69-07-N09-119

AFFIDAVIT OF ROBERT B. MACLEAN

I am Robert B. MacLean of 314 S. Berkley, Dearborn, Michigan. On August 4, 1971, I made an affidavit concerning the preparation under my supervision of a study estimating the effectiveness of various, alternative restraint systems for occupants of passenger cars. In that affidavit I stated that detailed materials supporting the principal assumptions and general methodology of that study were then under preparation.

The attached report, entitled "Restraint System Effectiveness," constitutes those materials. A few comments on its contents are in order. First, the estimates of lives saved shown in Figures 27 and 28 differ slightly from the estimates set forth in our earlier report because it was determined in the course of preparing this report that our treatment of the multiple impact accident placed too large a portion of the fatalities in the first impact.

Second, it should be understood that calculation of these estimates was based on test and design data derived from experimental designs pre-dating the computations, which were completed in July, 1971. Thus the head and chest decelerations assumed to be experienced by adult-sized occupants were derived from test data or air bag system designs current in the period January through March, 1971, rather than the later designs that have been developed to reduce the loads imposed on standing children by deployment of the air bag. Test results show that a consequence of this redesign of the air bag system has been to increase the decelerations experienced by adult-sized occupants. Accordingly, the estimates of lives saved by air bag systems tend to overstate the effectiveness of such systems as they are now designed.

The attached report was prepared under my supervision, and I believe that it fairly and accurately reflects the basis for the estimates set forth in the report attached to my affidavit of August 4, 1971.

Robert B. MacLean
Robert B. MacLean.

Subscribed and sworn to before me
this 21 day of September, 1971.

[signature]
Notary Public - WAYNE COUNTY
STATE OF MICHIGAN

National Highway ... SEP ...

1-9-62-009-119

Ford Motor Company

20000 Rotunda Drive
Dearborn, Michigan 48121
Mailing Address
P.O. Box 2053
Dearborn, Michigan 48121

RESTRAINT SYSTEM EFFECTIVENESS

by

Ernest S. Grush, Sherman E. Henson, and Orville R. Ritterling

Report No. S-71-40

Automotive Safety Affairs Office

September 21, 1971

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TABLE OF CONTENTS

INTRODUCTION

The general objective of the study reported here was a comprehensive assessment of the injury-reducing potential of various automobile occupant safety restraint systems, including both existing and proposed systems, some of which require occupant participation (active systems), some of which do not (passive systems), and some systems with both active and passive elements. An analysis of different systems employing the same benefit criterion and the same basic assumptions should enhance confidence in the comparative, if not the absolute, nature of conclusions about the effectiveness of the systems.

This report contains a main body discussing the model used in generating the results along with the results themselves. In addition, a number of technical appendices are included which describe in detail the underlying assumptions and computational procedures by which certain of the model parameters were developed. Each appendix is referenced in the main text at the time the relevant technique described in the appendix is discussed. Thus, if the main text is read by itself and the appendices disregarded, the findings of the study and the general outline of the method used will be revealed. On the other hand, some readers with in-depth interest will want to review each appendix as it is referenced in the main text.

Restraint Systems Studied

Fifteen restraint systems were studied. The driver in each system was assumed to have protection from a third-generation, energy-absorbing (E/A) steering column. A more complete description of the characteristics of this E/A column and the restraint systems studied will be found in later sections of this report. The 15 systems categorized by the restraint available to occupants in each seated position of the automobile, are listed below.

1. Lap Belts Only: 6 lap belts, one for each seated position.

2. Present Harness Configuration, Current Webbing: 6 lap belts plus shoulder belts for driver and right-front passenger.

3. Present Harness Configuration, Constant-Force Webbing.

4. Front-Seat Air Bag System: Air bags for center and right-front passengers, 3 lap belts in rear seat.

5. Front-Seat Air Bag System With Lap Belts: Air bags for center and right-front passengers plus 6 lap belts.

6. Front and Rear-Seat Air Bag System: 5 air bags for all occupants but driver.

7. Front and Rear-Seat Air Bag System With Lap Belts: 5 air bags plus 6 lap belts.

8. High-Impact Panel: Impact resistant instrument panel for center and right-front passengers, 3 lap belts in rear seat.

9. High-Impact Panel With Lap Belts: Impact resistant panel for center and right-front passengers plus 6 lap belts.

10. High-Impact Panel Front and Rear Seat: Impact resistant panel for all occupants but driver.

11. High-Impact Panel Front and Rear Seat With Lap Belts: Impact resistant panel for all occupants but driver plus 6 lap belts.

12. Harness System For All Occupants But Driver, Current Webbing.

13. Harness System For All Occupants But Driver, Constant-Force Webbing.

14. Harness System For All Occupants, Current Webbing.

15. Harness System For All Occupants, Constant-Force Webbing.

Selection Of The Benefit Criterion

The benefit criterion used in this study was the number of motor vehicle fatalities among unrestrained occupants which would be avoided through use of a safety restraint system. Although a number of additional criteria incorporating economic considerations and casualties other than fatalities could have been included, this analysis was made strictly in terms of lives saved, for the following reasons:

- The jump from fatalities to injuries and/or to dollar-loss as a criterion would be a large one. Analysis in terms of fatalities alone is complex and difficult; consideration of other criteria not only would increase the intricacy manyfold but, at the same time, would decrease enormously the validity of the necessary assumptions. This introduction of more-questionable assumptions, while expanding the scope of analysis, would reduce considerably the confidence with which the conclusions can be treated.

- Among other advantages of considering only lives saved is the unambiguity of fatality—an occupant is either dead or not dead. The same finality cannot be associated with non-fatal injuries. No universally accepted scale of injury severity has yet been developed. Attempting to rank different injuries on some scale of trauma involves either the adoption of an existing, questionable scale of injury, or the construction of a new scale. Developing injury-rating schemes is beyond the scope of this study. The problem is further confounded by the necessity of including fatality on the injury scale. The use of economic loss as a criterion involves establishing a dollar value for a life, among other necessary procedures; such analysis is, again, beyond the scope of this study.

- The higher reliability of fatality data provides additional justification for its use alone. Essentially all the motor vehicle fatalities which occur are counted; fatality is not a condition which can be faked or not reported for insurance reasons. The seriousness of the consequences of a fatal accident also enhances th likelihood that the accident investigator will be conscientious in collecting the relevant pieces of information about the accident.

Cautions In Interpreting Results

No attempt should be made to determine the benefit of a combination of restraint systems by summing benefits computed separately for each system. The population of lives saved by each system may overlap; in this case, summing the separate benefits constitutes eliminating a fatality more than once. In other situations the combination of systems may interact to produce benefits exceeding the sum of the benefits for each system considered alone. For example, the benefit of diagonal harnesses alone would be minimal, but when combined with a lap belt, the resulting system becomes extremely beneficial.

GENERAL DESCRIPTION OF METHOD OF THIS STUDY

The two major tasks in this study were, first, to develop a common method of assigning an effectiveness value to any automobile-occupant restraint system and, second, to compare one restraint system with another on the basis of number of occupant lives saved by applying this effectiveness value to fatal accident data.

The first task was accomplished by using mathematical models. Of necessity, the approach requires the formulation of a number of assumptions. However, each assumption is carefully formulated so as to have obvious boundaries and is reviewed completely in terms of the implications that assumption holds for the results of the study. Wherever any assumption tends to favor one restraint system over another, this fact and the reasons for it are pointed out.

Even though this approach to determining restraint effectiveness is limited principally to single-impact, frontal type collisions, its development is significant and will be fully explained in the next section of this report, which also deals with single-impact fatalities. The single-impact, frontal collision is by far the greatest producer of automobile occupant fatalities, and the approach developed provides an organized, methodical way of assigning the effectiveness of a restraint in preventing impact fatalities.

The second major task was an analysis of accident data to determine the relative frequency with which the various kinds of fatal accidents occur.

Two major sources of accident data were used. Total accident fatality data were drawn from the report of the National Safety Council for 1969, the latest year for which a report has been published. Distribution of fatalities by type of accident was developed using data provided by the Automotive Crash Injury Research activity of the Cornell Aeronautical Laboratory. After an effectiveness value was calculated for each restraint system studied, it was applied to each type of fatality-producing accident at the frequency with which each occurred, thus indicating lives saved in that type of accident. Adding lives saved in each type of accident showed total life savings for each restraint.

METHOD OF CALCULATING EFFECTIVENESS VALUES

The general approach taken in this study is outlined below; details of the method will be found in appropriate sections of this report.

For each restraint listed above, mathematical modeling of the occupant-restraint-vehicle system established potential head and chest decelerations of the occupants in a number of narrowly categorized crash situations. Human tolerance formulations were used to convert these decelerations into effectiveness values for each crash situation studied. These effectiveness values, which reflect the ability of a restraint to save lives in each given crash situation, were then applied to accident data showing the relative frequency of fatalities occurring in each such situation. This gave the number of these fatalities which would not have occurred had the restraint system been used. Summing the results for all situations leads to an overall estimate of lives saved by each restraint; this technique thus provides a direct comparison of the life-saving potential of each of the 15 occupant restraint systems studied.

