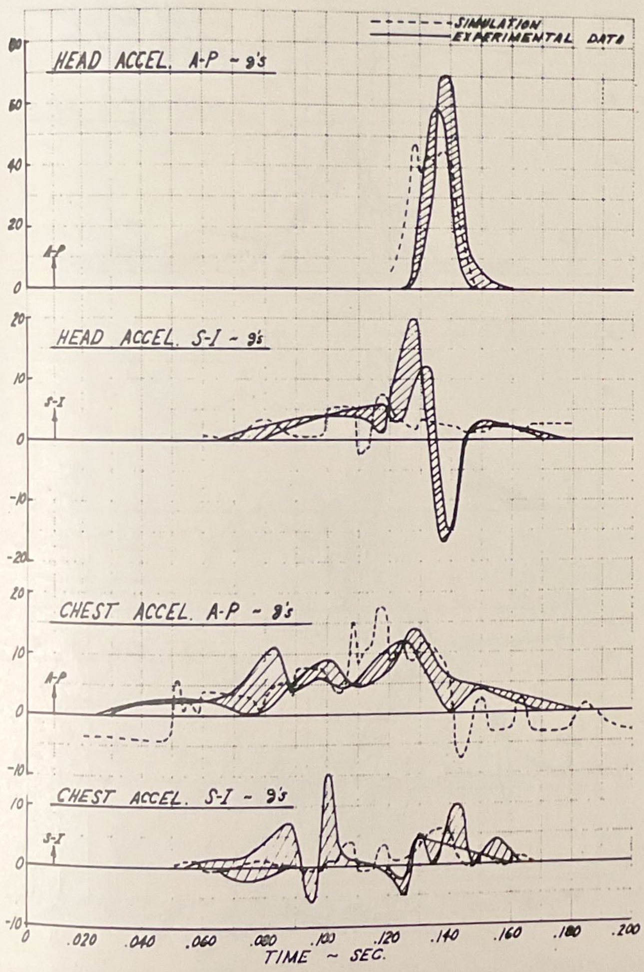

FIGURE 3

NO RESTRAINT

CART VELOCITY 10 MPH

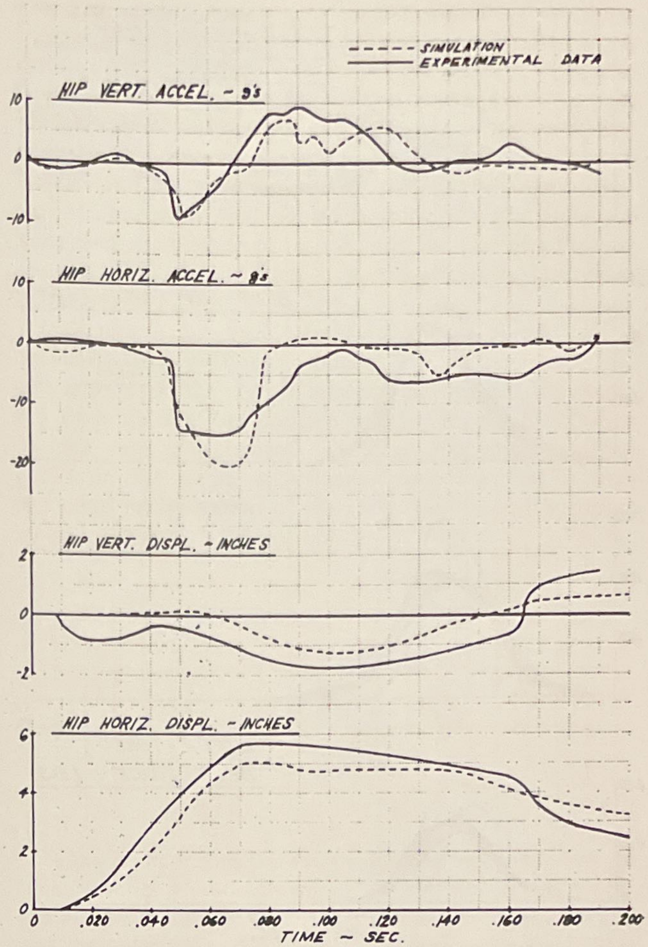

FIGURE 4

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(target positions adjusted to achieve contact on the appropriate regions of the dummy or sled speed reduced to avoid "bottoming-out" of target pads), improved measurements of component characteristics (target properties under conditions of oblique impact or dummy padding under belts at higher load levels) or analytical refinements (improvements in the simulation of torso and neck bending resistances).

Two Comparisons Yield Results

In the interest of brevity, only two of the detailed comparisons are presented.

1. Response Comparison for Unrestrained Dummy at 10 MPH Cart Velocity (Figures 2-4).

