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HSRI Report No. Bio M-71-2

IMPACT SLED STUDIES OF RIGHT FRONT PASSENGER INFLATING RESTRAINT SYSTEMS

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May 15, 1971

Final Report

January 1, 1969 - January 1, 1971

National Highway Traffic Safety Administration
U.S. Department of Transportation
Nassif Building
Washington, D. C. 20591

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Studies of Inflating Restraint Systems	15 March 1971
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
D. H. Robbins, A. W. Henke, V. L. Roberts	Bio M-71-2
9. Performing Organization Name and Address	10. Work Unit No.
Highway Safety Research Institute The University of Michigan Huron Parkway and Baxter Road Ann Arbor, Michigan 48105	11. Contract or Grant No. FH-11-6962
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Highway Traffic Safety Administration U.S. Department of Transportation Nassif Building Washington, D.C. 20591	Interim Final Report Jan. 1, 1969 - Jan. 1, 1971
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A total of 126 impact sled tests using dummy test subjects were conducted to study the protective potential of right front passenger inflating restraint systems. The experimental program consisted of: (1) selection and fabrication of a restraint system configuration based on the state of the art in 1969; and, (2) testing relative to parameters, such as crash velocity, use or non-use of lap belts, occupant size, impact direction, crash deceleration pulse, and occupant position. Test results were correlated with predictions of a purely mathematical model.

Performance criteria limiting body G-loadings and occupant motions were used to judge test results. The level of protection offered by the system is summarized as a series of proposed velocity threshold curves beyond which performance is expected to be marginal. It was found that restraint performance was marginally acceptable for 6-year through 95th percentile male dummy sizes in front impact up to 40 mph. Threshold velocities were reduced for 22.5° right front oblique impact.

A variety of tests were conducted on out-of-position occupants such as a child or adult touching the airbag, 3 year child on lap of adult, occupant wearing glasses, slouched passenger, and unsymmetric seating. In most cases system performance was satisfactory.

Recommendations were offered to: (1) vary the parameters away from the fixed geometry used in this test program, and, (2) improve the design of anthropometric dummies and establish their level of correlation with human response to impact.

17. [illegible]	18. [illegible]

19. [illegible]	20. [illegible]	21. [illegible]	22. [illegible]

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ACKNOWLEDGMENTS

This research program was carried out by the staff members of the Biosciences Division of the Highway Safety Research Institute, The University of Michigan. The program was under the direction of Drs. V. L. Roberts and D. H. Robbins. The impact sled testing was carried out by Mr. A. W. Henke with the assistance of Messrs. M. L. Dunlap, J. S. Brindamour and R. E. Pontius.

1.0 ABSTRACT

During this project a total of 126 impact sled tests using anthropometric dummy test subjects have been carried out by the Highway Safety Research Institute to study the protective potential of a right front passenger inflating restraint system. The two parts of this experimental program consisted of: (1) selection and design of a complete restraint system configuration based on prototypes available when the project was initiated in 1969; and, (2) the fabrication and dynamic testing of the chosen system in order to evaluate performance relative to parameters such as crash velocity, use with and without lap belts, occupant size, direction of impact, the shape of the crash deceleration pulse, and occupant position. Further, observed test results were correlated with the predictions of a purely mathematical model of crash victim motion.

The results gathered in the test program were evaluated using performance criteria limiting body G-loadings, occupant motions within the vehicle, and relative motions between adjacent parts of the body. Based on these results a variety of observations and conclusions were made regarding the level of protection offered by the prototype system which was used. Most of these are summarized as a series of proposed velocity threshold curves beyond which system performance is expected to be marginal. It was found that the restraint performance was marginally acceptable for dummy sizes ranging from a six-year-old child through a 95th percentile male at velocities up to 40 mph in frontal impact, the maximum speed possible with the HSRI sled during the contract period. Threshold velocities were reduced for 22.5° right front oblique impact but in most cases were 30 mph or more for all dummies except the non lap-belted 95th percentile male.

A variety of tests were conducted involving out-of-position occupants such as [illegible]

glasses, slouched occupants, and occupants not located symmetrically with respect to the undeployed system. In most of these cases system performance was found to be satisfactory on the basis of the performance evaluation criteria used for this study.

Finally, recommendations are offered which have the objective of changing the proposed threshold velocities upward. A combined experimental and analytical research program is suggested which: (1) varies the parameters of the airbag restraint system away from the geometry fixed for the current test program; (2) improves the design of anthropometric dummies and establishes the level of their correlation with human response to impact; and, (3) continues the study of energy management in vehicle structures.

2.0 INTRODUCTION

An extensive experimental and analytical research program has been carried out to evaluate a prototype airbag restraint system for the protection of the right front passenger in a standard-size motor vehicle. The need for development and implementation of passive restraint concepts for motor vehicle occupants is based on the fact that active belt restraint systems, although having a high level of protective capability, often are not used by drivers or their passengers. The state of the art of passive restraint system development is described briefly in Part 2.1 of this report in order to form a framework for the discussion of project objectives which follows as Part 2.2.

2.1 STATE OF THE ART RELATIVE TO INFLATING RESTRAINT SYSTEMS

Most studies of occupant protection which were carried out before the early 1960's were concerned with various types of belt systems. In the majority of cases, these systems were intended for use by aircraft occupants.

During the early 1960's the concept of an airbag restraint system gained a strong advocate in C. Clark. His early reports[1,2] were followed by more widely circulated publications in Stapp Car Crash Conference Proceedings[3,4].

The first widely publicized testing program involving living test subjects (baboons) restrained by airbag systems was reported by Snyder[5] in 1967. The level of protection offered by the airbag system appeared to be higher than for other systems evaluated in that program. Shortly after this series of tests was reported, Ford Motor Company and Eaton, Yale and Towne, Inc. collaborated in a report presented at the January 1968 SAE Automotive Engineering Congress held in Detroit[6]. The feasibility of the concept, systems development, performance requirements and application of production inflating restraint systems on a large scale production [illegible] such as: (1) the ob[illegible] restraint systems can reduce occupant loadings; (2) energy absorption must be provided by means of a bag pressure relief system to prevent excessive occupant rebound; (3) an inflating restraint system can be automatically activated by a crash sensor and deployed in the short time between crash initiation and the second collision of the occupant with the vehicle interior; (4) a parameter study was needed to determine system performance as occupant size is varied; (5) an operational criterion for sensors was needed; (6) reliability must be demonstrated; and, (7) the effects of noise should be investigated.

Later in 1968, the present project was initiated by the National Highway Safety Bureau under Contract No. FH-11-6962. Part of this project was to conduct a detailed analysis of work carried out on airbag restraint systems to determine their feasibility.

The topic of human auditory response to airbag inflation noise was covered in a report issued by Nixon[7] in March 1969. This generally minimized the noise problem for the general population in the case of right front passenger airbag inflations in the presence of human volunteers.

Later in the spring of 1969 the first impact sled tests involving pre-inflated airbags restraining 50th percentile male dummies were carried out at the Highway Safety Research Institute. Rapidly inflating airbags were in use for all sled tests conducted after June 1969. By the end of that month the system had been tested up to 30 mph in frontal collisions involving dummies both unrestrained and restrained by supplemental lap belts.

Extensive activity was begun by government, industry and independent research organizations on July 1, 1969 as the Secretary of Transportation issued an advanced notice of proposed rule making on inflatable occupant restraint systems. The great potential for these systems was demonstrated in an open meeting sponsored by the Department of Transportation, as well as potential problems with production lead time, system reliability, the [illegible] of [illegible], [illegible] out-of-position [illegible] and danger to a child passenger in inadvertent activation.

During the winter of 1969-1970 the importance of supplemental knee support was demonstrated and implemented in hardware both by a low-deploying, knee-catching airbag produced by General Motors Corporation and by an energy-absorbing lower instrument panel developed at the Highway Safety Research Institute for use with an airbag deployed from the upper instrument panel. By Spring 1970 successful tests were carried out at HSRI at 40 mph impact velocity and in right front oblique impact.

A conference held at the General Motors Proving Grounds in May 1970, sponsored by the North Atlantic Treaty Organization, and hosted jointly by the U.S. Department of Transportation and the U.S. Automobile Industry yielded an extensive document[8] on the state of the art of passive restraints up to that date. A wide range of views and technical data were presented by representatives from government and industry.

Since that time technical data have been presented at several professional meetings including the 1970 Stapp Car Crash Conference held at The University of Michigan[9,10], and the 1971 SAE Automotive Engineering Congress held in Detroit.[11,12,13,14,15,16,17] The airbag test program covered in this report was concluded in November 1970.

2.2 DESCRIPTION AND OBJECTIVES OF PROJECT

The three basic parts of this project were to: (1) select and design a complete prototype right front passenger inflatable restraint system for testing; (2) conduct full-scale dynamic tests to evaluate the prototype system relative to impact velocity, occupant size, non head-on impact, use or none-use of lap belts, variation of vehicle crash response, and the effect of occupant positioning; and, (3) correlate test results with the predictions of occupant motions using mathematical [illegible] simulators.

The first portion of the project involved the selection, design, fabrication, and trial testing of a complete airbag system based on prototype hardware which was available at the time the project was initiated in early 1969. Cooperation was established with Eaton, Yale and Towne, Inc. who made available the most advanced prototype hardware known at the time. The preliminary test program and resulting prototype configuration are discussed in Part 3.5 of the report.

Based on the configuration which was selected, a test matrix along with the associated performance evaluation criteria, test instrumentation and data handling procedures were chosen. Over 120 impact sled tests were conducted in varying parameters describing the occupant and the crash environment while keeping the prototype restraint configuration fixed. The test instrumentation and data handling procedures are described in Parts 3.3 and 3.4 while the matrix of tests and summary of test data are presented in Part 3.6. Using the results of the test program, the HSRI two-dimensional mathematical crash victim simulator was exercised to establish correlation between experiment and analysis. This work is described in Part 4.0.

The final product and major objective of the project was determination of velocity thresholds beyond which impact protection is believed to be marginal with the airbag restraint system. These thresholds are presented along with an analysis of test results in Part 3.7.

3.0 TEST PROGRAM

During this project a total of 126 impact sled tests have been carried out to study the protective potential of right front passenger inflating restraint systems. The two parts of this experimental test program consisted of: (1) the selection and design of a complete restraint system configuration based on available prototypes; and, (2) the fabrication and dynamic testing of the chosen system in order to evaluate performance relative to parameters such as crash velocity, use with and without seat belts, occupant size, direction of impact, non-conventional vehicle crash response, and occupant positioning.

3.1 TEST OBJECTIVES

The test program which has been carried out was based on a thorough evaluation of the state of the art relating to inflating restraint systems up to the end of the calendar year 1969. Without attempting to significantly improve upon the prototypes available at that time, a vehicle environment consisting of an airbag fabricated by Eaton, Yale and Towne, Inc. and a specially designed body buck based on the dimensions of a late model medium sized passenger vehicle was designed and fabricated. The first part of the test program was accomplished when this configuration was subjected to impact sled tests and, after modifications, approved for the bulk of the performance evaluation tests.

The major objective of the experimental program consisted of conducting impact sled tests to evaluate the protective potential offered by the approved restraint system under the following conditions:

1. variation of crash velocity from 20 to 40 mph;

2. use or non-use of a seat belt in conjunction with the inflating upper torso restraint;

3. effects of various occupant size combinations including a 6-year child, a 5th percentile female, a 50th percentile male, a 95th percentile male as well as a combination consisting of 95th percentile and 6-year child anthropometric dummies;

4. effects of both head-on and 22.5° oblique right-front impacts;

5. variation of the vehicle crash response; and,

6. effects of the position of the occupant including child-size anthropometric dummies within the vehicle in other than the normal seated position.

3.2 PERFORMANCE EVALUATION CRITERIA

The three criteria which have been used in studying and evaluating the results of the impact sled test involved: (1) limitations of body motions; (2) use of human impact tolerance data; and, (3) distribution of loads over the body surface. For the first of these criteria which is concerned with a limitation of body motions, the high speed movies which recorded occupant motion from cameras located both above and to the side of the impact site were studied to determine if the occupant had contacted elements of the vehicle interior not related to the restraint system and if relative motions between adjacent parts of the body were excessive. Although contact with the vehicle interior external to the seat and restraint system is not necessarily injurious, it does provide an indication that a restraint system must be supplemented by an environment designed to avoid application of excessive loads to the occupant. In those cases where contact with the interior of the body buck external to the seat and the airbag was observed, the fact was recorded in the summary prepared for each of the tests. If, in addition, this contact caused high acceleration levels in the test dummy, the associated maximum G-levels were also recorded.

The other aspect of occupant kinematics is concerned with relative motions between adjacent parts of the body, particularly hyperextension and twisting of the neck. Unfortunately, the construction of test dummies has not progressed to a state where these motions can be related to a specific level of injury. Therefore, the notation made in the summary for each test consisted only of an estimation of whether these motions exceeded the normal voluntary range of motions observed in humans (approximately 70° about a vertical axis for head twist and 60° about a horizontal axis lateral to the body for hyperextension). No potential injury level was estimated.

The second of the three performance criteria is concerned with currently proposed values for human impact tolerance[18,19]. The ones which have been used in this study are:

1. frontal head impact level should not exceed 80 G's for more than 3 ms;

2. frontal chest impact level should not exceed 45 G's (a conservative estimate); and,

3. pelvic belt loads should not exceed 5000 lbs.

High acceleration levels of short duration (less than 2 ms) are regarded as artifacts primarily related to the fact that current generation anthropometric dummies do not possess the damping characteristics of living tissue due to the extensive use made of metals in their fabrication. In addition to this, lateral G-loadings of 46 G's (effect of duration unknown) applied to the head and superior-inferior loadings to the torso exceeding 25 G's are believed to be potentially dangerous. Although a tolerance value of 1500 lb. direct loading applied to the knee-femur-hip complex is widely accepted, instrumentation was not available to measure this quantity during these experiments. Rough estimates of the knee loadings can be made based on the deformation of the simulated lower instrument panel.

The third of the performance evaluation criteria is concerned with the distribution of loads over [illegible] of the body. [illegible] are no effective experimental [illegible] been developed [illegible] distribution between two contacting surfaces, [illegible] of the body carried the loads applied during contact with the airbag. In most cases the airbags deployed properly and the loads were distributed evenly over the head, face, chest and mid-torso. In those cases where the bag deployed too high or too low, appropriate notations were made in the test summary. When the airbag deployed too high, most of the deceleration loading was absorbed by the head and neck whereas low deployment usually led to a restraint force exerted on the head which was too small to prevent contact with instrument panel structures. In both of these special (and uncommon) cases load distribution was considered to be inadequate if high G-loadings were observed.

In addition to these three criteria which are directly related to the safety or potential injury of the occupant, the performance of the airbag system, the impact sled, and the instrumentation were evaluated to determine whether the test results were valid. Such items as proper occupant positioning at the moment of impact, the timing of airbag detonation, the function of deflation or "blow-out" vents in the airbag, an adequate deceleration level, proper impact velocity, and function of the various transducers were noted.

3.3 TEST FACILITY (HSRI IMPACT SLED)

The impact sled which was used in conducting this test program is driven by a compressed gas operational ram which slowly accelerates the payload up to the impact velocity. The acceleration level experienced by the dummy during the acceleration phase is approximately 3 G's. Collision is then simulated by an abrupt stop caused by impacting an adjustable hydraulic shock absorber. The pulse shape may be varied from approximately square (rise time less than 10 ms) to a long or irregular shaped pulse depending on impact speed and supplementary crushable materials inserted on the end of the shock absorber. The deceleration stroke is up to three feet. [illegible] speed exceeds [illegible] and up to [illegible] G's deceleration may be obtained. The sled gross weight is [illegible].

A complete data acquisition and recording system has been incorporated in the sled design including high speed cameras and a 50,000 watt lighting system. Forces and accelerations are transduced and recorded simultaneously on magnetic tape and a light beam oscillograph. All controls are remotely operated using safety-interlocked electronic sequences. A picture of the impact sled laboratory is shown in Figure 1.

3.4 TEST INSTRUMENTATION, DATA ACQUISITION, AND DATA HANDLING

The anthropometric dummies used in this test program were manufactured by Sierra Engineering Company and represent: (1) 95th percentile male (Model No. 292-895); (2) 50th percentile male (Model No. 292-850); (3) 5th percentile female (Model No. 592-805); (4) six-year-old child (Model No. 492-106); and, (5) three-year-old child (Model No. 492-103). In setting up the tests, the various joint structures were torqued to a 1 G adjustment. The 5th percentile female, 50th percentile male, and 95th percentile male dummies were supplied with ball joint neck structures as original equipment while both child dummies were supplied with rubber necks. For part of the test program (explained in detail in part 3.7.3 of the report), a rubber neck fabricated by General Motors Corporation was installed in the 50th and 95th percentile male dummies.

The dummies were each instrumented with triaxial accelerometer packs in the head and chest. The individual accelerometers were Kistler Piezotron Model No. 818's. A Statham strain gage accelerometer was used to sense sled deceleration. Belt forces were recorded using Lebow seat belt force transducers in those cases where a lap belt installation was used to supplement the airbag. In addition, timing and impact velocity signals were produced and all these recorded both on a Honeywell 1612 light beam oscillograph and a Honeywell 7600 FM tape recorder. The light beam oscillographic data was filtered at 1,000 Hz and the tape data at 10,000 Hz. [illegible] on the oscillographic recording [illegible] record.

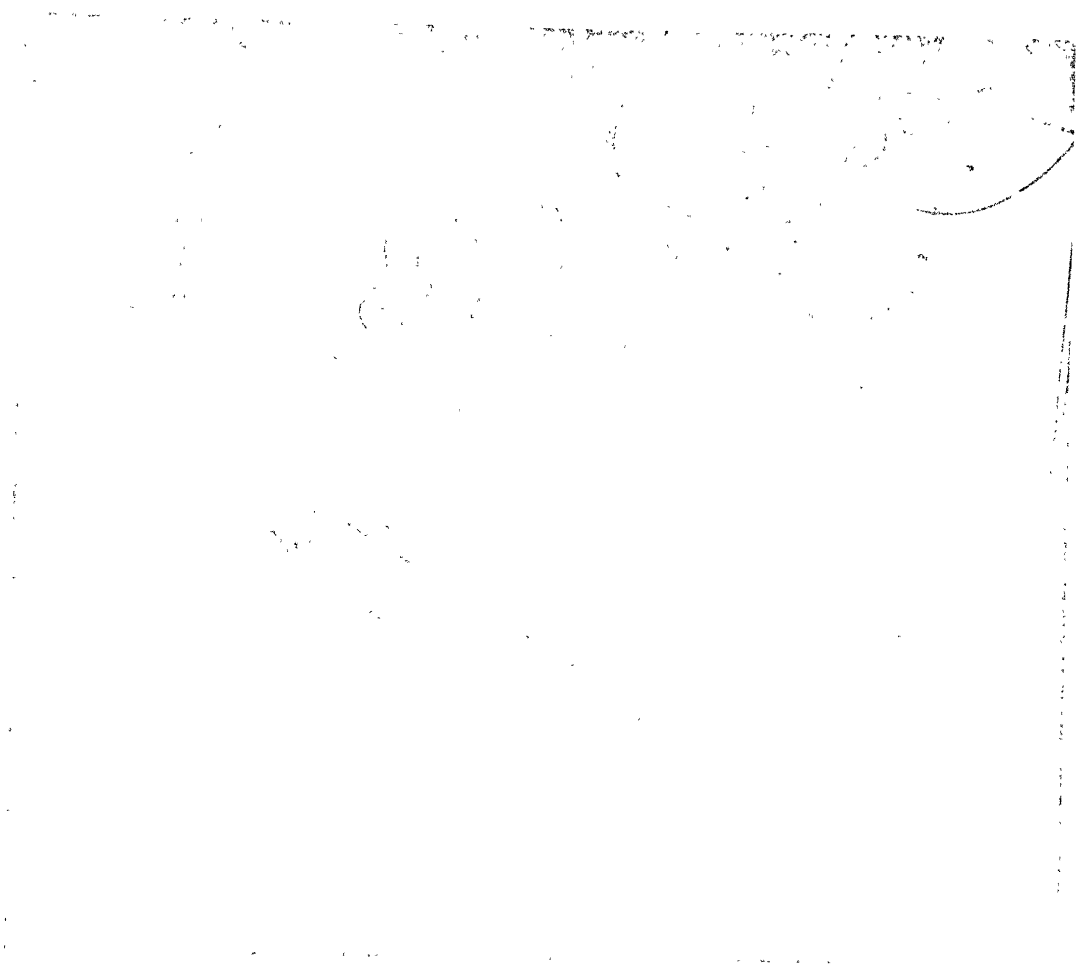


Fig. 1. HSRI Impact Sled

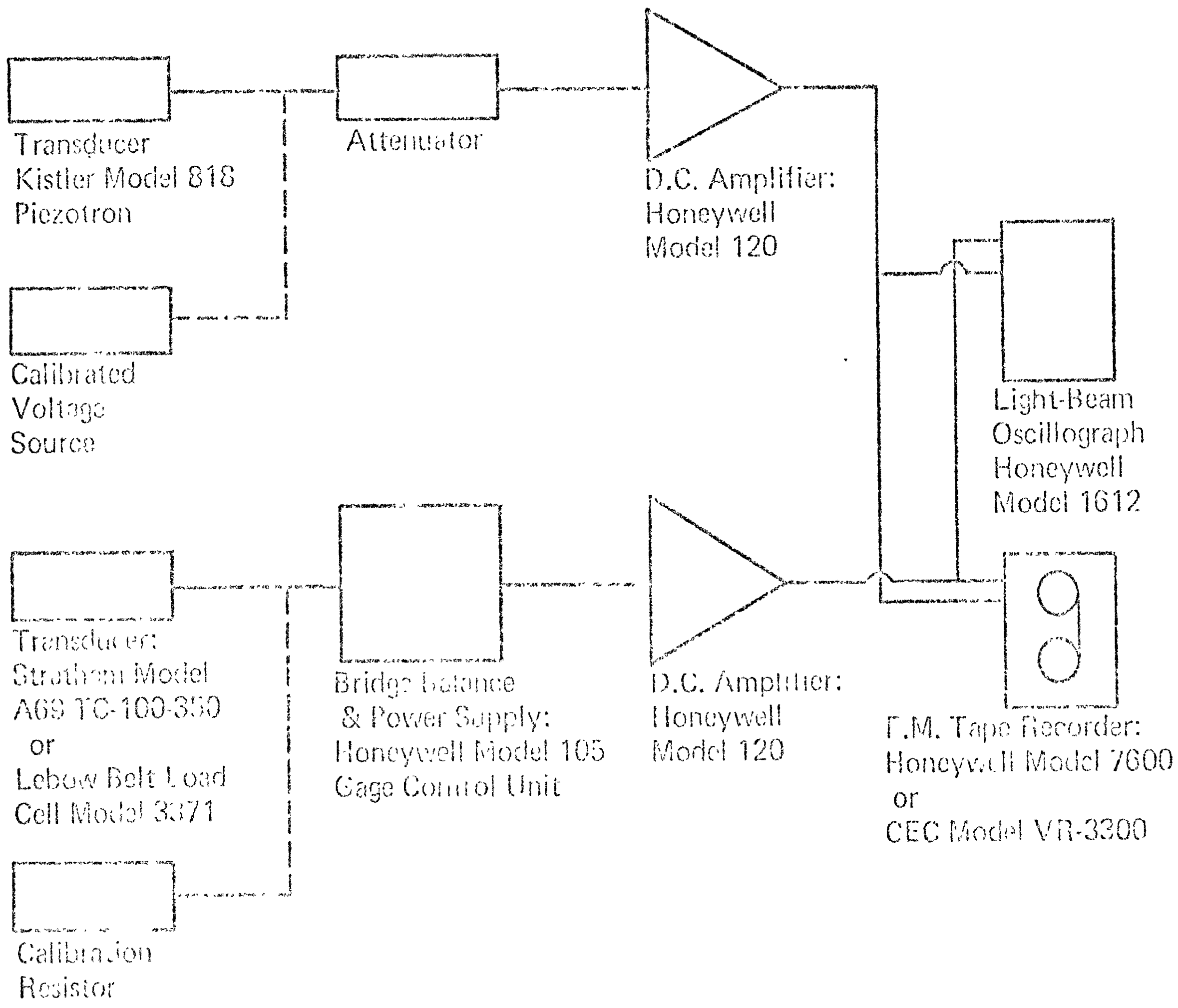


Fig. 2. Block Diagram - HSRI Impact Sled Data System

Hard copy of these records was assured in that each oscillographic record was photographed shortly after the test. A brief description of the equipment specifications and calibration procedures for each of the transducers and recording devices mentioned is included as the Appendix to this report and a block diagram showing the HSRI Impact Sled Data System is given as Figure 2.

High speed motion pictures were also taken for each test. A Photosonics 16mm camera was located directly to the side of the impact area, and another overhead and to the rear in order to view the motions of the head and upper torso as they interacted with the airbag. The frame rate normally used was 1000 fps. These motion pictures were also supplemented by slides taken before and after each test. Also, a Graph-chek sequence camera was used during the test program to provide an instantaneous evaluation of the test as a high-speed sequence of eight frames on a 4x5 inch Polaroid sheet.

3.5 DEVELOPMENTAL TEST PROGRAM

The first portion of the testing program which has been carried out involved the selection, design, fabrication, and trial testing of a complete right front passenger inflating restraint system based on prototype hardware which was available at the time the project was initiated in early 1969. Cooperation was established with Eaton, Yale & Towne, Inc. who made available the most advanced prototype hardware known at the time. They have continued to supply information and hardware to the project throughout its duration.

The vehicle configuration which was chosen for the mounting of this hardware was based on the interior geometry of a 1966 Ford Galaxie because a number of successful full-scale impact tests had already been carried out in other laboratories using a similar installation. A symmetric body buck with a flat windshield was constructed using the interior dimensions of the Ford Galaxie. Figure 3 shows a [illegible] of the [illegible] geometry [illegible] dimensions. The third geometry in this figure is an outline of a seating configuration suggested by the Automobile Manufacturer's Association as representing late model intermediate-sized passenger vehicles[20]. It should be noted that the Galaxie seat can be moved further to the rear than is the case with the AMA composite and the airbag installation fits well within the space designated for the instrument panel. Potential locations for mounting the restraint system hardware were suggested by Eaton, Yale and Towne, Inc.

The initial tests (A-065 and A-066) were carried out using a preinflated bag because of ease of installation and low turn-around time between tests. Photographs taken before and after one of these tests are shown in Figure 4. In both of these tests, severe rebound of the dummy into the seat structures was observed as the ventilation patches did not function allowing air to escape and energy to be absorbed in the impact.

The second series of preliminary tests (A-077, A-083 - A-088, A-102, A-103, and A-110) was carried out using a rapidly inflating airbag system installed in the symmetric body buck. Comparison of data from Test A-110 with either Test A-065 or A-066 shows a decrease in body G-loadings using the fast-inflating bag. The initial and final positions of the occupant in all these tests are similar and are shown in Figure 5. The relative initial positions of the airbag, the knees of the dummy, and the inflation air bottle are shown in Figure 6.

In order to provide an even more realistic simulation of the crash environment, the body (including windshield and front bench seat) of a 1966 Ford Galaxie was modified and installed on the HSRI sled. Eaton, Yale and Towne, Inc. provided mounting hardware and brackets to hold their system. This configuration, with the front seat in its rearmost adjustment position, is shown in Figure 7.

The airbag which was supplied for all remaining tests starting with No. A-165 was designed for an impact of approximately 40 mph. The air bottle had a volume of 160 in^3 and a filled pressure of 3500 psi. The full airbag had a volume of 10 ft^3. The air was released into bag by detonation of an electric blasting cap. The detonation was triggered by closing a switch at the beginning of the sled deceleration to simulate actuation by a sensor. Inflation of the bag was initiated approximately 6 ms later. As this test program was designed to determine the restraint effectiveness of an airbag system, a dynamic sensor was not employed to trigger the detonation.

The test configuration which has been described was used in conducting Test No. A-165 - A-171. In all these cases the airbag inflated and tended to rotate upward as the deceleration was felt by the vehicle interior and before substantial contact between the dummy and the airbag occurred. This resulted in the application of forces over the head and only a small portion of the torso of the dummy. Severe hyperextension was observed and under the performance evaluation criteria, performance of the system was considered to be inferior. A sequence of photographs showing the kinematics of the bag and the dummy in Test No. A-171 is shown in Figure 8.

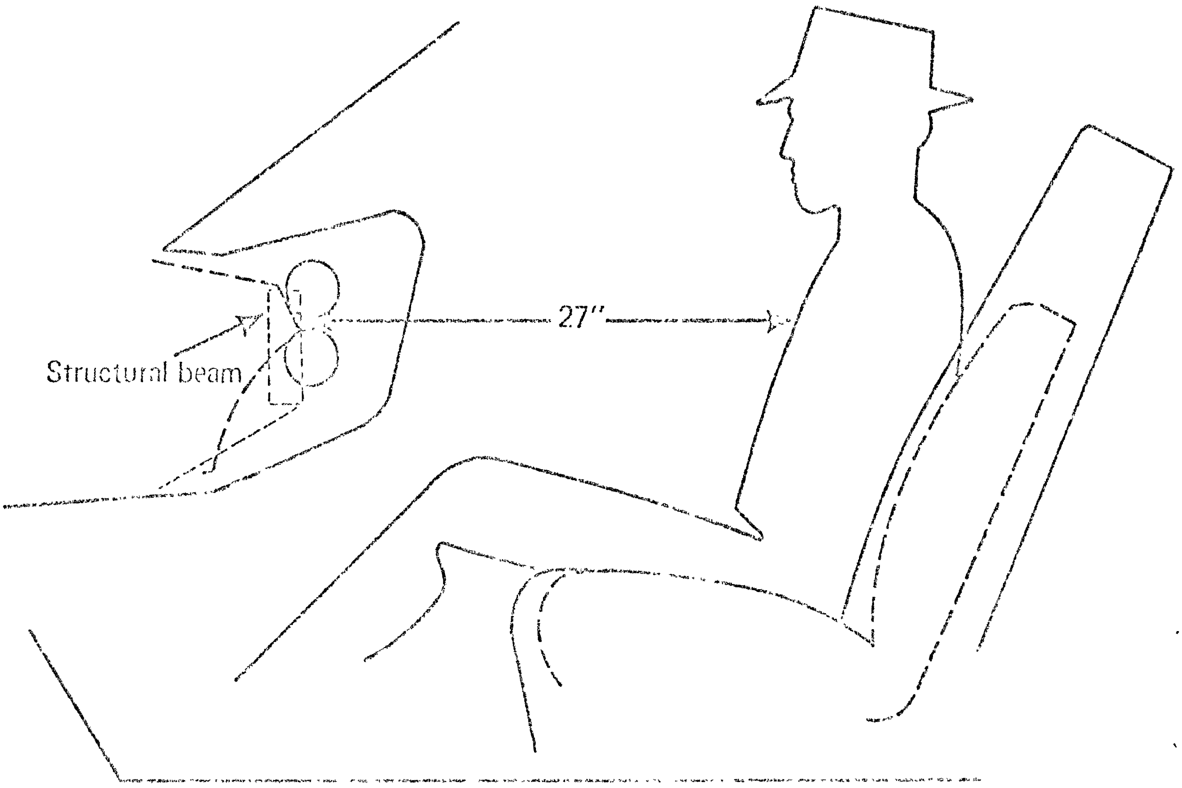
Observation of this phenomenon led to the conclusion that the bag should come into contact with the occupant as early as possible during the collision event both to insure proper placement of the bag after it is deployed and to maximize the space available for decelerating the occupant. Hence the car seat was moved forward in its adjustment track for the duration of the test program (Test Nos. A-172 - A-203). The effect of this change is illustrated in Figure 9 which shows a sequence of photographs from Test No. A-178.

The final problem, which had to be resolved before selection of a complete right front passenger inflating restraint system which could be used in the evaluation program, involved the motions experienced by dummies not using a lap belt in combination with the airbag upper torso restraint. Submarining of the dummy under the bag, under the instrument panel, and into the plenum structures of the firewall of the body buck resulted in excessive damage to the knees and lower back of the dummies as well as unusual kinematics in many of the tests including A-083, A-084, A-180, A-188, and A-189. A typical example is given in Figure 10, showing the occupant before and after Test No. A-189.

In order to avoid this problem, an energy absorbing lower instrument panel structure was added to the body buck as shown in Figure 11 before Test No. A-200 and for all subsequent tests. The material used to fabricate this structure was Styrofoam Type No. HD 300 manufactured by Dow Chemical Company. This foam has a density of 3.3 lb/ft^3 and resists a compressive stress of approximately 150 lb/in^2 before collapse using the standard 2-inch block specimen. When a dynamic load is applied to specimens of similar foam material, thus increasing the rate of strain in order to represent an impact load, the failure load is observed to increase approximately 15% when the load is applied to the test specimen at 10 mph.

An energy-absorbing material with these properties is appropriate for applying a restraint load to the knees of an occupant. If it is assumed that the cross-sectional area of contact between a knee and a lower instrument panel is 7.06 in^2 based on a diameter of 3 in, then the load required to crush the material would be approximately 1240 lbs.