The Computer Simulation of the Automobile Crash Victim (1), developed at the Cornell Aeronautical Laboratory, was used for all simulations except the air bag. Since the Cornell model does not presently include an air bag simulation, another model developed especially for air bag simulation was used. Ranges of occupant sizes and crash situations were used as inputs to both models.

Human Tolerance

Effectiveness values calculated in this study, as indicated above, reflect the ability of a restraint to save lives. As the severity of an impact increases, the probability of surviving that impact decreases. The more effective restraints will attenuate impact severity to a greater degree than the less effective ones. The measures of impact severity used in this study were peak head and chest deceleration. The relationship of these measures to probability of survival is shown in Figure 1.* For example, the probability (in percent) of surviving an accident in which the measured peak head and chest decelerations are 140 and 65 g's, respectively, would be obtained from Figure 1; the lower of the two probabilities, 32 in this case, is the effectiveness value. The derivation of Figure 1 is explained in detail in Appendix A.

Cornell Occupant Simulation

In motor vehicle crash simulation, an eleven-degree-of-freedom planar model of an occupant and a vehicle interior during a frontal collision, developed by the Cornell Aeronautical Laboratory, provides the highest degree of realism attainable at this time. A schematic of the model is shown in Figure 2.

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*Figure 1 is on the next page. All Figures are included within the text, near the point of first reference.

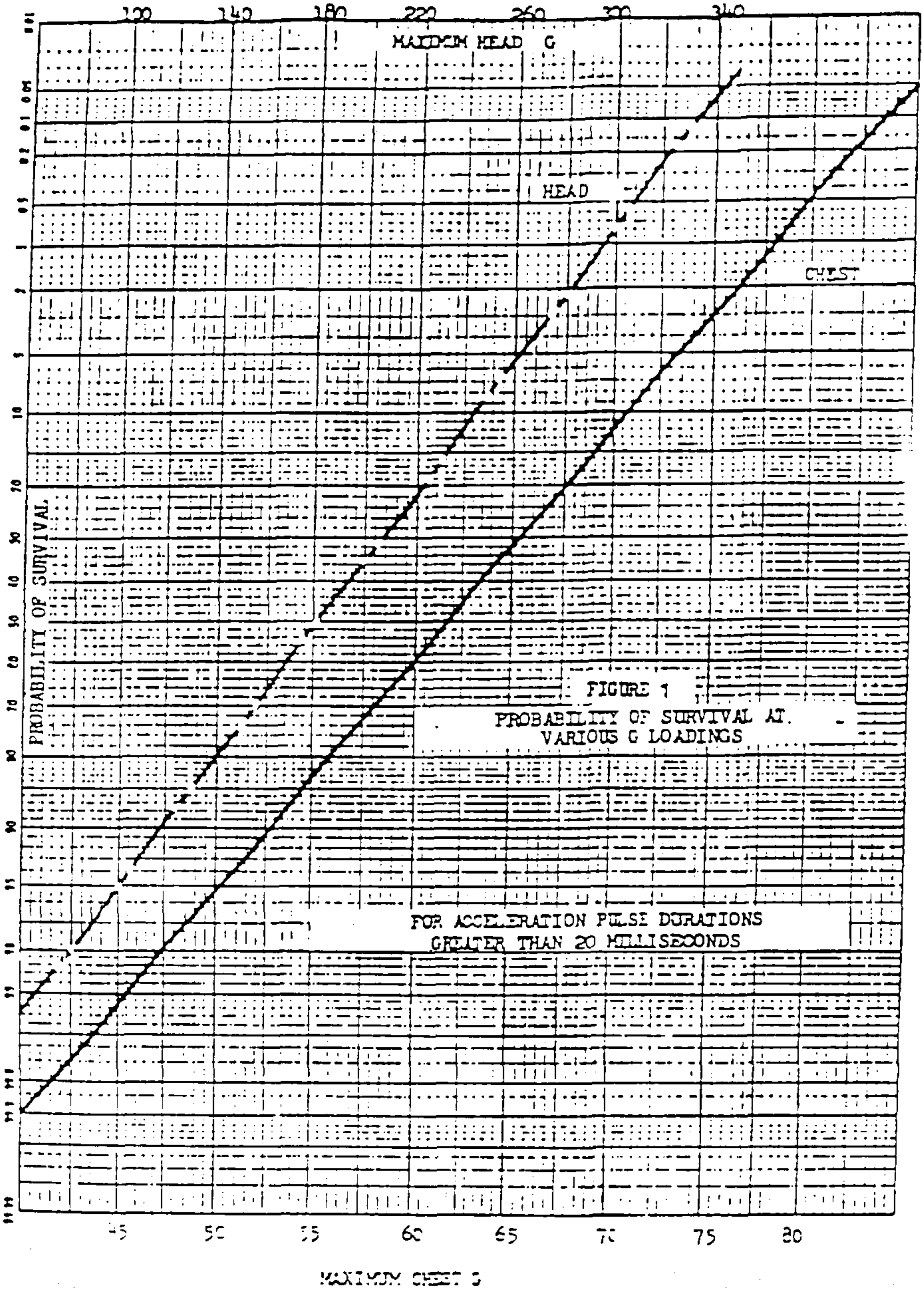
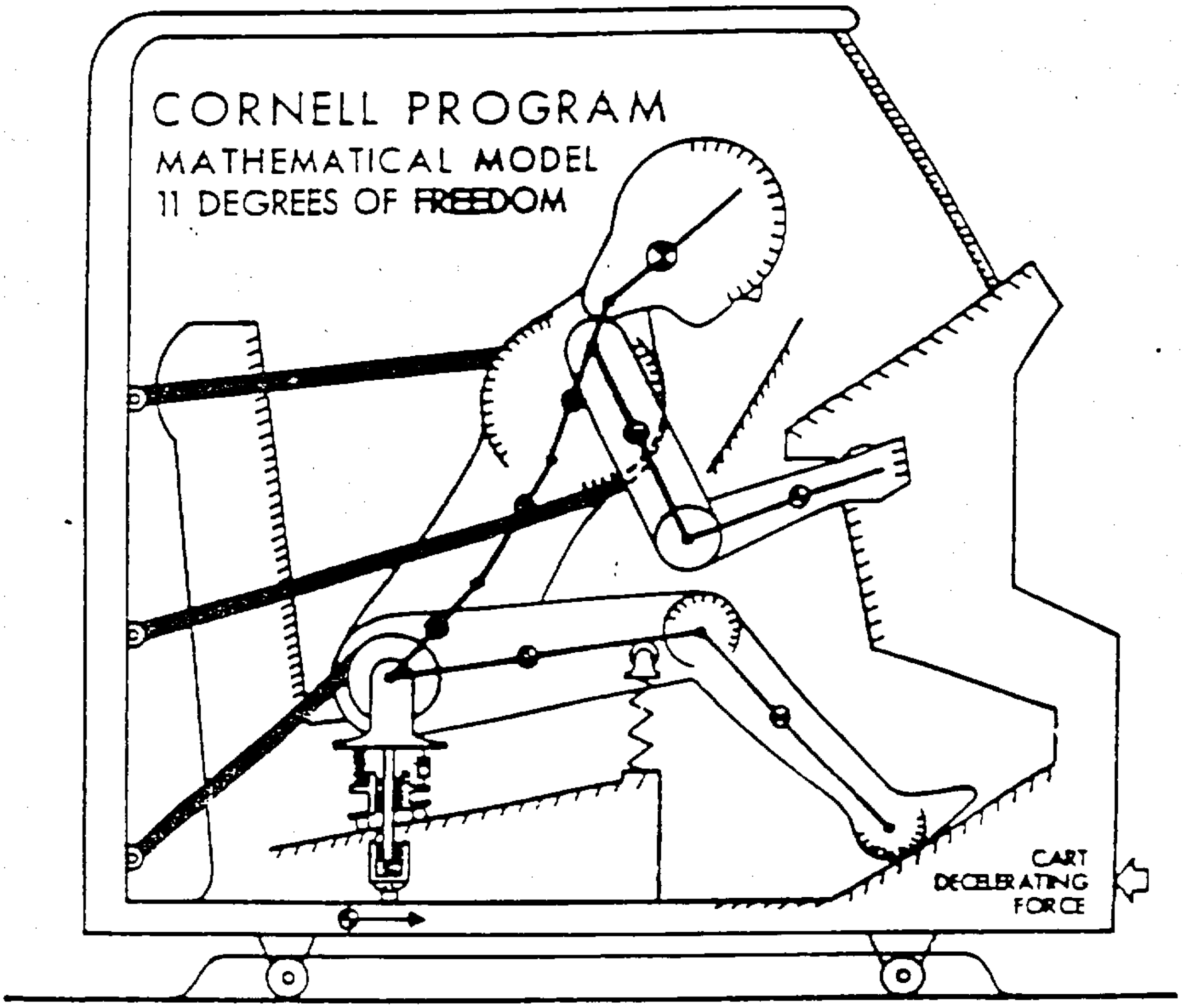


FIGURE 1
PROBABILITY OF SURVIVAL AT VARIOUS G LOADINGS

FIGURE 2


CORNELL PROGRAM
MATHEMATICAL MODEL
11 DEGREES OF FREEDOM
CART
DECELERATING
FORCE

The model of the human body consists of an articulate assembly of eight rigid mass segments whose dimensions and inertia properties are sufficient to provide characteristic motion of the torso and extremities.