In Figure 2 the generally higher calculated forces normal to the target surfaces may have been produced by the neglect of shear effects on the simulated target properties. Measurements of the target properties were made under conditions of perpendicular impact. It is hypothesized that widespread practice. Standardization of the design of compartment interiors is not seen as an early development, and the ranges of passenger size, weight, and physical condition encompass those of the entire population. The variety of possible impact conditions is almost limitless, although certain statistics are available regarding the relative rates of incidence and the relative severities for the various directions of impact and contact regions around the periphery of the vehicle.

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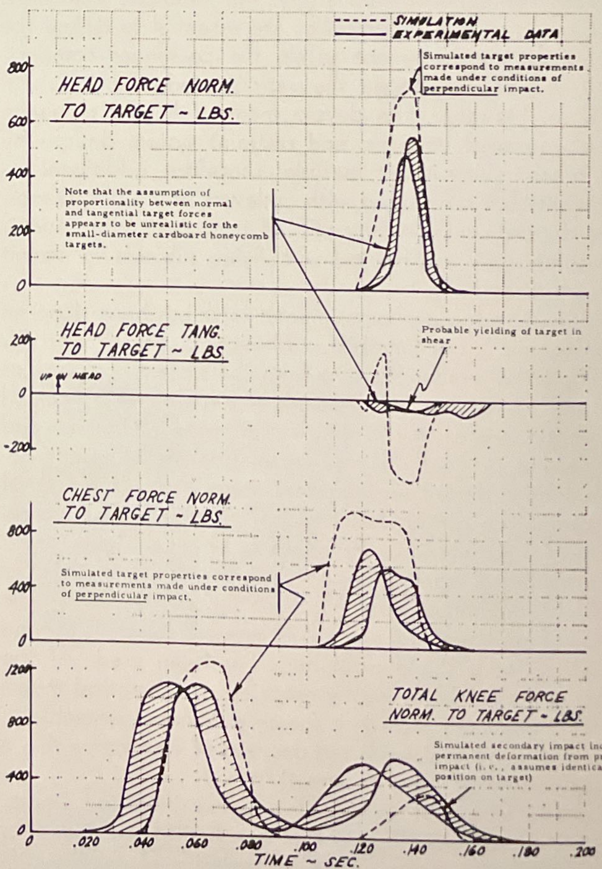