The effectiveness of this technique in avoiding submarining is demonstrated in Figure [illegible] which shows the position of the unbelted dummy before and after impact for test No. A-200. [illegible] has been lifted from the [illegible]



AMA interior

Galaxie and body back

Body back instrument panel

Scale = 5.26" to 1"

Fig. 3. Cross-Section Geometry of Body Bucks Used in the Test Program

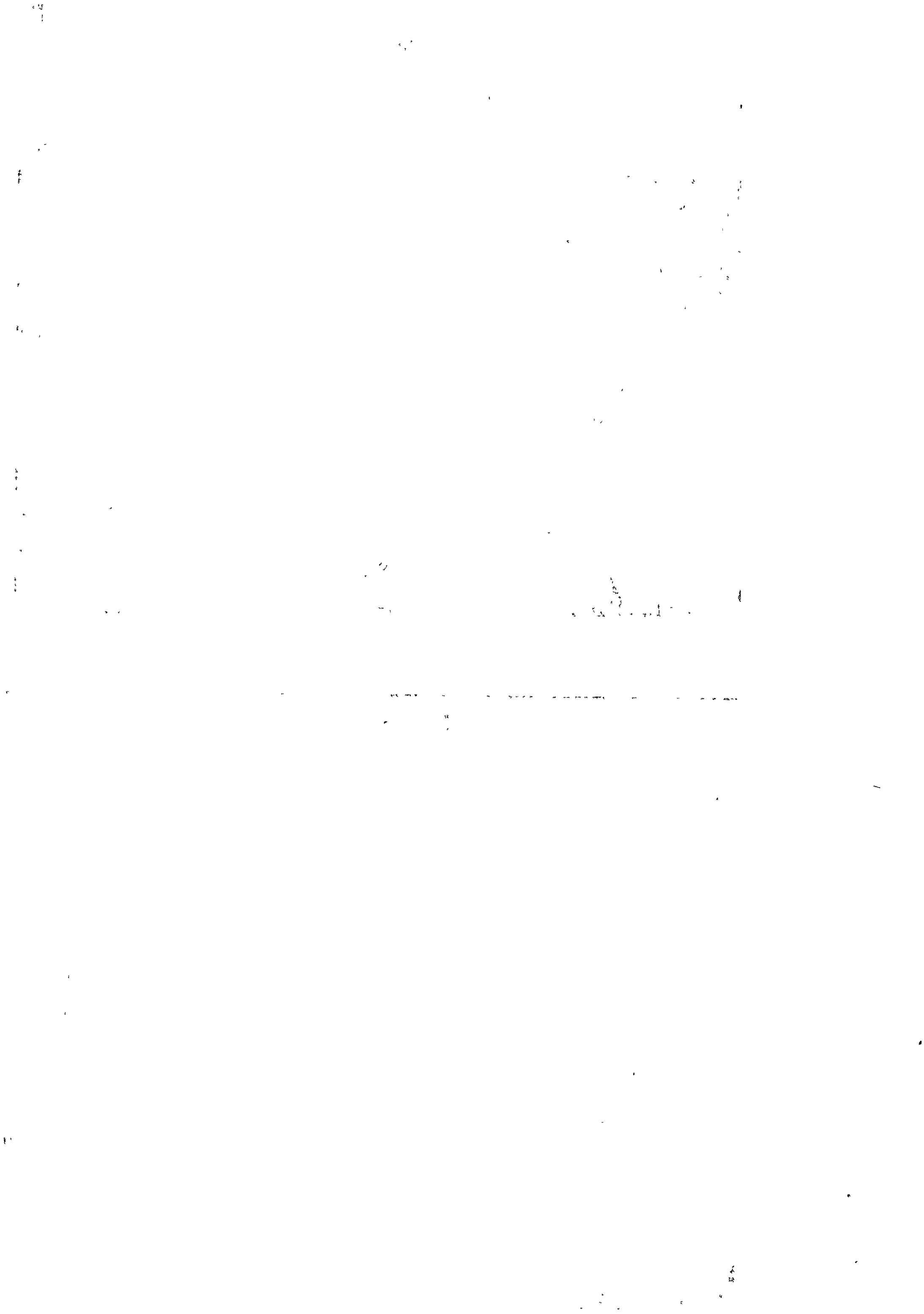


Fig 4. Photographs of Test Configuration Used in the Pre Inflated Airbag Tests

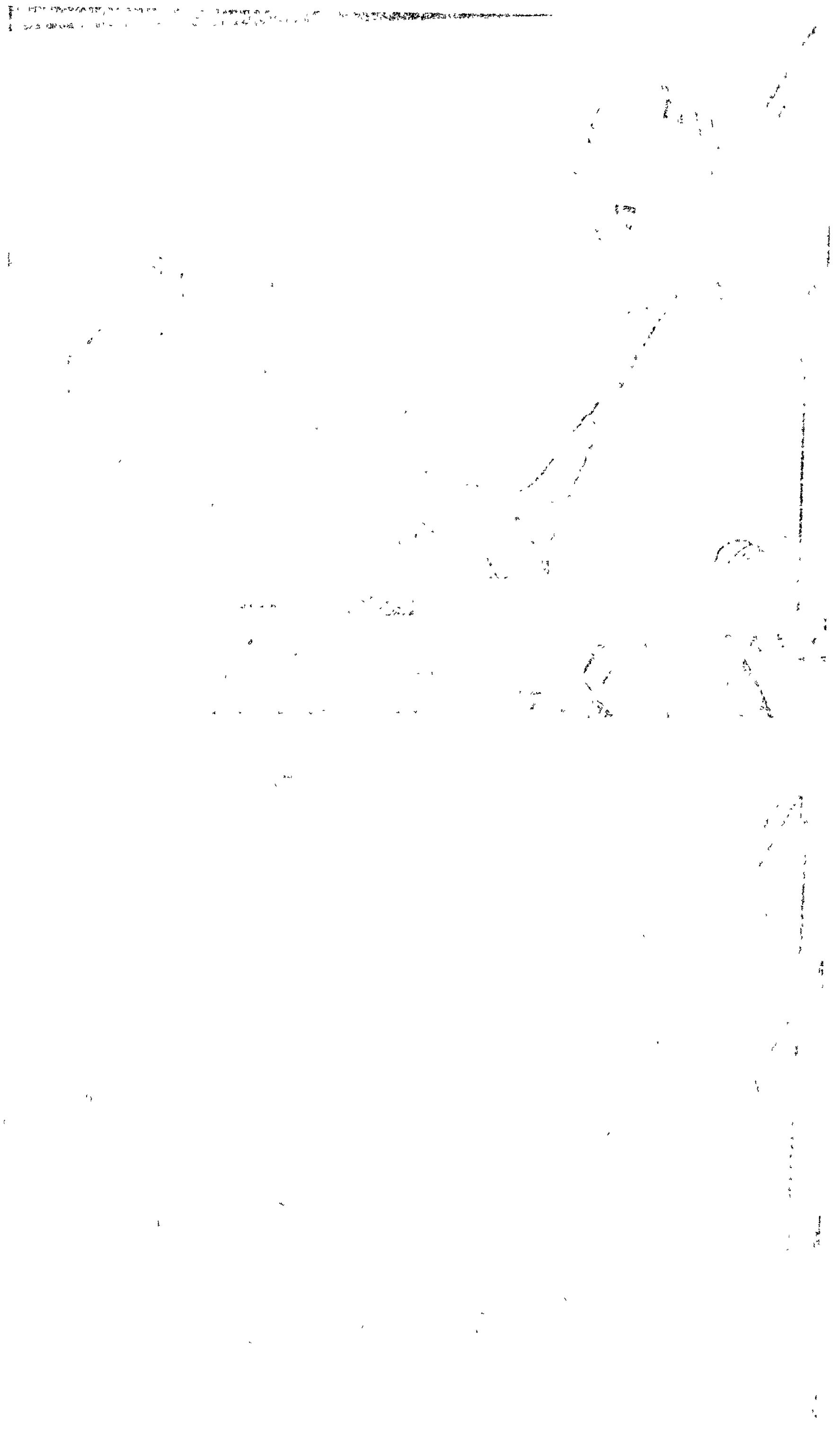


Fig. 5. Photographs of Test Subject Taken Before and After Test No. A-077

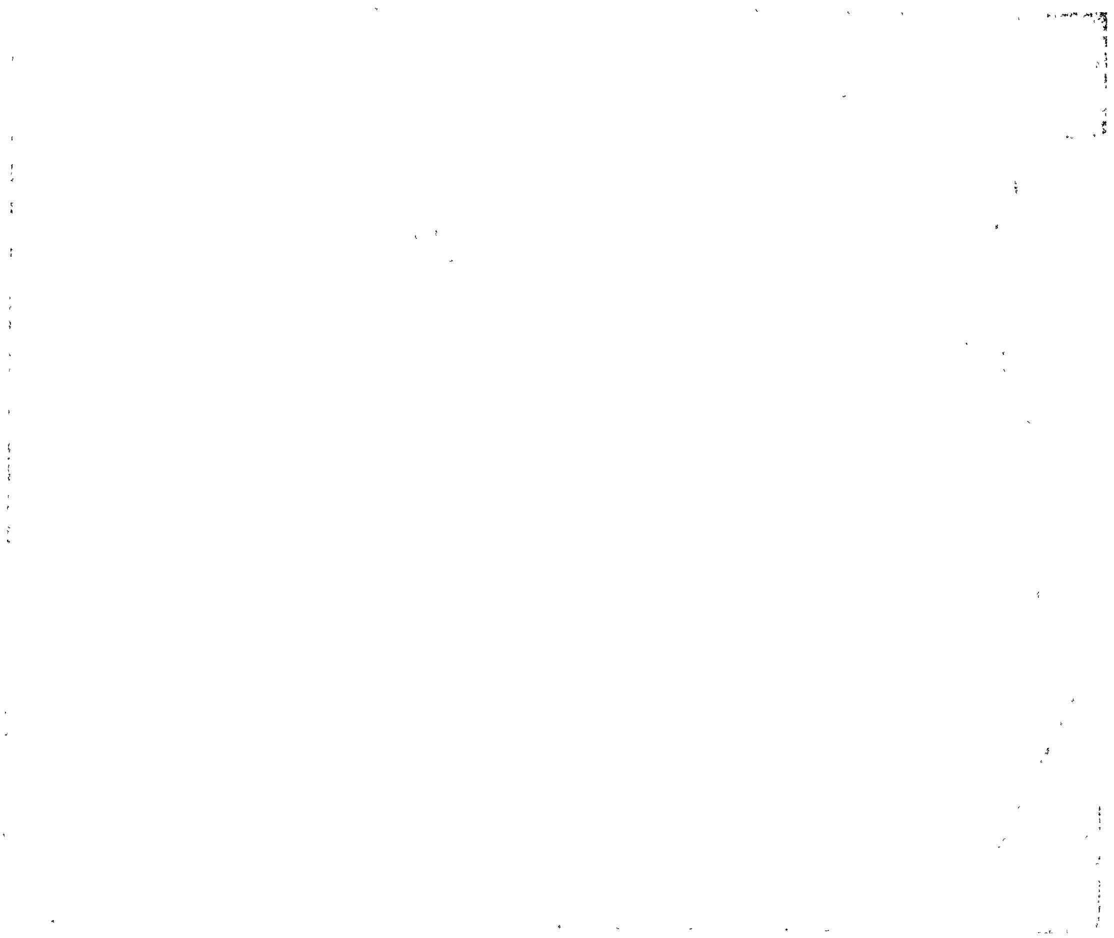


Fig. 6. Relation Between the Knees of the Dummy, the Mounted Airbag Location, and the Inflation Air Bottle

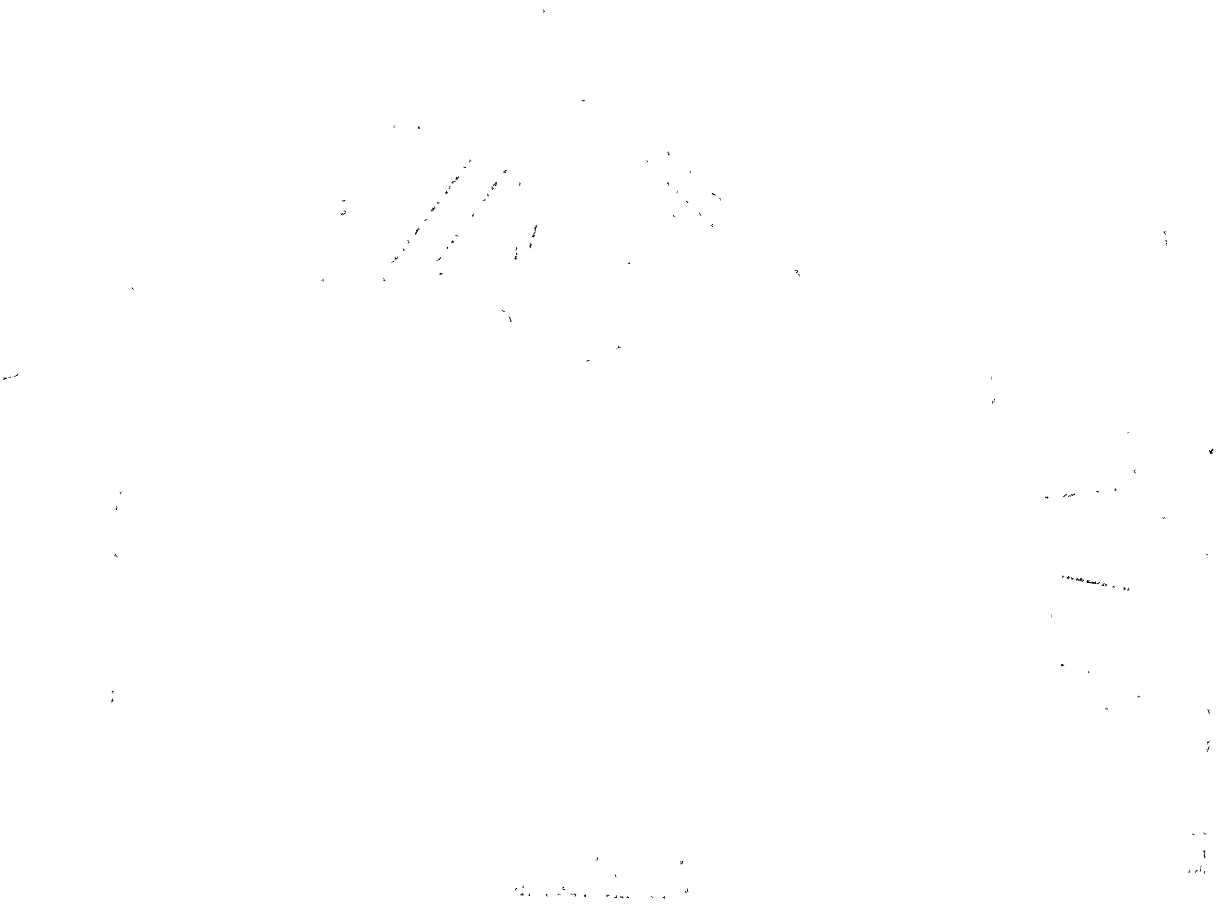


Fig. 7. Test Setup Using 1966 Ford Galaxie Body Buck

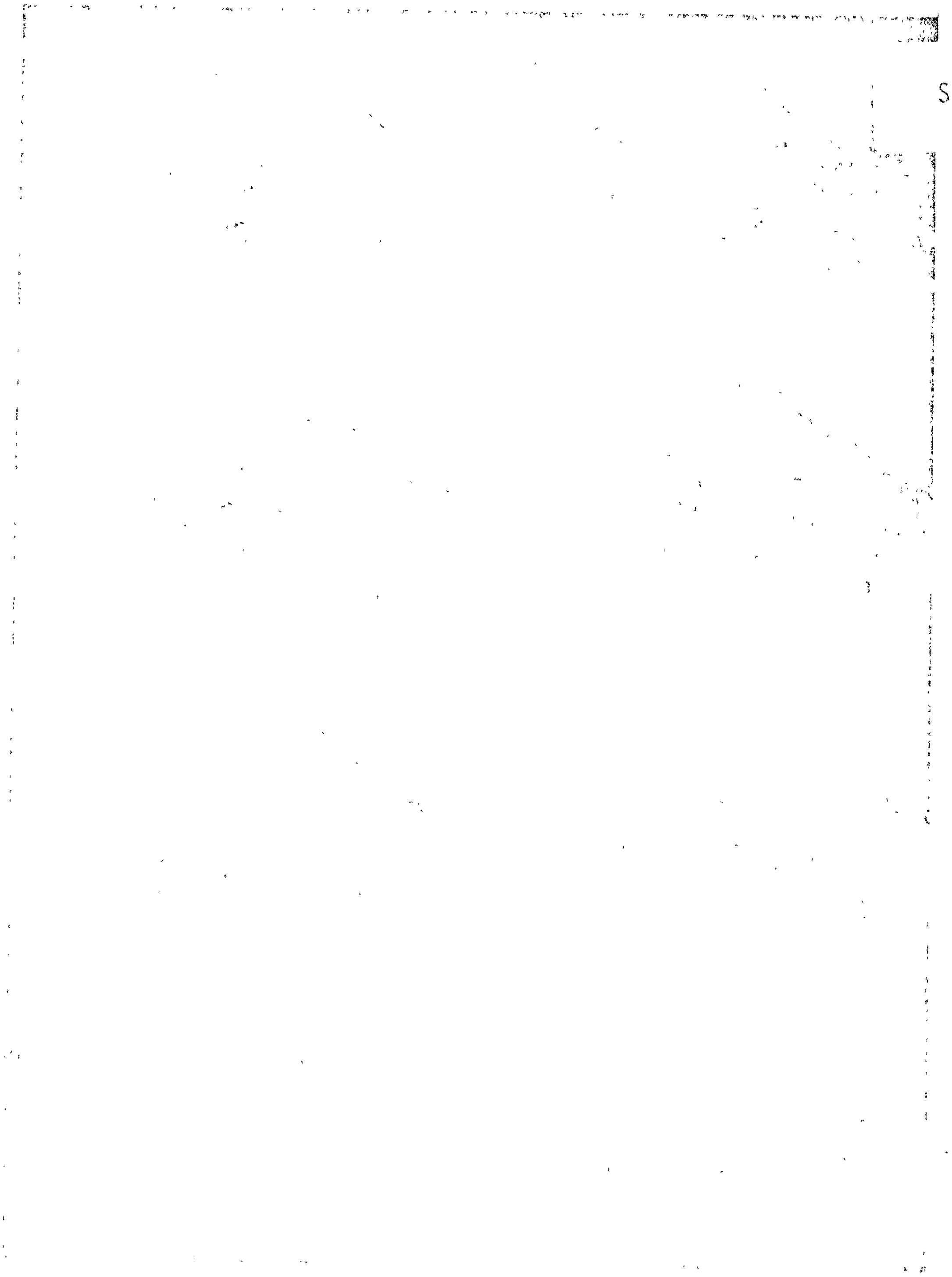
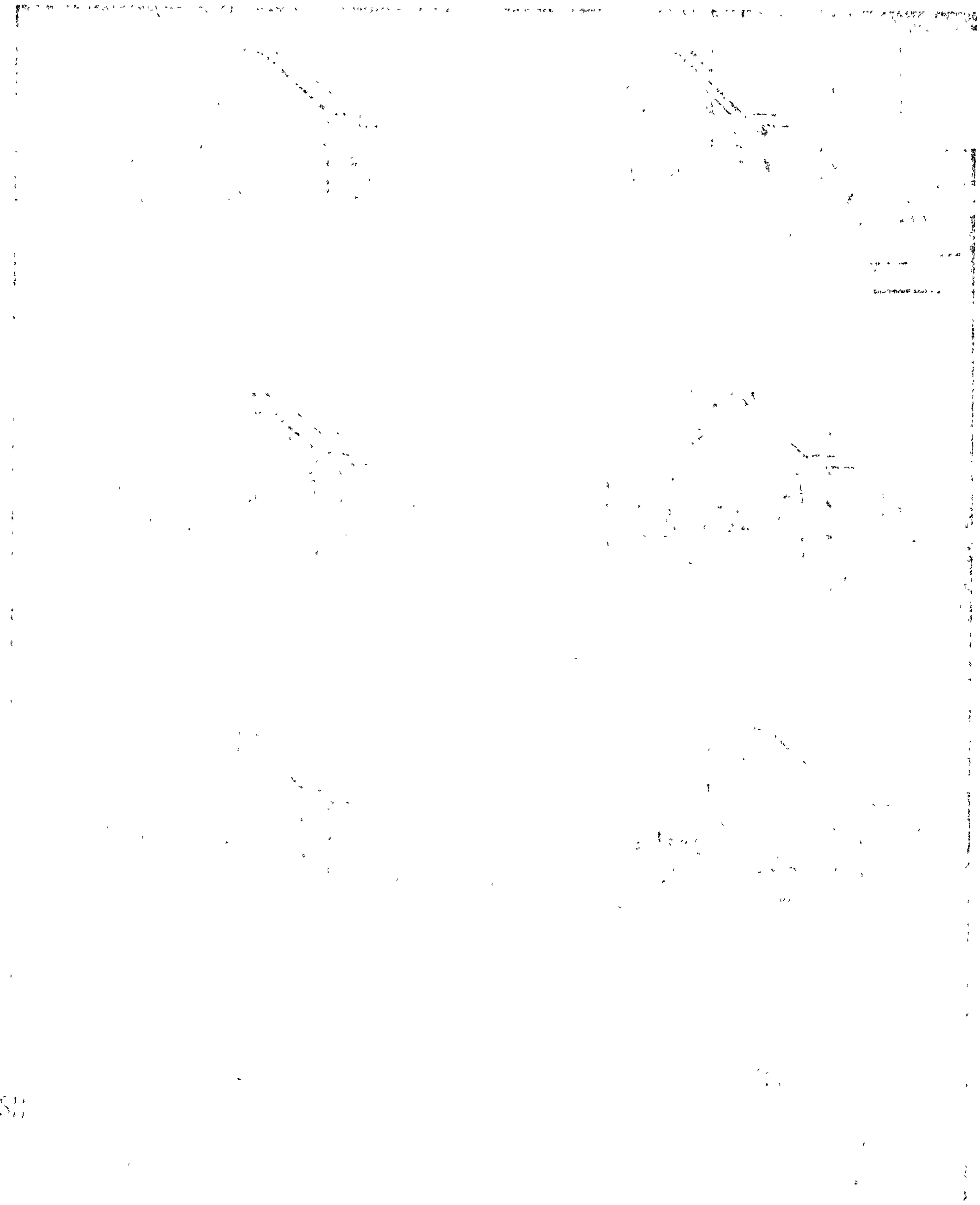


Fig. 8. Sequence of Photographs from Test No. A-171 (High Deployment)

START



FINISH

Fig. 9. Sequence of Photographs From Test No. A-178 (Improved Deployment)

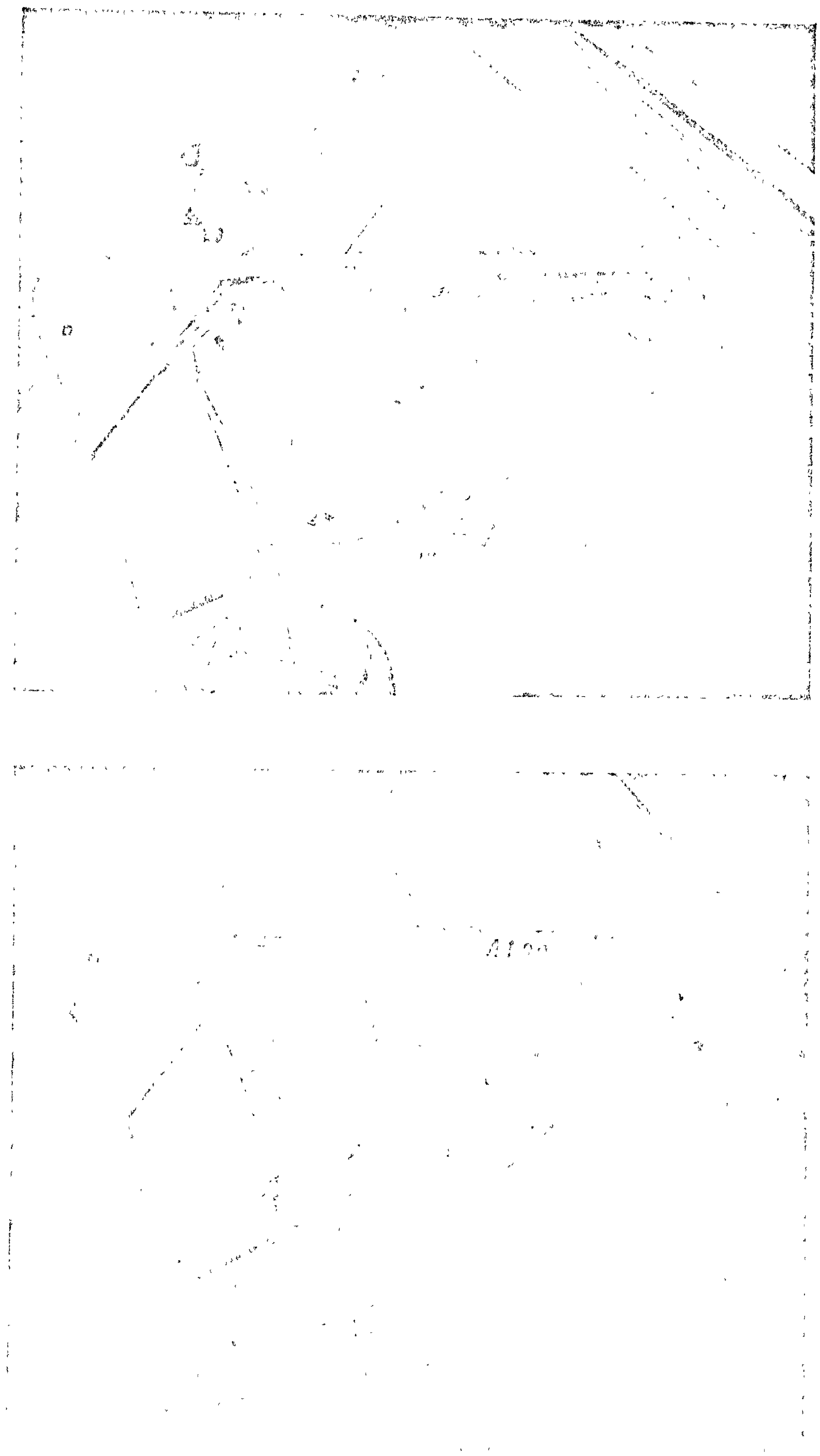


Fig. 10. Photographs Taken Before and After Test No. A 789 Showing Submarining

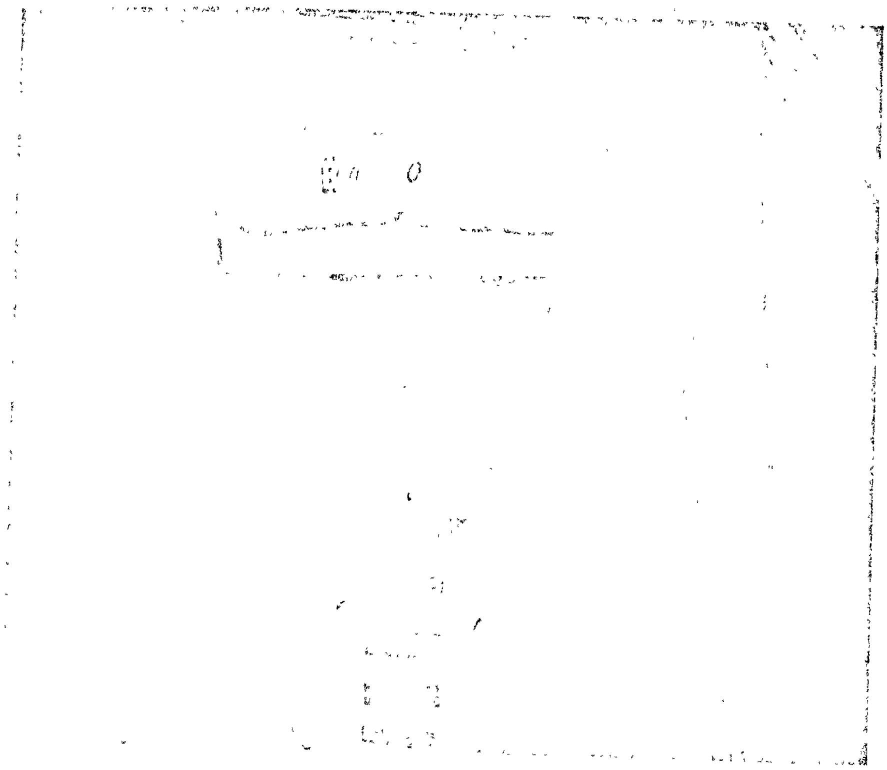
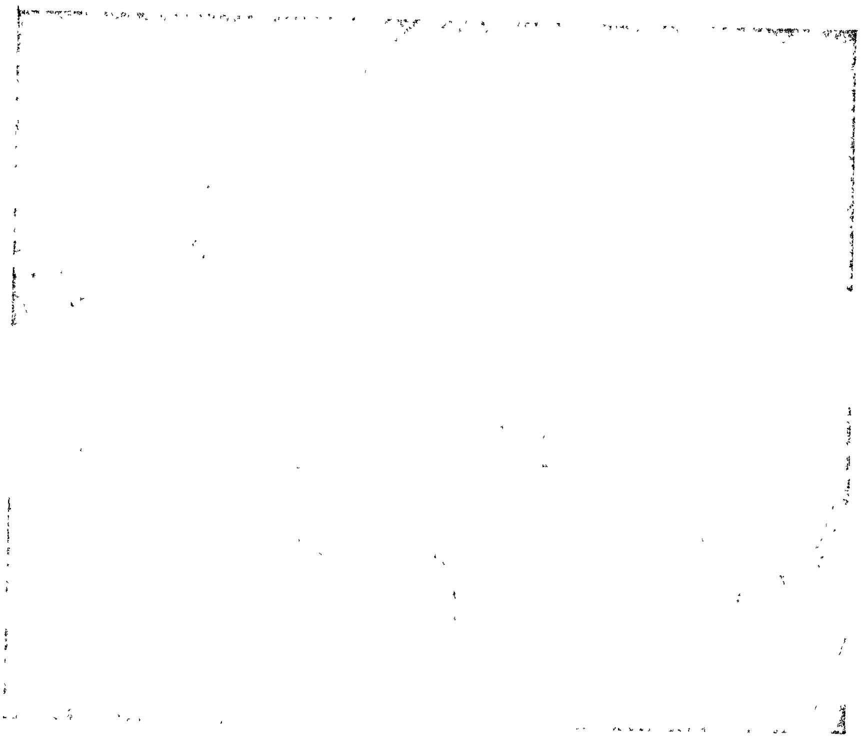


Fig. 11. Photographs Taken Before Test No. A-200 Showing the Installation of an [illegible] Instrument Panel



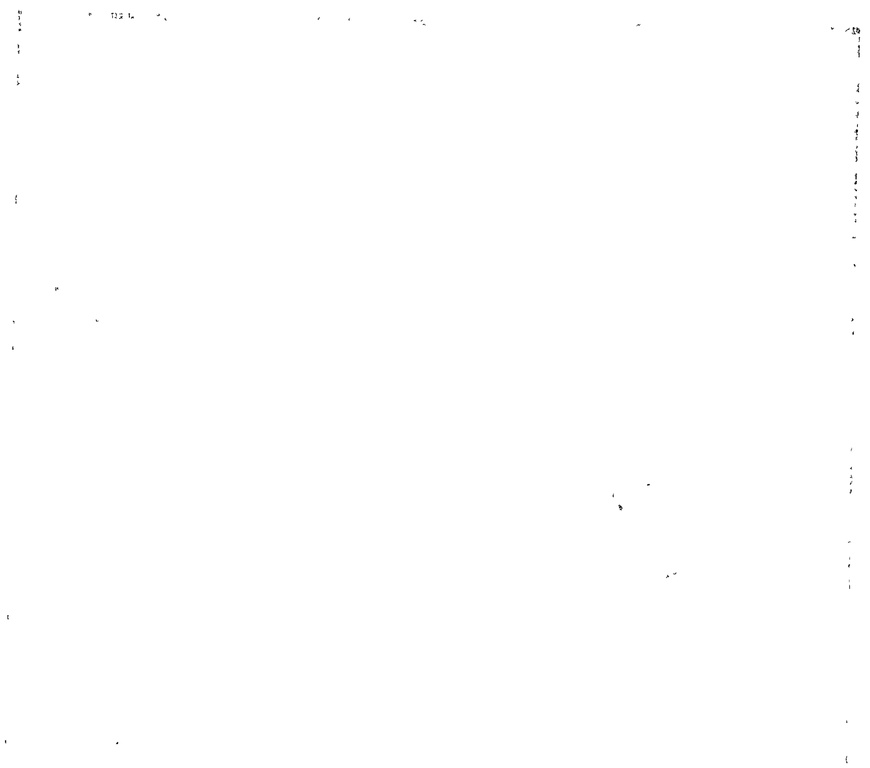
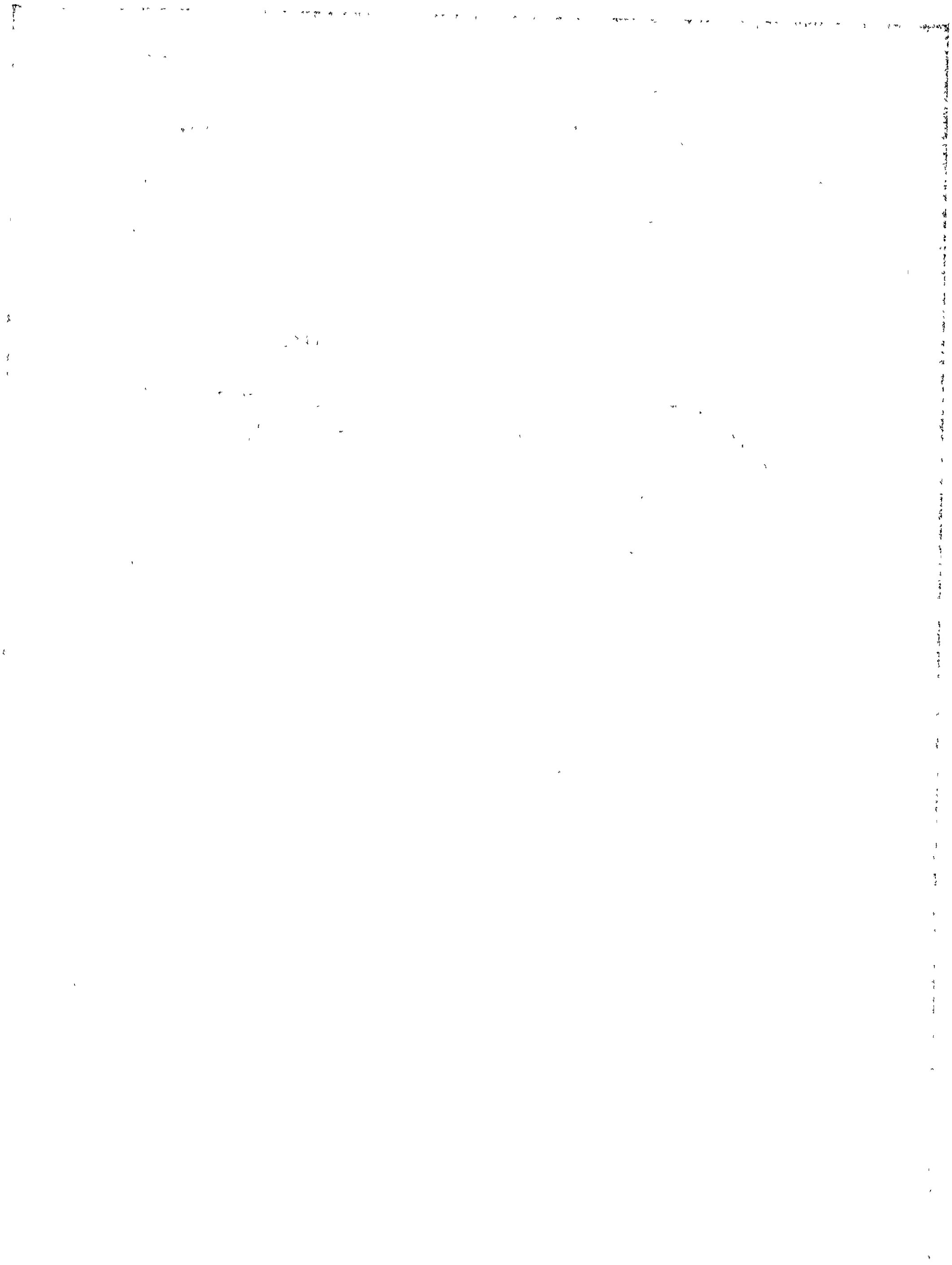


Fig. 12. Photographs Taken Before and After Test No. A 209 Showing Effectiveness of Energy-Absorbing Lower Instrument Panel

1



8

Fig. 13. Sequence of Photographs from Test No. A-203 (Energy-Absorbing Lower Instrument Panel)

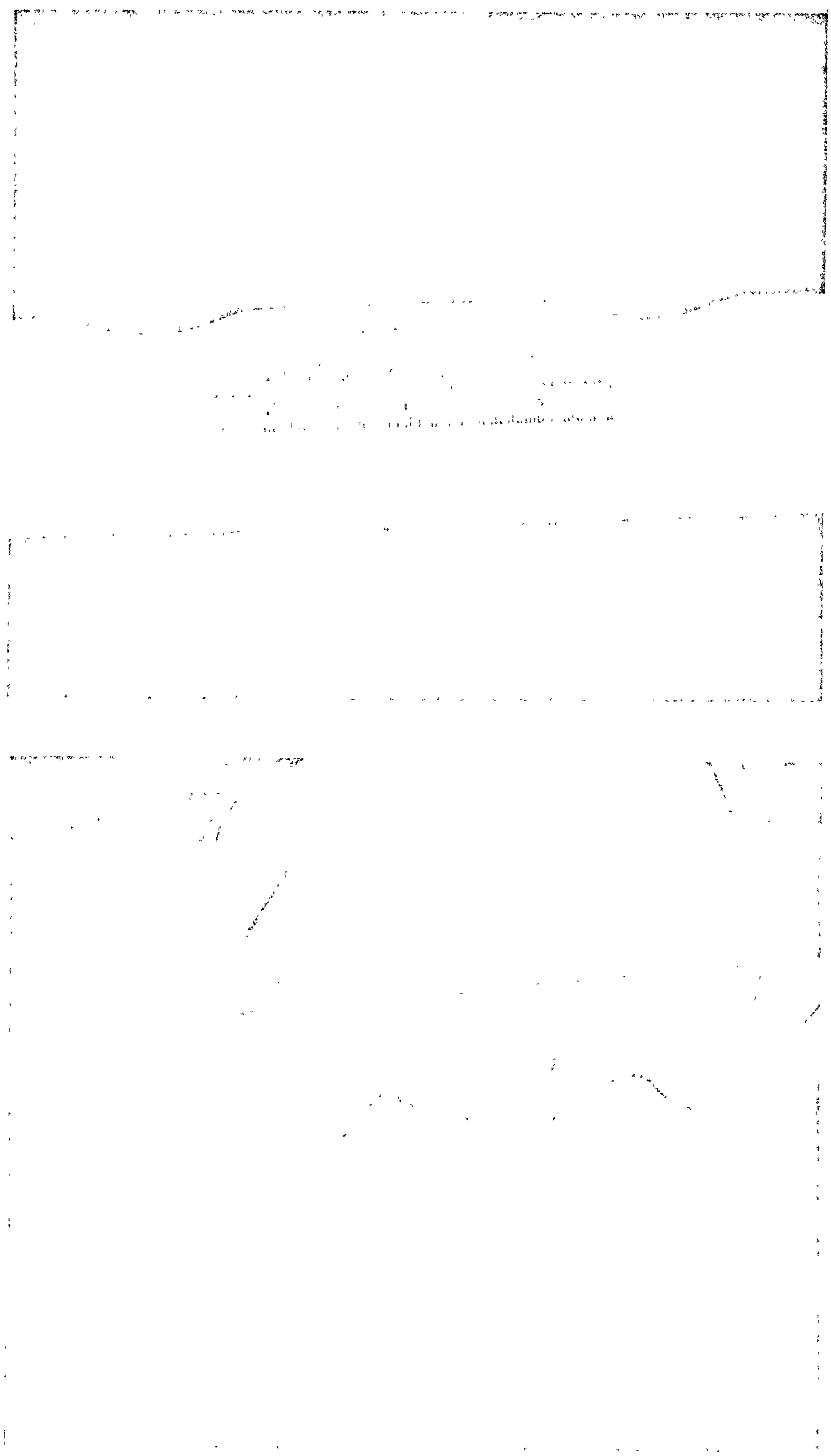


Fig. 14. Examples of Permanent Deformation of Energy Absorbing Lower Instrument Panel

the dummy in the photograph taken after the test in order to show the relationship between the knees and the lower instrument panel. The dummy nearly returned to his initial position during rebound. A sequence of photographs taken during Test No. A-203 (Figure 13) shows the kinematics of the dummy which occurs in tests of this type.

Examples of the permanent deformation experienced by the styrofoam blocks are shown in Figure 12. In the test labelled A-200 the block is still mounted in the body buck whereas the block has been removed to show the profile of the indentations in Test No. A-209.

This section of the report (3.5) has summarized the developmental test program carried out to fix the occupant compartment design which was to be used for the bulk of the airbag evaluation test program. The vehicle configuration for all tests with identification numbers larger than A-199 includes all improvements in design discussed in this section.

3.6 EVALUATION TEST PROGRAM

Based on the body buck and restraint system configuration which was developed and has been described in section 3.5 of this report, a series of impact sled tests was performed to evaluate the potential of the airbag system in protecting an occupant under a variety of conditions. The parameters which were varied included crash velocity, use or non-use of lap belts in combination with the aribag, effects of various occupant size combinations, effects of non-head-on impacts, effects of nonconventional type vehicle crash response, and the effects of position in the occupant compartment of various size occupants including children, in other than normal seated positions.