These rigid segments are connected by pin joints which incorporate adjustable friction, motion-limiting stops and elasticity.

The lap belt is assumed to remain tangent to a circle with center at the hip pivot and is rigidly anchored in 2-dimensional space.

The shoulder restraint consists of an upper torso strap which is assumed to pass through the shoulder pivot, and a lower strap whose intersection with the torso centerline remains fixed. The material characteristics of the restraint system are simulated by 5th order polynomials of displacement and velocity.

The seat cushion is represented by two separate vertical forces. The primary force is a non-linear function of vertical cushion deflection, assumed to act through the hip. The secondary force is a linear function of vertical deflection of the front edge of the seat cushion.

The belt, seat, and contact forces which act on the occupant are calculated from the relative displacements and velocities within the model system during the stepwise numerical intergration of the equation of motion. The dynamic characteristics of the seat and contact surfaces are represented by 5th order polynomials of displacement and velocity. The position and direction of the contact forces are made determinant by approximating the contact surfaces of the torso with circular arcs and representing the interior surfaces of the vehicle with plane surfaces.

The independent or input parameters to the Cornell Program detail the shape and material characteristics of physical components and subsystems such that the math model performs as a real-world event. These independent parametors, of which there are some 350, define:

- The Occupant -- which includes the dimensions and inertial properties of the articulated body segments, body joint characteristics and body initial conditions.

- The Vehicle -- which includes a special description of the vehicle interior relative to the time-zero position of the occupant's hip point and the vehicle initial conditions.

- The Material Characteristics — which define the load-deflection properties of the restraint system and of the vehicle interior contact surfaces.

- The Excitation Force -- which is the time-variant vehicle deceleration.

The dependent or output parameters of the Cornell Program define the response of the Cornell math model for a particular set of independent parameters. The simulated response includes the following:

- Occupant Kinematics — the time-variant position of the occupant and the acceleration of specific points on the articulated body such as the head, chest and hip.
- Contact Forces — the deflection and the velocity of deflection for the contact surfaces and the force of contact between the occupant and the vehicle interior.
- Belt Response — the elongation and the rate of elongation of the restraint system and the belt forces.

The responses of primary importance in this study were head and chest decelerations. The load-deflection properties of various restraint systems and the pertinent interior geometry contact surface locations are the variables affecting occupant response.

Occupant And Vehicle Package Assumptions

Small, medium and large occupants were simulated, corresponding to the 5th percentile female, 50th percentile male, and 95th percentile male. It was assumed that small occupants would have the front seat full-forward and large occupants full-rearward. A mid-H-point position of the front seat was assumed for the medium occupant and for all rear-seat occupants.

The interior geometry selected for this study was that of the 1973 Ford car. Vehicle deceleration-time characteristics were approximated by the curves shown in Figure 3 for 20, 30, 40 and 50 mph fixed barrier crashes.

Occupant Restraint Descriptions

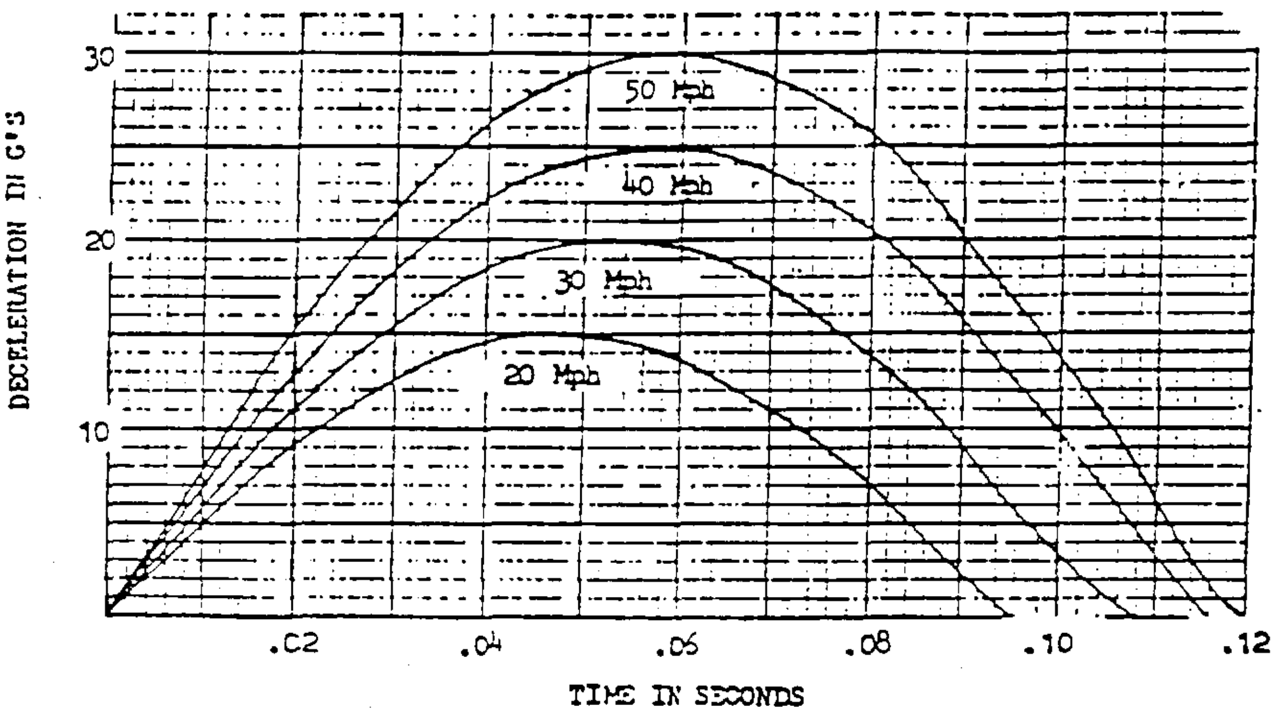
A review of the 15 occupant restraint systems (combinations of restraint components) included in the study shows that 7 basic restraints were evaluated. Each of these restraints is discussed separately, as follows:

1. Third Generation Energy-Absorbing Steering Column

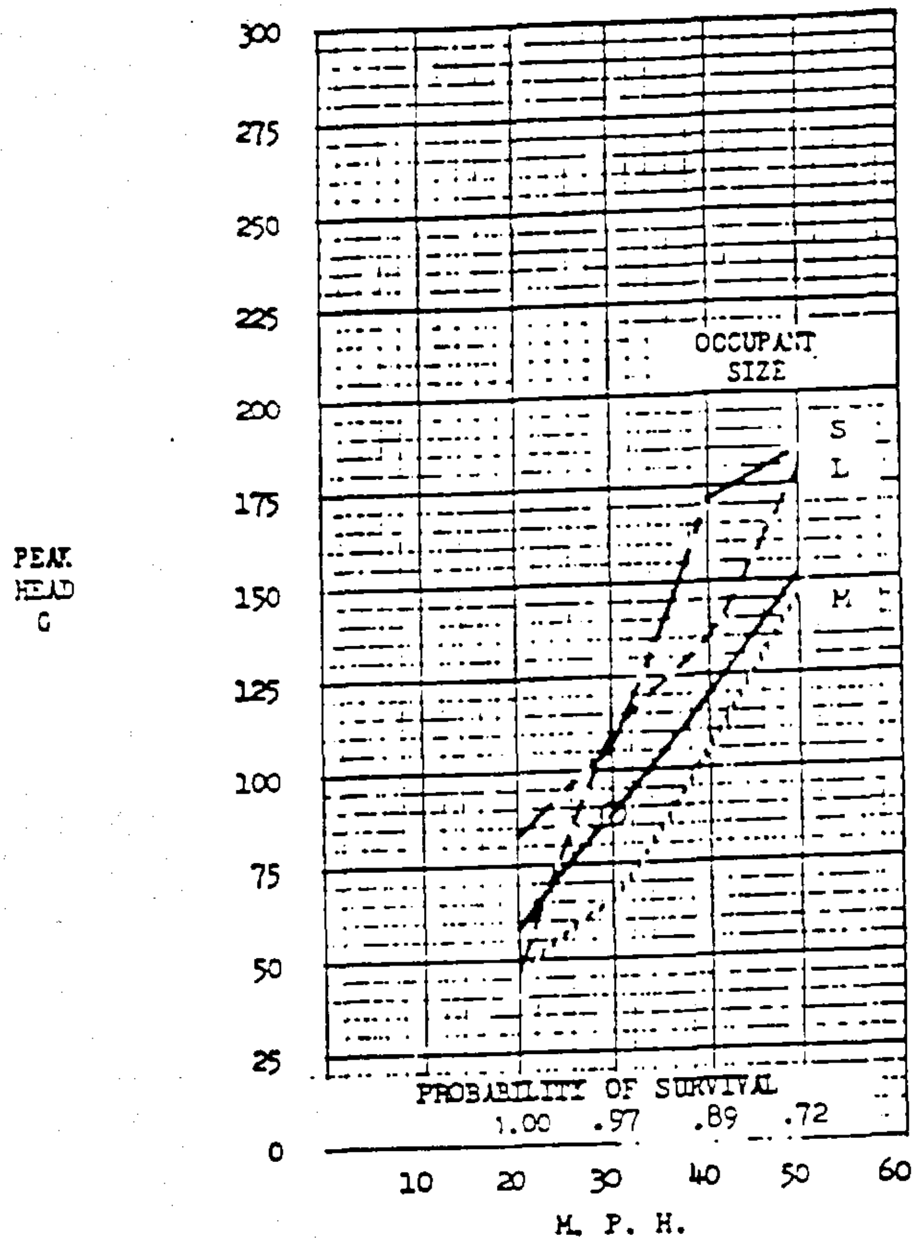
This is an advanced-design steering column system being developed to provide a higher level of safety than the current system, which has been effective in reducing fatalities and injuries. The force-deflection characteristics of the third generation column were obtained from impact tests. The curve was approximated by a polynomial because input to the Cornell mathematical model requires a polynomial of the fifth or lower order. This technique was used for all restraints evaluated with the Cornell model. The peak head and chest decelerations resulting from application of the model, for the three occupant sizes, are shown as a function of barrier impact speed in Figure 4. The solid line in this and the succeeding figures represents the value used to