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NO RESTRAINT

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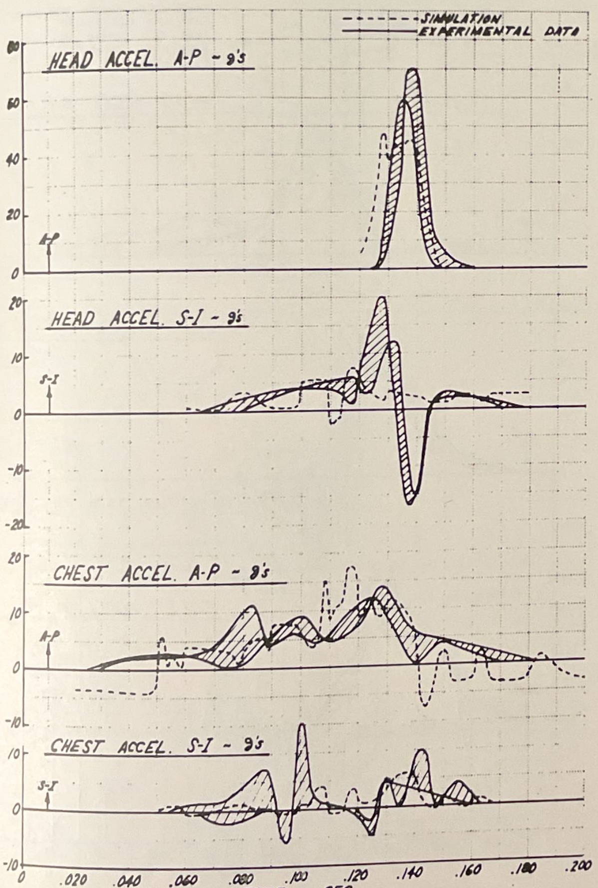