Table I shows the matrix of tests which was carried out to vary crash velocity, belt use, occupant size, and direction of impact. This is followed by Table II which shows the tests involving [illegible] and Table III showing variation [illegible] pulse. It should be noted in Table I that the 20 [illegible]

TABLE I. TEST MATRIX FOR VELOCITY, OCCUPANT SIZE, BELT USE, AND IMPACT DIRECTION

velocity mph	belt use	impact direction	6-year child dummy	5th percentile female	50th percentile male	95th percentile male	95th percentile male and 6-year child
20	B	F	198	190	172, 173	192, 195	210
20	U	F	206	204	202	200	212
30	B	F	199	191	179	194, 196 197	211
30	U	F	207	205	203, 292 299	201, 209 306	213
40	B	F	234	228	230	232	239
40	U	F	235	229	231, 308 309	233, 307	-
20	B	O	241	221	216, 217	252, 259	262
20	U	O	242	222	219	253	263
30	B	O	243	223, 224	218, 245	254	264
30	U	O	248	257	220	255	265
40	B	O	240	258	244	256	266
40	U	O	249, 251	-	260, 261	-	-

[illegible]
[illegible]

TABLE II. TEST MATRIX VARYING OCCUPANT POSITION

Test No.	Dummy	Velocity-mph	Occupant Position
208	3 yr.	0	Standing, looking out window with chin on diffuser.
287	6 yr.	0	Sitting erect on front edge of seat.
288	6 yr.	0	Sitting erect on front edge of seat with hands over diffuser.
289	6 yr.	0	Chin on diffuser and hands at side.
290	3 yr.	0	Sitting on edge of front seat with forehead touching diffuser.
291	3 yr.	0	Standing with arms and chin over instrument panel.
293	3 yr. 50 M	30	3 yr. dummy on lap of seat-belted adult.
294	3 yr. 50 M	30	3 yr. dummy on lap of unrestrained adult.
295	50 M	30	Dummy slouched in seat with knees on instrument panel.
296	50 M	30	Sideways sleeping position.
297	50 M	30	Slouched with arms behind head.
298	50 M	30	Forearms on top of instrument panel and head on arms.
299	50 M	30	Erect, wearing glasses.
300	5 F	30	Slouched with knees touching instrument panel.
301	5 F	30	Sideways sleeping position.
302	5 F	30	Sideways sleeping position.
303	5 F	30	Leaning forward in seat with legs spread, arms on knees, and head on diffuser.
304	95 M	30	Sideways sleeping position.
305	[illegible] M	30	Sideways sleeping position.

3 yr. [illegible] 6 yr. [illegible]
5 F [illegible]
[illegible] dummy

TABLE III. TEST MATRIX VARYING IMPACT
SLED DECELERATION PULSE

Test	Dummy	Velocity-mph	Belt	Deceleration Pulse
174	50 M	30	yes	Low level. 12 G average
178	50 M	30	yes	Low level. 12 G average
284	50 M	30	no	Ramp 26 G peak
285	50 M	30	no	Double peak. 34 G peak
286	50 M	30	no	High level. 20 G average

NOTE: The deceleration pulses described in the last column of this table represent variations possible with the HSRI impact decelerator during the period of this contract. Comparisons with full-scale vehicle crash pulses are made in Part 3.7.8 of this report using the mechanism of the HSRI Mathematical Crash Victim Simulator.

and 30 mph tests in frontal impact involving lap belt restrained dummies have test numbers numerically less than A-200. These were conducted during the developmental test program before installation of the energy-absorbing lower instrument panel but have been included in the evaluation test program. The tests conducted at 40 mph in frontal impact involving lap belt restrained dummies all used the energy-absorbing lower instrument panel. The only effect was to reduce peak lap belt loads when the knees interacted with the lower instrument panel structure. This is discussed in section 3.7.2 of this report.

A summary of the data gathered during each test was prepared based on the recordings of the transducer data as well as on the high speed motion pictures which were taken. The data set for each test includes a photograph of the light-beam oscillographic record including trace identification and calibration, a sequence of photographs showing a side view of the motions of the occupants, and a HSRI Summary Data Sheet. A sample of this summary is included as Figures 15, 16 and 17 describing Test No. A-209. The written summary (Figure 1) was used to record: (1) the test setup; (2) the functioning of the restraint system, sled acceleration and deceleration system, and data recordings; (3) dummy kinematics from the high speed motion pictures; and, (4) an evaluation of the performance of the restraint system based on the criteria outlined previously in this report. The oscillographic record and sequence of photographs serve as a compact source of supporting evidence.

The data for all tests which were carried out during this project, including developmental tests, are summarized in Table IV. Code letters are used in defining dummy size, dummy position, direction of impact, sled G-level deceleration type, and certain aspects of occupant kinematics. These are defined in Table V. The tests and test numbers are ordered chronologically starting with A-[illegible] which was conducted on 21 [illegible] and finishing with A-[illegible] on 6 [illegible]. Lap belt use, dummy size,

HSRI SUMMARY DATA SHEET

FH-11-6962

Test No.: A-209

Test Date: 21 January 1970

Restraint Description: Fast-Inflating Eaton, Yale and Towne, Inc. Airbag

Test Observations:

This test was carried out using a 95th percentile male dummy. The test velocity was 30 mph and represented a direct frontal impact. The deceleration was trapezoidal with an average value of 15 G's and a peak of 17 G's. The G-loadings experienced by the dummy were low and the airbag deployed properly. The knees of the unbelted dummy left an imprint approximately 1/2 inch deep in the styrofoam lower instrument panel.

Figure 15. HSRI Summary Data Sheet (Test No. A-209).

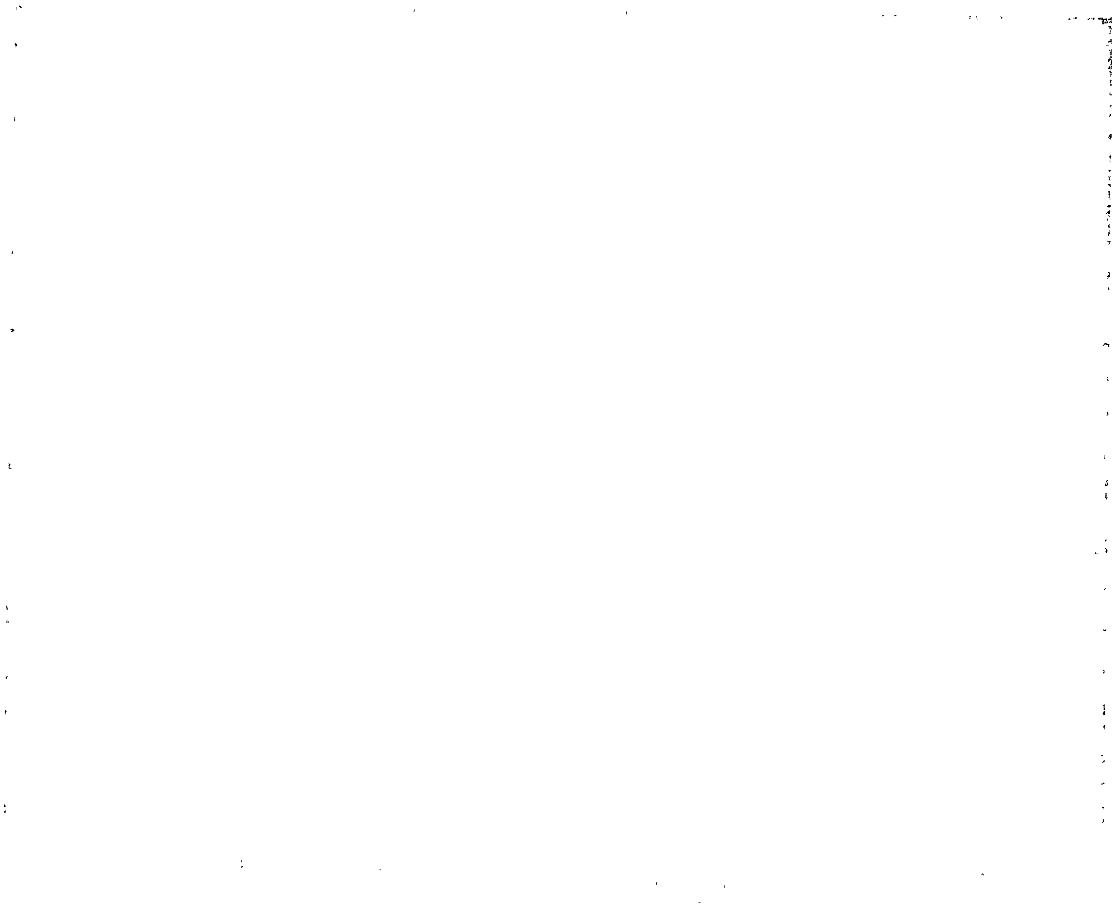
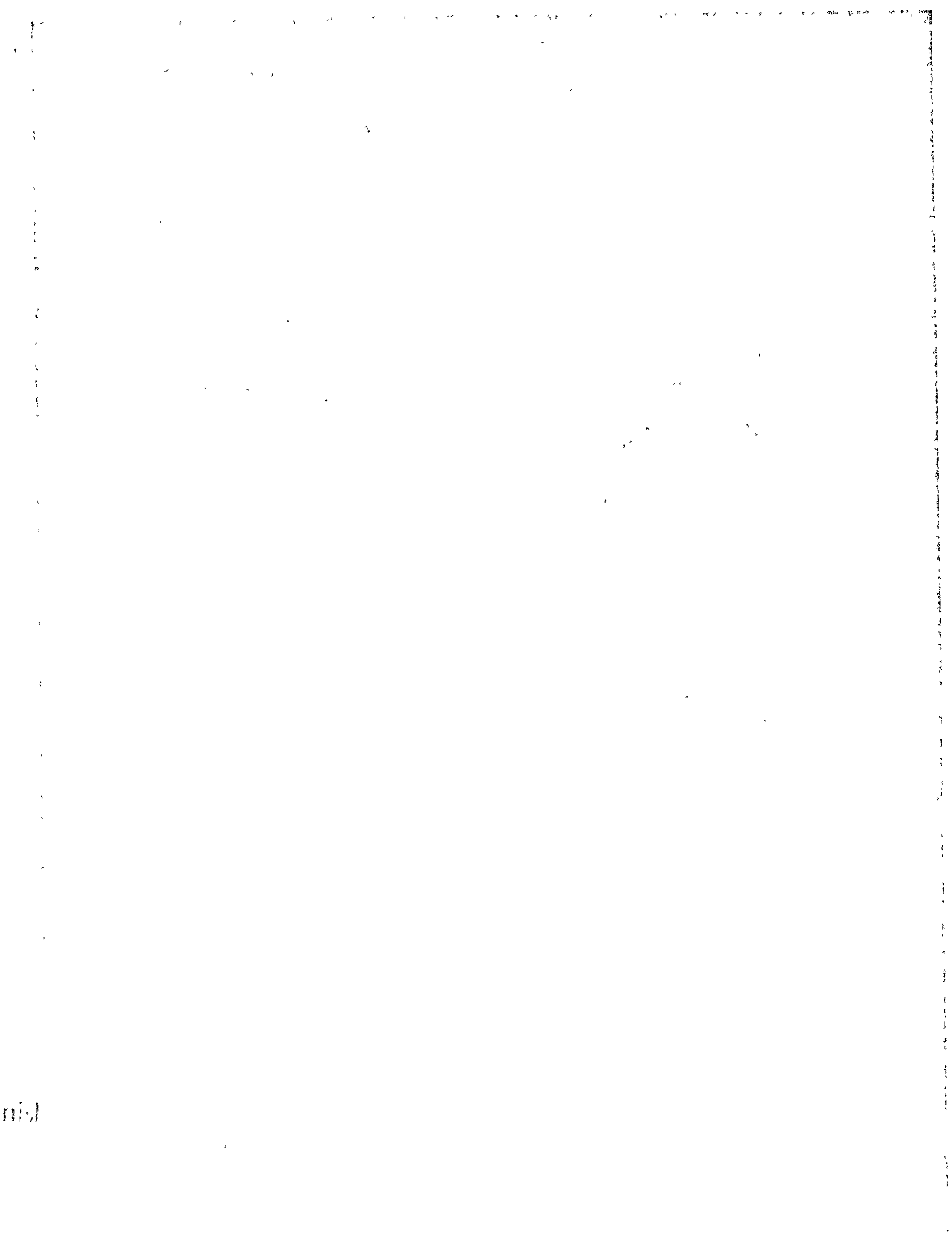


Fig. 16. Light Beam Oscillographic Data (Test No. A-209)

Start



Finish

Fig. 17. Photographic Sequence (Test No. A-203)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 1)

[illegible]	dummy/ dash type	impact velocity, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	E	21.2	F	16	N	-	760	55	14	9	30	35	-	Preinflated bag.
[illegible]	E	[illegible]	F	16	N	-	700	47	23	5	34	18	-	Preinflated bag.
[illegible]	E	[illegible]	F	16	N	330	1200	-	32	9	32	10	0	Fast-inflating bag. Time base lost.
[illegible]	E	21.2	F	16	N	-	-	27	10	5	27	4	3	Knees hit metal lower dash.
[illegible]	E	21.6	F	16	N	-	-	-	33	10	45	15	5	Knees hit metal lower dash and head contacted windshield.
[illegible]	E	20.4	F	~16	N	1770	1040	>80 for 3 ms	22	57	18	18	-	Low deployment. Part of sled deceleration record lost.
[illegible]	E	30.1	F	16	N	2550	1400	-	-	-	-	-	-	Cable failure for body accelerometers.
[illegible]	E	0	-	-	-	-	-	4	4	3	8	4	1	Static bag deployment test.
[illegible]	E	0	-	-	-	-	-	4	4	3	8	2	3	Static bag deployment test.
[illegible] yes 50 [illegible]	E	0	-	-	-	-	-	4	4	4	8	3	4	Static bag deployment test.
[illegible] yes 50 [illegible]	E	0	-	-	-	-	-	8	10	17	8	2	7	Static bag deployment test.

Note: [illegible] definition of code letters.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 2)

[illegible]	[illegible]	[illegible]	[illegible]	direction of impact	sled G-level	decel-ation type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	21.2	F	16	[illegible]	1850	1240	27	13	4	25	13	0	Last test with symmetric buck.
[illegible]	[illegible]	E	20	F	16	[illegible]	-	-	-	-	-	-	-	-	Failure of data recording system. Bag deployment high. (H)
[illegible]	[illegible]	E	22.8	F	16	N	790	950	32	20	10	25	17	10	New body buck installed for remaining tests. Bag deployment high. (H)
[illegible]	[illegible]	E	20	F	16	N	-	780	25	17	-	28	15	10	Time base malfunction. Bag deployment high. (H)
[illegible]	[illegible]	E	20	F	15	N	-	-	-	-	-	-	-	-	Failure of data recording system. Bag deployment high. (H)
[illegible]	[illegible]	E	19.9	F	15	N	-	800	40	15	-	25	22	15	Bag deployment high. (H)
[illegible]	[illegible]	E	20.0	F	15	N	-	830	33	15	-	30	20	15	Bag deployment high. (H)
[illegible]	[illegible]	E	19.7	F	16	N	-	960	32	12	-	20	21	10	Bag deployment high. (H)
[illegible]	[illegible]	E	18.[illegible]	F	16	N	-	830	27	8	8	14	7	5	Seat moved forward to extent of its adjustment for remaining tests. Bag deployment high. (H)
[illegible]	[illegible]	E	19.8	F	16	N	-	1040	18	18	-	29	14	8	Initial position of head incorrect.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 3)

est	use of lap belt	dummy size	dummy position	impact velocity, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	[illegible]
174	yes	50 M	O	29.1	F	12	NL	-	960	35	20	-	30	22	5	[illegible]
178	yes	50 M	E	28.0	F	12	NL	980	1010	28	25	10	47	15	10	[illegible]
79	yes	50 M	E	30.0	F	17	N	1930	1880	20	35	-	50	20	20	[illegible]
80	no	50 M	E	20.3	F	16	N	-	-	25	11	15	40	-	20	[illegible]
88	no	95 M	E	19.9	F	15	N	-	-	15	20	30	25	-	5	[illegible]
89	no	5 F	E	19.6	F	15	N	-	-	40	-	48	40	-	5	[illegible]
90	yes	5 F	E	19.9	F	15	N	1300	990	40	33	10	>50 for 10 ms	-	15	[illegible]
91	yes	5 F	E	30.6	F	15	N	1360	1220	40	46	10	>50 for 5 ms	-	20	[illegible]

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 4)

[illegible]	[illegible]	dummy	impact velocity, mph	direction of impact	sled G-level	acceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	E	13.6	F	15	N	1130	930	26	25	-	13	5	-	
[illegible]	[illegible]	E	[illegible]	F	15	N	1330	1540	25	20	-	30	15	20	Detonation late by 15
[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	2550	2370	30	25	25	25	25	10	Record of sled G-puls lost. Right leg of c broken on airbag supp Seat back broken duri rebound.
[illegible]	[illegible]	E	20.4	F	17	N	-	1060	42	35	7	15	-	5	Seat moved back to re most adjustment. Hig bag deployment. (H)
[illegible]	[illegible]	[illegible]	[illegible]	F	15	N	-	2600	-	18	14	30	-	10	Seat belt failed.
[illegible]	[illegible]	[illegible]	29.9	F	14	N	-	2350	32	>75 for 3 ms	15	24	25	25	Seat at rear adjustme position. High deplo ment. (H)
[illegible]	[illegible]	E	20.4	F	16	N	-	680	30	11	13	20	5	10	
[illegible]	[illegible]	[illegible]	31.4	F	16	N	850	770	22	12	17	35	5	11	High bag deployment.
[illegible]	[illegible]	E	20.3	F	15	N	-	-	20	27	25	23	20	20	Energy-absorbing lowe instrument panel inst to restrain knees. (T
[illegible]	[illegible]	[illegible]	29.6	F	15	N	-	-	25	38	-	25	17	10	Dummy slid down out o position during accel ation of sled. (T,H)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 5)

[illegible]	[illegible]	[illegible]	impact velocity, [illegible]	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	E	[illegible]	F	16	S	-	-	25	20	10	20	25	5	Deceleration G-pulse nearly sine wave. Bag deployed high. (H)
[illegible]	[illegible]	E	[illegible]	[illegible]	15	N	-	-	22	33	10	20	15	5	(H)
[illegible]	[illegible]	[illegible]	21.2	[illegible]	13	N	-	-	50	17	35	13	33	10	(H)
[illegible]	[illegible]	E	[illegible]	F	16	N	-	-	52	23	60	20	35	15	(H)
[illegible]	[illegible]	E	30.5	F	16	N	-	-	40	30	10	15	20	5	Ringing in most channels caused by bag slap.
[illegible]	[illegible]	E	31.4	F	17	N	-	-	31	45	40	20	40	22	Ringing during bag slap.
[illegible]	[illegible]	D	-	-	-	-	-	-	>150 (3 ms)	>100 (3 ms)	30	>100 (3 ms)	40	50	Dummy standing looking out front window with chin on diffuser. Original diffuser geometry. Dummy was catapulted over front seat back.
[illegible]	[illegible]	E	21.9	F	15	N	-	-	42	20	24	30	12	5	Dummy somewhat slouched.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 6)

[illegible]	[illegible] posi- tion	impact velo- city, mph	direc- tion of impact	sled G-level	decel- era- tion type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level		head s-i G-level		head l-r G-level		chest a-p G-level		chest s-i G-level		chest l-r G-level		Remarks
						95	6 r	95	6	95	6	95	6	95	6	95	6	95	6	
[illegible]	E	20.0	F	15	N	600	465	14	24	30	-	13	10	33	-	11	-	17	2	(H)
[illegible]	E	25.4	F	15	N	680	470	29	29	23	-	11	10	30	27	10	15	10	2	
[illegible]	E	20.[illegible]	F	15	N	-	-	18	40	25	10	32	12	35	17	23	20	-	15	(H)
[illegible]	E	20.4	F	15	N	-	-	28	30	40	15	15	5	35	35	15	40	-	13	(H)
[illegible]	E	[illegible]	O	16	N	1200	1350	>100		>60		>60		50		>25		40		Airbag did not deploy.
[illegible]	E	20.[illegible]	O	15	N	880	890	20		27		14		20		8		15		Dummy contacted side structures. (T)
[illegible]	E	[illegible].0	O	14	N	750	610	>15		>15		10		>20		10		38		Several channels questionable. Dummy contacted side structures. (T,H)
[illegible]	E	19.9	O	16	N	-	-	15		20		15		15		15		25		Dummy contacted door structures. (T,H)
[illegible]	E	2[illegible].4	O	16	N	-	-	15		20		15		30		20		25		Dummy contacted door structures. (T,H)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 7)

[illegible]	[illegible]	[illegible]	[illegible]	impact speed, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	O	19	N	1100	720	37 bag slap 15 event	30	26 bag slap 21 event	25 bag slap 20 event	33	17	Dummy submarined under lap belt.
[illegible]	[illegible]	[illegible]	E	19.6	O	19	R	-	-	32 bag slap 12 event	19	25	20 bag slap 10 event	25	15	(T,H)
[illegible]	[illegible]	[illegible]	O	23.7	O	15	R	1870	1310	34 bag slap 27 event	42	54	20	15	39	Dummy leaning to side of position. No side structures.
[illegible]	[illegible]	[illegible]	E	23.2	O	15	N	1310	520	24 bag slap 17 event	34	25	35 bag slap 20 event	25	25	(T)
[illegible]	-	[illegible]	-	-	O	-	-	-	-	-	-	-	-	-	-	Failure of acceleration mechanism.
[illegible]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Setup test.
[illegible]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Timing setup test.
[illegible]	[illegible]	[illegible]	[illegible]	40.2	F	20	N	1350	1060	28 bag slap 18 event	-	16	40	17	15	(H) (H)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 8)

[illegible]	[illegible]	[illegible]	[illegible]	impact velocity, [illegible]	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	F	[illegible]	F	16	N	-	-	25	30	12	30	35	10	
[illegible]	[illegible]	[illegible]	E	[illegible]	F	16	N	1030	1030	35(?)	25(?)	42(?)	35	15	10	Spikes toward end of test make the peaks uncertain. Knees hit instrument panel even with lap belt. (H)
[illegible]	[illegible]	[illegible]	E	[illegible]	F	16	N	-	-	50(?)	40(?)	50	45	20	15	Spikes toward end of test make the peaks uncertain. Knees hit instrument panel even with lap belt. (H)
[illegible]	[illegible]	[illegible]	E	[illegible]	F	16	N	950	880	34	58	27	45	28	8	Dummies knees touched ba[illegible] causing high deployment. (T,H)
[illegible]	[illegible]	[illegible]	E	40.5	F	16	N	-	-	24	45	33	41	25	6	Dummies knees touched ba[illegible] causing high deployment. Seat back broken on rebound. (T,H)
[illegible]	[illegible]	[illegible]	E	[illegible]	F	15	N	780	590	30 bag slap 23 event	30 bag slap 14 event	15	25	5	15	
[illegible]	[illegible]	[illegible]	E	39.6	F	16	N	-	-	37 bag slap 35 event	33	35	43	8	25	Left shoulder hit airbag support. Dummy submarined under bag.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 9)

Test	use of lap belt	dummy size	dummy position	impact velocity, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	[illegible]
-236	-	-	-	20	F	-	-	-	-	-	-	-	-	-	-	[illegible]
-237	-	-	-	30	F	-	-	-	-	-	-	-	-	-	-	[illegible]
-238	-	-	-	40	F	-	-	-	-	-	-	-	-	-	-	[illegible]
								95	6 yr	95 / 6	95 / 6	95 / 6	95 / 6	95 / 6	95 / 6	
-239	yes	95 %, 6 yr	E	40.0	F	16	N	750	670	23 / 37	50 / 14	30 / 14	44 / 23	16 / 30	22 / 5	[illegible]
-240	yes	6 yr	E	39.0	0	15	N	850	550	27 bag slap 14 event	25	40	24	10	20	Dummy rolled [illegible] structures
-241	yes	6 yr	E	19.2	0	11	R	850	450	35 bag slap 18 event	32	37 bag slap 20 event	17	10 bag slap 10 event	14	
-242	no	6 yr	E	18.5	0	11	R	-	-	33 bag slap 18 event	40	32	17 bag slap 11 event	10	7	[illegible] rolled [illegible] structures.
-243	yes	6 yr	E	20.1	0	15	N	1020	600	20 bag slap 20 event	35	56	19	-	35	[illegible]

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 10)

[illegible]	[illegible]	[illegible]	Impact velocity, [illegible]	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	E	[illegible]	0	14	N	1020	1260	30	28	37	37	-	>50	Plexiglass plate added to improve side door support. Shoulder and head of dummy contacted door. (T)
[illegible]	[illegible]	E	27.7	0	15	N	960	700	15	37	20	45	10	20	Dummy was positioned left of center of the bag initially. (T)
[illegible]	[illegible]	E	30.0	0	15	N	-	-	37 bag slap 80 g event	30 bag slap 40 event	45	25	20	25	
[illegible]	[illegible]	[illegible]	40.0	0	16	N	-	-	42 bag slap 42 event	36 bag slap 36 event	110 rebound	30 bag slap 30 event	25	40	Dummy out of position upon acceleration. Leaning almost on door.
[illegible]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Setup test.
[illegible]	[illegible]	E	40.4	0	16	N	-	-	37 bag slap 53 event	20 bag slap 15 event	76 rebound	20 bag slap 26 event	20	33	
[illegible]	[illegible]	E	19.3	0	14	N	610	480	28 bag slap 18 event	16	25	20 bag slap 22 event	15	15	(T)
[illegible]	[illegible]	E	19.2	0	13	R	-	-	23 bag slap 13 event	20 bag slap 35 event	25	20 bag slap 25 event	25	15	(T)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 11)

[illegible]	[illegible]	[illegible]	[illegible]	impact velocity, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	E	19.6	0	16	R	1250	1240	44	18 bag slap 35 event	35	25 bag slap 40 event	>25 for 3 ms	45	Shoulder of dummy contacted door structures. (T)
[illegible]	[illegible]	[illegible]	E	29.8	0	16	R	-	-	67	42	33	25 bag slap 45 event	>25 for 2 ms	35	Shoulder and elbow of dummy contacted door side structures. (H,T)
[illegible]	[illegible]	[illegible]	E	[illegible]	0	17	N	1140	200	32 bag slap 80 event	35	35 bag slap 25 event	33	18	42	Head and shoulders of dummy contacted door side structures. (H,T)
[illegible]	[illegible]	[illegible]	E	29.3	0	16	R	-	-	25 bag slap 25 event	30 bag slap 25 event	20 bag slap 55 event	25 bag slap 20 event	20	-	(H,T)
[illegible]	[illegible]	[illegible]	E	40.4	0	16	N	1400	740	25 bag slap 30 event	20 bag slap 60 event	35	25 bag slap 30 event	35	40	(H,T)
[illegible]	[illegible]	[illegible]	E	19.5	0	15	R	810	470	25 bag slap 10 event	20	15	35	15	18	
[illegible]	[illegible]	[illegible]	E	39.4	0	15	N	-	-	25	30	38	40	20	40	Late bag deployment (25 ms). Dummy contacted door side structures. (T)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 12)

[illegible]	[illegible]	[illegible]	dummy type	impact velocity, [illegible]	direction of impact	sled G-level	decel-eration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level		head s-i G-level		head l-r G-level		chest a-p G-level		chest s-i G-level		chest l-r G-level		Remarks
[illegible]	[illegible]	[illegible]	E	40.0	0	15	N	-	-	30		-		30		22		-		40		Shoulder of dummy contacted door side structures. (T,H)
								95	6 yr	95	6	95	6	95	6	95	6	95	6	95	6	
[illegible]	[illegible]	[illegible]	E	23.5	0	14	R	1450	200	33	30	15	50	-	17	-	33	20	12	23	22	Shoulder of 95th percentile dummy contacted door side structures. (95T,H)
[illegible]	[illegible]	[illegible]	E	15.5	0	14	R	-	-	36	34	25	15	-	17	-	35	25	15	22	30	6 yr. child dummy slid under bag. 95(T)
[illegible]	[illegible]	[illegible]	G	31.4	0	15	R	1040	280	65	40	30	40	37	65	-	25	20	12	40	20	6 yr. dummy was out of position upon acceleration with legs to side. Head and shoulder of 95th percentile dummy contacted door side structures. 95(T,H)
[illegible]	[illegible]	[illegible]	E	23.2	0	16	N	-	-	70	45	30	40	37	65	-	25	20	12	40	20	6 yr. child dummy slid under bag. Shoulder of 95th percentile dummy contacted door. (T)
[illegible]	[illegible]	[illegible]	E	41.5	0	16	N	810	600	50	37	45	38	35	30	-	39	20	18	20	20	Knees of 95th percentile dummy deformed i.p. and shoulder contacted door. (T,H)
[illegible]	[illegible]	[illegible]	E	30.4	F	25	R	-	-	~200 >100 for 3 ms		~50		15		-		~50		25		Setup test. Diffuser slot orientation 15° down. Airbag failed to deploy.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 13)

[illegible]	[illegible]	[illegible]	[illegible]	impact velocity, [illegible]	direction of thrust	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	25	R	-	-	30	46	25	56	14	23	Setup test. Diffuser s[illegible] orientation 15° down.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	[illegible]	R	-	-	10	30	13	40	14	12	Setup test. Diffuser sl[illegible] orientation horizontal.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	[illegible]	[illegible]	-	-	25	33	50	45	15	20	Sled G-level high. (T,H)
[illegible]	[illegible]	[illegible]	0	0	-	0	-	-	-	20 bag slap 85 rebound	15 bag slap 19 rebound	15 bag slap 27 rebound	20 bag slap 17 rebound	16 bag slap 8 rebound	10 bag slap 7 rebound	Dummy is erect sitting [illegible] front edge of seat.
[illegible]	[illegible]	[illegible]	0	0	-	0	-	-	-	15 bag slap 40 rebound	12 bag slap 7 rebound	6 bag slap 2 rebound	35 bag slap 9 rebound	10 bag slap 3 rebound	<5 bag slap <5 rebound	Dummy sitting erect on front edge of seat with hands over diffuser.
[illegible]	[illegible]	[illegible]	0	0	-	0	-	-	-	35 bag slap 92 rebound	12 bag slap 35 rebound	15 bag slap 9 rebound	35 bag slap 21 rebound	15 bag slap 16 rebound	<5 bag slap <5 rebound	Dummy leaning forward wi[illegible] chin on diffuser and han[illegible] at side.
[illegible]	[illegible]	[illegible]	0	0	-	0	-	-	-	82 bag slap 31 rebound	55 bag slap 41 rebound	10 bag slap 22 rebound	67 bag slap 51 rebound	10 bag slap 17 rebound	- bag slap 12 rebound	Dummy sitting on edge of front seat with forehead touching diffuser. (H)
[illegible]	[illegible]	[illegible]	0	0	-	0	-	-	-	40 bag slap >215 for 3 ms event	30 bag slap 122 rebound	5 bag slap >150 rebound	43 bag slap 57 rebound	15 bag slap 12 rebound	13 bag slap 15 rebound	Dummy standing with arms and chin above instrumen[illegible] panel. Arm became detached.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 14)

[illegible]	[illegible]	[illegible]	[illegible]	impact velocity, mph	direction of impact	sled G-level	deceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	-	-	33	20	18	33	8	10	Rubber neck in dummy. (T
										50 / 3	50 / 3	50 / 3	50 / 3	50 / 3	50 / 3	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	700	200	50: 52 / 3: >80 for 3 ms	50: 22 / 3: 98	50: 30 / 3: 40	50: 30 / 3: >45 for 10 ms	50: 51 / 3: 23	50: 31 / 3: 30	3 yr. dummy on lap of lap belted 50 M dummy. Head contact between dummies led to high G-levels.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	-	-	50: 90 / 3: >200	50: 36 / 3: >200	50: 19 / 3: 80	50: 37 / 3: >45 for 10 ms	50: 29 / 3: 46	50: 25 / 3: 45	3 yr. dummy on lap of 50 M dummy. Head contact between dummies led to high G-levels.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	-	-	39	47	5	30	41	30	Dummy is slouched down with knees touching lower instrument panel.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	-	-	31	56	10	48	13	15	Dummy "sleeping" with head back and knees to right. (H)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	F	16	N	-	-	24	12	25	45	53	70	Dummy slouched with hands thrown up due to failure of positioning device.
[illegible]	[illegible]	[illegible]	[illegible]	30.2	F	16	N	-	-	32	35	30	>45 for 2 ms	31	41	Dummy forearms are crosse on diffuser with head on arms. Right hand became detached during contact with windshield.
[illegible]	[illegible]	[illegible]	[illegible]	30.2	F	16	N	-	-	33	75	56	60	34	30	Dummy wears glasses. (H, T)

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 15)

[illegible]	[illegible]	[illegible]	dummy posi-tion	impact velo-city, mph	direc-tion of impact	sled G-level	occal-era-tion type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]		[illegible]	[illegible]	2[illegible].8	F	16	N	-	-	50	23	60	20	35	15	Dummy slouched with knee on lower instrument panel.
[illegible]	[illegible]	[illegible]	C	29.9	F	16	N	-	-	20	20	85	40	-	-	Test was failure. Sleeping dummy had foot out car door.
[illegible]	[illegible]	[illegible]	O	[illegible].2	F	16	[illegible]	-	-	37	23	21	35	28	-	Dummy in sleeping positi[on] with head back and body partially sideways. Dum[my] slid under bag and ended up on floor.
[illegible]		[illegible]	O	[illegible]	F	16	N	-	-	39	51	20	40	25	25	Dummy leaning forward wi[th] legs spread, arms on kne[es] and head on diffuser.
[illegible]	[illegible]	[illegible]	E	[illegible]	F	16	N	-	-	14	38	38	>45 for 5 ms	13	10	Incorrectly installed rubber neck. Glasses.
[illegible]	[illegible]	[illegible]	O	[illegible].8	F	16	N	-	-	20	27	23	40	27	17	Dummy in sleeping positi[on] with head back and body partially sideways. (H)
[illegible]	[illegible]	[illegible]	E	30.2	F	16	N	-	-	23	36	25	45	16	8	Dummy equipped with rubb[er] neck structure.
[illegible]	[illegible]	[illegible]	E	[illegible]	F	16	N	-	-	45	44	18	50	15	9	Dummy equipped with rubbe[r] neck structure. (H) Air-bag deployment was high.
[illegible]	[illegible]	[illegible]	E	[illegible].5	F	16	N	-	-	35	18	21	35	20	-	Dummy equipped with rubbe[r] neck structure. Time bas[e] failure.

TABLE IV. AIRBAG TEST DATA SUMMARY (Sheet 16)

[illegible]	[illegible]	[illegible]	impact velocity	direction of impact	sled G-level	acceleration type	left seat belt load, lbs	right seat belt load, lbs	head a-p G-level	head s-i G-level	head l-r G-level	chest a-p G-level	chest s-i G-level	chest l-r G-level	Remarks
[illegible]	[illegible]	[illegible]	[illegible]0.5	5	16	N	-	-	26	49	10	42	17	-	Dummy equipped with rubb neck structure. (H)

TABLE V. ABBREVIATED CODES USED IN AIRBAG TEST DATA SUMMARY

Dummy size:

- 50 M = 50th percentile male dummy
- 95 M = 95th percentile male dummy
- 5 F = 5th percentile female dummy
- 6 yr = 6-year-old child dummy
- 3 yr = 3-year-old child dummy

Dummy position:

- E = erect seated position
- O = out-of-position or additional feature such as glasses

Direction of impact:

- F = direct front barrier impact
- O = 22.5° right front oblique impact

Sled G-level:

- 15 = a 15 G average deceleration

Deceleration type:

- N = normal trapezoidal deceleration pulse
- L = low average value for deceleration pulse
- S = sine wave shape for deceleration pulse
- R = ramp shape for deceleration pulse
- H = high average value for deceleration pulse

Remarks on dummy kinematics:

- H = hyperextension of neck
- T = twisting of neck

dummy position, impact velocity, direction of impact, sled G-level, and deceleration type are given in the next several columns. The magnitude of the peak values of lap belt loads if lap belts are used and the six accelerations are then indicated in the next eight columns. A blank space for an acceleration indicates a malfunction of the data recording system, or most often, a break in the cables connected to the accelerometer. The duration in milliseconds of a head a-p, chest a-p, or chest s-i accelerometer reading above 80 G, 45 G, or 25 G, respectively, is listed if the duration is longer than 2 ms for the chest accelerometer channels or longer than 3 ms for the head accelerometer channel. This is done to facilitate evaluation using the performance evaluation criteria stated in Part 3.2 of this report. Because bag slap often produced higher loadings on the dummy than the deceleration event, peak values are given for both. The average value of sled deceleration is listed under "sled G-level." This value was determined by hand-smoothing the deceleration profile, a procedure accurate within 1 G based on comparisons with samples where an accurate average was computed. A question mark by a number indicates uncertainty about its magnitude and the "greater than" sign (>) indicates that it was possible to determine the acceleration value up to the indicated value. The last column in Table IV contains specific remarks concerning the type of test, proper positioning of the dummy, the functioning of the sled and deceleration system, the recorded data, performance of the airbag restraint system, as well as the motions and vehicle interior contacts experienced by the dummy.

3.7 ANALYSIS OF TEST RESULTS

The analysis of the test results gathered during the course of the inflating restraint system evaluation project has been carried out by viewing individually the three components describing the engineering system. These three components are the occupant, the physical environment inside the vehicle and the motion environment during an impact event.