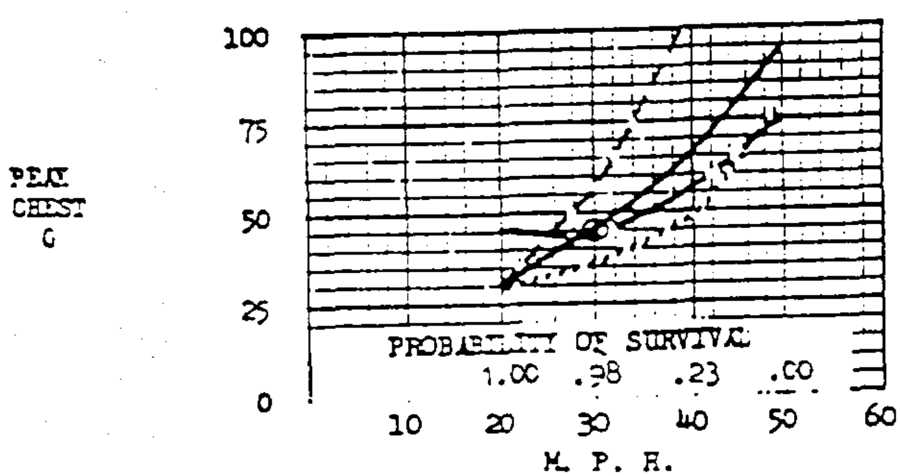
FIGURE 3

VEHICLE DECELERATION-TIME CHARACTERISTICS



RESTRAINT 1: THIRD GENERATION
E/A COLUMN





estimate overall probability of survival at 20, 30, 40, and 50 mph, utilizing the tolerance curves of Figure 1. In Figure 4 and subsequent figures, a circle represents the mean of test data and S, M, and L represent the curves for small, medium, and large occupants, respectively. The minimum probability at each speed is indicated on Figure 4, and it is used to obtain a speed-probability matrix that describes the overall effectiveness of the restraint in a 12 o'clock impact.

Because approximately 30 percent of vehicles on the road in 1969 were equipped with an E/A steering column, the effectiveness of the 3rd generation column was modified by the following technique:

$$E = .7 \times E_{3G} + .3 \times I$$

where E_{3G} = unmodified effectiveness of new system

I = improvement in effectiveness over current E/A column.

The calculation is shown in the following Table:

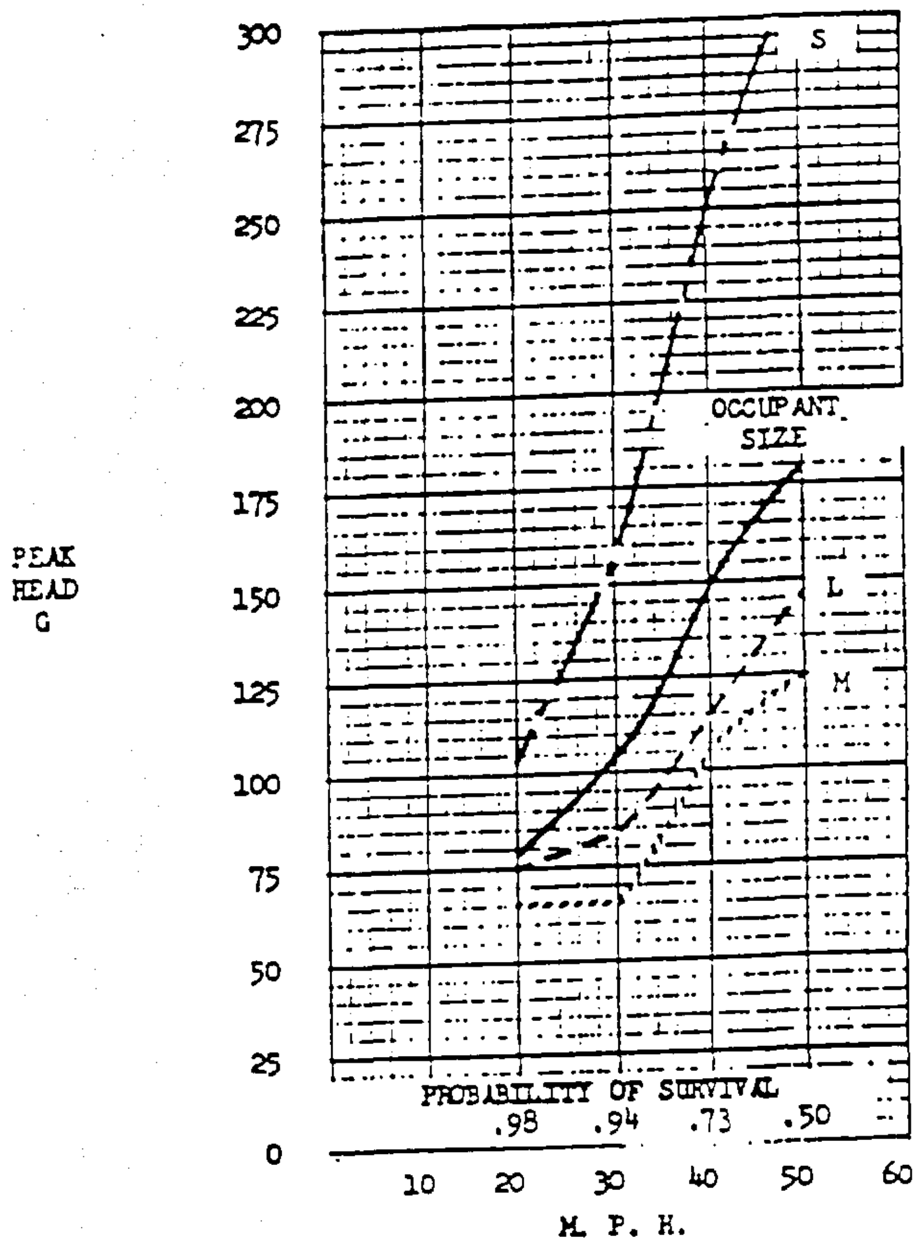
Barrier-Equivalent Speed, MPH	Effectiveness, % E_{3G}	Effectiveness, % $E_{current}$	Improvement I	.3 x I	.7 x E_{3G}	Modified E
0-15	100	93	7	2	70	72
16-25	100	70	30	9	70	79
26-35	97	45	52	15	68	83
36-45	23	10	13	4	16	20
46-55	0	0	0	0	0	0
56 & Up	0	0	0	0	0	0

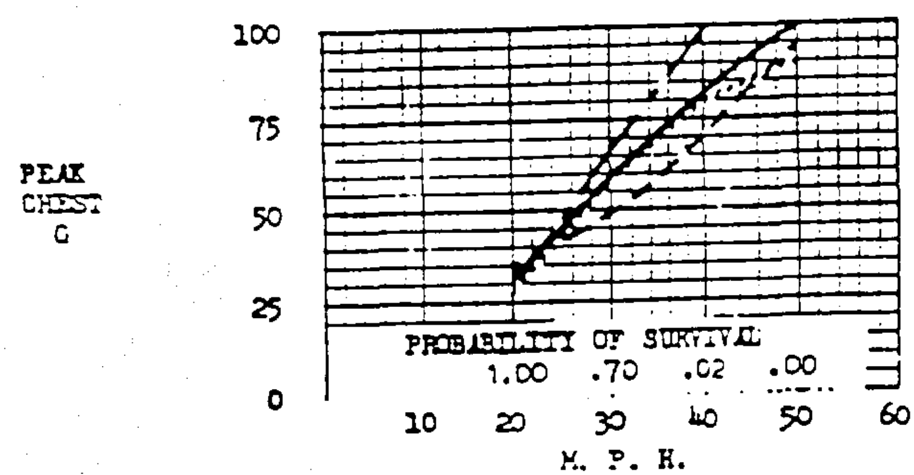
For multiple impacts and rollovers, the benefit for the driver behind an E/A column can be enhanced by a lap belt, since the lap belt will keep the operator in position, preventing ejection and reducing hazards of secondary impacts.

2. Lap Belts

The lap belts used in these effectiveness estimates are simulations of belts used in current vehicles. That they are reasonably effective at crash speeds up to 30 mph is seen in Figure 5. In the absence of an effective upper-torso restraint, lap belts are comparatively ineffective in reducing fatalities at higher impact speeds. However, the lap belt does provide an important function at higher speeds by retaining vehicle occupants inside the vehicle during rollover accidents.