FIGURE 3

NO RESTRAINT

CART VELOCITY 10 MPH

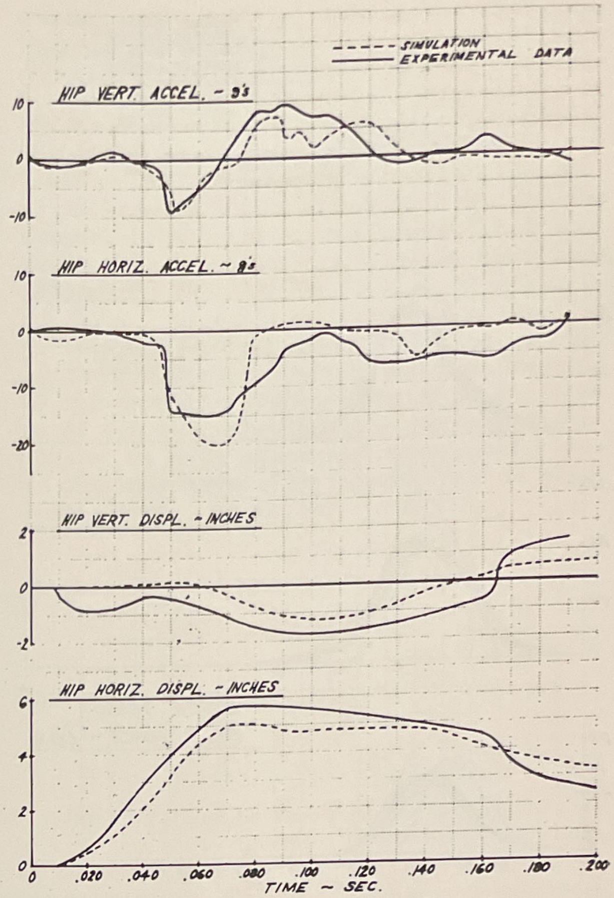

FIGURE 4

NO RESTRAINT

CART VELOCITY 10 MPH

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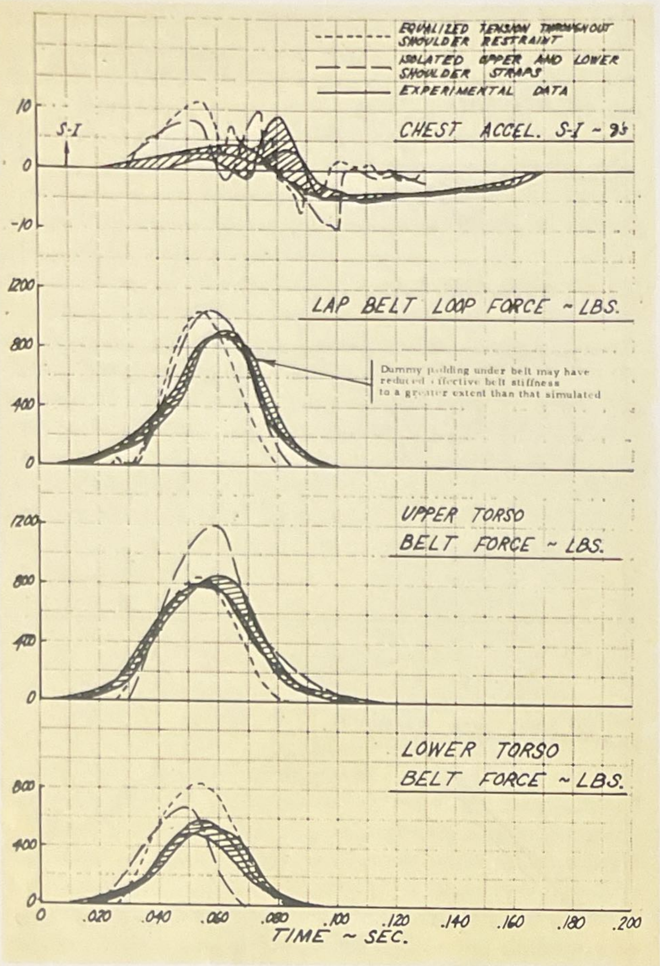

FIGURE 5

LAP AND TORSO RESTRAINT
CART VELOCITY 10 MPH

the relatively small (six inch diameter) four-inch thick cardboard honeycomb targets tend to yield in shear at a relatively low tangential force level, thereby reducing the resistance to perpendicular loading. The assumption of proportionality between tangential and normal forces on the small diameter honeycomb targets appears to be unrealistic from a comparison of the two upper plots.

Note that the small diameter cardboard honeycomb targets constitute a unique form of contact surface that appeared to be well suited for this basic validation study but is not representative of the interior surfaces of real automobiles.

The calculated peak value of knee forces is approximately 16 per cent higher for the first peak and 42 per cent lower for the second peak as compared with the experimental mean values. The delayed and reduced second calculated peak value could have been produced by the analytical retention of permanent deformation from the first contact (the analytical treatment assumes that the second impact takes place at the identical location of the target of the first impact).

In Figure 3, the calculated peak head acceleration in the A-P direction is approximately 27 per cent lower than the mean experimental value. This direction of error was unexpected in view of the larger calculated force normal to the target in Figure 2. The fact that the approximate "effective" head mass appears to be more reasonable in the calculation (the corresponding "effective" head weights at the time of occurrence of peak acceleration are approximately 8 lbs. from the experiment and 16 lbs. from the calculation) casts some doubt on the experimental results. Note that the existence of a chest force at the time of occurrence of peak load acceleration could conceivably make the comparison of "effective" head weights invalid.

The chest acceleration was expected to produce the worst agreement in view of the simulation of a rigid chest segment. The actual dummy construction includes steel ribs, which could produce large discrepancies between calculation and experiment. In view of this, the time histories of chest acceleration components are considered to be quite good.

Horizontal and vertical displacements of the hip were obtained from the film records. In general, Figure 4 is considered to show good correlation.

2. Response Comparison for Lap Belt and Shoulder Strap at 10 MPH Cart Velocity (Figures 5-7).

The simulation program includes two options in the treatment of a shoulder strap. In the first option, the web-