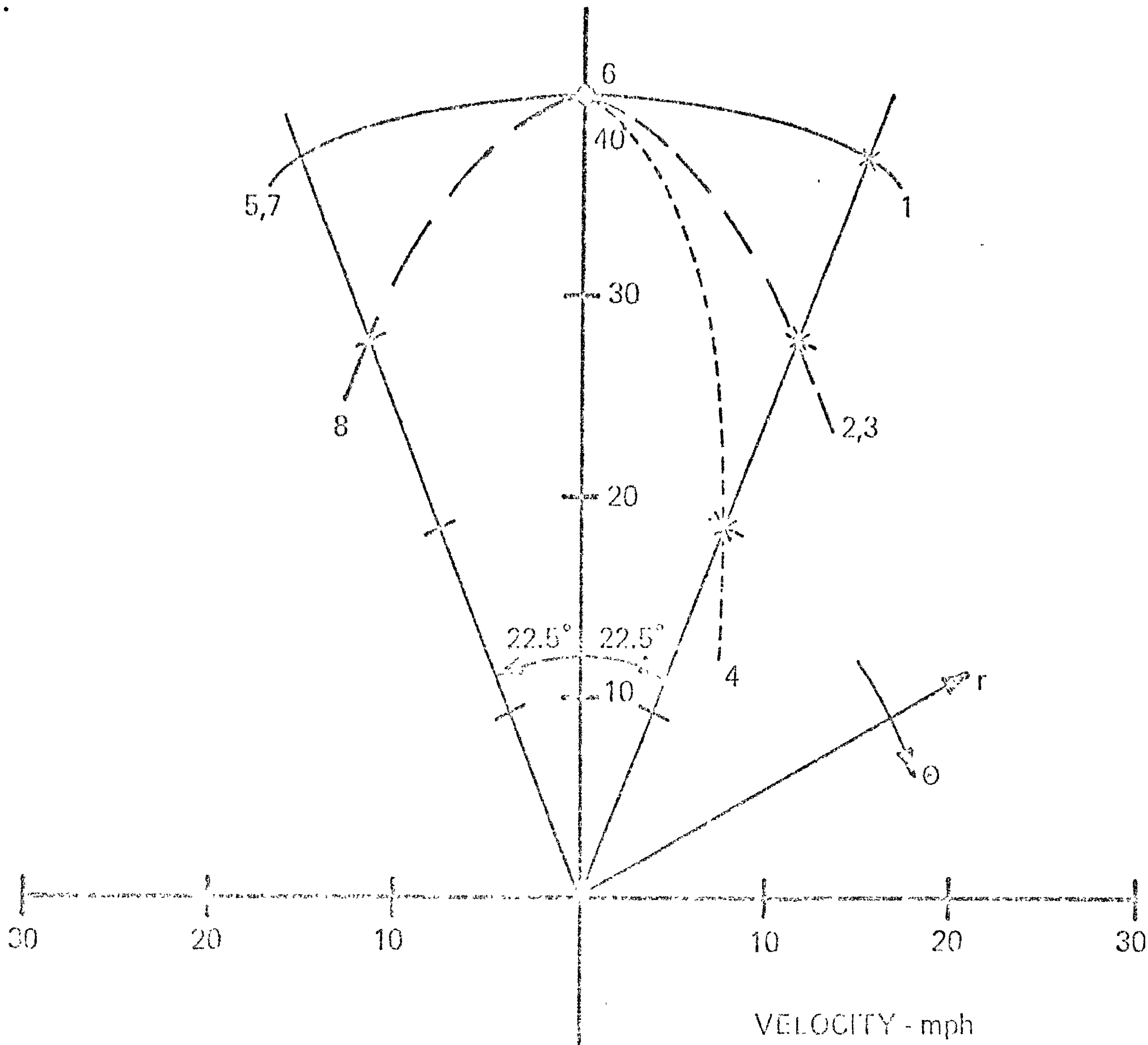
Those parameters involving the occupant which have been varied and are discussed separately are size (6-year-old child through 95th percentile male dummies), the construction of the various dummies with particular reference to the neck, and the position of the dummy with respect to the interior of the vehicle. The cases of inadvertent actuation of the airbag system, particularly with reference to the case of a child close to the diffuser, are considered along with those cases involving adult dummy sizes.

Because the vehicle interior configuration was fixed prior to the initiation of the major part of the test program, the only parameter which was varied was use or non-use of a lap belt in combination with the passive airbag restraint.

Three aspects of the motion environment have received special attention. These were impact velocity, impact direction and deceleration pulse shape. The velocity was varied from 20 to 40 mph, the direction of impact varied from 0° to 22.5° right front oblique, and the pulse shape changed from a trapezoid to a ramp configuration.

3.7.1 Velocity Threshold with the Airbag Restraint System

To summarize the results presented in Part 3.7 of this report, the concept of threshold velocity is introduced. This consists of a polar plot with linear velocity in miles per hour and direction of impact in degrees measured away from the direction of a direct frontal impact. The curves placed on this polar plot form an upper bound on the impact velocity at which restraint system performance is adequate. For the current test program involving the [illegible], Yale and Towne, Inc. system installed in a [illegible] Ford [illegible] body buck, the threshold velocity curves are shown in Fig. [illegible].



DEFINITION OF CURVES:

1. 50% Male, belted
2. 50% Male, unbelted
3. 95% Male, belted
4. 95% Male, unbelted
5. 5% Female, belted
6. 5% Female, unbelted
7. 6 Year Old Child, belted
8. 6 Year Old Child, unbelted

Fig. 10. Threshold Velocity Curves

The boundary curves have been drawn for those velocities at which restraint system safety performance is estimated to be marginal based on the performance evaluation criteria outlined in Part 3.2 of this report. In some cases, the velocity of 40 mph may be too low because of the limited velocity capacity available at the present time on the HSRI impact sled. The limiting criteria are based both on the G-levels recorded from the body accelerometers and the motions observed in the high speed motion pictures.

The 50th percentile male dummy was provided with marginal protection at 40 mph both in the frontal and oblique tests when a lap belt was used. The limiting factor in these tests was a combination of head twist and hyperextension in the frontal impacts and head twist in the oblique case. Performance appeared to be somewhat reduced when the dummy was not restrained by a lap belt in the oblique tests and actually improved in the frontal collisions indicating that the threshold velocity might be somewhat higher for this case.

The 95th percentile male dummy, because of its greater mass, tended to have greater excursion and interacted with greater severity with items in the vehicle interior unrelated to the restraint system. This fact led to marginal response for both the belted and unbelted cases at 40 mph in frontal collision and threshold velocities for oblique impact lower than for the 50th percentile male.

The level of protection offered to the 5th percentile dummy was the lowest experienced by any of the dummies. Problems with the neck construction of the dummy were experienced in all tests both belted and unbelted. A tentative threshold velocity was set at 40 mph for the lap belted 5th percentile female both in frontal and oblique impact because of the relatively low G-loadings and the uncertainty of the comparison between neck motions experienced by dummies and humans. The unbelted dummy received marginal protection at 40 mph in the forward collision simulation but in all other tests failed either the G- or motion-criterion or both. The threshold velocity is represented as a point at 40 mph.

Generally the 6 year old child dummy received the greatest level of protection offered to any of the dummies. Both in the belted and unbelted cases the threshold is a minimum of 40 mph in frontal impact due to limitations in the HSRI sled system. In the oblique case, the threshold for the belted dummy is also a minimum of 40 mph and is reduced to 30 mph for the unbelted dummy because of contact with vehicle interior structures.

3.7.2 The Effect of Occupant Size

Four aspects of the effect of occupant size will be considered in this discussion: (1) the values of peak G-loadings received by the various dummies; (2) the values of lap belt loadings felt by the dummies in those cases where lap belts were used; (3) the kinematics experienced by the various dummy sizes; and, (4) the effect of bag deployment. Only direct frontal impact simulations are considered here as oblique tests are presented in a later section.

The peak body accelerometer readings as a function of dummy size and impact velocity have been presented in Table VI. The tests from which this data was obtained are listed in Table I. Only unbelted cases are considered. If more than one test was conducted on a dummy at a given speed, the average value of the peak accelerometer readings for these tests is listed in Table VI.

In studying the head anterior posterior G levels it appears that smaller dummies receive more severe loadings at the low speeds than do the larger dummies. However, there is little difference between the response of the various dummies at a test velocity of 40 mph. Due to the [illegible] of the 6-year-old child and 5th percentile female dummies, it is possible that the [illegible] of the airbag are [illegible] at the lower speeds where [illegible]

TABLE VI. PEAK BODY ACCELEROMETER READINGS
AS A FUNCTION OF DUMMY SIZE AND IMPACT VELOCITY

Dummy Size	Head a-p G-level			Head s-i G-level			Head l-r G-level		
	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph
6 yr child	40	31	35	30	45	33	10	25	35
5% female	50	52	25	17	23	30	35	60	12
50% male	25	29	37	20	42	36	10	28	27
95% male	20	30	35	27	31	44	25	25	25

Dummy Size	Chest a-p G-level			Chest s-i G-level			Chest l-r G-level		
	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph
6 yr child	15	20	43	20	40	8	10	22	25
5% female	13	20	30	33	35	35	10	15	10
50% male	20	38	41	25	19	19	5	15	15
95% male	23	33	45	20	15	20	20	8	8

In the case of the superior-inferior head acceleration, there is some increase in G-level with velocity but no clearly defined variation with occupant size. Some comparisons can be made between the average of the acceleration values obtained for the four dummy sizes at 20 and 40 mph and for the head anterior-posterior and superior-inferior accelerometers. It is interesting to note that the average of the peak G-loadings at 20 mph is 23 G's whereas, for the anterior-posterior mounts under similar conditions, it is 34 G's. At 40 mph the average of the peak G-loadings in the superior-inferior direction has increased to 36 G's while the anterior-posterior loading has remained nearly constant at 33 G's. This probably reflects the increased hyperextension which is observed at the higher velocity levels.

The G-levels experienced by the head left-right accelerometers do not show any clearly defined trends either as a function of velocity or as a function of dummy size. However, the values are generally lower than those experienced by the superior-inferior and the anterior-posterior mounted accelerometers as should be expected in a nearly symmetric frontal impact simulation. The only exception is the reading obtained using a 5th percentile female dummy at 30 mph. This high level appears to be associated with the severe hyperextension observed in the test (See Figure 19).

The acceleration levels recorded from the chest anterior-posterior accelerometers show a pattern of increasing G-levels as impact velocity is increased. This phenomenon should be expected both from the thermodynamic and the geometric properties of airbags and will be discussed in Part 3.7.5 of this report.

It should also be noticed in Table VI that there are no clearly defined differences in chest anterior-posterior G-loadings between the various sized dummies. [illegible] form of the equations [illegible] by [illegible][15] the resultant force provided by an airbag is

$$F = P\,\Delta A + T\,\Delta l$$

where $P\,\Delta A$ is the bag pressure times the contact area swept out by the occupant and $T\,\Delta l$ is the normal component of the membrane force per unit length of bag material times the length of the perimeter of the contact region. For the smaller dummies swept area, perimeter, and possible pressure are reduced, thus lowering the restraint produced by the bag. The fact that the small dummies have reduced mass tends to equalize the G-loadings between the large and small dummies.

There are three observations which can be made in general concerning the chest superior-inferior and the left-right peak G-levels: (1) there is a decrease in level with size of the dummy as the 95th percentile male seemed to receive the gentlest ride; (2) both sets of values are lower than are recorded in the chest anterior-posterior direction; and, (3) the left-right G-levels have the lowest values of all as should be expected with a nearly symmetric frontal impact simulation. The remarkable decrease in chest superior-inferior G-level for the 6-year-old child dummy at 40 mph becomes clear from the motions. Figure 20 shows the dummy submarining under the bag and lower instrument panel. From the high speed movies the dummy is then observed to roll to the left towards the center of the vehicle.

A lap belt restraint system supplemented the air bag in certain of the tests and the resulting belt loadings are presented in Table VII. The tests from which this data was obtained are listed in Table I. Only lap belted cases are considered. If more than one test was conducted on a dummy at a given speed, the average value of the peak lap belt loads for these tests is listed in Table VII. As would be expected the values are observed to increase both with dummy size and with impact velocity as it increases from 20 mph to 30 mph. The decrease in loadings between 30 mph and 40 mph tests is explained by noting that the 30 mph tests were carried out before the body buck was equipped with an energy-absorbing lower instrument panel and the 40 mph tests [illegible]. In all the 40 mph tests, the [illegible] of

TABLE VII. LAP BELT LOADS

Dummy Size	Lap Belt Loads, Lbs.		
	20 mph	30 mph	40 mph
6 year child	1360	1620	1370
5% female	2290	2580	2420
50% male	1870	3810	2110
95% male	2090	4940	1830

TABLE VIII. COMPARISON OF PEAK G-LEVELS BETWEEN 1 AND 2 DUMMY TESTS

Dummy Size	Head a-p G-level			Chest a-p G-level		
	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph
6 year child	40	31	35	15	20	43
95% male	20	20	35	23	33	45
6 year child	40	30	-	17	35	-
95% male	18	28	-	35	35	-

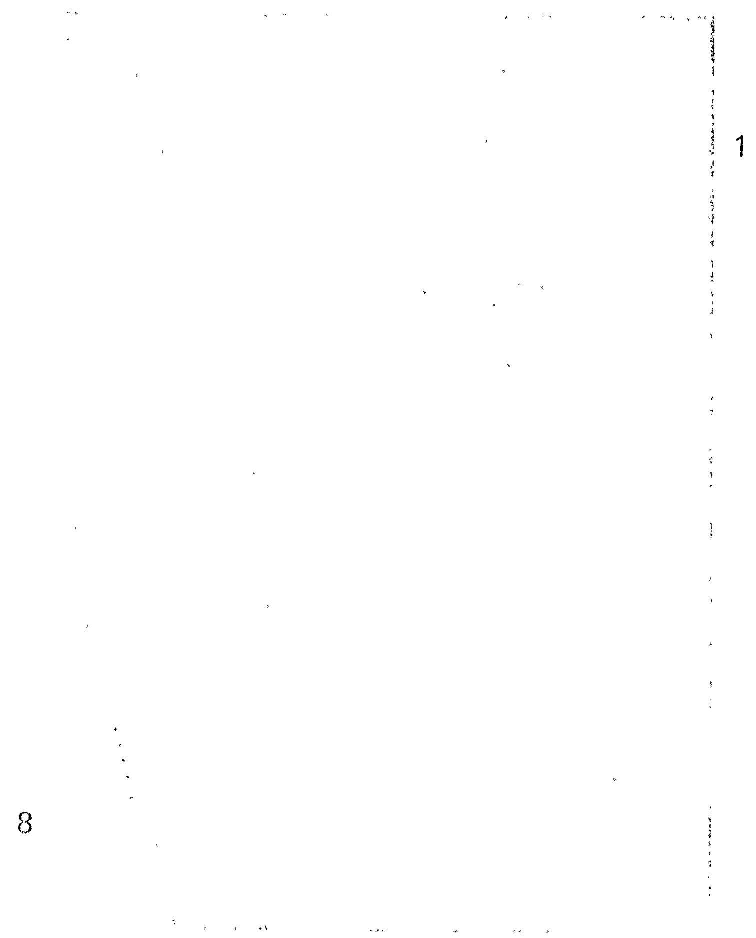


Fig. 19. Photographic Sequence (Test No. A-205)

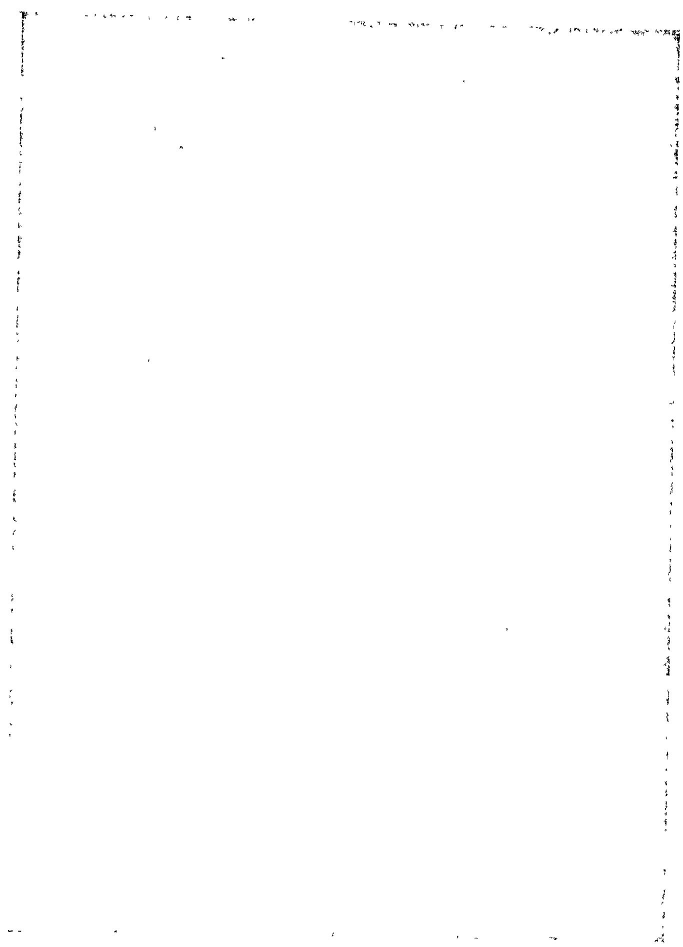
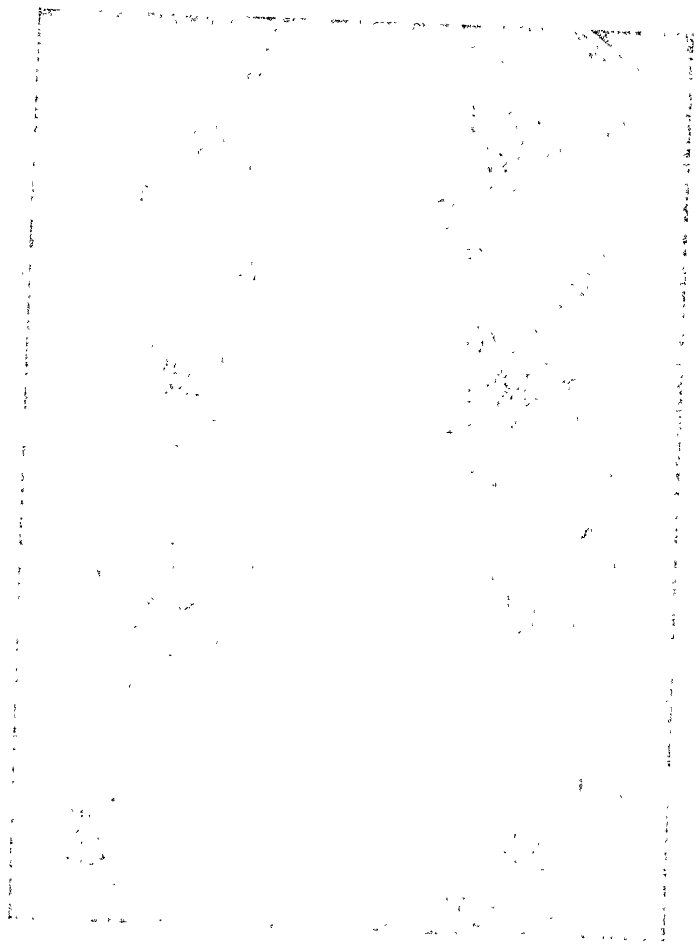


Fig. 20. Photographic Sequence (Test No. A-207)

8



1

Fig. 21. Photographic Sequence (Test No. A-308)

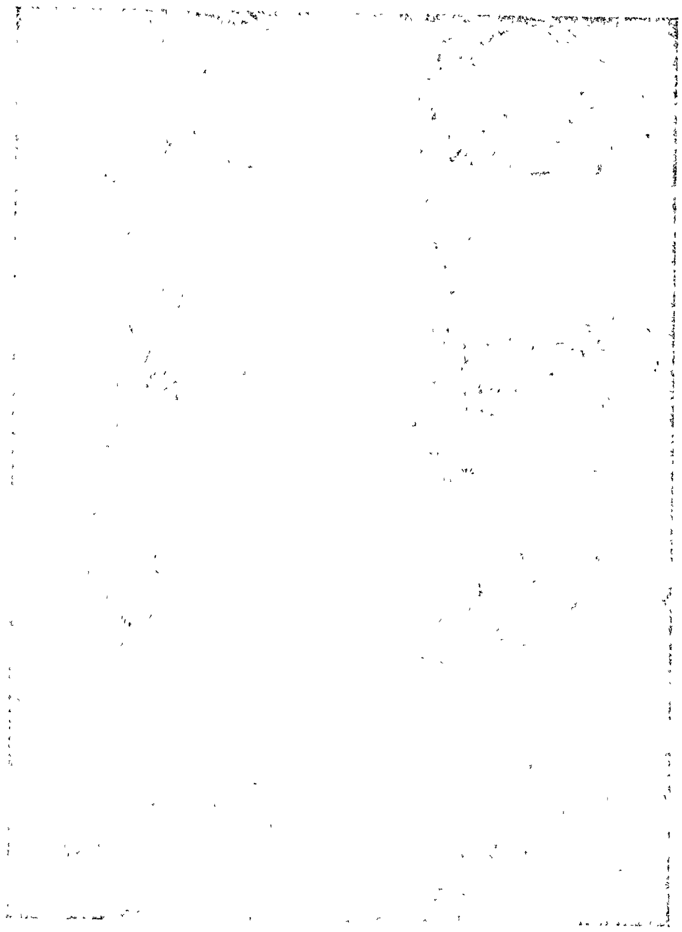


Fig. 22. Photographic Sequence (Test No. A-306)

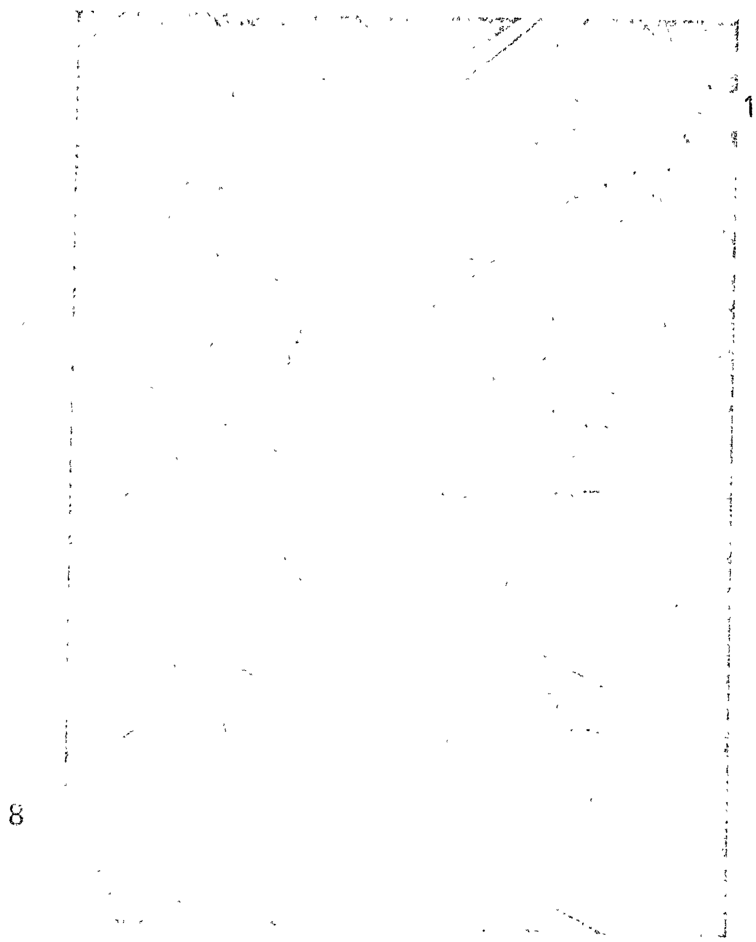


Fig. 23. Photographic Sequence (Test No. A-212)

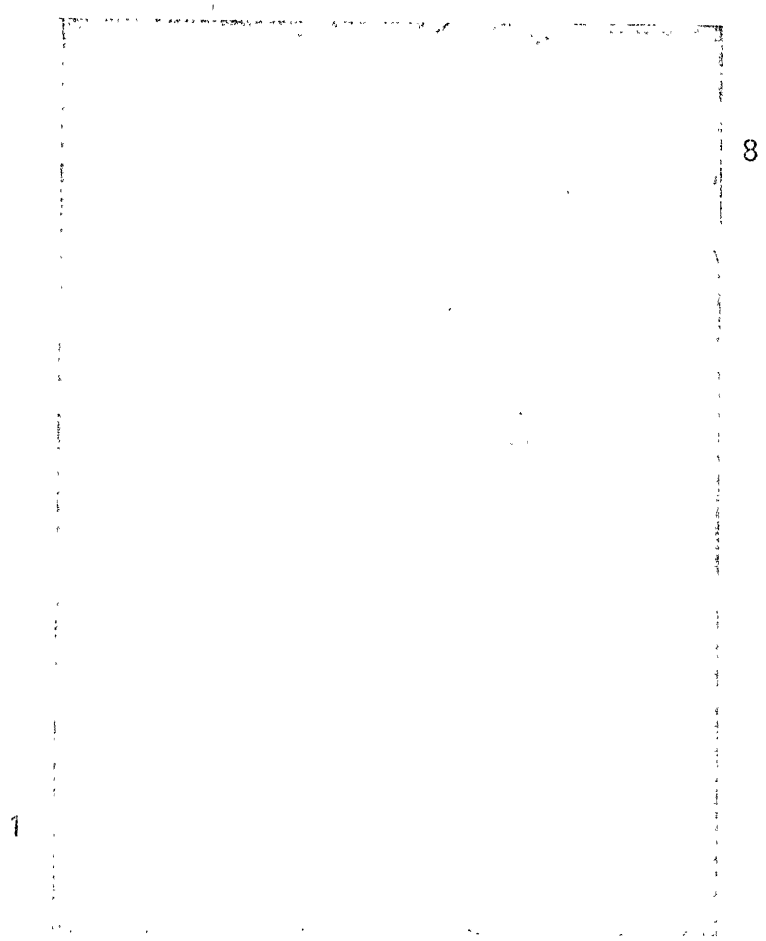


Fig. 24. Photographic Sequence (Test No. A-239)

the dummies interacted with the lower instrument panel whether they were belted or not.

The motions experienced by the occupant depended on occupant size and the resultant placement of both the airbag and the knee restraint. Figure 19 shows deployment on the 5th percentile female dummy in a 30 mph test while Figure 21 shows the 50th percentile male in a more severe test at 40 mph. In the former case the restraint load is carried high on the upper torso and head causing severe hyperextension whereas the excellent deployment on the 50th percentile male in the later case avoids this problem completely. However, if bag deployment is high on a larger dummy (an unusual case of which is shown in Figure 22 for the 95th percentile male dummy tested at 30 mph), performance can also be severely degraded.

Several tests, as outlined in the last column of Table I, were carried out using two dummies - the 95th percentile male and the 6-year-old child. A comparison between these tests and individual tests using the two dummies separately is given in Table VIII. The G-levels in the one- and two-dummy tests are similar indicating that the addition of the small dummy does not substantially affect restraint system performance. This contention is borne out in an examination of the motions experienced by the two dummies as recorded in the high speed motion pictures. A test carried out at 20 mph using unbelted dummies is shown in Figure 23 while a 40 mph test with lap-belted dummies is shown in Figure 24. Even though the 6-year-old child dummy was observed to slide off the side of the bag in most of the tests, its velocity was reduced to the extent that the G-loadings received in contacting the vehicle interior were not severe.

3.7.5 The Out of Position Occupant and Inadvertent Actuation

This series of tests [illegible] a wide variety of occupant configurations as listed in Table II. [illegible] inadvertent actuation on a child positioned close to the bag. The second part of the series covers out-of-position occupants in a variety of configurations including a child on the lap of an adult, slouched adults, adults sprawled in a sleeping position, and adults leaning forward as has been proposed as a possible configuration during vehicle braking. Three tests involving occupants wearing glasses were also conducted.

Six tests were carried out to study the effect of inadvertent actuation on child dummies - three with the 6-year-old and three with the 3-year-old child dummies. The first test (A-208) used the 3 year old child dummy. Photographs taken both before and after this test are included as Figure 25. High G-levels of approximately 100 G's in most accelerometer channels were observed both during initial contact with the bag and later as the dummy was catapulted over the back of the front seat contacting various vehicle structures. Prior to the next test Eaton, Yale and Towne, Inc. increased the diameter of the diffuser from 2 in. to 3 in. in order to lower the exit velocity of the gas entering the bag, thus tending to lower the initial velocity of the bag as it begins to deploy. This was designed to reduce the initial G-loading on the child. In addition to this change, the slot arrangement of the diffuser was changed to produce lower deployment in order to deploy the bag further down on the chest of the dummies, to more uniformly distribute the restraint loadings, and to lower the angle of attack of forces applied to the occupant in the case of inadvertent actuation. The intended effect of this was to force the occupant down into the seat rather than to catapult him into roof structures in the event of inadvertent actuation.

Test No. A-209 was set up similarly to No. A-208 with the exception of the new diffuser. The initial G-loadings produced by the bag inflation were within current tolerance [illegible]. The [illegible] was pushed straight back into the front [illegible] back where high G-loadings occurred. This problem could be avoided with appropriate energy-absorbing padding added to structural members of the seat frame or by energy-absorbing design of the structures. Two photographs taken before this test and one taken afterwards are included as Figure 26.

In Test No. A-209 the 3-year-old child dummy was positioned with his head touching the diffuser. The resulting peak G-loadings applied to both head and chest during initial bag contact appear to be somewhat in excess of currently proposed tolerance levels. The levels recorded during rebound were not nearly so severe. Two photographs taken before and afterwards are shown in Figure 27. It is believed that this test is more severe than the case of a production-packaged unit. With a production unit it would not be possible to place the child so near to the diffuser because of system shielding.

Test Nos. A-287, A-288 and A-289 were carried out using the 6-year-old child dummy to study inadvertent actuation. Positions ranged from leaning forward with the chin touching the diffuser to the case where the dummy sat erect on the edge of the front seat. In each case the dummy was pushed straight back into the front seat back and received tolerable G-loadings during the initial contact with the bag. The loadings received during contact with the seat back were higher but mostly within currently estimated tolerance levels. Photographs taken before and after each of these three tests are included as Figures 28, 29 and 30.

Two tests (A-293 and A-294) were designed to determine the effectiveness of an airbag in restraining a combination consisting of a child sitting on the lap of an adult. In Test A-293 the adult dummy was lap-belted. During both tests the heads of the dummies were observed to contact each other leading to high accelerometer readings. High G-levels were also apparent in the chest accelerometer pulses; however, there was no evidence that the dummies swept through the bag to contact the diffuser. The apparent problem is with force interactions between the two dummies. Photographs of these tests are presented in Figures 31 and 32.

The dummies were in an initially slouched position during Test A-295 involving a 50th percentile male and A-300 involving the 5th percentile female. Deployment of the bag was excellent in A-295 and the G-levels experienced by the dummy were approximately the same as the average recorded in tests involving erect dummies. A sequence of photographs from this test is shown in Figure 33. The ride experienced by the 5th percentile female in Test A-300 was softer in most respects than the similar test involving an erect dummy. Head G-loads were lower for the out-of-position test and chest G-loads were higher. The 60 G spike in the chest anterior-posterior accelerometer was about 2 ms in duration and may be an artifact as the average G-level was about 35 G's. Hyperextension was reduced for the out-of-position dummy due to the fact that it was leaning back approximately 45° at the beginning of the test. Photographs taken before and after this test are included as Figure 34.

Tests were also carried out using the three adult dummies in what is called the sleeping position. This can be described as a twisted position with buttocks near the vehicle center line, knees toward the right door, and head leaning to the side to rest on the back of the front seat. The initial positions for the 5th percentile female and the 95th percentile male are shown in Figure 35. It should be noted that the knees of the large dummy were approximately 1 inch from the energy-absorbing instrument panel while they were located several inches further away for the female.

In all cases the dummy entered into contract with the bag in a semi-sideways position and then rebounded to the left. The female dummy slid under the bag and ended up partially on the seat with the head on the driver's side of the vehicle. The 50th and 95th percentile male ended up mostly in the drivers' position. Photographs showing the two types of final positions are included as Figure 36.

The G-loadings experienced by the dummies in these three tests were within current estimates of tolerance in all cases. The spikes observed in the chest anterior-posterior accelerometers had a duration of approximately 1 ms.

Two tests were carried out using adult dummies which were leaning forward with their heads near the diffuser. In Test No. A-298 the 50th percentile male dummy was leaning forward with its forearms resting on top of the diffuser and its head leaning against them. Only the arms were positioned differently in Test No. A-303 with the 5th percentile female dummy. In this case the dummy leaned forward on the seat with elbows resting on spread knees and the chin on the airbag. Photographs showing the initial positions are included as Figure 37.

In the test with the male dummy, the bag began to deploy through the ring formed by the folded arms, forcing them apart. The right forearm struck and broke the windshield. In the case of the female dummy, the bag deployed downward straightening the legs. The right leg was broken above the knee during the simulation. It is not known whether this is due to the straightening, contact with the seat frame, or a reaction in the leg due to decelerative forces acting at the foot. The location of the windshield damage in Test A-296 is shown in Figure 38 and the motions of the female dummy in Test No. A-303, in Figure 39. Loads in the anterior-posterior direction are at the tolerance level with spikes rising above with a duration of approximately 2 ms.