RESTRAINT 2: LAP BELTS





3. Current Harness, Driver

The current harness is made of webbing having essentially linear force-elongation characteristics. It consists of a lap belt and diagonal shoulder belt. The responses for this restraint are given in Figure 6.

4. Current Harness, Passenger

This restraint is identical to that described in the preceding section. The minor differences in effectiveness shown in Figure 7 are due to a difference in package geometry.

5. Harness With Constant-Force Webbing

Lap belts and diagonal shoulder belts made of force-limiting webbing can substantially reduce peak decelerations sustained by victims of an automobile crash, as shown in Figure 8. The shoulder belts are designed to elongate at a constant force of 950 lbs, thus dissipating energy more efficiently than linear belts. Tests show that these belts also provide large hysteresis, thereby reducing the possibility of injury due to rebound into seat backs or other occupants.

In the 50 mph crash, the driver restrained by a constant-force harness received slightly lower chest accelerations than the passenger. This raised the driver's probability of survival to .38, compared to .33 for the passenger.

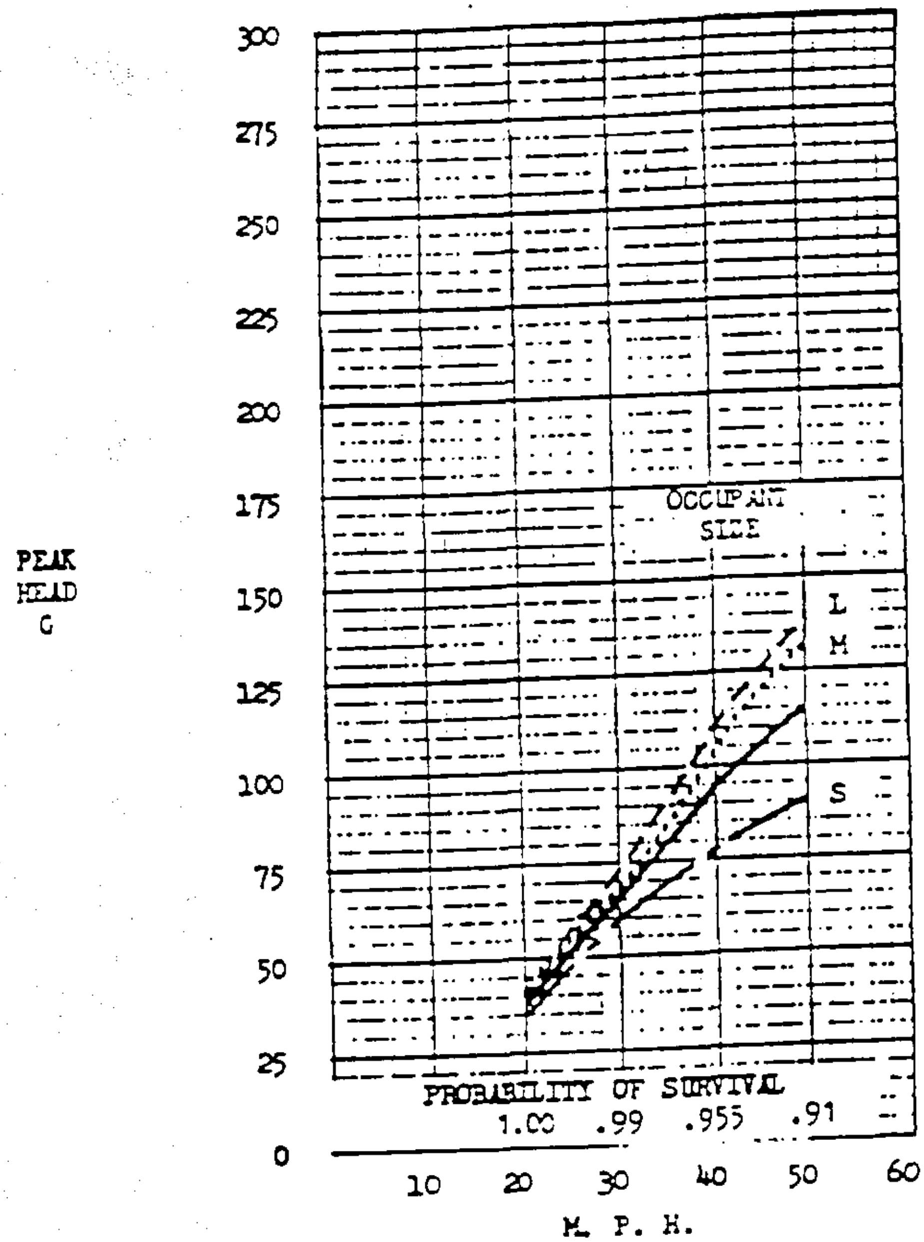
6. Air Bag

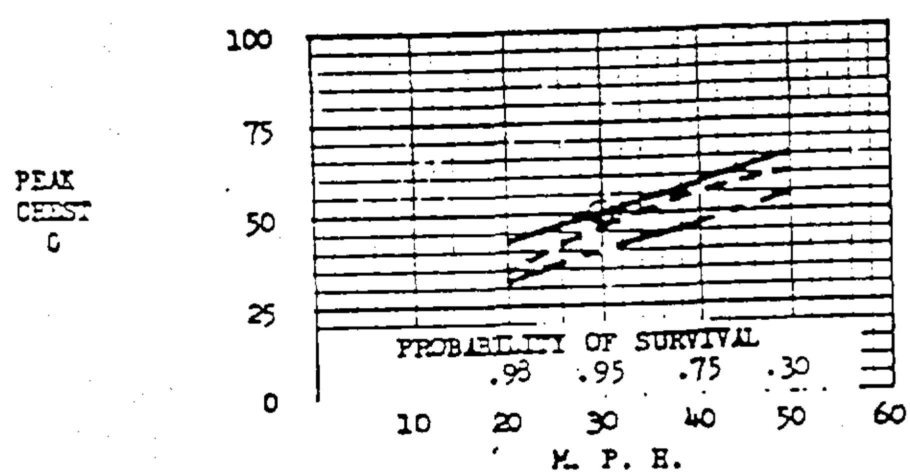
Since at the time of this study the Cornell model could not simulate occupant dynamics when restrained by air bags, it was necessary to use another model. The only model in existence suitable for occupant simulation with air bag restraint was a single-degree-of-freedom model developed by Ford in 1968. This model is shown in Figure 9, and is described in detail below.

The air bag system is functionally analogous to a piston, cylinder and orifice assembly. The energy of an impacting body is dissipated by compressing the gas in the bag and forcing the compressed gas through an exit orifice. The model was made to accurately predict occupant upper torso motion with the air bag restraint by adjusting some of the occupant parameters until correspondence with actual test results was achieved. The equations of motion for this model were developed as follows:

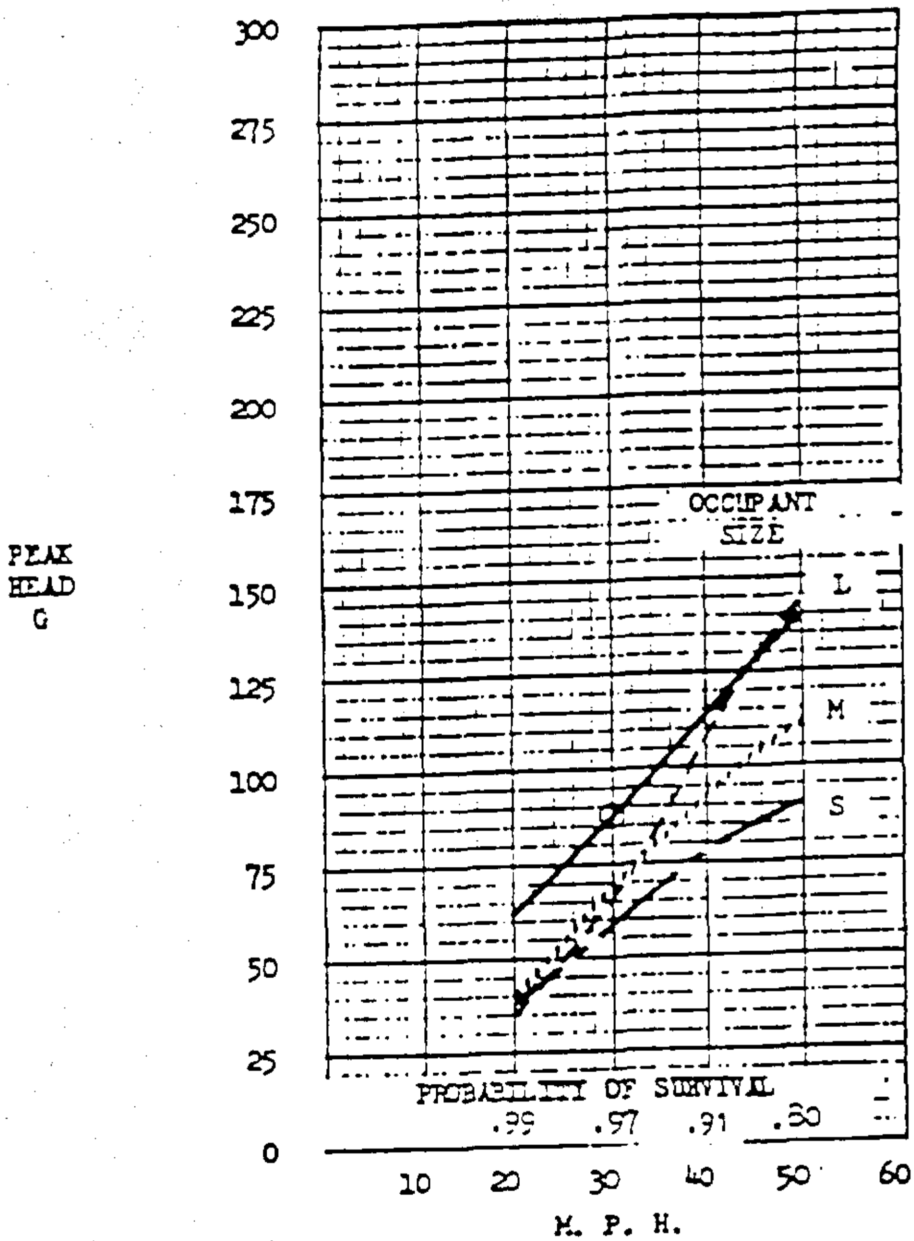
(Text continues on page 18.)