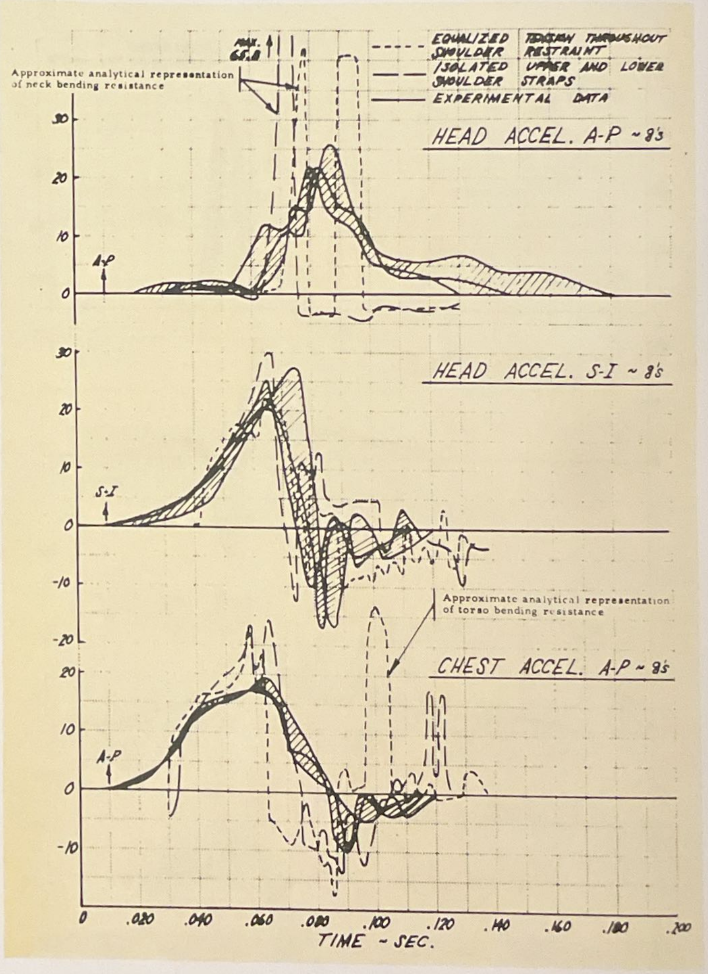

FIGURE 6

LAP AND TORSO RESTRAINT
CART VELOCITY 10 MPH

bing tension is equalized throughout the strap. In the second, the two ends of the strap are treated separately (completely isolated from each other). It is hypothesized that the behavior of the actual physical system lies somewhere between these two extremes. In this response, both options are applied for purposes of comparison.

In Figure 5, the kinematics of the simulated dummy are seen to be in excellent agreement with those of the test dummy. It is interesting to note that the simulated dummy arms appear to "average" the kinematics of the experimental arms. The unsymmetrical should strap produced differences in the experimental responses of the individual arms which, of course, are not simulated in the present plane-motion analysis.

The comparison of calculated and measured lap belt forces in Figure 6 shows a discrepancy attributed to shortcomings in the measurement of dummy padding properties. The other plots are considered to show a fairly good correlation. The equalized-tension option in the shoulder strap appears to be the better approximation.

However, the comparison of calculated and experimental head accelerations shows a poor correlation. The difficulty in the case is probably due to the approximate analytical representation of the neck bending resistance. The use of constant friction and limit stops appears to provide a poor simulation in cases like the present one where large neck deflections occur. The calculated "spikes" on the chest acceleration plot are also probably produced by the simulation of excessively abrupt limit stops in the spinal "joints" and the neck. The present representations of bending resistances are first approximations. Unfortunately, the presented comparison of responses is the first one that has been available upon which a second approximation could be based.

In Figure 7, the erratic behavior of the calculated hip accelerations is probably produced by the discussed difficulties with spinal and neck bending resistances. The recovery of horizontal hip position is seen to deviate further for the case of equalized tension in the shoulder strap. However, the single experimental response that is plotted gives no indication of the repeatability of the experimental recovery of hip position.