Glasses were worn by the test dummies on three different occasions (Test Nos. A-299, A-[illegible] and A-301) and the results were similar in each case. The frames of the eye glasses were bent around the foreheads of the dummies, conforming somewhat to the curvature of the forehead. The frames remained intact and in

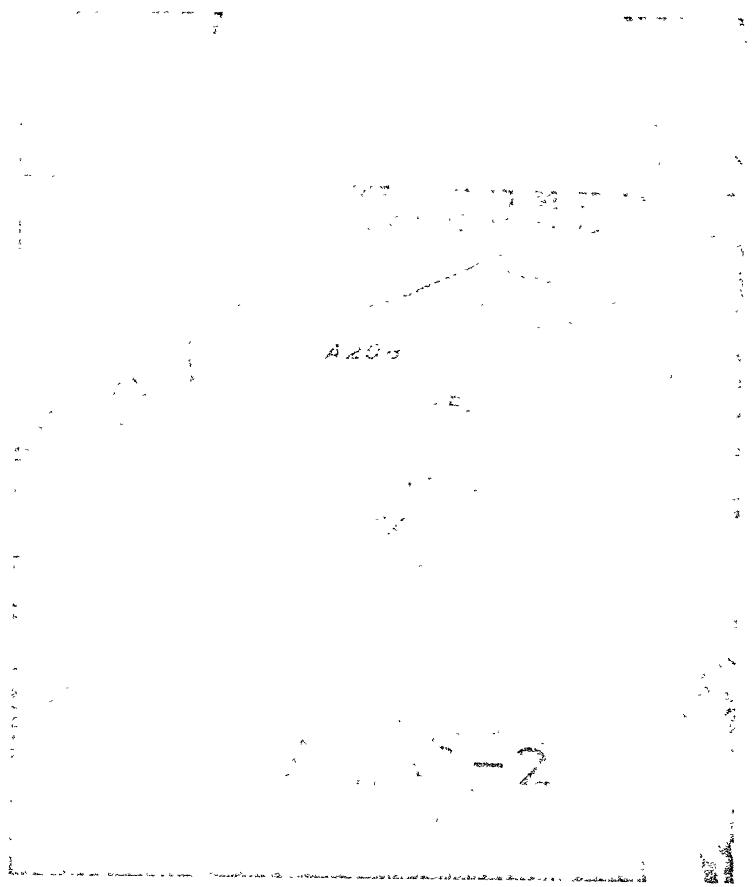


Fig. 25. Photographs Taken Before and After Test No. A-208 Showing Dummy Motions

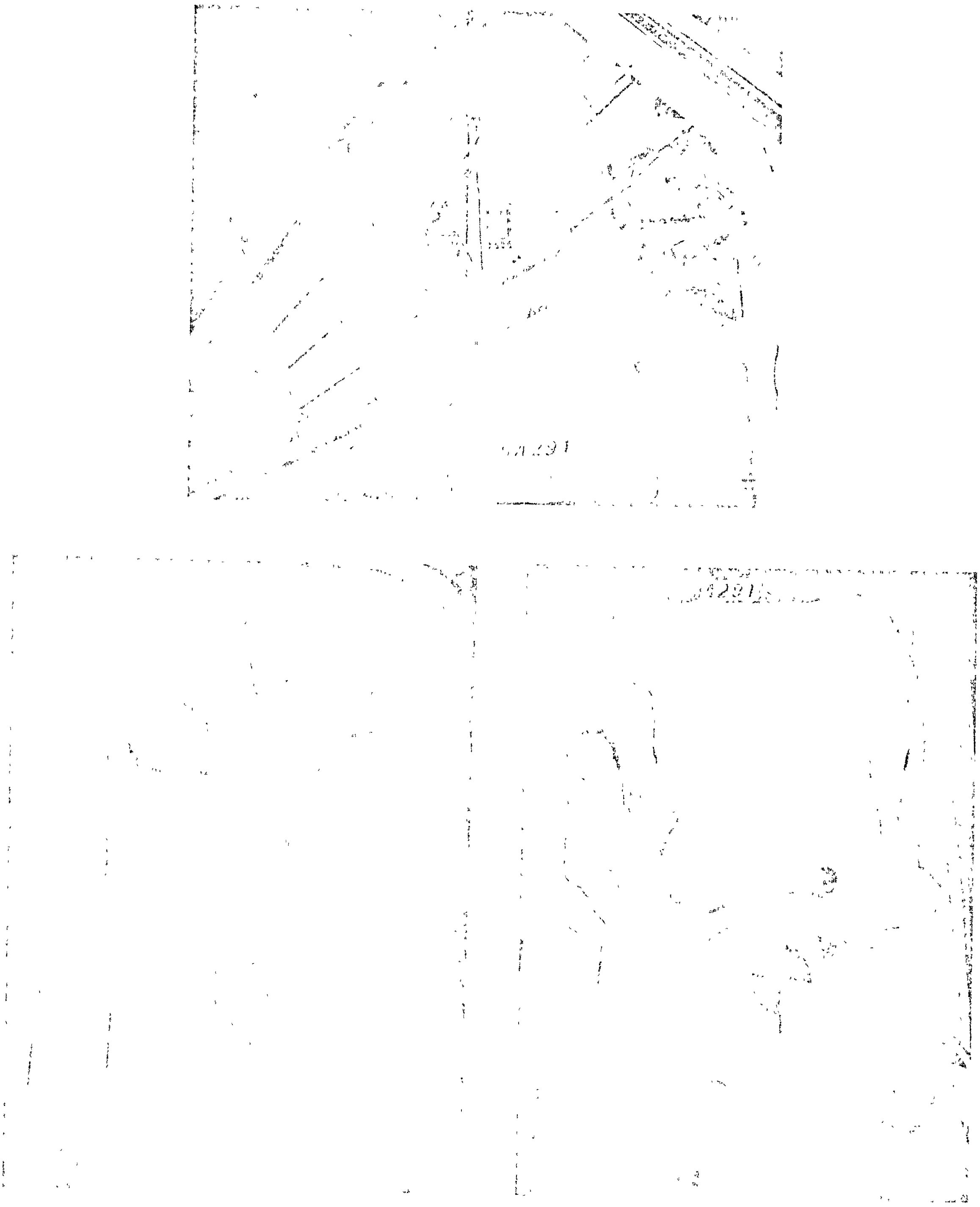


Fig. 26. Photographs Taken Before and After Test No. A-291 Showing Dummy Position

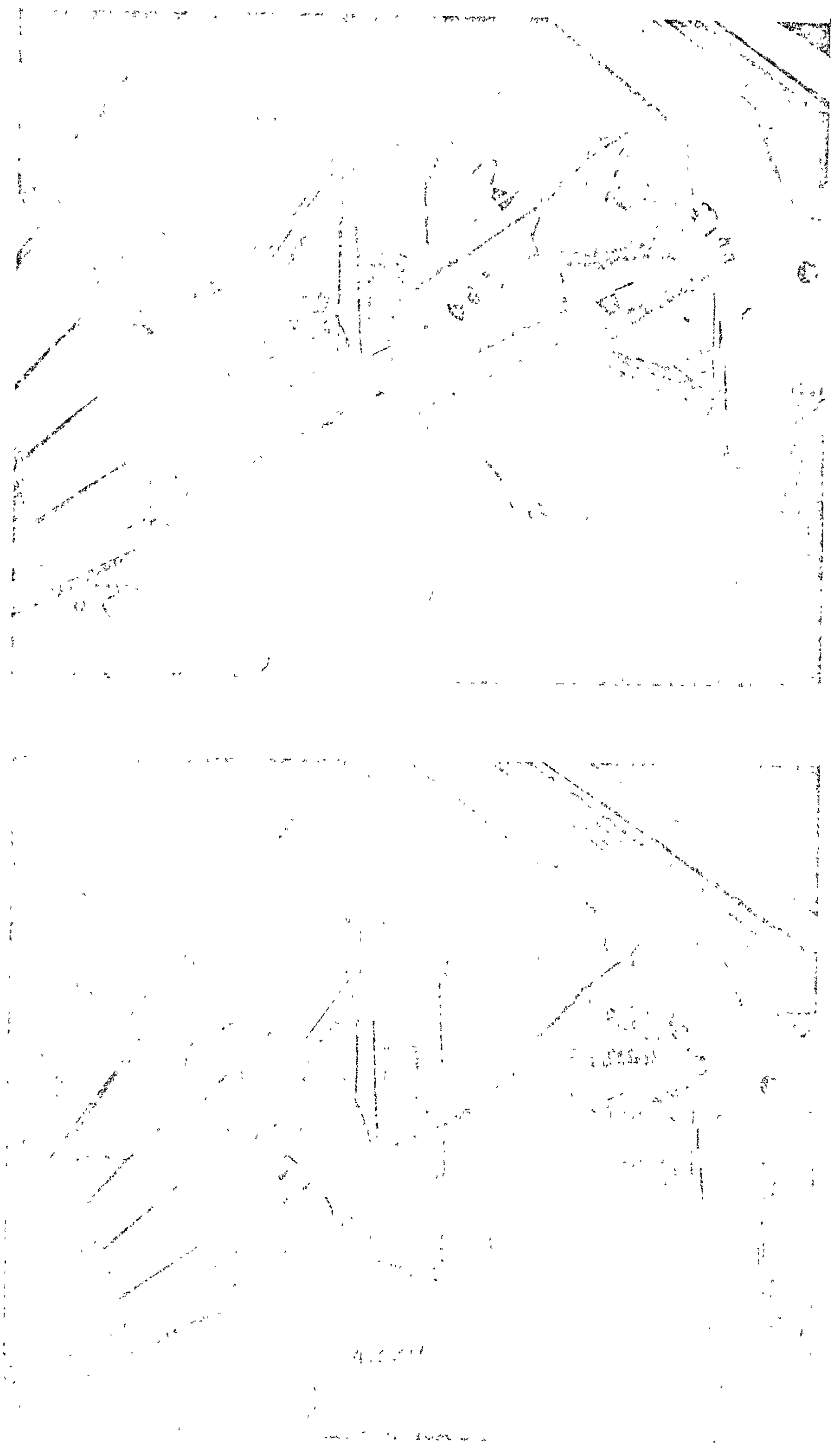
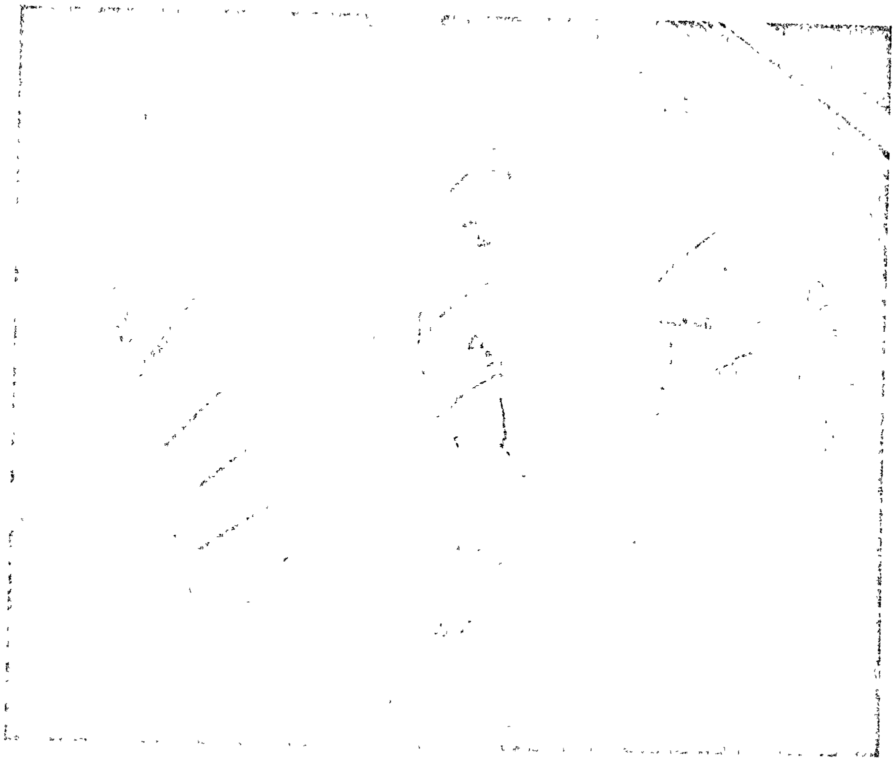


Fig. 27. Photographs Taken Before and After Test No. A-290 Showing Dummy Position



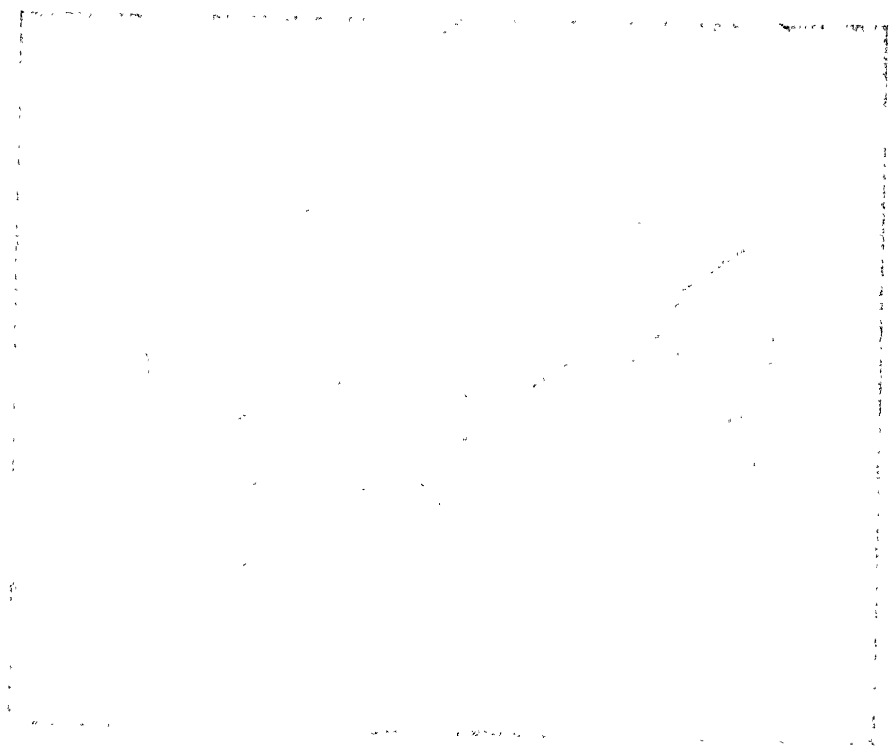


Fig. 28. Photographs taken Before and After Test No. A-237 Showing Dummy Position

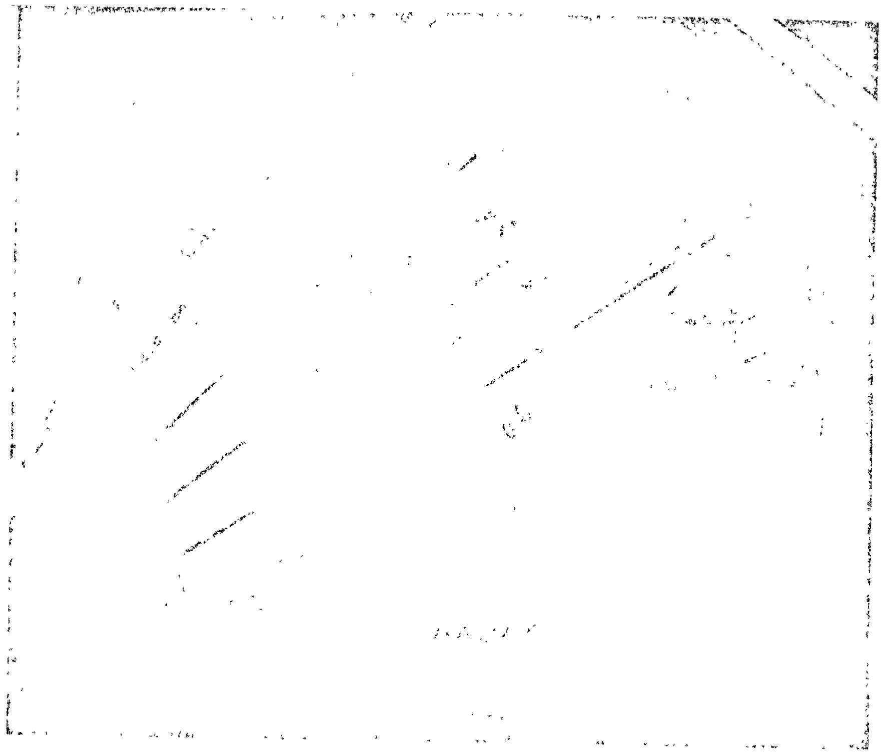


Fig. 29. Photographs Taken Before and After Test No. A-283 Showing Dummy Position

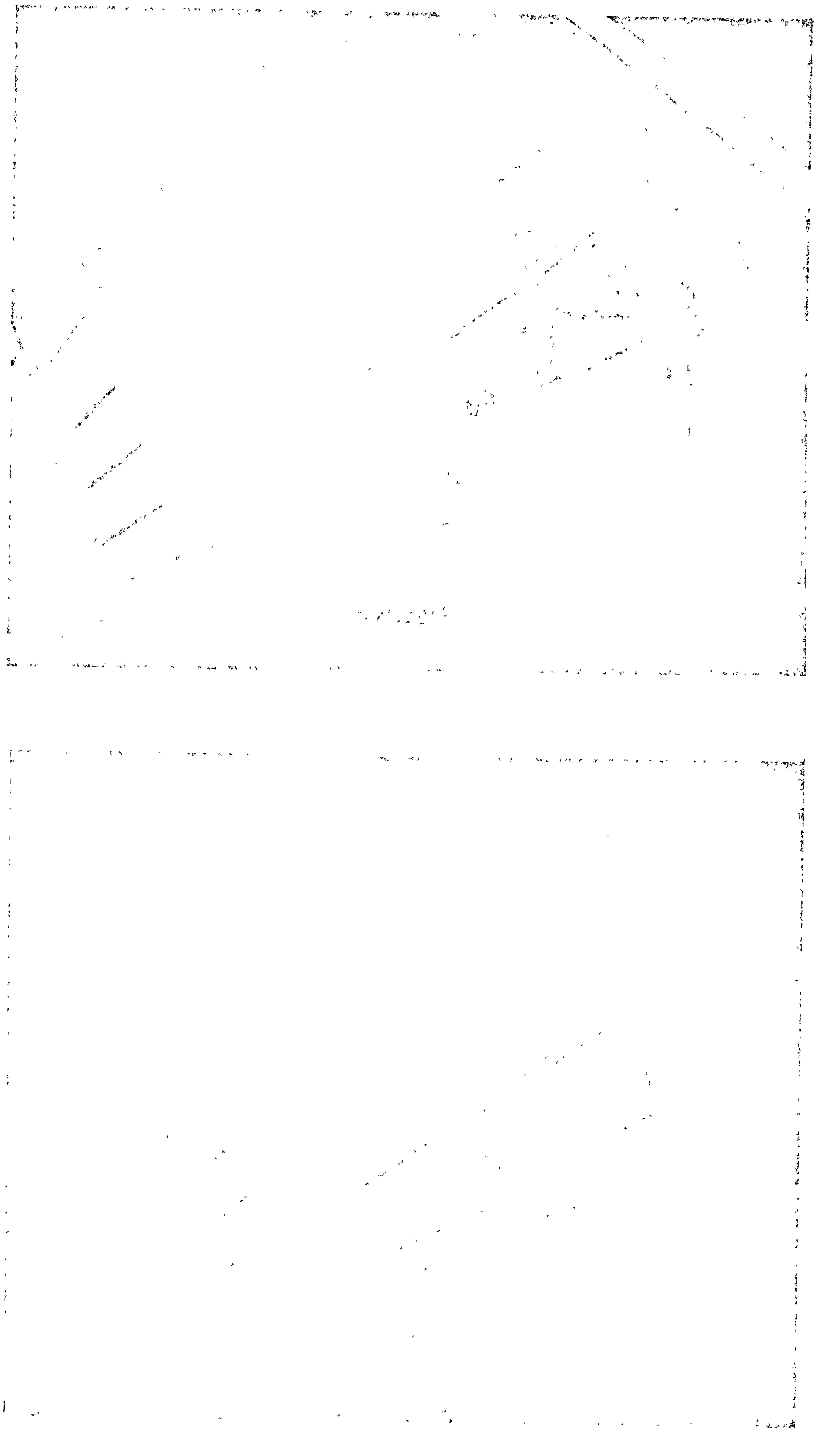
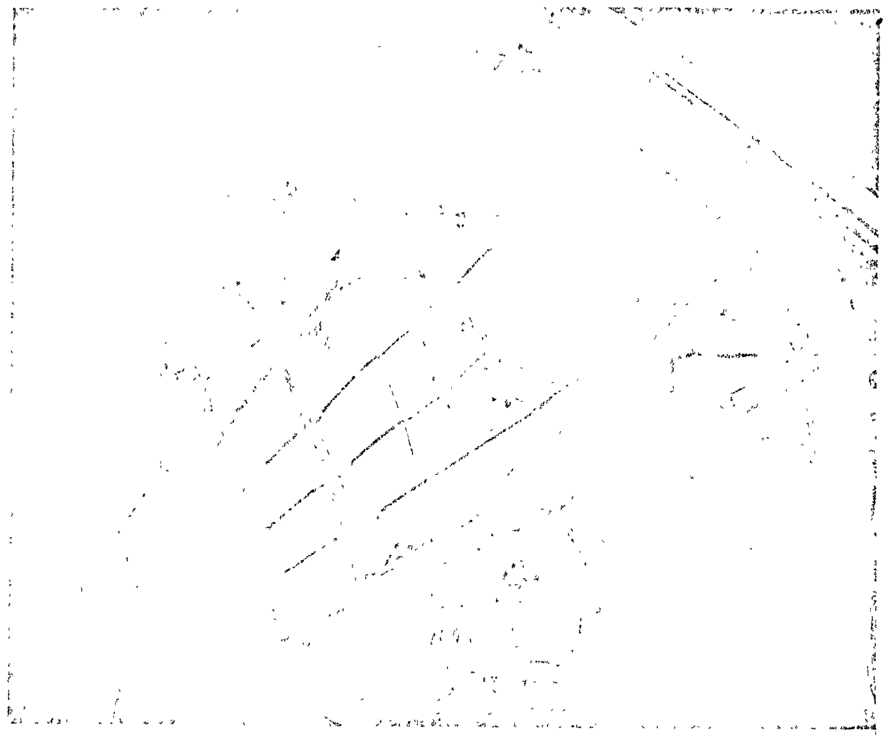


Fig. 30. Photographs Taken Before and After Test No. A-289 Showing Dummy Position



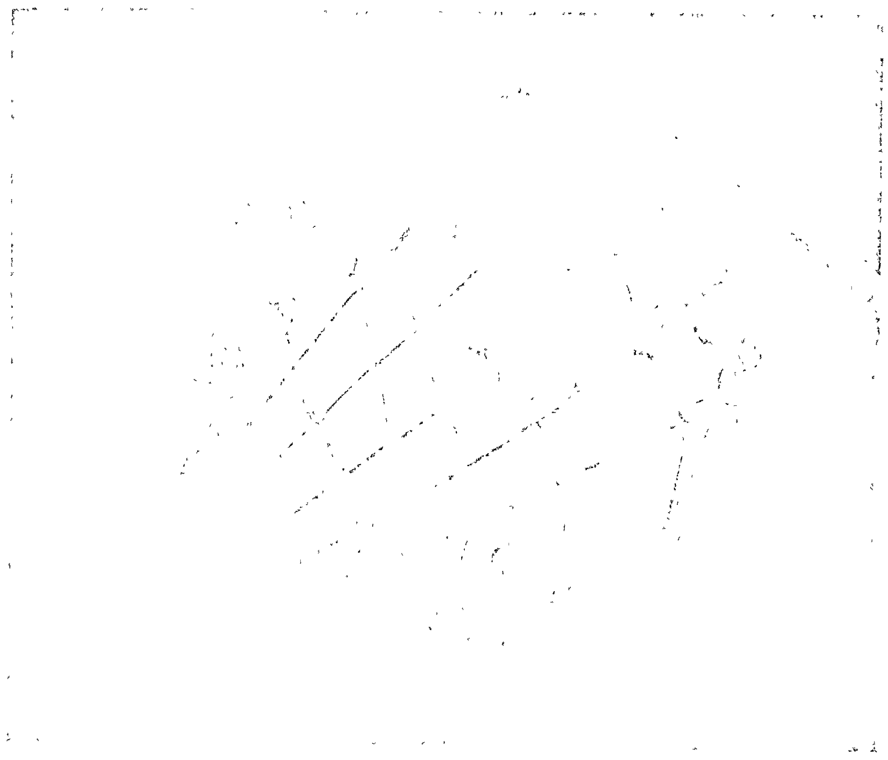


Fig. 31. Photographs Taken Before and After Test No. A-293 Showing Dummy Position

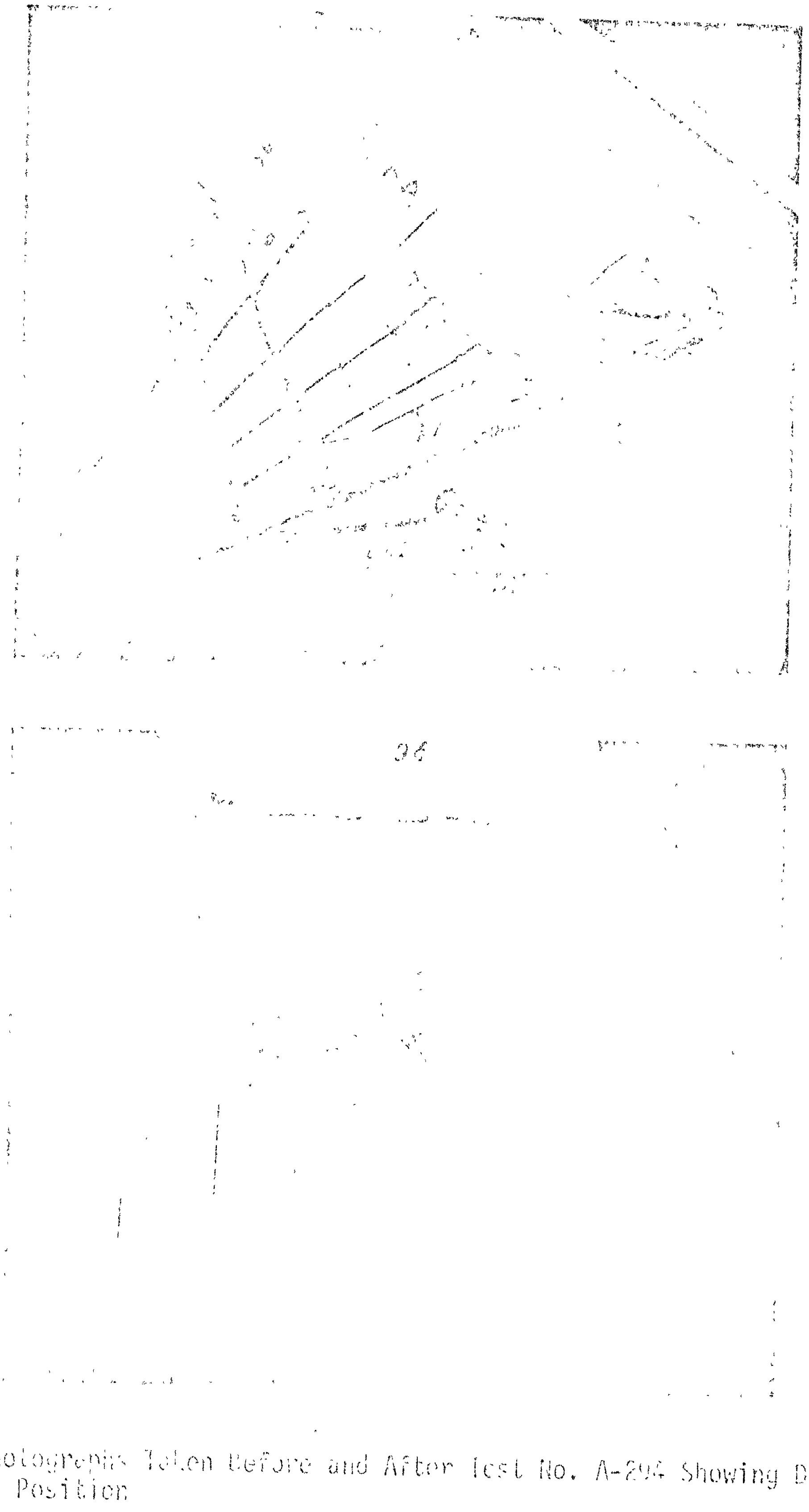


Fig. 32. Photographs Taken Before and After Test No. A-294 Showing Dummy Position

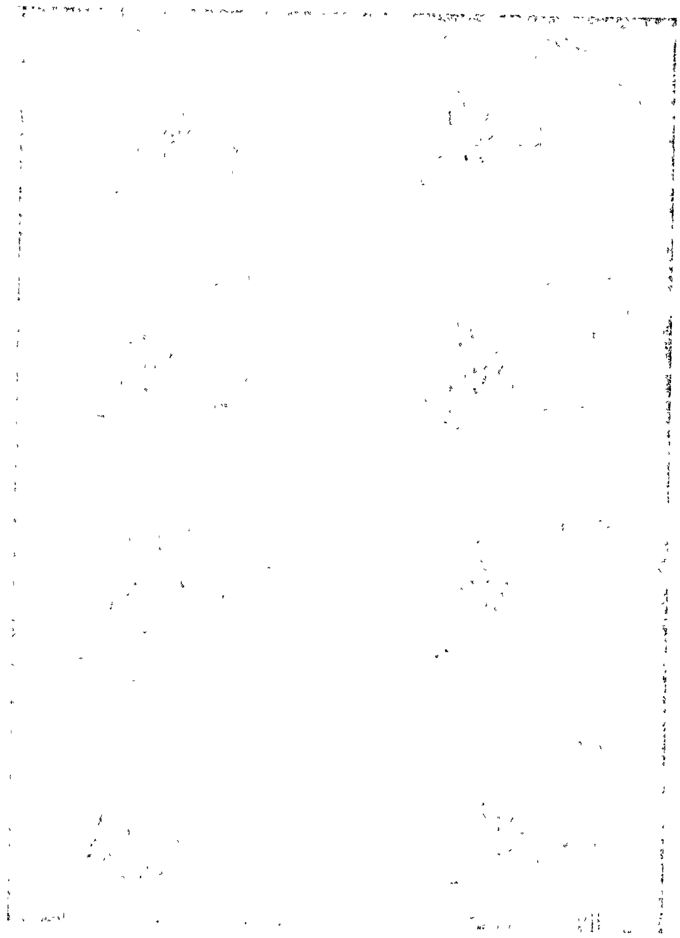
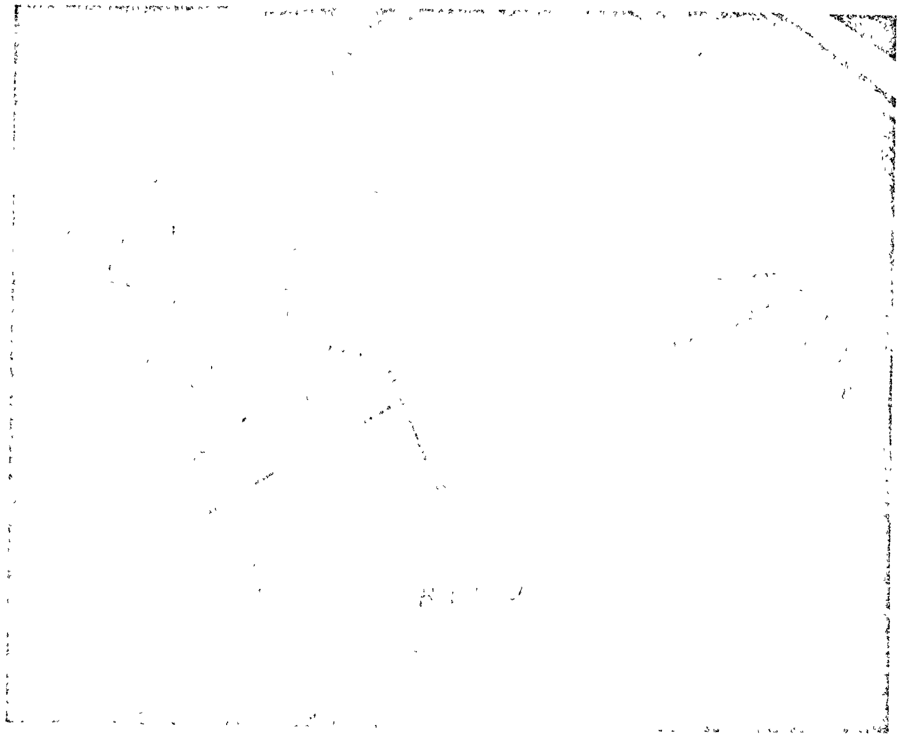


Fig. 33. Photographic Sequence (Test No. A-295)



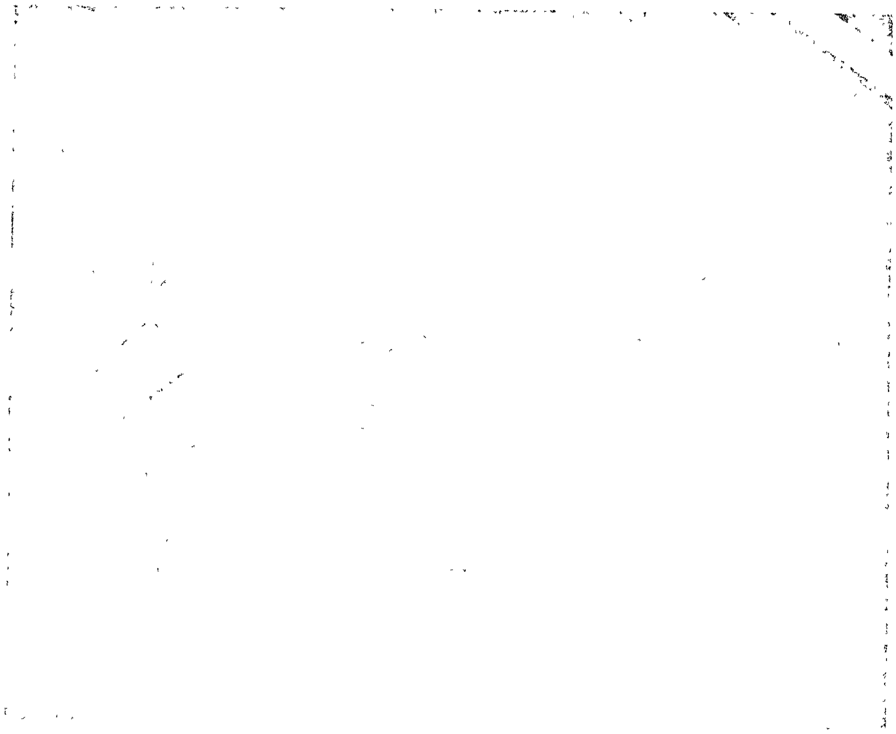


Fig. 34. Photographs Taken Before and After Test No. A-300 Showing Dummy Position

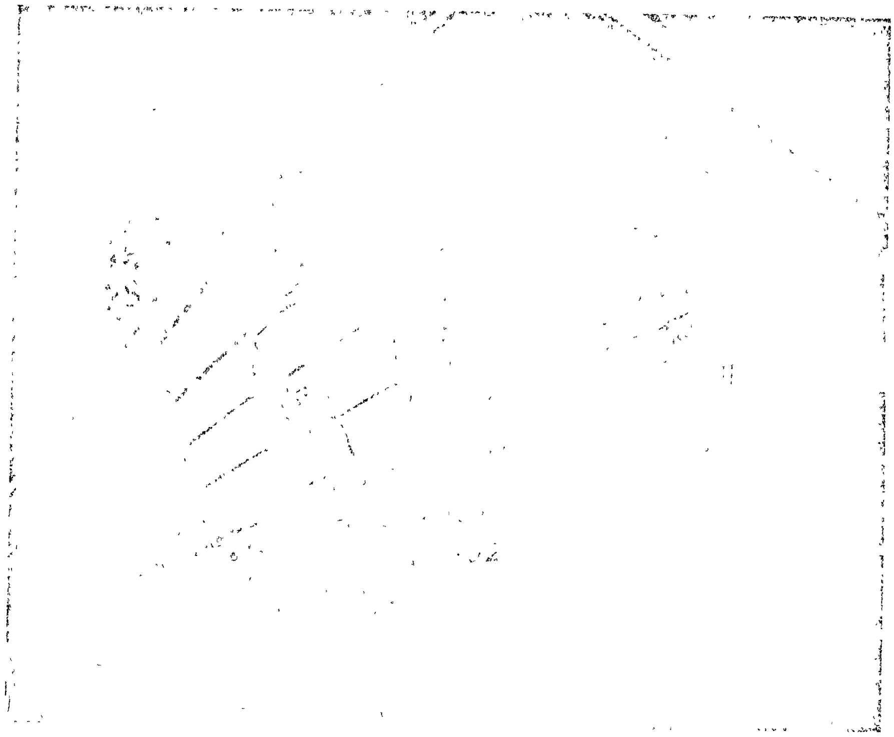


Fig. 35. Photographs of Dummies in "Sleeping Position"