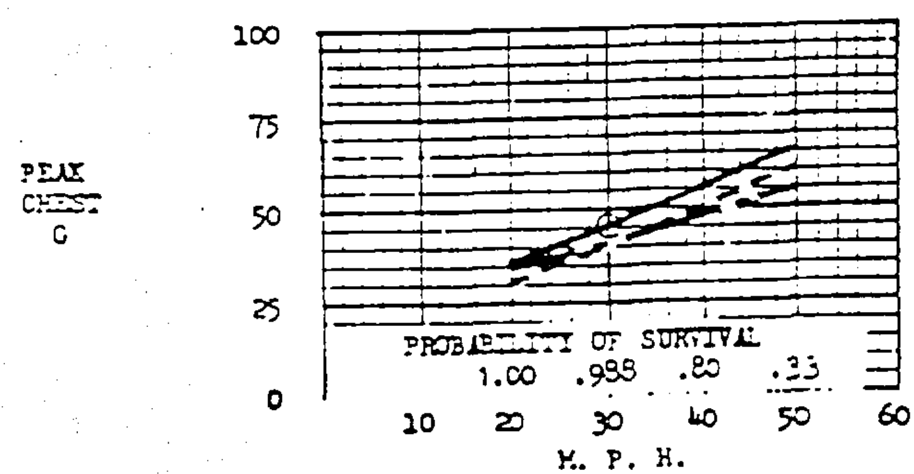
RESTRAINT 3: CURRENT HARNESS, DRIVER



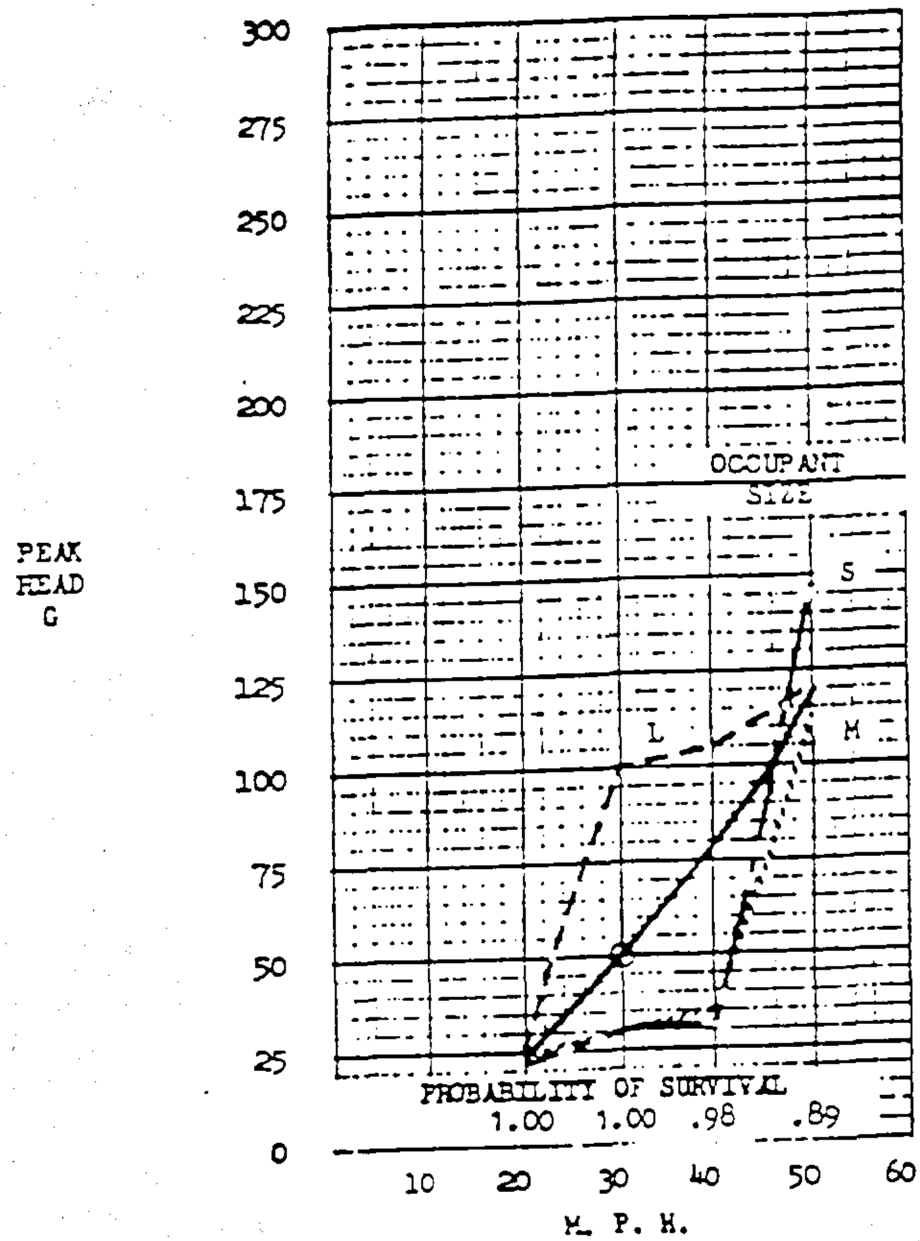


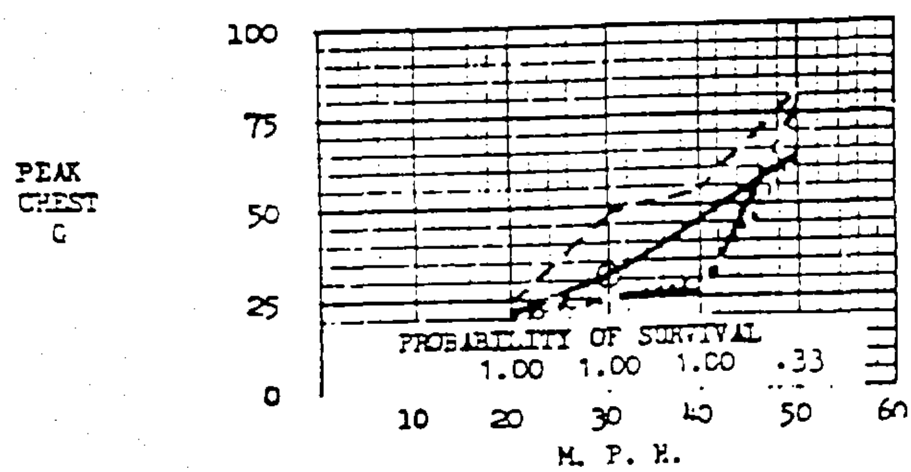
RESTRAINT 4: CURRENT HARNESS, PASSENGER





RESTRAINT 5: HARNESS WITH CONSTANT-FORCE WEBBING





As the mass impacts the system, Newton's law governing the motion of the mass and piston is:

$$M\ddot{X} = \sum F_x \qquad (1)$$

where:

M = mass of the impacting body

$\sum F_x$ = sum of the forces acting in the X direction.