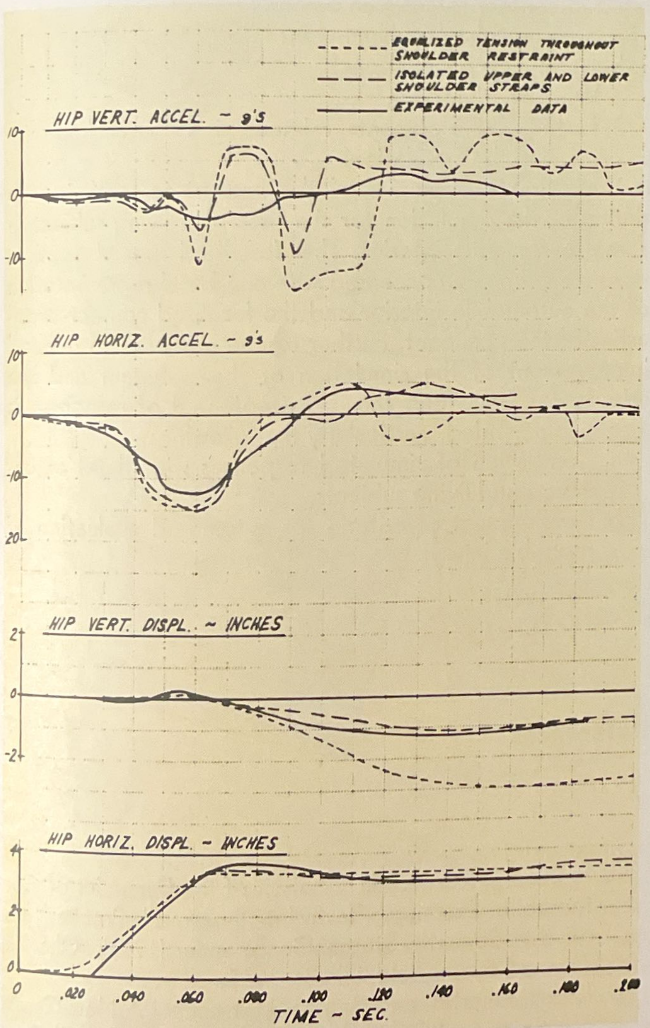

FIGURE 7

LAP AND TORSO RESTRAINT

CART VELOCITY 10 MPH

Conclusions

1. The comparisons between simulated and experimental time historics show agreement in the timing of events, the occupant kinematics, the general levels of peak values, and the waveforms of responses, despite recognized shortcomings in some of the parameter data and recognized limitations imposed by simplified analytical representations.

In those parts of the validation study where significant differences exist between the computed and experimental responses, there are either obvious reasons for the differences (the dummy elbows were **locked** in four of the six test conditions, a physical constraint that could not readily be simulated; or the "target" positions in one of the test conditions produced impact on a target edge, rather than a direct hit, by a portion of the dummy other than that on which the corresponding contact force is simulated) or logical explanations (the targets were impacted under conditions that differed significantly from those under which the characteristics were measured).

2. The present combination of analytical treatment of torso and neck bending and associated parameter data do not produce an adequate degree of correlation of the waveforms of calculated acceleration time histories with those of moderate to high severity experiments to permit direct application of available information on human tolerances. This finding is not surprising in view of the "first guess" nature of the present treatment of torso and neck bending. The differences between the simulated and experimental acceleration waveforms are of a type that would be expected from the use of improperly spaced and excessively abrupt travel limits.

3. The "first approximation" parameters used in the analytical representations of spinal and neck bending resistances are excessively nonlinear.

4. The assumption of proportionality between tangential and normal forces on the six-inch diameter four-inch thick

honeycomb cardboard targets used in the reported test series is not valid. However, this assumption may be a reasonable first approximation for surfaces less susceptible to shear failure.

5. The analytical simulation of seat cushion friction is not adequate for conditions of large vertical deflection of the cushion. On the basis of a 20 MPH test condition with the lap belt restraint, it appears that some "plowing" or "digging-in" effects exist under conditions of large vertical deflection of the seat cushion. The assumption of proportionality between horizontal and vertical forces on the seat cushion is a poor approximation under these conditions.