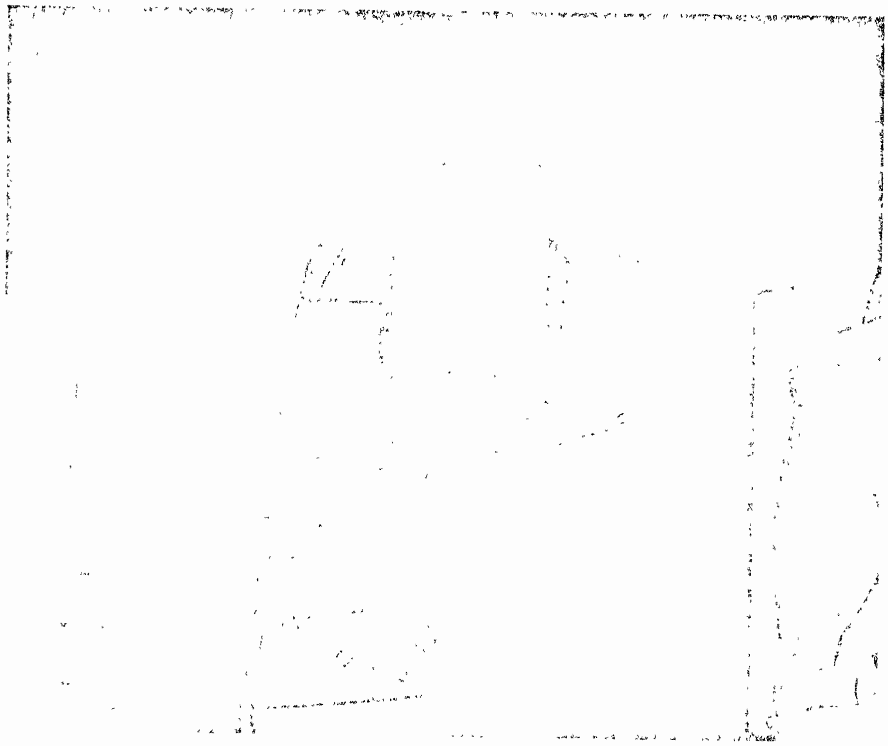


Fig. 36. Photographs of Initially "Sleeping" Dummy After the Tests

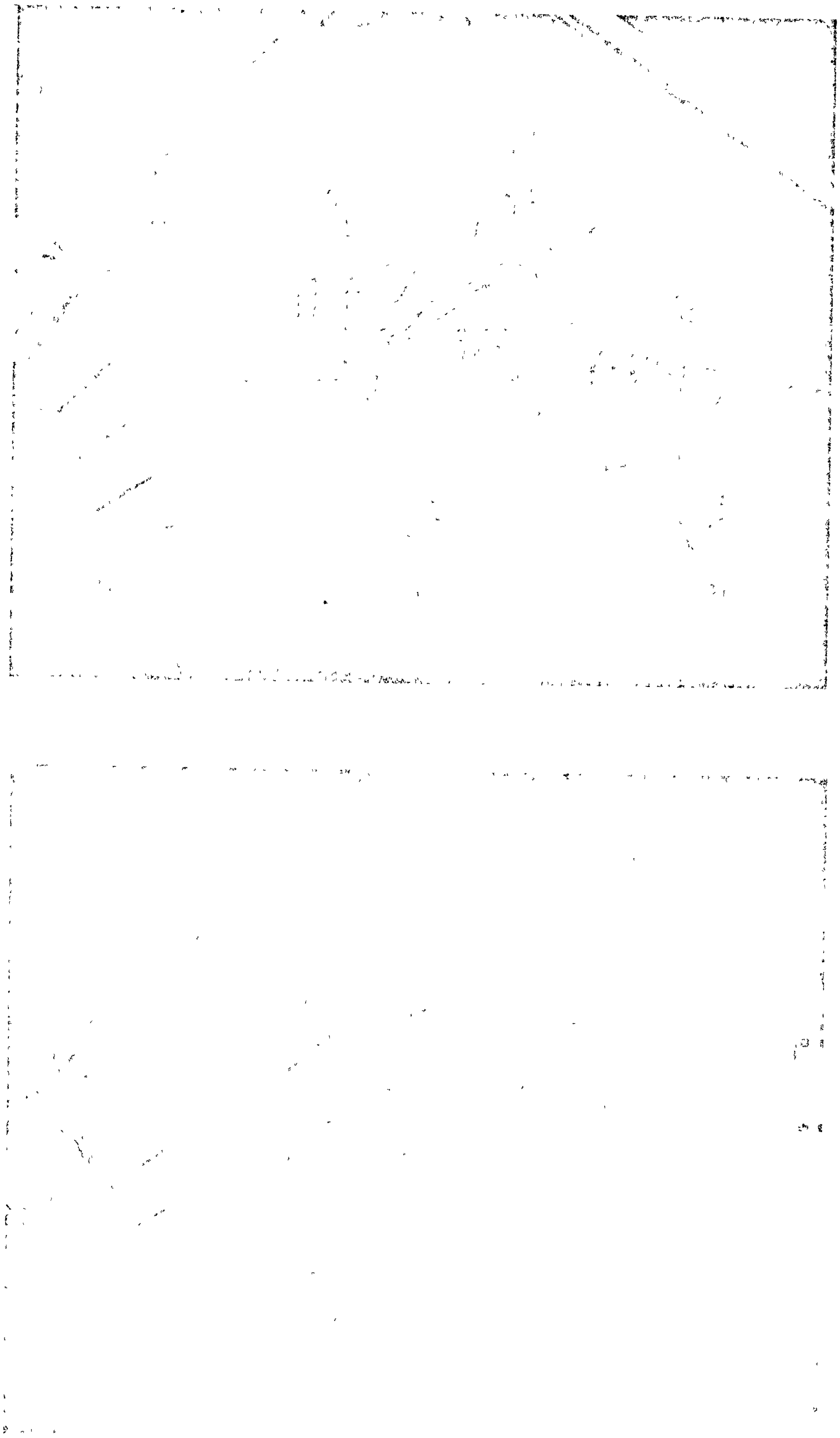


Fig. 37. Photographs of Runner Leaning Forward Initially

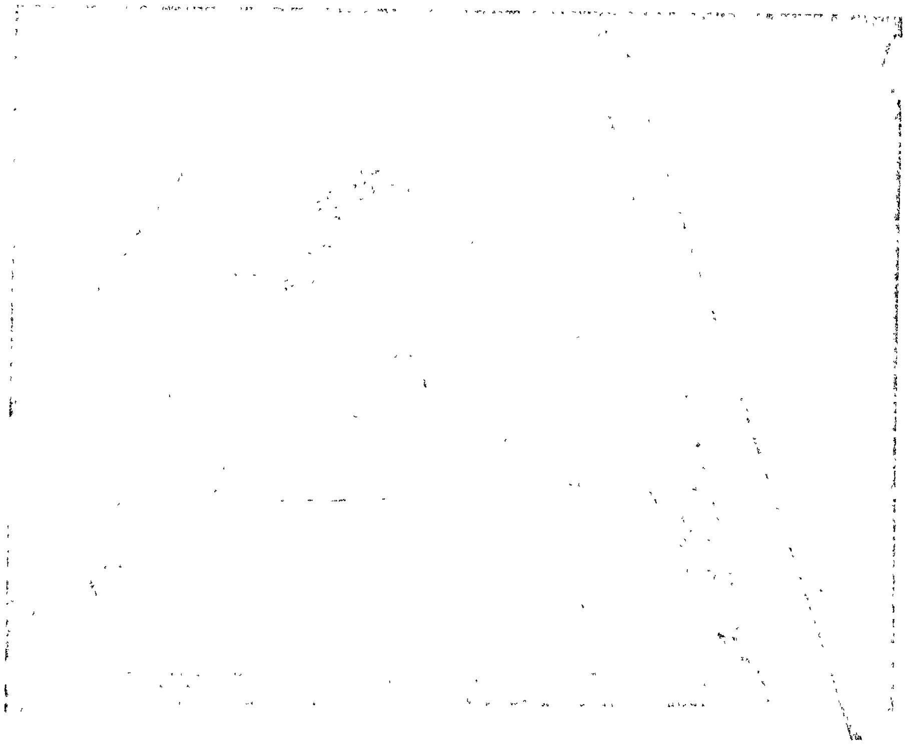


Fig. 38. Photograph of Windshield Broken by Hand Contact

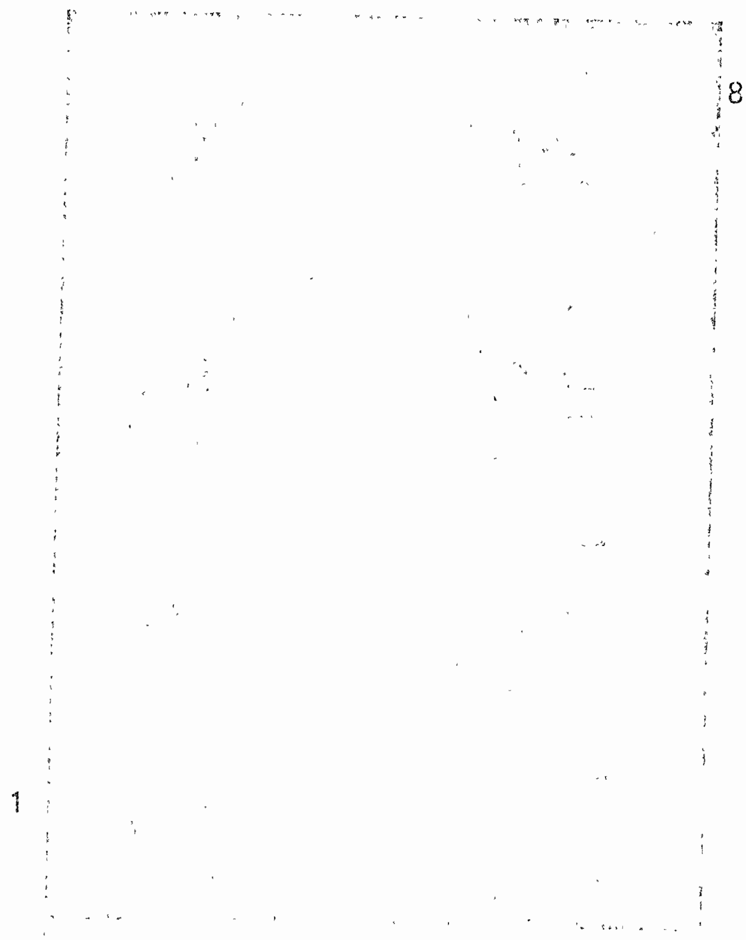


Fig. 39. Photographic Sequence (Test No. A-303)

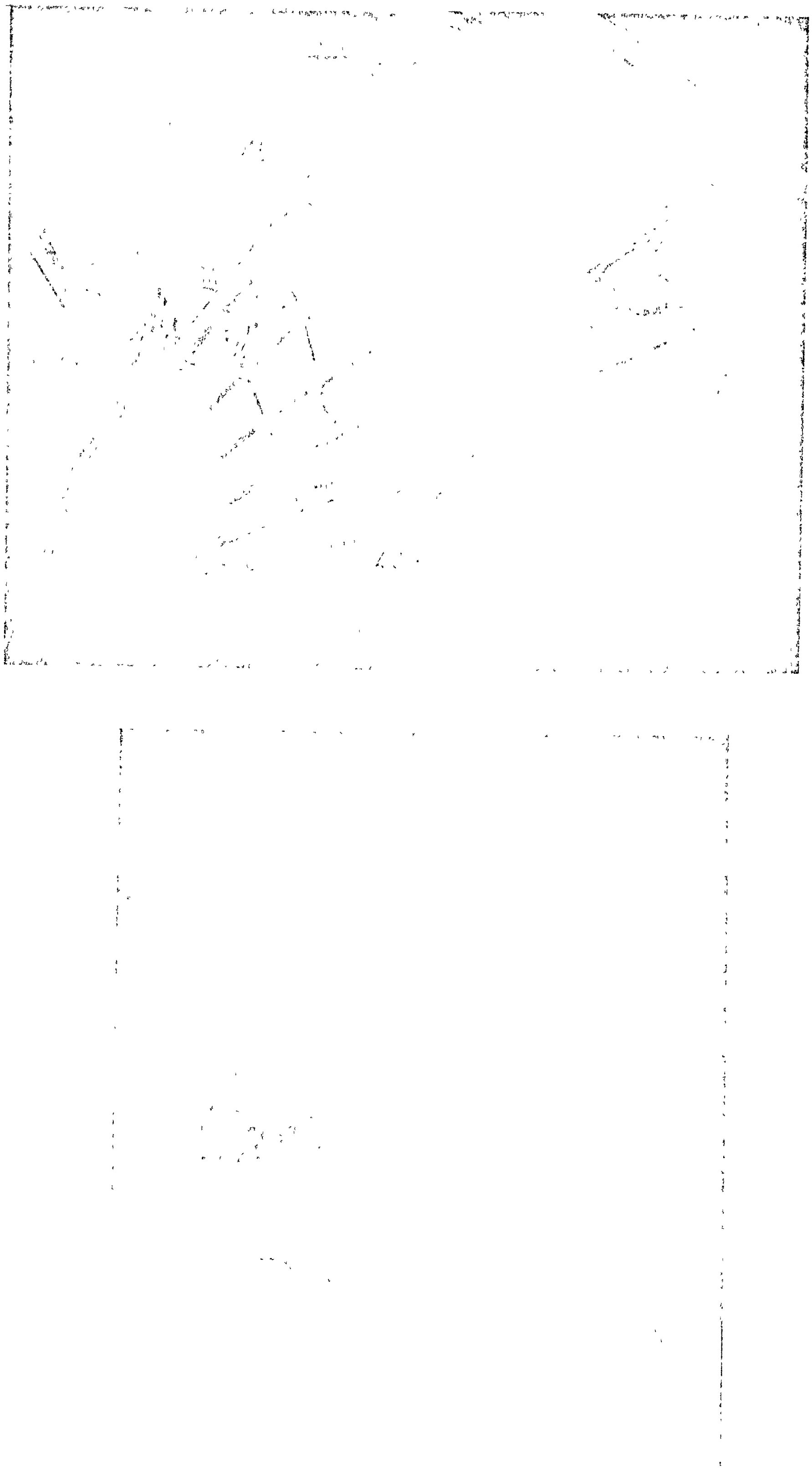


Fig. 40. Photographs Before and After Test of Dummy Wearing Glasses

the frames. There is no evidence from these tests that the wearing of eyeglasses would be a problem in the safe functioning of the airbag restraint system. Photographs taken before and after Test No. A-299 are shown in Figure 40.

3.7.4 Dummy Neck Structures

Two types of neck structures were used in the dummies during this test program. One was the standard arrangement of ball and socket joints found in the adult Sierra dummies and the other was a rubber neck fabricated by General Motors Corporation. The GM neck consisted of a rubber cylinder with two steel end plates for mounting to the head and torso of the dummy. The end plates are held in position by two cables extending through the rubber cylinder. The cables provide tension strength when the rubber cylinder is compressed during head motions relative to the torso. Exposed views of the two necks are shown in Figure 41.

Four tests involved rubber neck structures - two with a 50th percentile and two with a 95th percentile dummy. The head motions observed with both types of necks were quite similar although the extent of twisting and hyperextension appeared to be greater with the ball and socket arrangement.

Comparative G-loadings in both types of tests are given in Table IX. In most cases the G-loadings experienced by the head in the left-right direction were higher with the ball and socket arrangement. This may be due to the fact that during the tests the neck was twisted and the head jammed down on the left shoulder until it appeared to bottom out. Also, in most of the cases the chest anterior-posterior G-loadings were higher with the rubber neck. The fact that the rubber neck was elastically coupled to the torso may have caused some portion of the loads ordinarily carried by the head to be transferred to the torso. It was difficult to establish any patterns in the other accelerometer channels.

Fig. 41. Dummy Rubber and Ball-Socket Neck Structures

TABLE IX. DUMMY RUBBER NECK STRUCTURE COMPARED TO STANDARD BALL AND SOCKET JOINTS

Test	Dummy	Impact Velocity, mph	Neck	Head a-p G-level	Head s-i G-level	Head l-r G-level	Chest a-p G-level	Chest s-i G-level	Chest l-r G-level
A-292	50 M	29.8	rubber	33	20	18	33	8	10
average of values from A-203, A-284, A-285, A-299.	50 M	29.9	ball and socket	24	46	26	39	19	17
A-309	50 M	40.5	rubber	26	49	10	42	17	-
average of values from A-231, A-308	50 M	~40	ball and socket	21	29	35	40	20	15
A-306	95 M	30.2	rubber	23	36	25	45	16	8
average of values from A-201, A-209, A-304	95 M	29.9	ball and socket	27	32	21	36	14	8
A-307	95 M	41.1	rubber	45	44	18	50	15	9
A-233	95 M	40.5	ball and socket	24	45	33	41	25	6

If the phase of the motions experienced by the head and chest of the dummies differ in time, it is possible that hyperextension of the neck could occur. As this problem has been observed in some of the tests carried out in this program, it is recommended that a research program be initiated to develop a neck structure for dummies which yields motions similar to those observed in humans and which is capable of being used to estimate cases of potential trauma. This is not believed to be possible with either of the current neck structures.

3.7.5 Use Versus Non-Use of Lap Belts with Airbag Torso Restraint

As indicated in Table I tests were carried out involving both belted and unbelted dummies. No degradation of the safety potential offered by the airbag system was observed by eliminating the use of the lap belt in front end collision simulations at any of the speeds from 20 to 40 mph.

In the tests which were carried out to represent oblique impact (22.5° right front impact), some advantage was gained when a lap belt was used at the higher speeds and with the larger dummies. Their use tended to reduce the tendency to slide around the end of the bag into the direction of the impact and into the side structures of the body buck. This problem will be discussed in greater detail in Part 3.7.7 of this report which covers the oblique tests.

The motions experienced by the occupants using and not using seat belts were different in some cases. The energy-absorbing lower instrument panel was installed to replace the active lap belt system with a purely passive device. The major difference between the panel and the belts is adjustment. The panel must function for all sizes of occupants whereas the belts can be snugged up by smaller passengers.

The small 6-year-old child dummy was observed to submarine under the bag and panel, ending up on the floor of the body buck. When a lap belt was used the rather high deployment of the bag on the small occupant caused a possible [illegible]

The 5th percentile female dummy did not move as far forward as the child. The hip point moved forward about 6 inches when a lap belt was used compared with 12 inches in the unbelted case at 40 mph impact velocity. Hyperextension was more pronounced when a lap belt was used as the torso tends to pitch forward during peak belt loading.

The 50th and 95th percentile male dummies experienced similar G-loadings and motions when belted and unbelted. In this case belt stretch and slack was comparable to the excursion of the knees before contact with the lower instrument panel.

It appears from these tests that there is some advantage to the purely passive system when compared to an auxiliary lap belt in frontal collision. Hyperextension was reduced in the smaller dummies and the additional excursion of the torso did not appear harmful.

3.7.6 The Effects of Impact Velocity

The major restraint loads provided by the airbag system are applied to the chest. In Table VI it is seen that the resulting chest anterior-posterior G-loadings increase with impact velocity. It has been previously stated that the airbag restraint force can be formulated as

$$F = P\,\Delta A + T\,\Delta l$$

where $P\,\Delta A$ is the bag pressure times the contact area swept out by the occupant and $T\,\Delta l$ is the normal component of the membrane force per unit length of bag material times the length of the perimeter of the contact region. The membrane force, T, is also a function of pressure, P. For an ideal gas

$$P = \frac{mRt}{V}$$

where m is mass of gas, R is the gas constant, t is temperature, and V is bag volume. [illegible] volume is [illegible] having a tendency [illegible] tests which have been carried out, the bag is essentially full approximately 40 ms after the beginning of the collision simulation and hence, only a small quantity of gas is supplied to the bag from the reservoir after this time. Thus, the change in temperature of the gas in the bag is primarily a linear function of the mass flow rate out of the bag through the vents and of the rate of work done at the moving boundary of the airbag.

In the series of sled tests carried out during this test program the average impact decelerations were nearly the same in most cases. However, the duration of the sled pulse was increased for the higher velocities. This has the effect of increasing the length of time during which the occupant is in contact with the bag, thus yielding positive values of exhaust mass rate and work on the boundary of the bag over a longer period. As a result the rate of temperature change remains positive and the gas temperature can increase to a higher level in the higher velocity impacts. This will increase bag pressure and also the bag membrane force thus resulting in a stiffer bag capable of providing greater restraint force and higher G-loadings. This effect is moderated somewhat by the fact that the mass of gas in the bag decreases.

A geometric effect also contributes to the stiffening of the bag. At the time of initial contact with the bag, the tensile force in the membrane is directed parallel to the area of contact and offers little restraint. However, as the occupant sweeps through the bag the membrane forces rotate toward a perpendicular to the sweeping plane and thus become more effective in restraint. The further the occupant sweeps through the bag, the stiffer it becomes from this geometric effect. At the higher impact velocities, the occupant sweeps further into the bag resulting in higher G-loadings.

Several factors relating to the airbag system, the occupant, and the particular crash event itself will serve to define a limiting velocity beyond which restraint protection cannot be expected. The quantities mentioned in the preceding discussion which influence the G-loads applied to the occupant and, thus, limiting velocity are inflated bag shape, total stored gas volume, diffuser design, physical properties of the inflation gas, vent size to determine exit flow, and total stored gas pressure. This restraint force can be applied only for a limited time due to the finite inflation gas supply. The supply will be used up more rapidly for the larger occupants and for the higher speeds. The limiting velocities for this airbag system determined in the current testing program have been given as a function of occupant size and impact direction in Part 3.7.1 of this report.

3.7.7 <u>Oblique Impact</u>

A series of tests, as listed in Table J, was initiated to determine the level of protection offered by an airbag restraint system in an oblique impact. Occupants were supplied with supplementary lap belts or rode unbelted at speeds ranging from 20 to 40 mph. In order to represent an oblique impact on the HSRI impact sled, the 1966 Ford Galaxie body buck was oriented at an angle of 22.5° with respect to the direction of travel of the sled in order to simulate a right front oblique impact. A plexiglass plate supported by tubular aluminum struts was used to represent right door side structures and to allow camera coverage of the right front passenger. The case of left front oblique impact was not considered in this test program because of the lack of body buck hardware such as the steering wheel and a possible airbag for the driver at the time the right front passenger airbag system design was finalized. A photograph showing the body buck mounted at an angle on the HSRI impact sled is included as Figure 4[illegible].

Other than the oblique mounting of the body buck, this series of tests was conducted in exactly the same manner as the forward impacts. Several differences in the level of impact protection which was offered to the occupants were noted particularly with respect to twisting of the head while the torsos of the dummies tended to slide around the end of the airbag toward the direction of the impact, with respect to a general increase in G-loadings experienced by the dummies caused by contact with the panel representing the door side structures, and with respect to a higher degree of restraint offered by the supplemental lap belt.

Peak values of acceleration recorded from the head and chest triaxial accelerometer packs are listed in Table X. A general increase in the magnitude of these quantities will be noted when compared with values recorded in the forward impact tests and listed in Table VI. This is particularly in evidence in the tests conducted at the higher speeds where contact occurred with the interior of the vehicle and in the left-right accelerometer channels both in the head and chest.

During the tests the anthropometric dummies moved in the direction of the impact. This occurred in two ways. In the case of the 6-year-old child and 5th percentile female dummies, both of which had some tendancy to submarine under the bag, the motion was directly toward the impact. One case of this is Test A-222 (See Figure 43) where the head was twisted to the left and then bent down. The adult male dummies, which received more support on the upper torso, also tended to move in the impact direction, leading with the right shoulder and sometimes sliding around the bag as is shown in Figure 44, a sequence photograph of Test No. A-261. This path for the motion should not be considered necessarily injurious as G-loadings were mostly within tolerance limits and dummy neck motions have not been proved to represent in vivo human neck motions.

The use of a supplemental lap belt had a tendency to reduce the amount of motion experienced by the dummies in the direction of the impact, particularly with the small [illegible] on the knees and the energy absorbing

TABLE X. PEAK ACCELEROMETER READINGS FOR 22.5° OBLIQUE AIRBAG TESTS

[illegible]	[illegible]	Head a-p G-level			Head s-i G-level			Head l-r G-level			Chest a-p G-level			Chest s-i G-level			Chest l-r G-level		
		20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph	20 mph	30 mph	40 mph
[illegible]	yes	10	20	14	32	36	25	20	56	40	17	19	24	10	-	10	14	35	20
[illegible]	no	10	30	53	40	40	15	32	45	76	11	25	25	10	20	20	7	25	33
[illegible]	yes	15	17	30	30	34	60	21	25	35	20	20	60	33	25	35	17	25	40
[illegible]	no	12	25	-	15	25	-	26	55	-	10	20	-	25	20	-	15	-	-
[illegible]	yes	20	15	39	27	37	28	14	30	37	20	45	37	8	10	-	15	20	50
[illegible]	no	14	15	30	20	20	-	15	15	30	15	30	22	15	20	-	25	25	40
[illegible]	yes	16	44	80	16	35	35	25	35	25	22	40	33	15	40	18	15	45	42
[illegible]	no	13	67	-	35	42	-	25	33	-	25	45	-	15	20	-	15	35	-

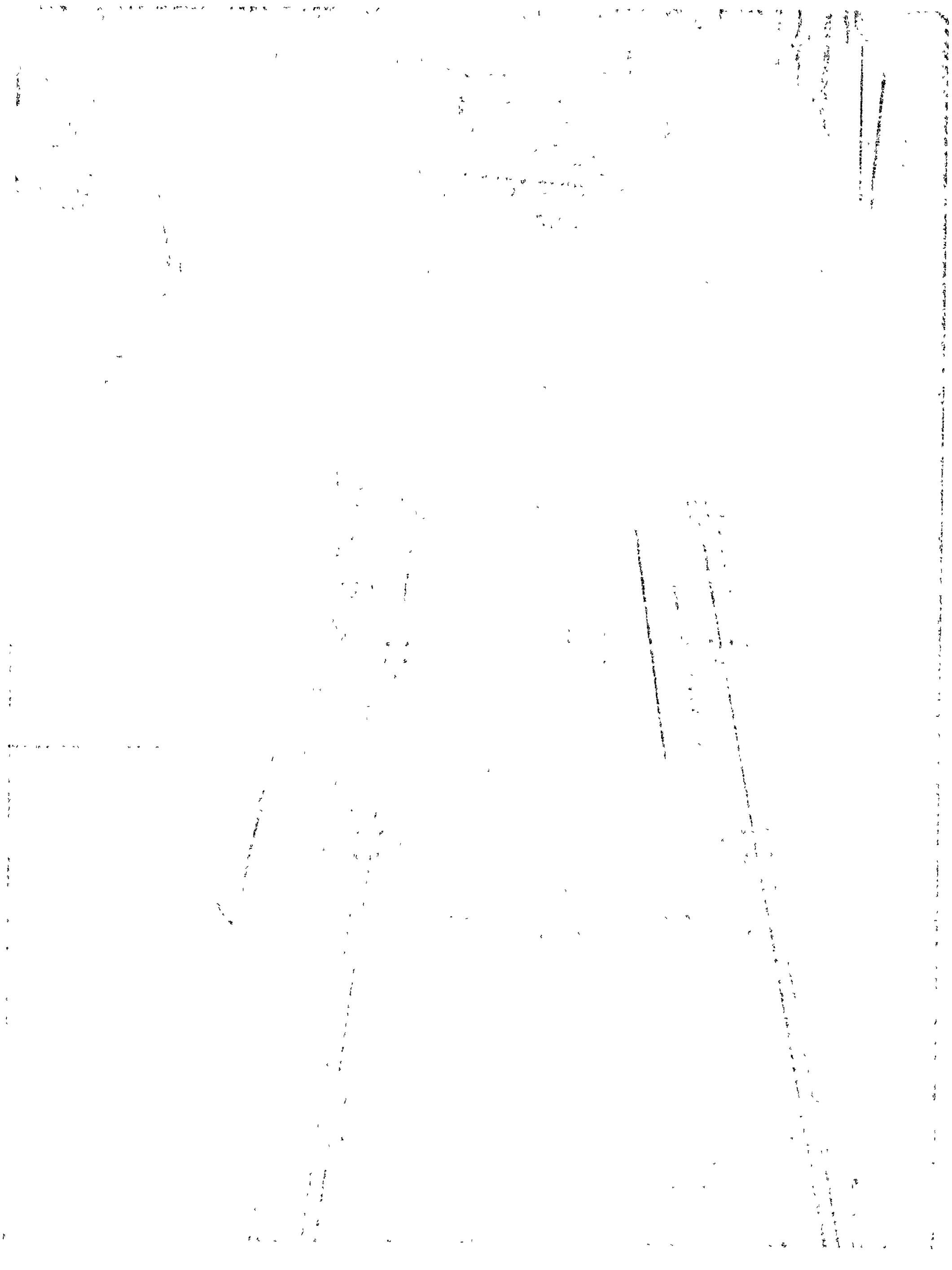


Fig. 42. Body Buck Mounted for Oblique Impact

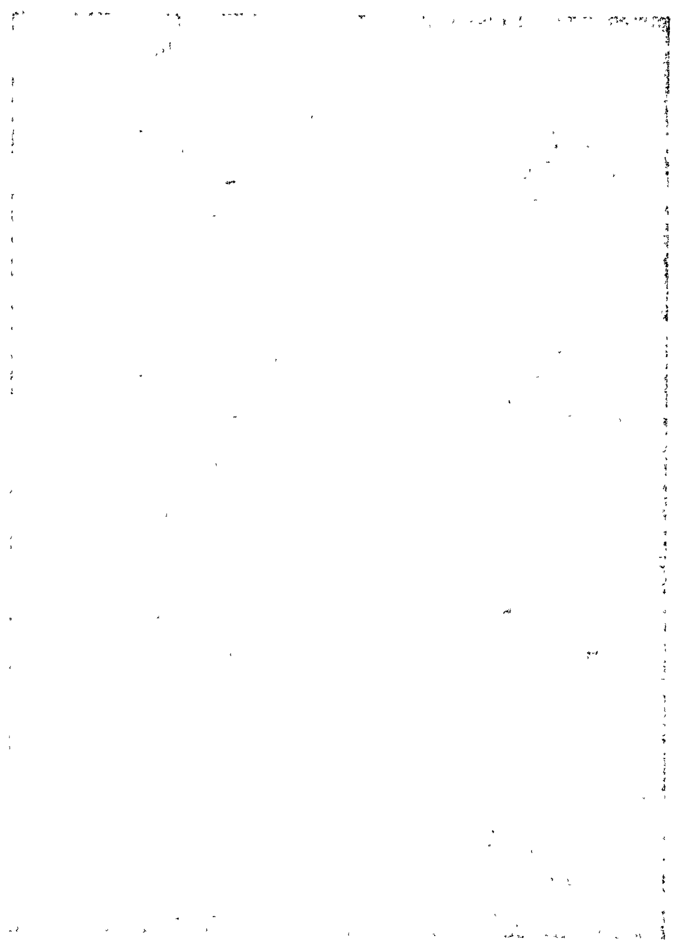
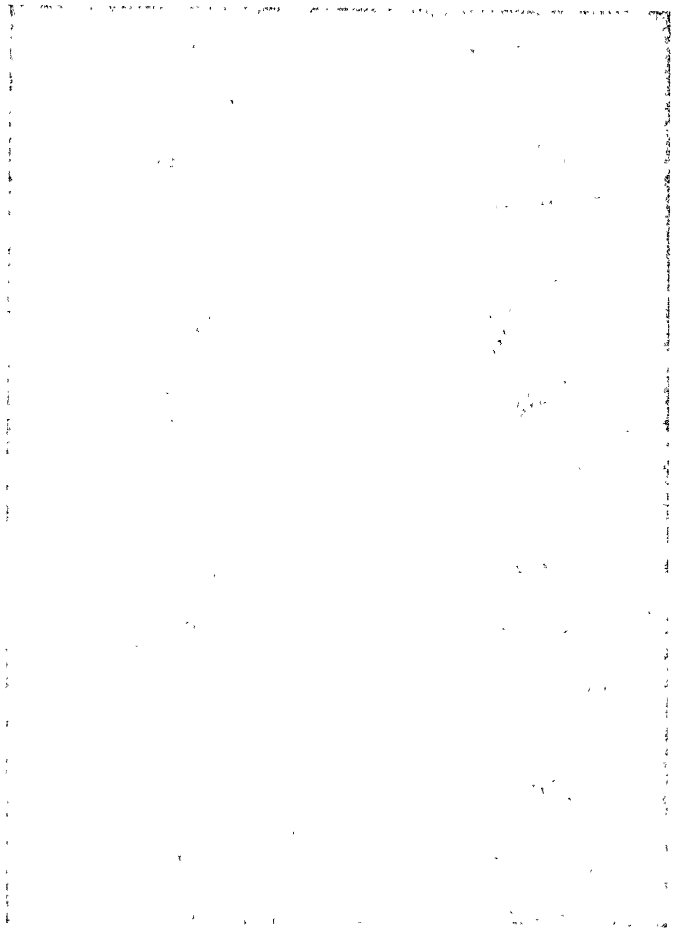


Fig. 43. Photographic Sequence (Test No. A-222)



1

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Fig. 44. Photographic Sequence (Test No. A-261)

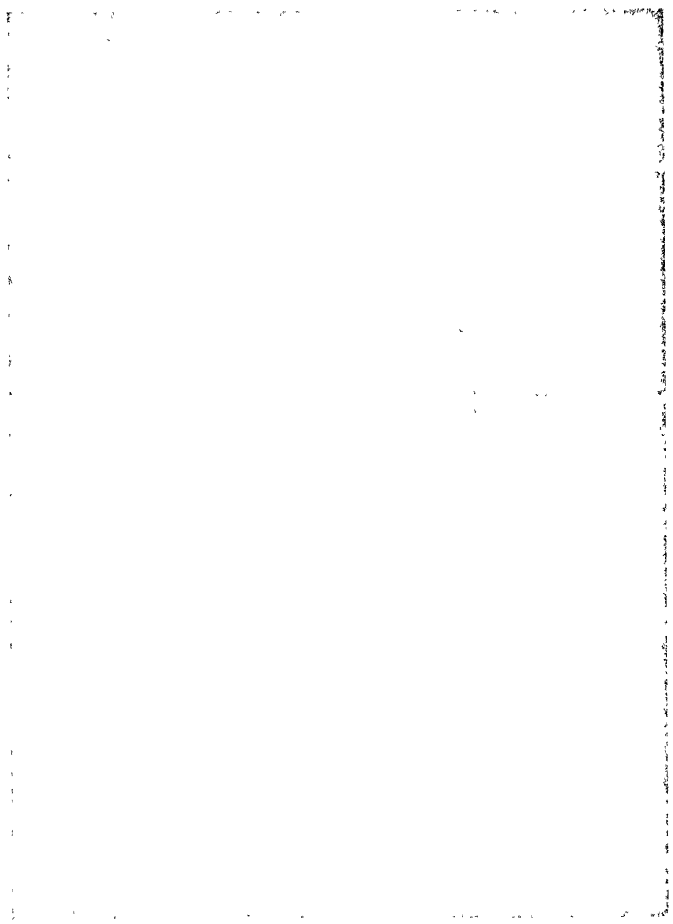

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Fig. 45. Photographic Sequence (Test No. A-257)

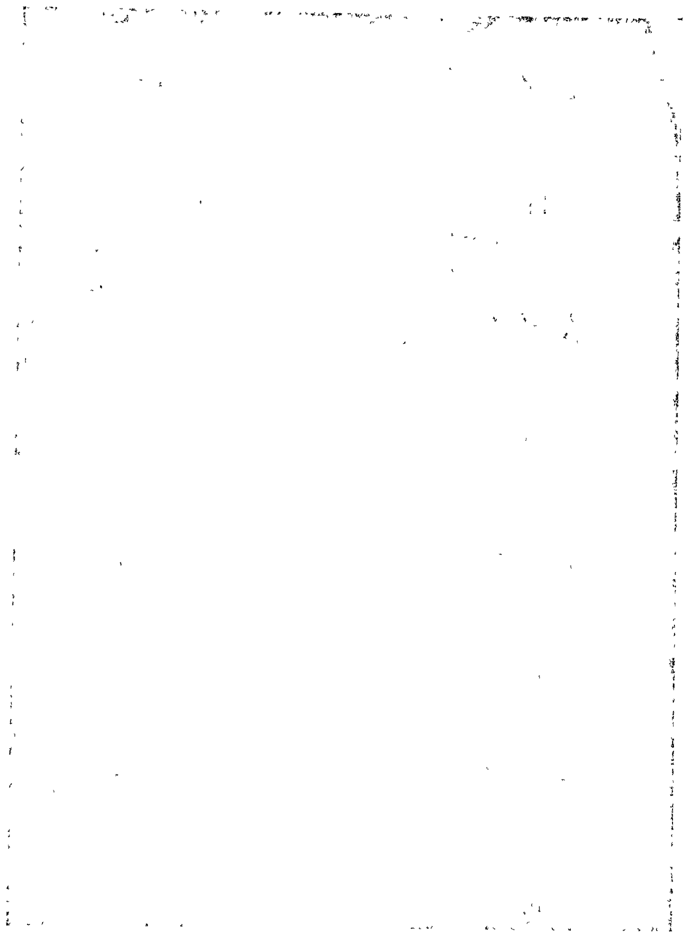

Fig. 46. Photographic Sequence (Test No. A-224)

lower instrument panel. Figure 45 shows Test No. A-257 where the 5th percentile female dummy moved toward the door structures in a 30 mph impact sliding almost off the seat cushion while Figure 46 shows Test No. A-224 where the lap-belted dummy experiences considerably less excursion of the hip. The seat was in its forwardmost adjustment position for these tests. Comparative peak lap belt loads are given in Table XI.

The conclusion which can be drawn from this portion of the test program is that considerable protection is possible for a right front passenger with an air-bag restraint system in impacts which are not frontal. In the case of 22.5° right front oblique impact, marginally acceptable restraint performance has been observed at 30 mph for the 50th percentile male and 6 year old child dummies without the use of supplemental lap belts.

3.7.8 Variation of Deceleration Pulse Shape

Impact sled tests and analytical studies were conducted to determine the effect of a variation of deceleration pulse shape on the level of protection provided for the occupant. Variations of the HSRI decelerator pulse were made from its normally trapezoidal shape with a magnitude of approximately 17 G's to higher and lower G-levels and to a ramp-shaped pulse with the peak G-level occurring near the end of the pulse. In order to compare the effects of the HSRI impact sled pulse with the effects of actual full-scale vehicle crash pulses, the HSRI Two-Dimensional Mathematical Crash Victim Simulator[21] was exercised with deceleration data from: (1) a 40.5 mph HSRI impact sled test; (2) a 38 mph frontal barrier crash; and, (3) a 38 mph frontal pole crash. The full scale crash data was obtained at Cornell Aeronautical Laboratory, Inc.[22]

TABLE XI. BELT LOADS FOR FRONTAL AND OBLIQUE IMPACT TESTS AT 40 MPH

Dummy Size	Belt Load, Lbs. Front Impact	Belt Load, Lbs. Oblique Impact
6-yr. child	1370	1500
5 F	2420	2140
50 M	2110	2580
95 M	1830	1940
6-yr. child	1340	1200
95 M	1500	1620

The HSRI impact sled deceleration pulses are described in Table XII along with the resulting peak body accelerometer readings. In comparing the results from the low deceleration levels of Test Nos. A-174 and A-178 with the results of Test No. A-179, it is seen that the chest accelerometers all produced lower readings as should be expected. No clearly discernible trend is observed in the head accelerometer readings. In Test No. A-284 involving a ramp function with its peak late in the deceleration event, both head and chest G-levels were higher than for Test No. A-292 where the deceleration pulse approximated a trapezoid. This shows the desirability of involving the occupant with the airbag as early in the event as possible to make use of as much of the inflation gas as possible.

A comparison between the HSRI impact sled deceleration pulse and representative full scale barrier and pole crash pulses is made in Figure 47. The flat barrier pulse possesses an initial spike representing initial sheet metal collapse followed later by pulses representing engine involvement. The pole barrier pulse does not show significant sheet metal crush but includes the effects of engine involvement. The impact sled pulse provides early involvement of the occupant compartment in the pulse while avoiding the high G-levels associated with engine involvement.

The HSRI Two-Dimensional Mathematical Crash Victim Simulator was exercised for these three pulse shapes. The properties and geometry of the airbag restraint system and the vehicle interior were representative of the configuration used in the evaluation test program.

The peak body accelerometer readings are given in Table XIII for the HSRI sled and the full-scale vehicle pulses. The impact sled pulse yielded a more gentle ride for the simulated occupant than did either the flat barrier or the pole barrier [illegible] by the G-levels. This is due to the fact that the deceleration is spread more evenly over the duration of the pulse.