The forces acting on the piston are due to the pressure inside the cylinder and the atmospheric pressure outside the cylinder. Equation 1 becomes:

$$M\ddot{X} = P_o A - P_i A \qquad (2$$

where:

P_o = atmospheric pressure
P_i = pressure in the cylinder
A = area of the piston

Since the compression occurs quickly, the heat transfer is small, and the process is nearly adiabatic. If the gas in the cylinder is ideal:

$$P_i v^n = C \qquad (3)$$

where:

v = specific volume
n = ratio of the constant pressure and constant volume specific heats of the gas
c = a constant determined by the conditions at the beginning of the compression

By definition

$$v = \frac{V}{W} \qquad (4)$$

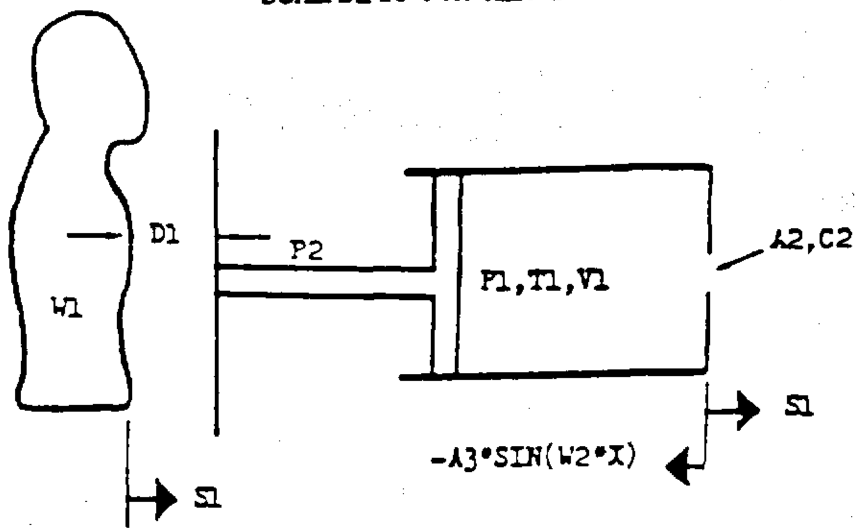
where

V = the volume of the cylinder
W = the mass of the gas in the cylinder

$$V = V_i - AX \qquad (5)$$

where V_i = initial volume of the cylinder. Substituting 5 into 4, and the result into 3 and solving for P_i gives:

SCHEMATIC FOR AIR BAG MODEL



Independent Variable	Symbol	Units
Initial Bag Pressure	P1	psi
Atmospheric Pressure	P2	psi
Initial Temp. of Gas In Bag	T1	°F
Gas Constant	R1	
Orifice Discharge Coefficient	C2	
Occupant Contact Area	A1	ft^2
Occupant Effective Weight	W1	lb.
Bag Initial Volume	V1	ft^3
Orifice Area	A2	ft^2
Vehicle Impact Velocity	S1	ft/sec
Maximum Vehicle Deceleration	A3	ft/sec^2
Frequency of Half-Sine Pulse	W2	rad/sec
Initial Occupant Displacement	D1	ft

$$P_i = C\left(\frac{W}{V_i - AX}\right)^n \tag{6}$$

substituting 6 into 2 gives:

$$M\ddot{X} = P_o A - AC\left(\frac{W}{V_i - AX}\right)^n \tag{7}$$

w, the amount of gas in the cylinder at any time depends on the flow rate of the gas through the orifice, which is a function of the pressure and temperature inside the cylinder.

The expression for flow rate of air through an orifice for $P_i/P_o < 1.89$ is given by:

$$\frac{dW}{dt} = \dot{W} = -\sqrt{\frac{2g}{RT_i}}\; A_o\theta \;\sqrt{P_o\,(P_i - P_o)} \tag{8}$$

$$\theta = \sqrt{\frac{\frac{n}{n-1}\left(\frac{P_i}{P_o}\right)^{\frac{n-1}{n}}\left[\left(\frac{P_i}{P_o}\right)^{\frac{n-1}{n}} - 1\right]}{\frac{P_i}{P_o} - 1}}$$

where:

g = gravitational constant
R = universal gas constant
T_i = temperature in the cylinder
A_o = orifice area

from the perfect gas equation of state:

$$P_i v = RT_i \tag{9}$$

$$v = \frac{RT_i}{P_i}$$

equation 3 solved for v gives:

$$v = \left(\frac{C}{P_i}\right)^{1/n} \tag{10}$$

equating 9 and 10, and solving for T_i :

$$T_i = \frac{P_i}{R}\left(\frac{C}{P_i}\right)^{1/n} = \frac{P_i^{\frac{n-1}{n}}\, C^{1/n}}{R} \tag{11}$$

substitute 11 into 8, and 6 into the result:

$$\dot{W} = -\sqrt{\frac{n}{\left(\frac{W}{V_1 - AX}\right)^{n-1} C}} \cdot A_o \phi \sqrt{P_o\left[C\left(\frac{W}{V_1 - AX}\right)^n - P_c\right]} \quad (12)$$

$$\phi = \sqrt{\frac{\frac{n}{n-1}\left[\frac{C}{P_o}\left(\frac{W}{V_1 - AX}\right)^n\right]^{\frac{n-1}{n}}\left\{\left[\frac{C}{P_o}\left(\frac{W}{V_1 - AX}\right)^n\right]^{\frac{n-1}{n}} - 1\right\}}{\frac{C}{P_o}\left(\frac{W}{V_1 - AX}\right)^n - 1}}$$

If $P_1/P_o \geq 1.89$ the orifice is choked and flow for air is given by:

$$\dot{W} = -.532 A_o \frac{P_1}{\sqrt{T_1}} \quad (13)$$

substituting equations 6 and 11 into 13 gives

$$\dot{W} = -.532 A_o \sqrt{R} \quad C^{1/2} \quad \left(\frac{W}{V_1 - AX}\right)^{\frac{n+1}{2}} \quad (14)$$

The right hand side of both equations 12 and 14 must be multiplied by a discharge coefficient. The value of the discharge coefficient ranges from .56 to .99 depending on the shape of the orifice.

Equation 7, when combined with 12 and 14 results in a system of non-linear differential equations which are discontinuous at $P_1/P_o = 1.89$. This system can be solved for X as a function of time, and the associated derivitives to give the velocity and acceleration.

Before using this model in the present study, it was correlated with air bag test results on the Hyge sled. The limitation of this model to predict chest deceleration only does not affect the accuracy of the study since tests have shown that chest deceleration will be the predominant factor influencing fatality with the air bag design that was simulated.

In simulating the air bag, it was assumed that a sensor capable of responding to crashes up to plus or minus 30° from head-on will be available. At present, such a sensor is still under development.

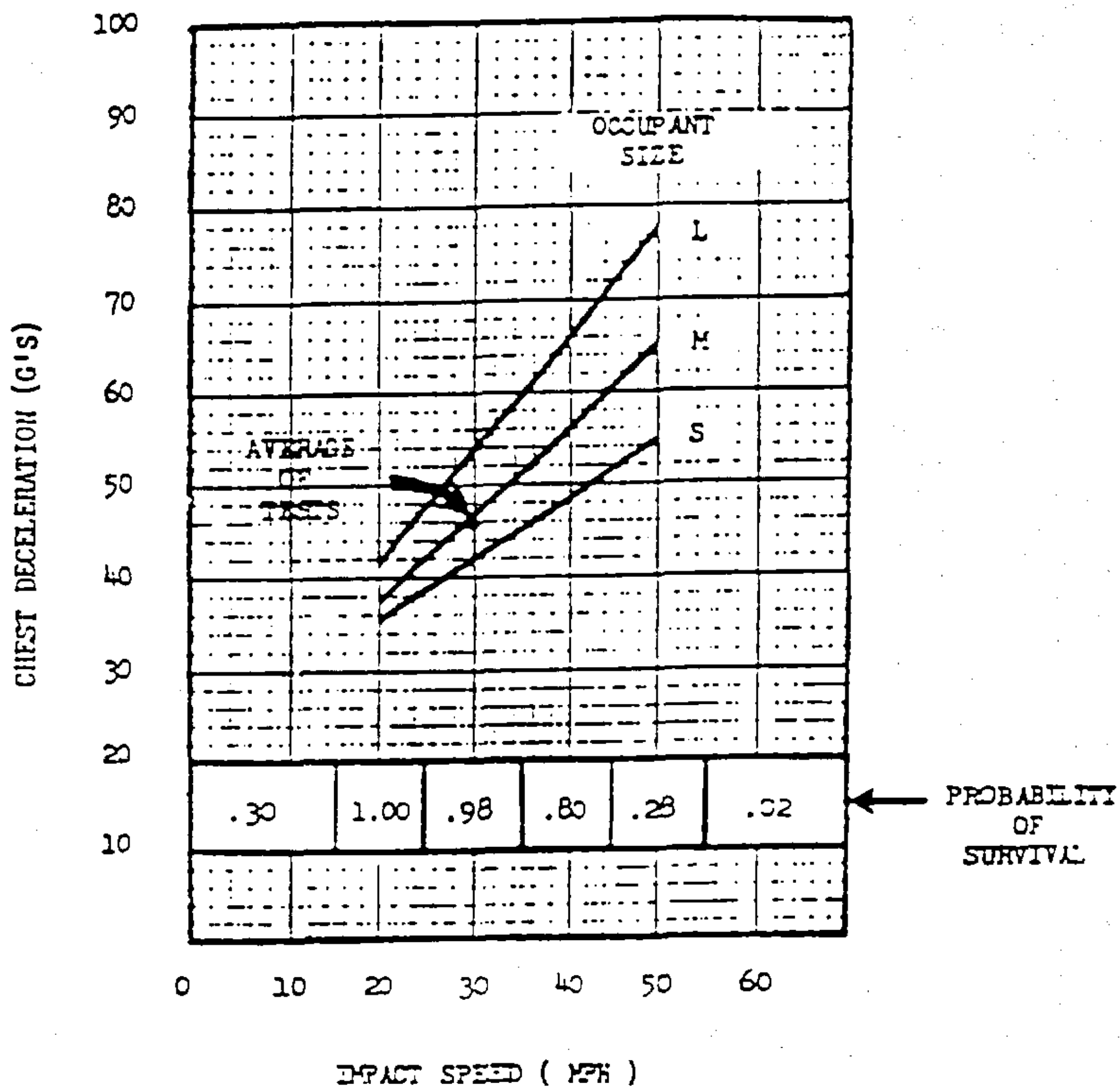
To allow for normal sensor actuation and air bag inflation time, the model allowed the occupant six inches of unrestrained forward motion before contacting the air bag. This distance is based on Hyge sled test results, and was used for all impact speeds included in this study.