6. The actual dynamic vertical stiffness of the seat cushion is somewhat higher than that simulated.

7. The measurement in this validation study of load-deflection properties of padding on the dummy structure under the lap belt did not include a sufficiently large range of loading.

Recommendations

The previously discussed difficulties in scheduling tests and in obtaining reduced test data in a timely fashion restricted the present validation study essentially to a "first-shot" comparison of responses. For this reason, the objectives of the reported research have not been fully achieved.

However, these comparisons and other completed comparisons are sufficient to justify certain applications to current related problem areas. Also, by working backward from the reported comparisons with exploratory adjustments, it is possible that some of the recognized shortcomings in the present analytical representations and parameter data can be at least partially remedied (Conclusions 3-7). Exploratory adjustment of parameters would not have been appropriate in the reported validations study.

The following tasks should be included in future research:

1. Applications in Present Form.

a. Generation of Response Information for Design Guidance.

The recently increased attention being focused on performance specifications for crash injury countermeasures has revealed a dearth of applicable information on occupant responses. For example, relationships between head velocity, normal to a specific contact surface, and vehicle speed immediately prior to impact, in a frontal collision, are not known to be defined. Similarly, the corresponding inertial loading of the head during contact with an interior surface of the vehicle is not known to be defined (the "effective head mass" during impact on the instrument panel).

Factors that determine the ranges of head velocities and the inertial loading of head contacts, in a given collision, include the impact type (time history of compartment deceleration), compartment dimensions, occupant size, condition of restraint, position of seat adjustment, or muscular tension. Definitions of the above two aspects of occupant response, among others, would appear to be essential for the development of design improvements and related performance specifications. The present version of the computer simulation is ideally suited for the generation of applicable response information.

b. Specification of Dynamic Test Procedures for Acceptance Testing of Restraint Belts.

There is an extensive current interest in dynamic acceptance testing of restraint belts. The development of specifications for an acceptable test procedure involves the resolution of many controversial issues. The present version of the computer simulation could constitute a means for resolving existing differences of opinion regarding the extent of sophistication that is required in components of a test facility (time test dummy, the seat). It could also be applied to the problem of tolerance specifications in a dynamic test procedure. For example, the sensitivities of the peak belt loading and the time history of belt elongation to specific types and magnitudes of variations in the waveform of sled deceleration, to errors in the sled speed, could be evaluated analytically.

2. Further Developments Aimed at Special Applications.

For particular areas of interest requiring more detailed treatment of specific aspects of the simulation, the selected form of programming will permit easy modifications in the analytic geometry and the logic associated with force generation. Several areas of particular interest, related to contact forces, can be anticipated:

a. Steering wheel/column-chest interactions.
b. Instrument panel impact.
c. Windshield impact.

3. Further Developments Aimed at General Improvement of the Simulation.

The ultimate objective of the present research is validation of the simulation for the case of a living subject in a real automobile interior. The described special applications are primarily concerned with analytical representation of the automobile interior and the localized contact properties of the occupant. Further research related to general improvement of the simulation of the occupant and the criteria for evaluating the injury potential of responses is also recommended, particularly the following:

a. Correlation of simulated responses with those of cadavers and living subjects.
b. Development of criteria for automated evaluation of probable injury.

References

1. McHenry, Raymond, "Analysis of the Dynamics of Automobile Passenger-Restraint Systems," Proceedings of the Seventh Stapp Conference (1963), Charles Thomas, Springfield, Illinois, 1965.
2. Kroell, Charles, and Patrick, Lawrence, "A New Crash Simulator and Biomechanics Research Program," Proceedings of the Eighth Stapp Conference (1964), Wayne State University Press, Detroit, 1966.
3. McHenry, Raymond, and Naab, Kenneth, "Computer Simulation of the Automobile Crash Victim in a Frontal Collision—A Validation Study," CAL Report No. YB-2126-V-1, July 1966.

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