TABLE XII. PEAK BODY ACCELEROMETER READINGS FOR VARIOUS DECELERATION PULSES

[illegible]	[illegible]	[illegible]	[illegible] Velocity, mph	Deceleration Pulse Shape	Peak G-level	Total Duration	Head G-levels			Chest G-levels		
							a-p	s-i	l-r	a-p	s-i	l-r
[illegible]	[illegible]	Yes	28.6	low level trapezoid	13	110 ms	31	23	10	39	19	10
[illegible]	[illegible]	Yes	30.0	high level trapezoid	20	80 ms	20	35	-	50	20	20
[illegible]	[illegible]	No	29.4	ramp with late peak	26	105 ms	30	46	25	56	14	23
[illegible]	[illegible]	No	29.8	standard trapezoid	16	100 ms	33	20	18	33	8	10

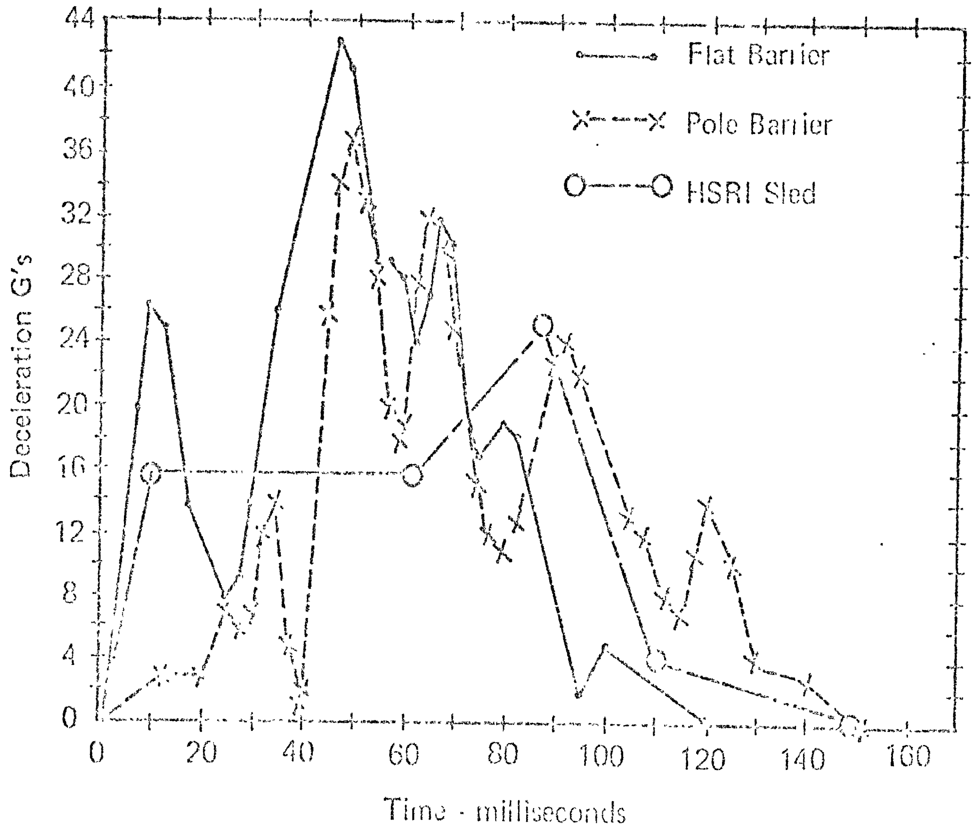

Fig. 47. Deceleration Pulse Shapes

TABLE XIII. BODY ACCELEROMETER READINGS FOR SLED AND VEHICLE CRASH PULSES

Test No.	Dummy	Belt Use	Impact Velocity, mph	Deceleration Pulse Shape	Peak G-level	Total Duration	Resultant Head Accelerometer G-level	Resultant Chest Accelerometer G-level
[illegible]	50M	No	40.5	HSRI sled	25	150 ms	29	32
[illegible] 272	50M	No	38	flat barrier	43	120 ms	32	43
[illegible]	50M	No	38	pole barrier	37	150 ms	31	35

The conclusion which can be reached from this study is that the occupant compartment deceleration profile which is determined as a function of the vehicle crush characteristics is an important variable in influencing airbag restraint system performance. It is advisable to involve the occupant with the restraint system as early as possible and keep the decelerative G-levels as low as possible.

4.0 ANALYTICAL STUDIES

At the same time as the test program was being conducted, an analytical study was being made using the HSRI Two-Dimensional Crash Victim Simulator[21]. The objectives of this parallel effort were to simulate prototype airbag restraint systems using mathematical models of the crash victim and to validate the results of the computations with impact sled tests involving both lap-belted and unbelted dummies. This part of the report contains sections describing the techniques which have been used to mathematically describe airbag restraint system performance, the preparation of computer data sets to describe the verification tests which were carried out on the impact sled, and comparisons between the analysis and the experiments.

4.1 MATHEMATICAL SIMULATION OF AIRBAG RESTRAINT SYSTEM PERFORMANCE

The HSRI Two-Dimensional Mathematical Crash Victim Simulator has been used to model the performance of an airbag restraint system for comparison with impact sled tests. This model contains suitable physical descriptions of the occupant, the protective environment offered by an airbag, and the deceleration G-level describing the impact event in order to provide meaningful correlation between analysis and experiment.

Contacts between an occupant and the interior of a vehicle are represented as force interactions between circular segments attached to the various body elements of the occupant and stationary flat surfaces representing the interior of the vehicle including the components of the restraint system. The magnitude of the force of contact is written as a complex polynomial function of the penetration and rate of penetration of the contact sensing elements into the various components of the vehicle interior. The force-penetration relations allow any contact surface to absorb energy because permanent displacement of contact surfaces can occur when a force is applied. These features are all necessary for modeling force interaction between an airbag and an occupant.

An initial location must be specified for each flat surface segment used to model the interior of the vehicle and its restraint system. Because of this it is not possible to model deployment of the bag with the analysis as it is presently written. In the tests conducted during the experimental program it was observed that motion of the head and hip of the dummies was approximately 1 inch or less during the first 40 ms of the sled deceleration. This was also the approximate time required for full deployment of the airbag. Therefore, it has been assumed that the predictions of the model, using a vehicle interior in which geometry of the bag is based on its deployed position, would not vary more than a few percent from predictions of a model using an airbag which deploys. It is possible that this model for the location of the airbag surfaces would be inadequate for studying cases where deployment is very slow, impact velocity is high, or actuation is inadvertent.

Two types of data must be obtained from the experiment to provide input data for the analytical description of the airbag performance. One of these is the position of the bag and the other is its ability to resist force. The initial position of the bag was estimated directly from high speed motion pictures of the impact simulation while the force-penetration relations for the head and torso (the body elements most often interacting with the airbag) were obtained directly from the experimental data gathered for each test. This was necessary as an experimentally validated three-dimensional thermodynamic model of the airbag capable of providing the force-penetration relations as output was not available during the time span of this project. To develop the force-penetration relations [illegible] both high speed photography and [illegible] accelerometer data. The motions of the head and chest were measured using photometric techniques from the movies and applied forces estimated using the G-levels developed in the body in conjunction with known body segment weights. With this information as data the HSRI Two-Dimensional Crash Victim Simulator was then exercised.

4.2 CORRELATION BETWEEN ANALYTICAL AND EXPERIMENTAL RESULTS

The two basic types of tests conducted during this project involved belted and unbelted occupants. Data was acquired from one test of each type and prepared as input for the purely mathematical simulation. After exercising the analytical model and comparing predicted with experimentally determined results, it was concluded that the analytical model is valid and can be used to predict system performance trends when airbag system force-deformation and geometric parameters are varied.

4.2.1. Data Acquisition

The two tests which were chosen for the purpose of correlation with analytical studies were Test Nos. A-179 and A-292. These were regarded as tests typical of the overall test matrix and both involved 50th percentile male dummies riding the sled at approximately 30 mph. In Test No. A-179 the dummy was supplied with a lap belt. The data for these tests were gathered in the manner described in Part 3.4 of the report.

4.2.2. Preparation of the Input Data Set for Computation

The preparation of data sets for exercising the computer model included four major parts: (1) determination of the position of the dummy relative to the vehicle interior at the beginning of the deceleration; (2) determination of the initial impact velocity and the deceleration pulse; (3) determination of the location of the airbag as well as its force deformation properties; and (4) [illegible]

In order to determine the position of the dummy relative to the interior of the vehicle, a tracing was made of the first frame of the high speed motion picture of the test. The locations of head target, neck joint, shoulder joint, H-point, and knee point were then noted on the tracing. These points were then connected and the resulting lines used to determine the angular orientation of the various body segments as shown in Figure 48.

The sled deceleration G-pulse which was measured for each of the two tests is shown in Figure 49. These curves were used as input data for exercising the mathematical model. The velocity at the beginning of the impact was 30.0 mph for Test No. A-179 and 29.8 mph for Test No. A-292. A rebound of approximately 3 mph occurred in each case.

In order to study the dynamic interaction of the dummy occupant with the restraint system and vehicle, it was necessary to determine the force-deformation interactions between the dummy and the airbag. Three techniques were available to the project for accomplishing this. The first of these involved the use of experimental data from controlled tests conducted outside HSRI where torso blocks were dropped into rapidly inflating airbags. This was rejected in that the torso blocks were not equipped with heads making impossible the determination of a force-deformation characteristic for head-bag interaction. The second technique involved use of an analytical description of airbag performance [15] for which no experimental validation is yet available. This technique was also rejected in favor of the third technique which involved determination of force-deformation data directly from the high-speed motion pictures and transducer output recordings made during the two tests. There are two reasons why this empirical procedure should be expected to yield satisfactory results. First, it is a dynamic procedure and it takes into account differences which may exist between head and chest force-deformation relations and, second, it yields an empirical force-deformation characteristic providing a good fit to the experimental data.

The first step in formulating the force-deformation characteristics was to measure the position of the dummy as a function of time using the high speed motion pictures. This task proved to be difficult in that some targets were hidden when the airbag enveloped the dummy. Upon viewing the movies two observations were made which served as assumptions in analyzing the dummy motions: (1) the head moved essentially in a horizontal plane for the duration of the crash event; and, (2) the foot did not move thus fixing the ankle joint as a point attached to the body buck. The measurements made from the film were horizontal motion of head, angular pitch of head, location of knee, and angle of upper leg. From this data it is possible to locate approximately both the hip and neck joints of the dummy. After connecting the locations of these two joints with a straight line to represent the location of the torso, the location of the chest accelerometer pack can be estimated as a function of time. The location of the various body segments as estimated by this technique is shown in Figure 50 for Test No. A-292. The motion of the head and chest into the airbag was then measured directly from a plot similar to this.

The second step in formulating the force-deformation characteristic was to estimate the forces applied to the head and chest of the dummy as it interacted with the airbag. This was accomplished by determining the resultant head and chest accelerations experienced by the dummy, assuming a value of effective mass for these two body segments, and then computing force from F = ma. In choosing the masses [illegible] the head and torso were assumed to be uncoupled dynamically, a valid assumption as the neck joint [illegible] not [illegible] to bottom out in the [illegible] [illegible] the value of the [illegible] 15.8 [illegible] [illegible] of [illegible] difficult. [illegible] half the [illegible] to be restrained by the airbag and half by the lower restraint (either a lap belt or an energy-absorbing lower instrument panel). In addition, the mass of the arms was added to the upper half of the torso leading to a total of 52 lbm. for the effective mass of torso restrained by the airbag.

Based on this data analysis it was possible to plot the experimental force and motion points graphically as is shown in Figures 51 and 52 for the two experiments. For the computer simulations the force-deformation curves were represented by the analytical forms shown by solid and dotted lines in the two figures. In all cases the initial loading was represented by a parabola and unloading by a linear form with steep slope to model the energy-absorbing airbag. The form for the head penetration in Test No. 179 has a parabolic initial loading curve and, in addition, is force-limited to a maximum value of 450 lb. The analytical expressions for the four curves are:

Test No. A-179 Head-Airbag

$$F = 135.6\delta - 7.38\delta^2$$

Test No. A-179 Chest-Airbag

$$F = 325.0\delta - 16.03\delta^2$$

Test No. A-292 Head-Airbag

$$F = 56.5\delta - 1.597\delta^2$$

Test No. A-292 Chest-Airbag

$$F = 282.5\delta - 11.3\delta^2$$

where F is the applied force and δ is the deformation.

The final problem in preparing the mathematical simulation of contact between the occupant and airbag was locating the contact surfaces in the vehicle. The locations which were chosen are shown in Figure 53. The angular orientation of the airbag impact surfaces shown in this figure represents their position at the point in time when the forces applied to the occupant are estimated to be maximum as determined from the high speed motion pictures and recordings of transducer data. Thus, the location of these surfaces is based on a "final geometry" concept. This technique insures that the contact forces developed between the body and the airbag (which in the analysis are applied perpendicular to the line representing the contact surface) are applied in the correct direction during that time period when the maximum forces are produced.

The mass and geometric properties of the anthropometric dummy used in these two tests were measured experimentally. The centers of gravity of the various body parts were found by suspending the pieces by wires and observing the location of intersecting lines of actions while the eight moments of inertia required for exercising the Two-Dimensional Crash Victim Simulator were found by suspending each piece on a trifilar pendulum. The weights were measured on a precision scale and a correction to the moments of inertia was made based on the weight and distribution of the body skin element. The data and experimental techniques are described in detail in Reference 21.

4.2.3 Comparison of Analytical with Experimental Results

Two computer exercises have been conducted using the input data described in previous sections of this report. Comparative tracings and graphs of occupant motions, head and chest G-levels, and forces resulting from airbag contact are included as Figures 54-63.

Figures 54 and 55 show a comparison of the occupant position at the point of greatest forward motion. In both the case of the belted and the case of the unbelted occupant the maximum forward excursion predicted by the model was similar to the experimentally determined values. Similarly, agreement between predicted and observed values of head resultant G-level, head-airbag contact force, chest resultant G-level and chest-airbag contact force is good as indicated [illegible] is shown.

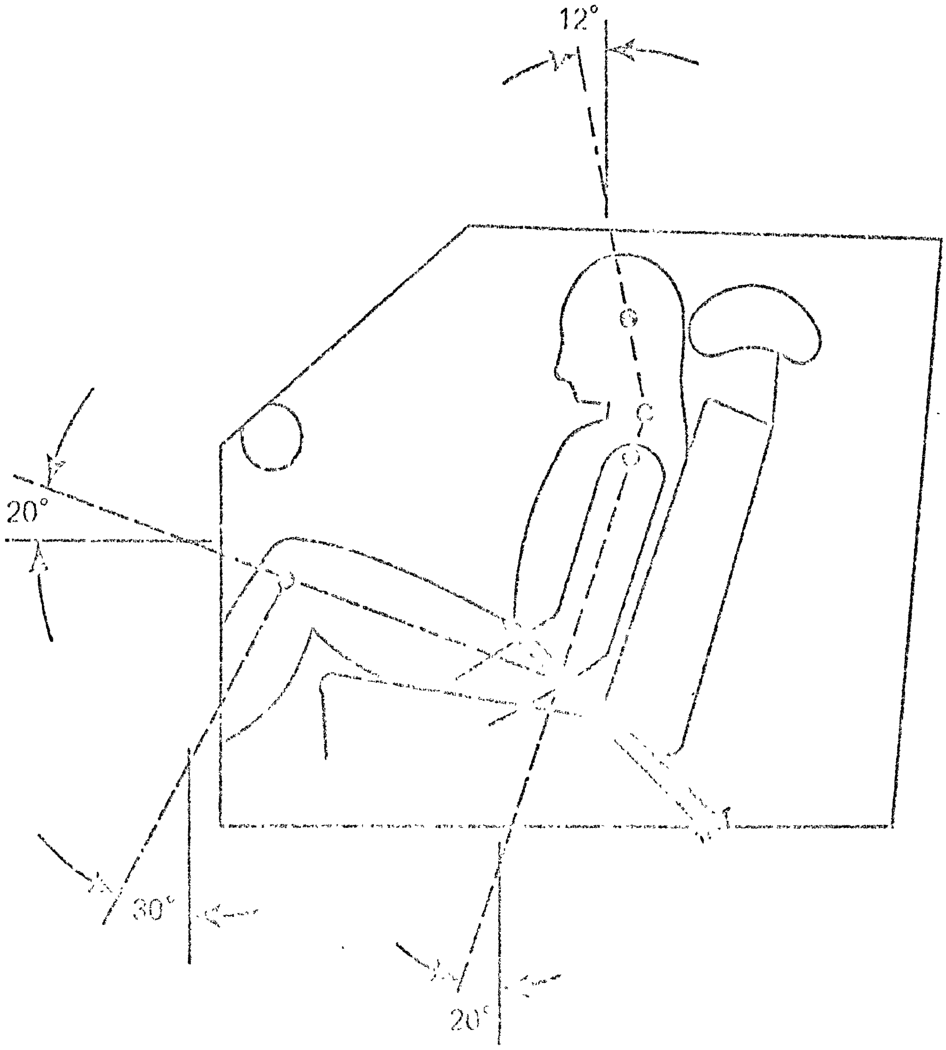

Fig. 48. Tracing of Dummy Initial Position (Test No. A-179) and Orientation of Body Segments for Computer Simulation

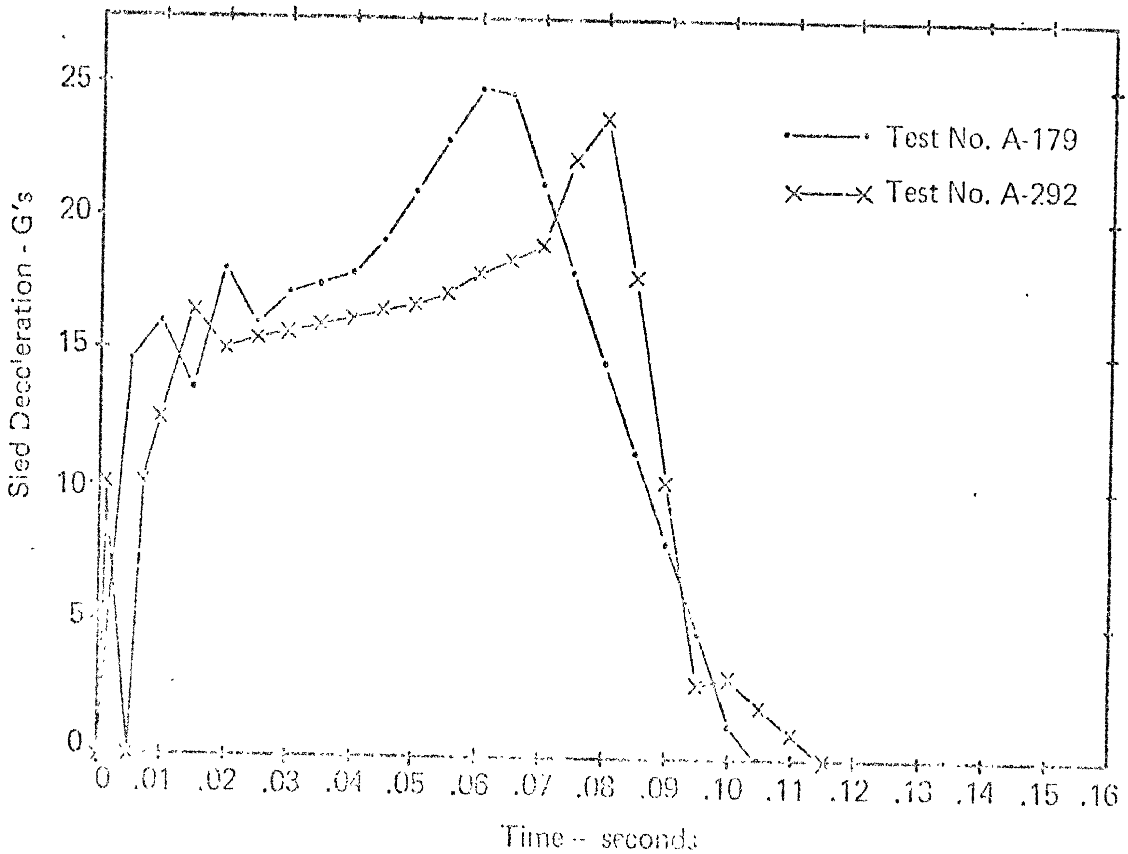

Fig. 49. Sled Deceleration Pulses Used in Computer Simulations

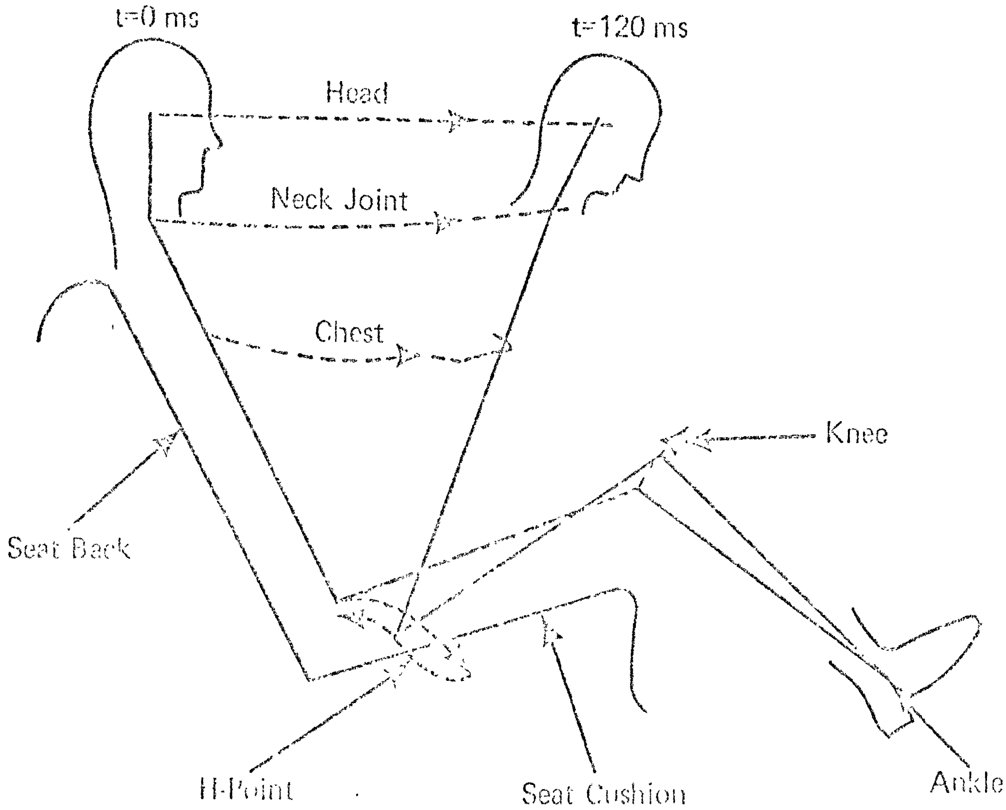

Fig. 50. Determination of Head and Chest Locations for Preparation of Force-Deflection Profiles (Test No. A-292)

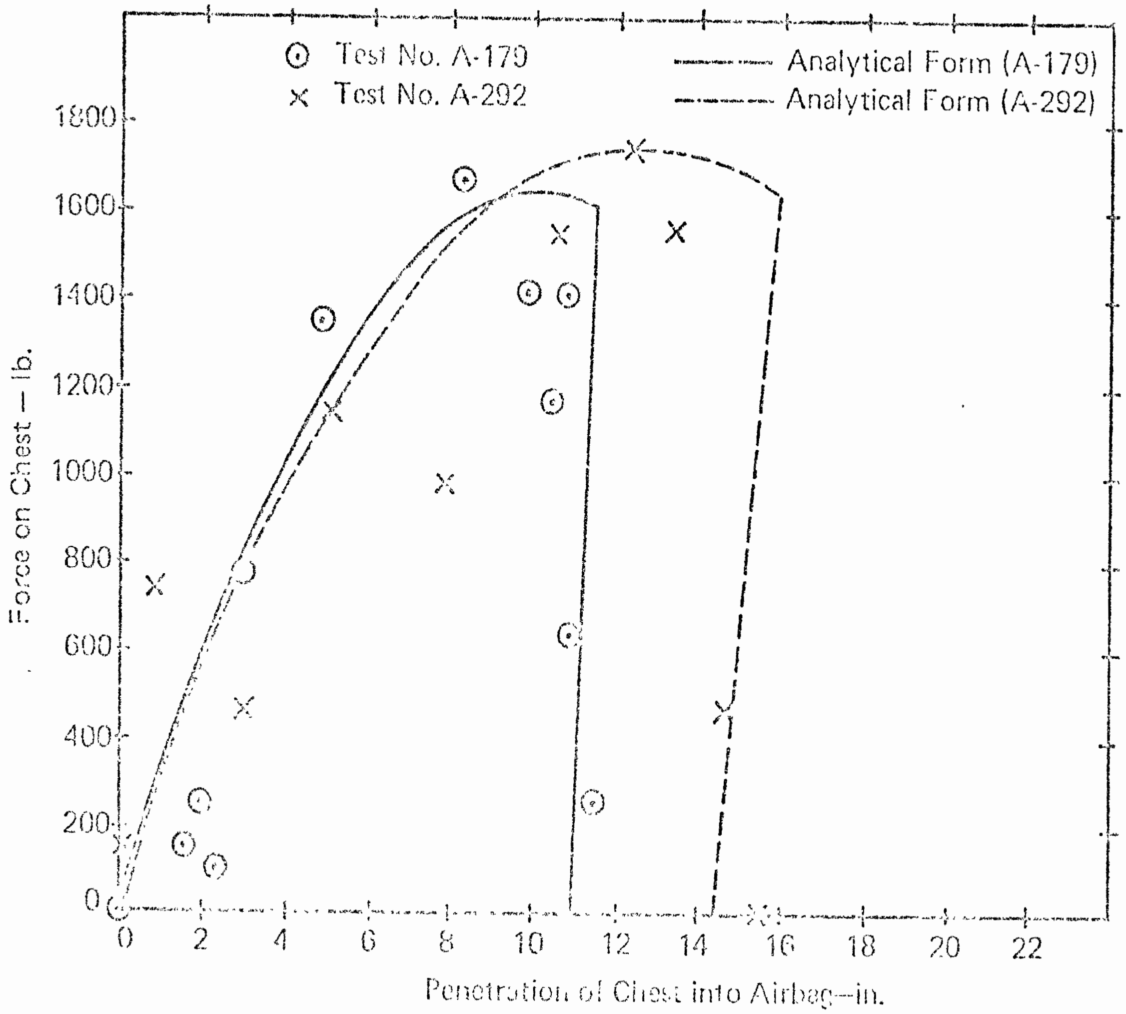

Fig. 51. Force-Deflection Curves for Chest-Airbag Contact

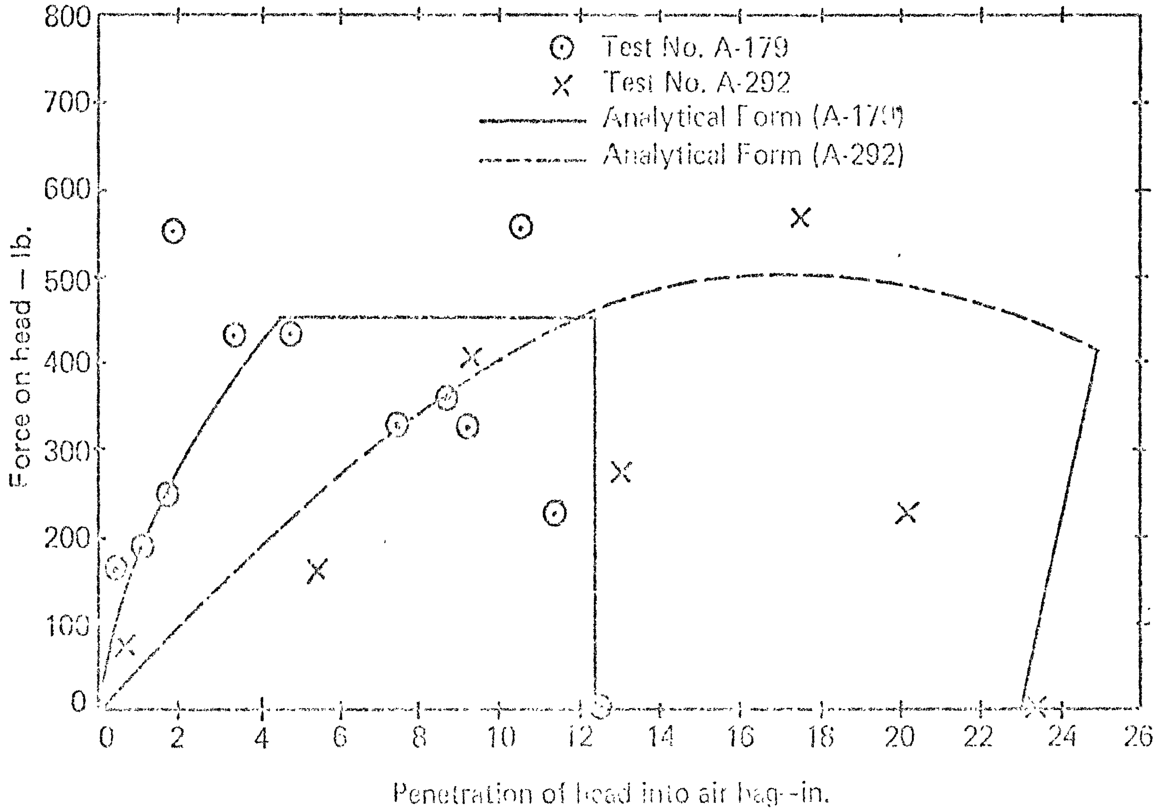

Fig. 52. Force-Deflection Curves for Head-Airbag Contact

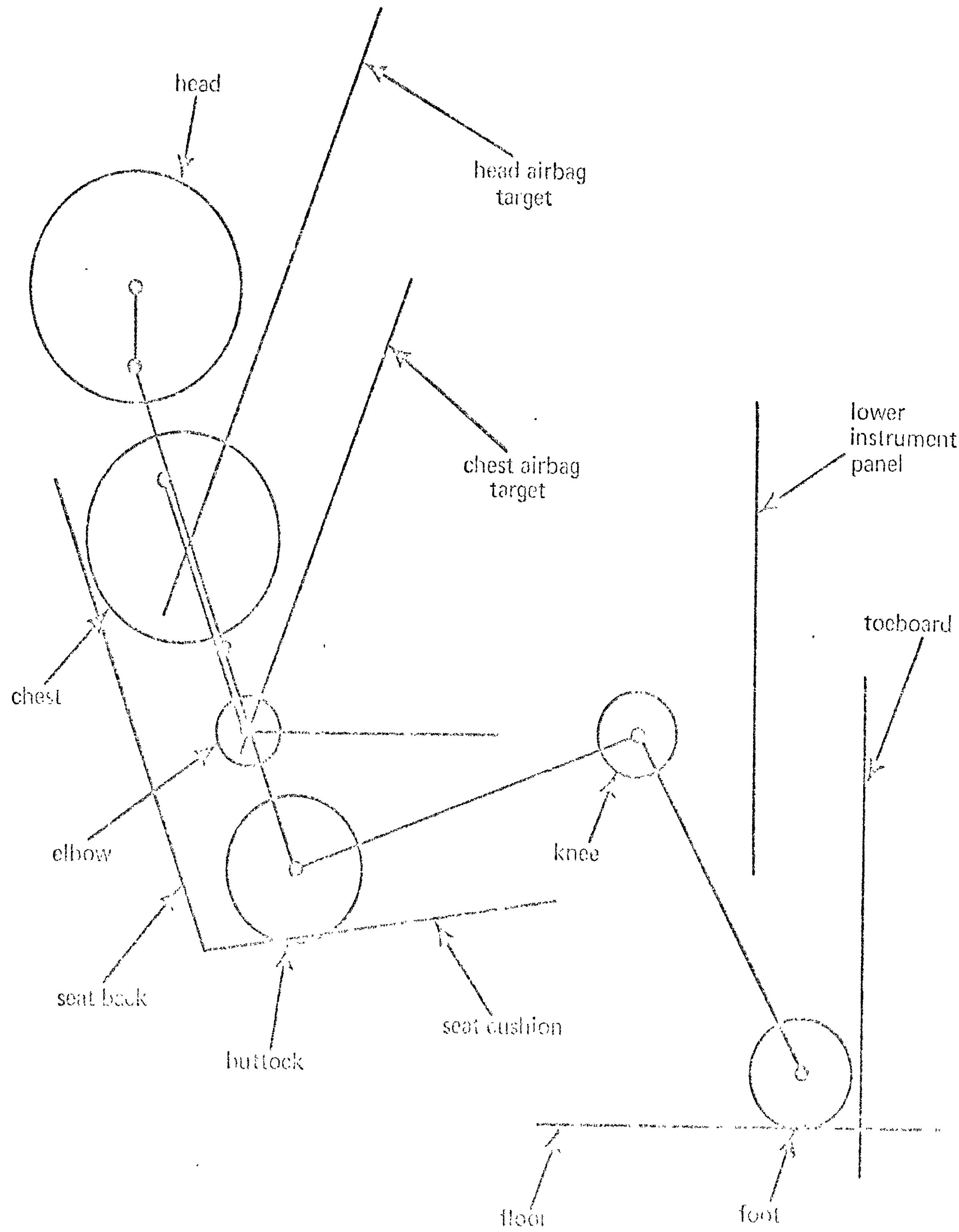

Fig. 53. Initial Geometry for Computer Simulation of Test No. A-292

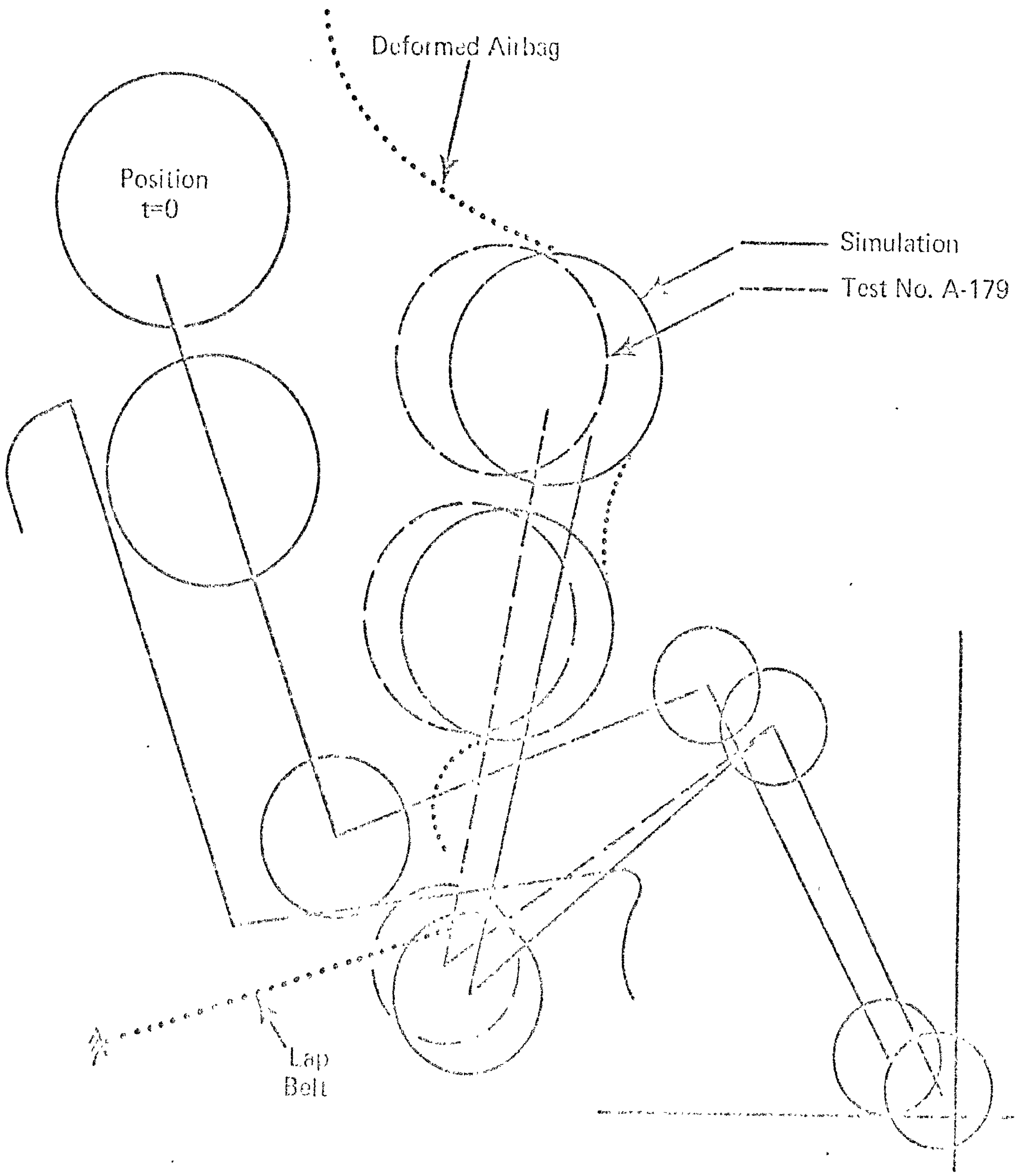

Fig. 54. Comparison of Simulated and Experimental Occupant Position at t=100 ms
(Test No. A-179)