With the above assumptions, the chest decelerations with air bags were calculated for the range of impact speeds and occupant sizes for collisions head-on and at 30°. The results, shown in Figure 10, indicate that the current air bag design will have the same effectiveness for all frontal collisions up to 30°. Laboratory test results for the 50th percentile male crash dummy at 30 mph show that the model results are realistic.

FIGURE 10

AIR BAG - FRONT AND REAR

PEAK CHEST DECELERATION AND PROBILITY OF SURVIVAL VS. BARRIER IMPACT SPEED



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determined by referring the mean peak chest deceleration [illegible] occupant sizes in the simulated crashes to the human tolerance curves. The results are shown in Figure 10.

Occupant Mis-positioning. The probability of survival with air bag restraint shown in Figure 10 assumed proper occupant positioning; however, studies have shown that occupant positioning relative to the instrument panel can vary at the time of air bag inflation for a number of reasons. The air bag may not be effective in preventing a fatality for some out-of-position occupants. Tests have also shown that the air bag can in some cases cause high decelerations on a mis-positioned occupant, higher than if the occupant were unrestrained.

For this study, the theoretical effectiveness values for the air bag were reduced to compensate for occupants who are out of position due to severe braking preceding the crash, and who are leaning forward prior to the impact. A recent study[3] has shown that up to 36 percent of crashes are preceded by heavy braking (20 mph or more speed change prior to impact in accident investigators' reports), and lab tests have shown that even an attentive occupant can be forced against the instrument panel by the braking force. While the actual number of out-of-position occupants is not known, it was assumed that all occupants in crashes preceded by heavy braking were potentially out of position, and that half of these were actually out of position. Thus, it was assumed that in 18 percent of the frontal accidents, occupants will be out of position due to severe braking. Another study[4] indicates that an additional 1 percent of occupants will be leaning forward at the time of the impact. It was further assumed that the effectiveness of the air bag for out-of-position occupants should be reduced only in the higher speed ranges (above 25 mph).

In addition, the air bag effectiveness was reduced for collisions in the 0–15 mph range since the air bag will not operate below 10 mph.

The above assumptions accounting for out-of-position occupants and low speed ineffectiveness reduced the probability of survival for the air bag by 19 percent, resulting in the final air bag effectiveness matrix shown in Figure 11.

7. High-Impact Instrument Panel

A high-impact panel was used in some of the restraint systems in this study to protect rear-seat passengers as well as front-seat passengers. This concept, whether incorporated in the instrument panel or whether in a rear seat protective panel, involves a fixed energy-absorbing composite structure extending closer to the passenger than current instrument panels. Panel design was assumed to be optimized for protection of unrestrained occupants and, hence, was not accorded the higher effectiveness valuation that would be appropriate for a design optimized to provide upper torso restraint to lap-belted occupants. The passenger H-point-to-panel relationship was maintained constant for the rear-seat occupants. The panel performance is depicted in Figure 12.

Example Of Effectiveness Calculation

The method used to calculate the lives saved by a given restraint system was as follows:

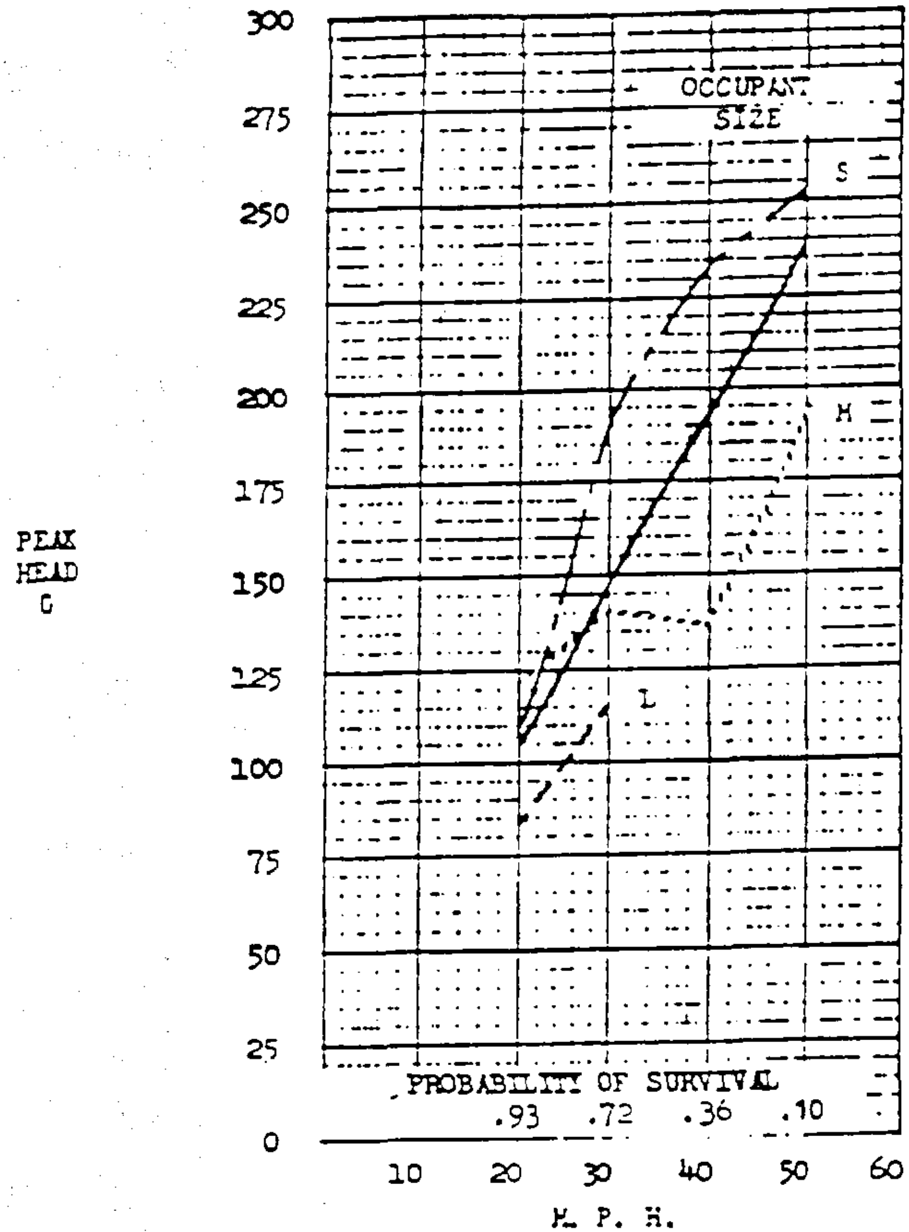
The effectiveness value table for the present harness configuration with current webbing is shown in Figure 13. Each of these values represents the

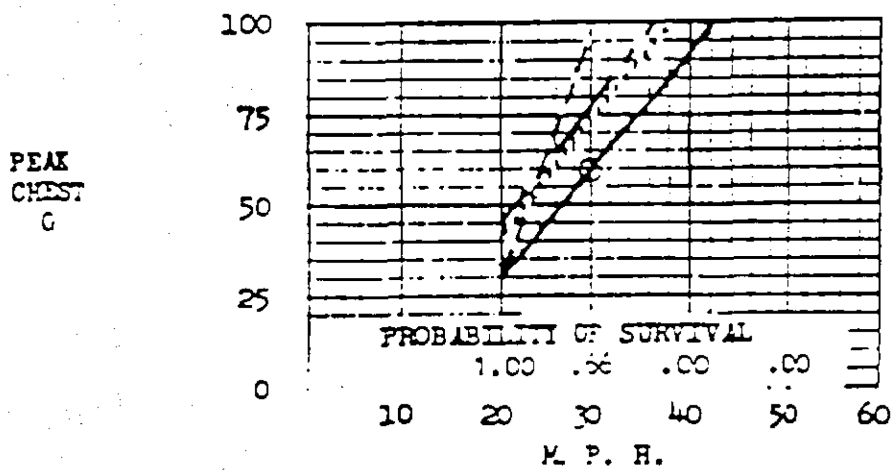
FIGURE 11

AIR BAG EFFECTIVENESS

BARRIER-EQUIVALENT IMPACT SPEED

	Impact Direction		
	11	12	1
0-15	30	30	30
16-25	100	100	100
26-35	79	79	79
36-45	65	65	65
46-55	23	23	23
56 & Over	2	2	2


PEAK HEAD G
300
275
250
225
200
175
150
125
100
75
50
25
0
OCCUPANT SIZE
S
M
L
PROBABILITY OF SURVIVAL
.93 .72 .36 .10
10 20 30 40 50 60
M. P. H.


PEAK CHEST G
100
75
50
25
0
PROBABILITY OF SURVIVAL
1.00
10 20 30 40 50 60
M. P. H.