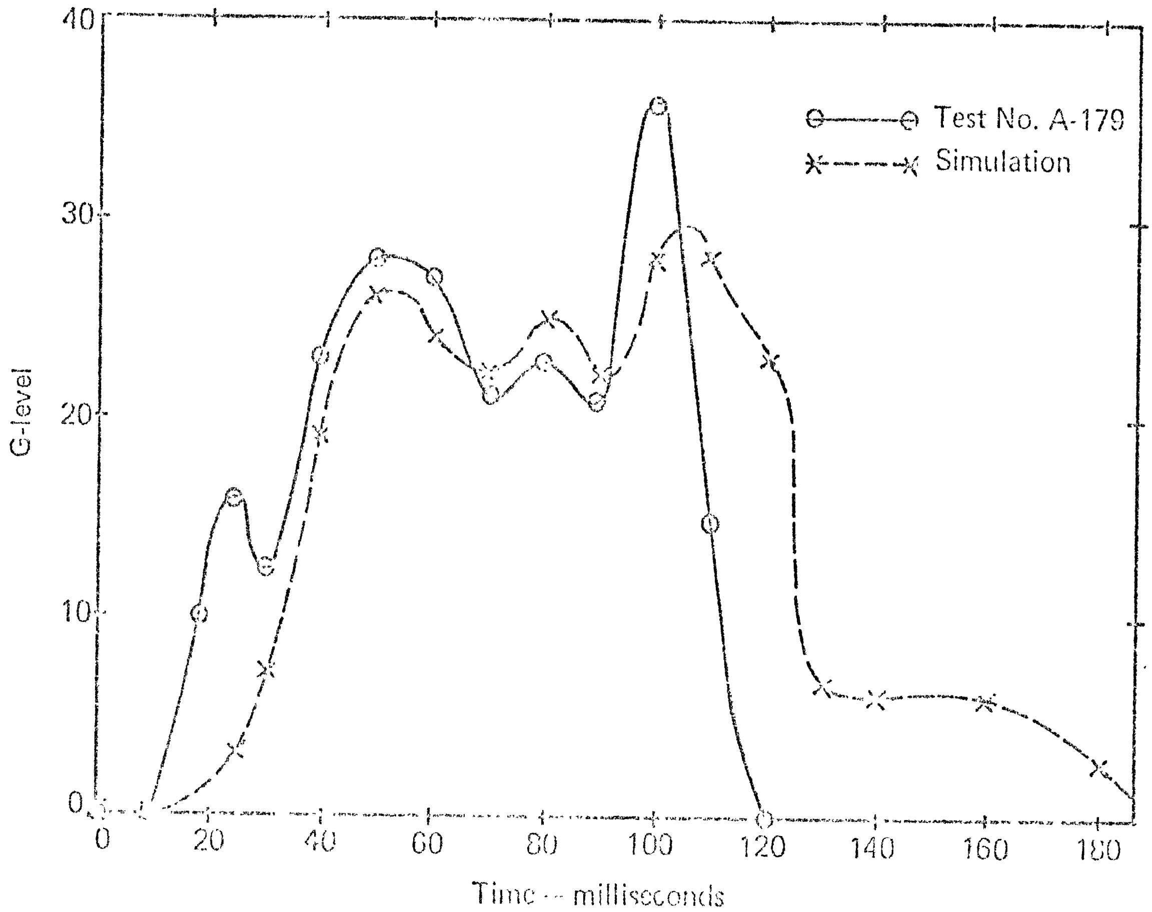

Fig. 55. Head Resultant G-Level. Test No. A-179 vs. Simulation

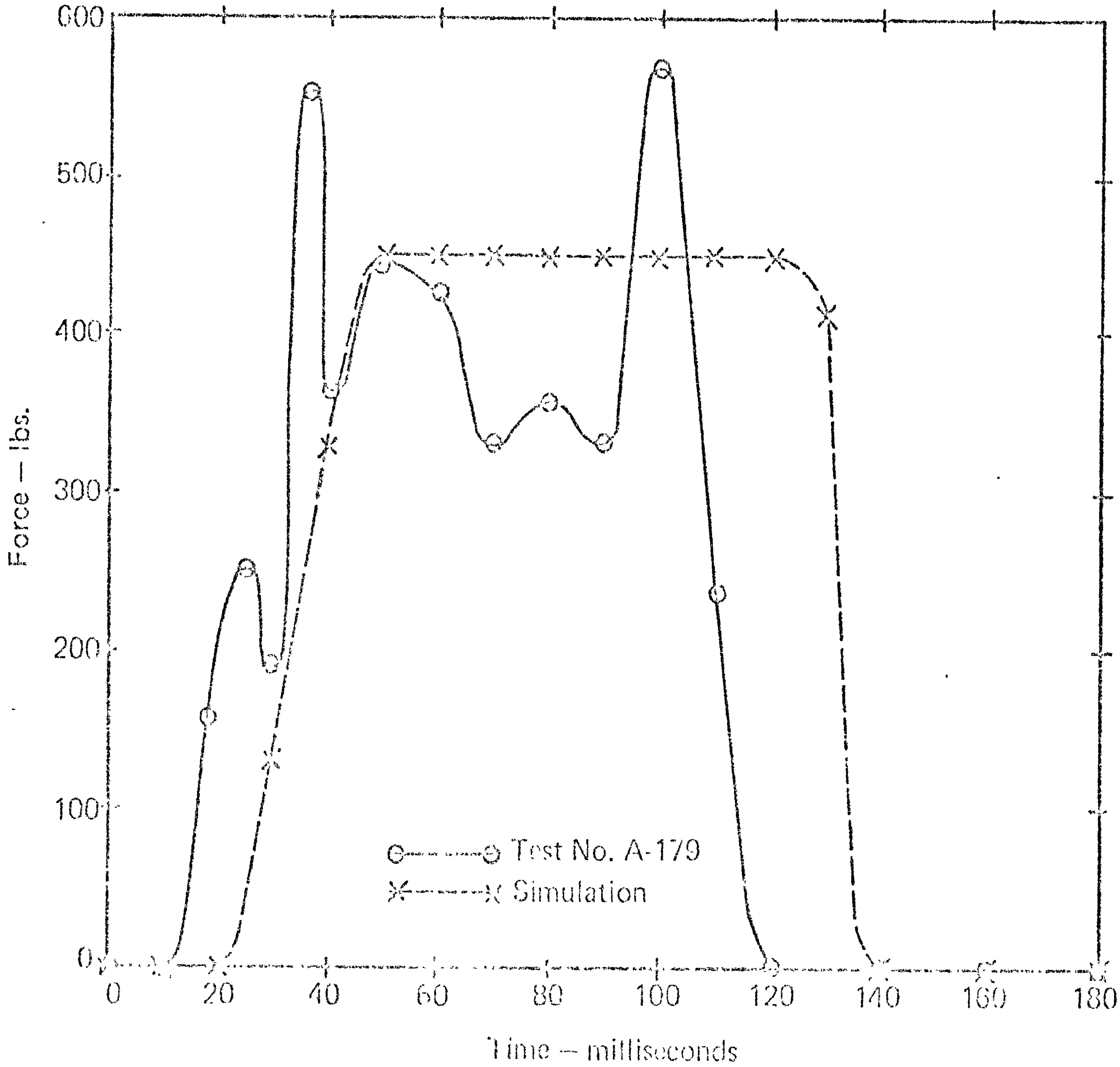

Fig. 56. Force Applied to Head by Airbag. Test No. A-179 vs. Simulation

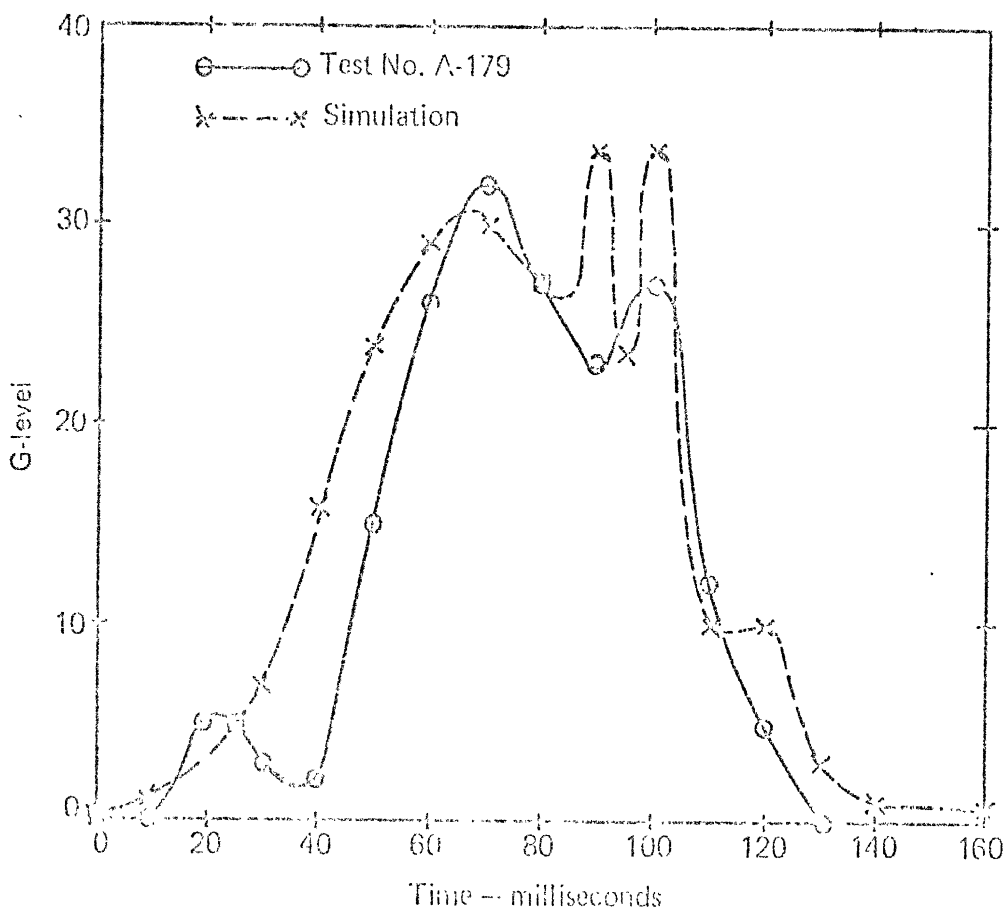

Fig. 57. Chest Resultant G-level. Test No. A-179 vs. Simulation

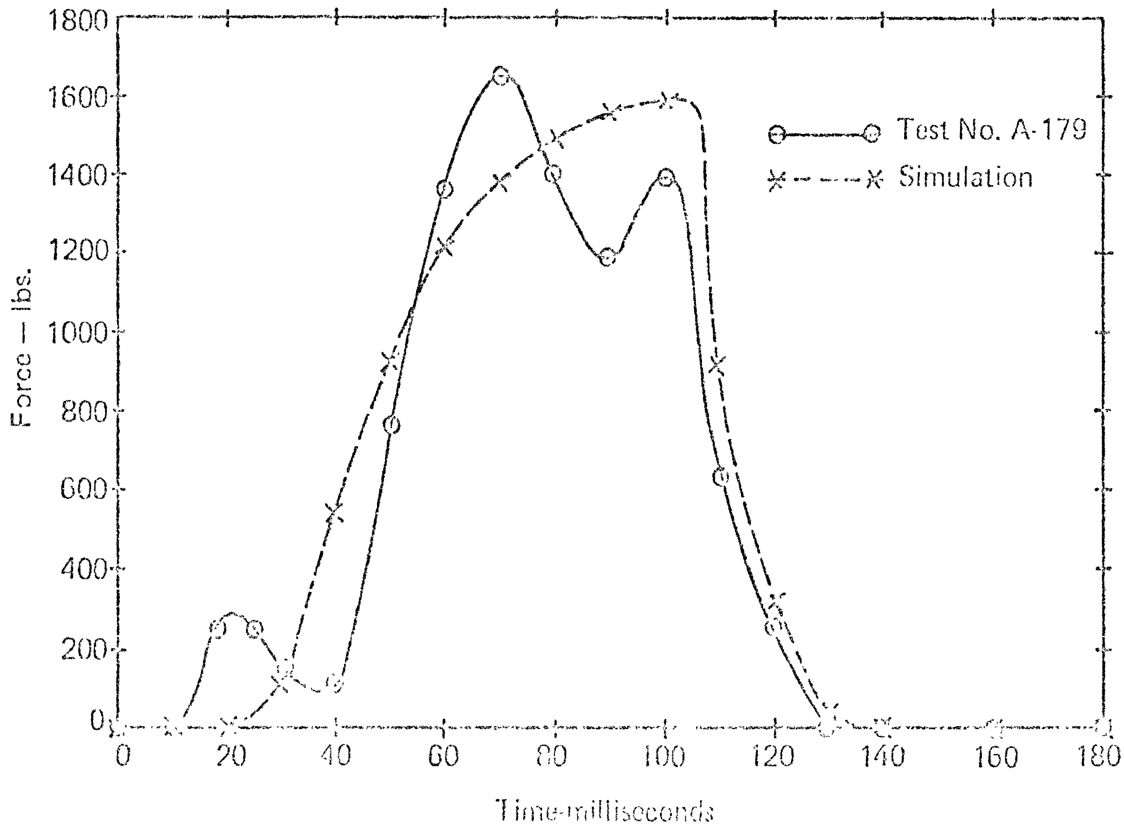

Fig. 58. Force Applied to Chest by Airbag. Test No. A-179 vs. Simulation

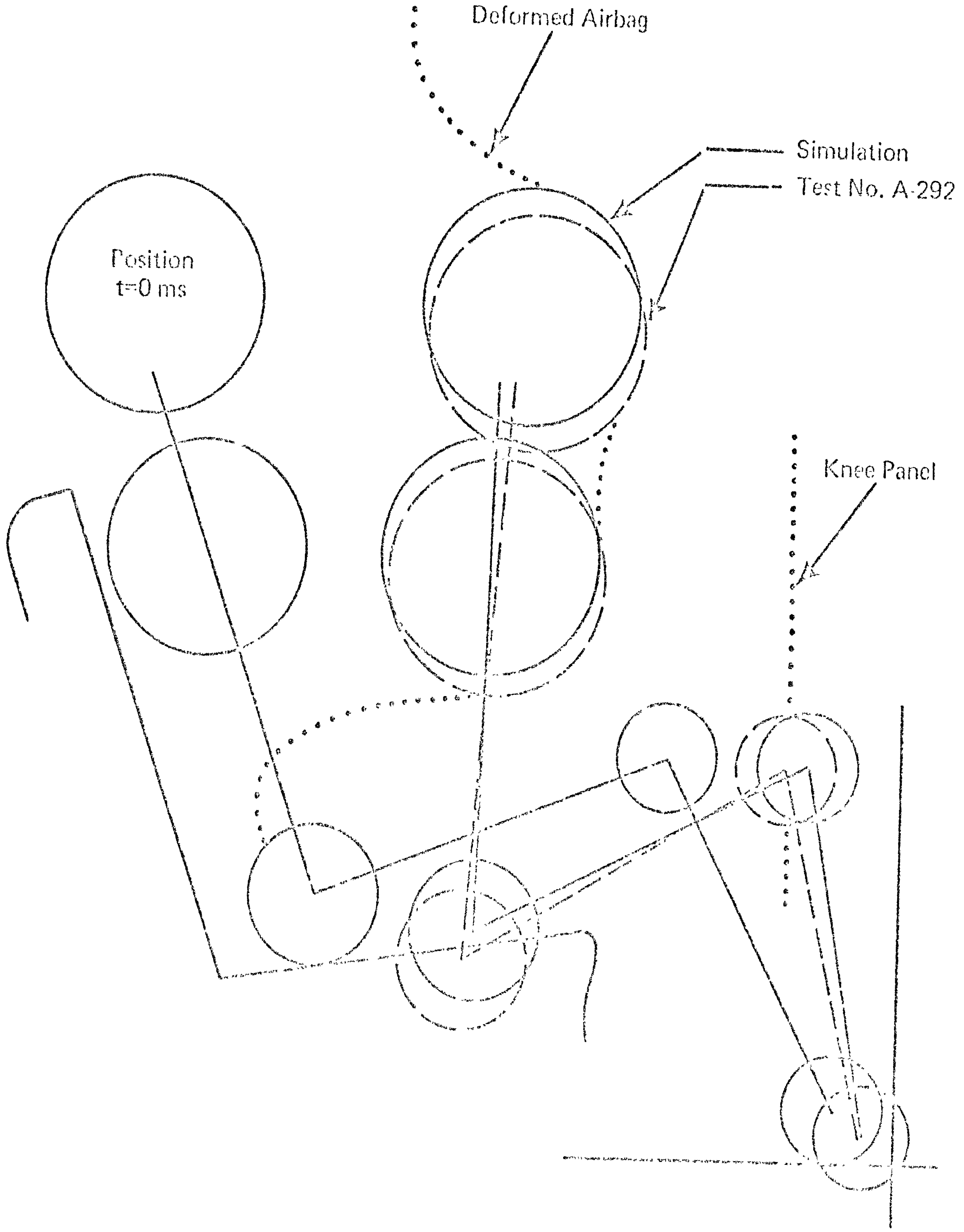

Fig. 59. Comparison of Simulated and Experimental Occupant Position at t 100 ms (Test No. A-292)

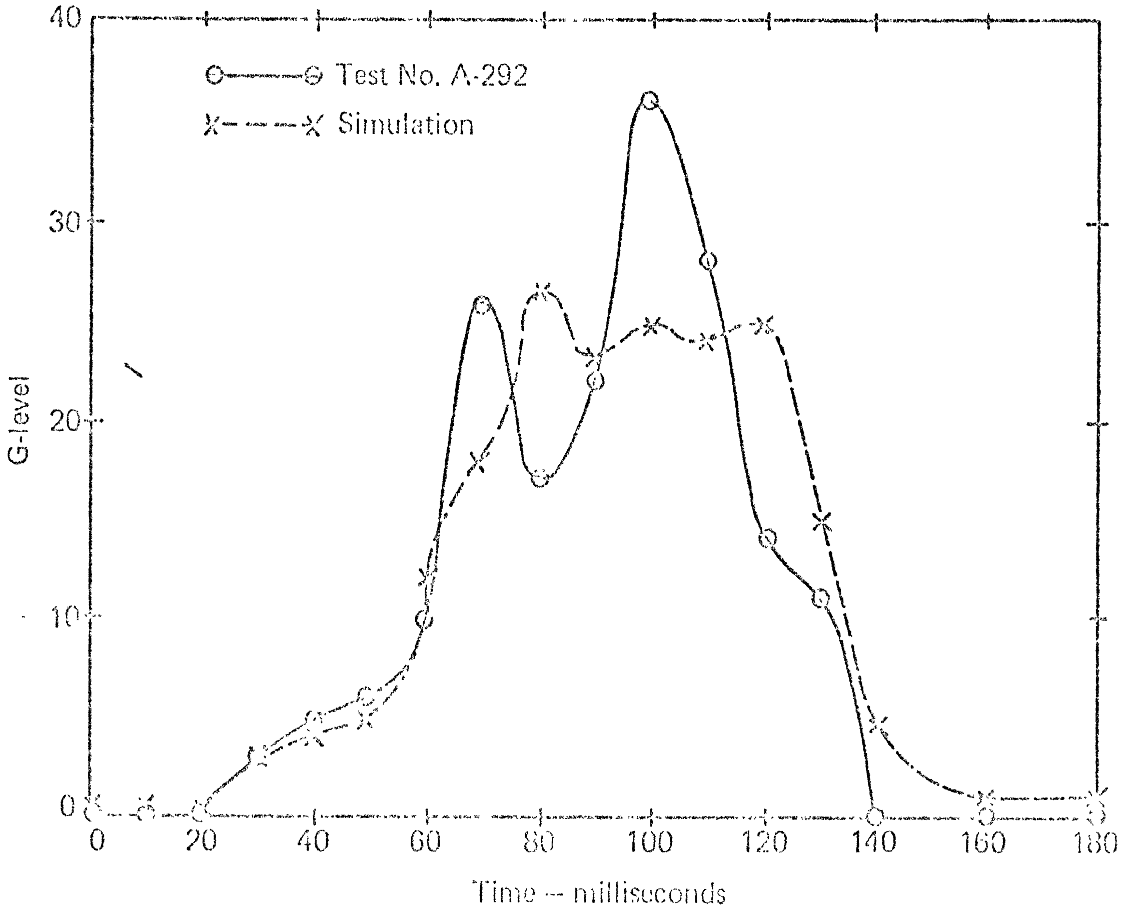

Fig. 60. Head Resultant G-Level. Test No. A-292 vs. Simulation

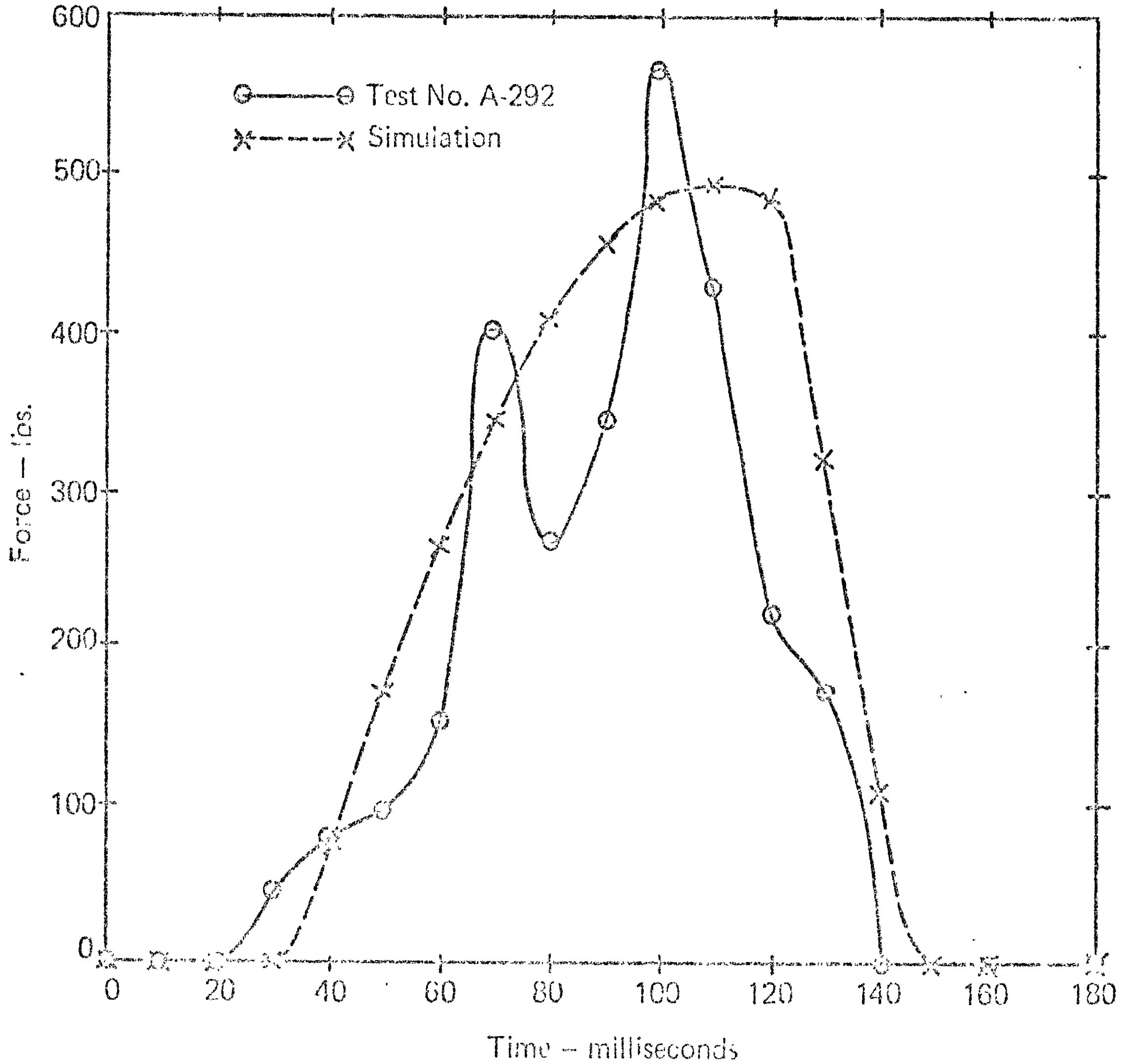

Fig. 61. Force Applied to Head by Airbag. Test No. A-292 vs. Simulation

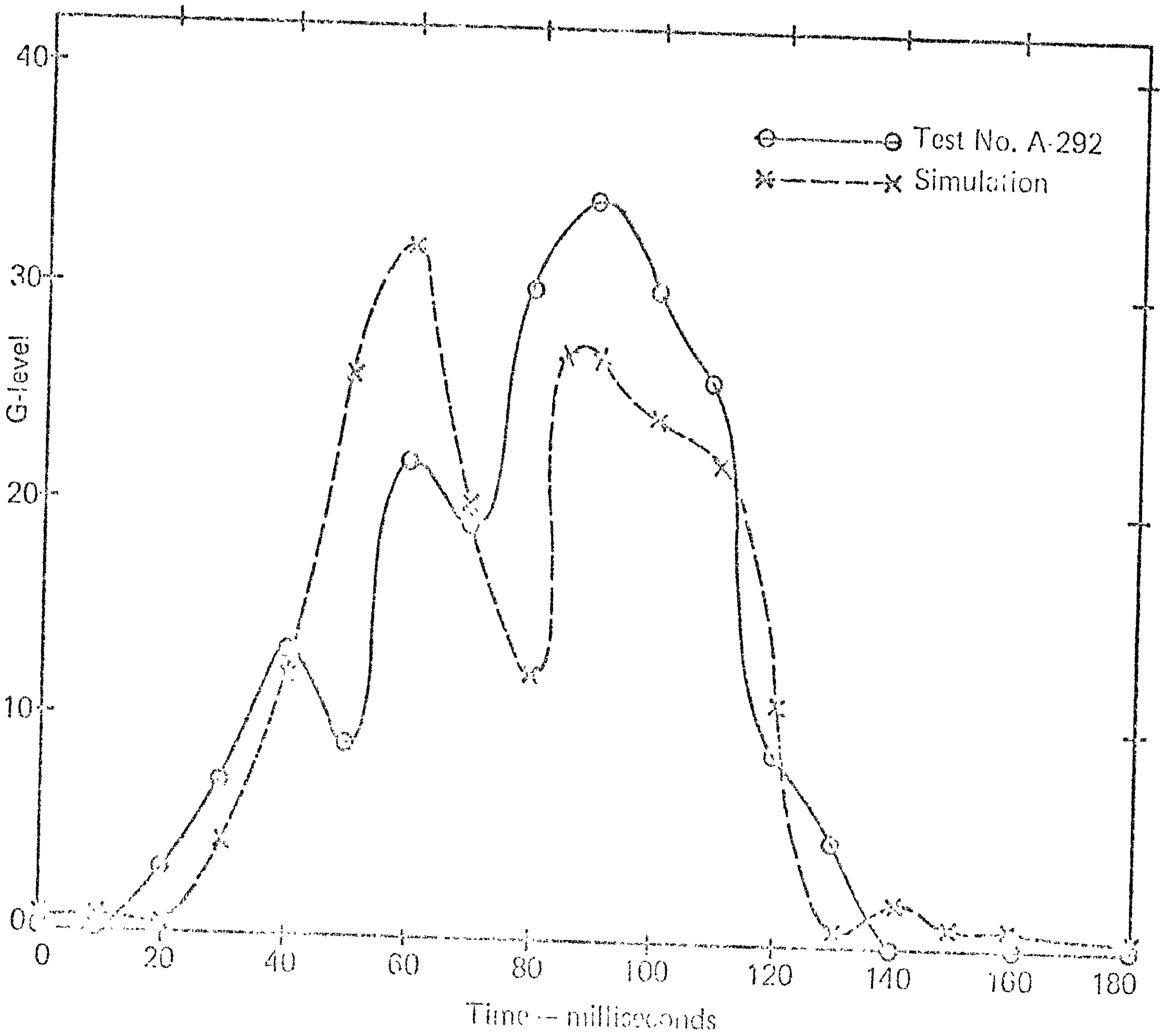

Fig. 62. Chest Resultant G-Level. Test No. A-292 vs. Simulation

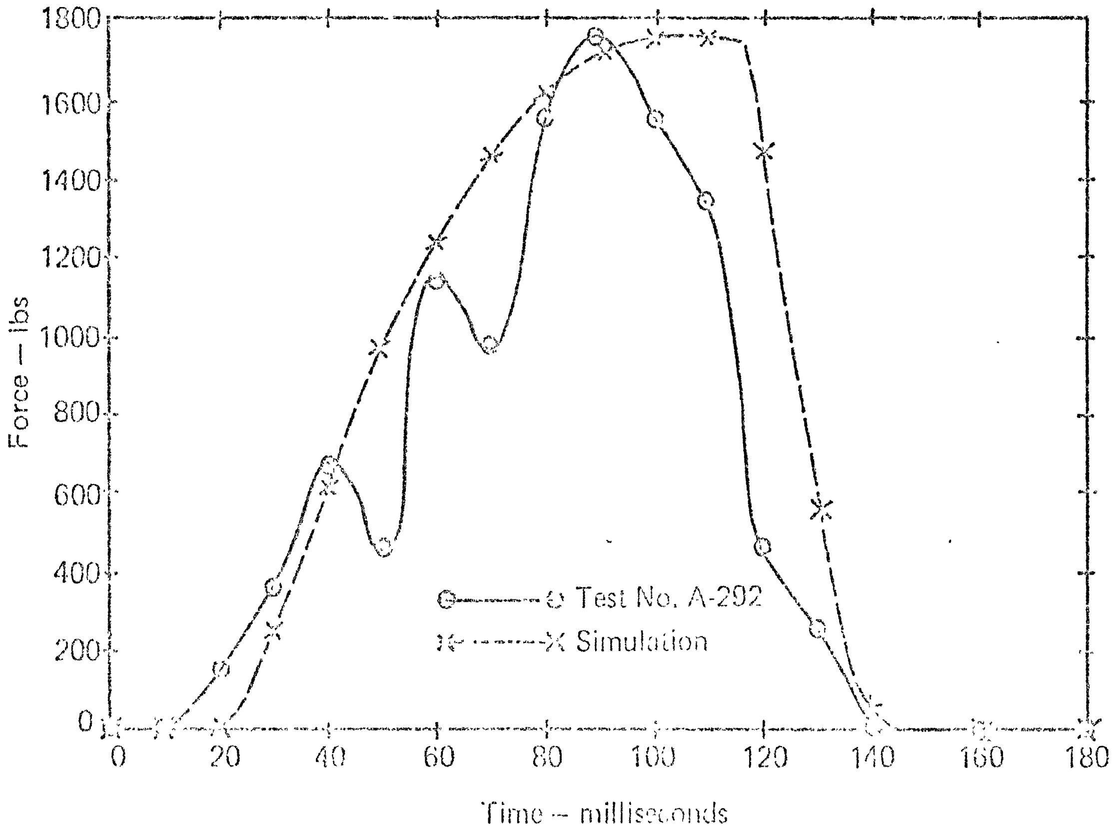

Fig. 63. Force Applied to Chest by Airbag. Test No. A-292 vs. Simulation

4.2.4 Sample of the Use of the Airbag Model

A comparison has been made between the results of two impact sled tests and the predictions of purely mathematical descriptions of occupant motions in the crash event. This rather complex exercise in determination of specific input data for use with the mathematical modeling tools can serve as a starting point for parameter studies of airbag restraint systems designed to define performance trends when system geometry and force-deformation characteristics are varied.

An example has already been given in the report of this type of application of the mathematical models. In Section 3.7.8 a study was made of the effects of variation of the deceleration pulse shape. In order to compare the effects on the occupant of pulse shapes available on the HSRI impact sled with those occurring in actual full-scale barrier crash tests, use was made of the HSRI Two-Dimensional Crash Victim Simulator. Geometry and force-deformation characteristics of the airbag restraint system, similar to those used in the comparison between analytical and experimental results, were held fixed while impact sled, pole barrier, and flat barrier deceleration pulses were supplied as input data to the model. The deceleration pulses are shown in Figure 47 and sample body accelerometer predictions are shown in Table XIII. It can be estimated from these computer results that the sled pulse is likely to provide a more gentle ride for the occupant than the barrier pulses. It can also be estimated that the effect on airbag system performance of a variation of deceleration crash pulse is significant and that tuning of restraint to deceleration type is necessary. This result was obtained with the modest expenditure of $48.75 in computer services and one/half man-day of personnel costs.

The model has been used in this case to estimate a performance trend. To validate this trend, it would be necessary to conduct further tests or to develop a mathematical representation of the airbag system capable of predicting the geometry and force-deformation characteristics (verification of which would require extensive testing).

The basic reasoning behind the use of the mathematical model in this manner is clear. Once the mathematical model has been validated for a baseline case, the program input data can be varied away from the baseline input data to estimate resulting performance trends. The level of sensitivity of occupant response to changes in restraint system, seat, or deceleration parameters can be determined. This information, which can be obtained quickly and inexpensively, can then be used as a guideline in establishing research and developmental priorities.

4.2.5 Conclusions

Correlation has been established between the predictions of the HSRI Two-Dimensional Crash Victim Simulator and tests conducted using anthropometric dummies riding on an impact sled. In part, the reason for the relatively good agreement between mathematical predictions and test observations is the fact that the force-deformation properties of the airbags were determined directly from the tests. Because of the correlation, the analysis offers an inexpensive and powerful tool for carrying out additional parameter studies of airbag restraint systems.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Many observations and conclusions were made during the course of the testing program. These are summarized as a list in Part 5.1. This is followed by the concluding part of the report which offers recommendations for increasing the threshold velocity above which protection to the occupant is currently estimated to be marginal.

5.1 SUMMARY OF CONCLUSIONS AND OBSERVATIONS

1. The level of protection offered by the restraint system used in this test program is conveniently expressed in terms of threshold velocity curves (See Figure 18) beyond which performance is expected to be marginal. It was found that restraint performance was marginally acceptable for 6-year through 95th percentile male dummy sizes in front impact up to 40 mph. Threshold velocities were somewhat reduced for 22.5° right front oblique impact.

2. Hyperextension was observed in most tests involving the 5th percentile female dummy leading to the lowest apparent level of protection observed during the test program. (See Part 3.7.1).

3. Use of a standard lap belt appears to increase the potential for hyperextension as the pelvic area of the dummies is held back while the torso pitches forward. (See Part 3.7.5).

4. No degradation of the safety potential offered by the airbag system was observed by eliminating the use of the lap belt in front end collision simulations at any of the speeds from 20 to 40 mph when a supplementary energy-absorbing lower instrument panel was in place. (See Part 3.7.5).

5. In the tests representing 22.5° right front oblique impact, a general increase in G-levels felt by the dummies was noted particularly in the left-right accelerometer channels. Often this occurred because of contact with simulated door sill, [illegible] as the dummies slid around the end of the airbag. (See Part 3.7.[illegible]).

6. In the tests representing 22.5° right front oblique impact, some advantage was gained when a lap belt was used at the higher speeds and with the larger dummies. (See Parts 3.7.5 and 3.7.7).

7. The deceleration profile experienced by the occupant compartment is important in predicting the level of performance offered by the airbag system. It was observed that the peak vehicle deceleration levels should be kept as low as practical without compromising the occupant compartment in high level crashes and the occupant should interact with the airbag system as early in the collision event as possible in order to make the greatest use of the inflation gas and the available space.(See Part 3.7.8).

8. In the case of inadvertent actuation of a correctly deploying airbag with a three-inch diffuser diameter, the 6 year old child dummy will be pushed straight back into the seat back with a low potential for injury on the basis of the criteria used in this report. Any high G-loadings result from contact with elements of the seat structure which lack sufficient padding. (See Part 3.7.3).

9. It is not advisable for children to ride on the laps of adults. The danger of high G-loadings to the head is predicted from force interactions between the dummies used in the impact sled tests. (See Part 3.7.3)

10. In the testing of out-of-position occupants, dummies which were slouched in the seat with their knees touching the lower instrument panel did not experience decreased performance from the restraint system. This may be due to the fact that the initial backward orientation of the torso reduced the tendancy for hyperextension in the smaller dummies. (See Part 3.7.3).

11. Dummies which were initially placed unsymmetrically with respect to the [illegible] centerline, e.g. in a sideways sleeping position, did not experience unacceptably high [illegible] unsymmetrically. (See Part 3.7.3).

12. In those tests where an adult dummy was placed close to the airbag diffuser, the G-levels recorded from the chest accelerometers were marginal. (See Part 3.7.3).

13. In tests where dummies wore glasses, no problems in system protective performance were observed. (See Part 3.7.3).

14. The G-loadings felt by the dummy heads in the anterior-posterior direction appear to be larger for small dummies than for the adult male sizes, especially at the lower impact velocities. Due to the smaller mass of the 6 year old child and 5th percentile female dummies, it is possible that the vents of the airbag are not used as effectively as energy-absorbing devices at lower speeds where the energy of the impacting dummy is small. (See Part 3.7.2).

15. The G-loadings felt in the dummy chests in the anterior-posterior direction increase as impact velocity increases. This should be expected both from thermodynamics and the geometric properties of airbags. (See Part 3.7.2).

16. The G-loadings felt in the dummy chests in the anterior-posterior direction are approximately the same for the various sizes of dummies. The smaller dummies have a smaller swept area of contact with the bag resulting in a lower applied force. In addition, their mass is smaller. On the basis of F - m these facts tend to equalize the applied G-loadings. (See Part 3.7.2).

5.2 RECOMMENDATIONS

The recommendations which are offered in this concluding part of the report have the objective of changing the threshold velocities proposed in Figure 18 upward. In order to accomplish this a combined experimental and analytical research program must be implemented which: (1) varies the parameters of the airbag restraint system away from the geometry fixed for the current test program; (2) improves the design of [illegible] and establishes the level of [illegible], (3) continues the study of [illegible] in vehicle structures.

There are several aspects of airbag system construction which could lead to possible improvements in the level of performance offered by the particular system used in the current test program. First, if the Eaton, Yale, and Towne bag were deployed in a more downward direction into the lap of the occupant, more effective protection could be offered to the 5th percentile female passenger. Possible means to accomplish this are the addition of bag material to fill up this region of the vehicle interior or the inclusion of a guide in the upper instrument panel and the windshield (if this last can be accomplished without endangering the out-of-position occupant).

The second means for increasing the threshold velocity by modifying the system designed for this project is to increase the volume of inflation gas which is provided. This would lengthen the time period during which effective restraint is offered.

The third means which could increase the threshold velocity, particularly in oblique collisions, involves changing bag geometry. Material should be added to improve the potential for pocketing the occupant more toward the center of the inflated bag. This would tend to keep the occupant away from door side structures and also could tend to provide more symmetric rebound for the out-of position occupant.

The problem with dummy construction which was most apparent during this test program involved the neck structures - particularly with respect to hyper-extension. Two steps must be taken to determine the capacity of the dummy neck for predicting injury. The first is to establish the level of correlation between the motions observed with the dummies and with human subjects. If the resulting correlation is poor it is recommended that design modifications be made to eliminate the problem.

This one segment of dummy construction is but part of the larger problem in the use of anthropometric dummies as devices for testing compliance to both Federal and industry standards. In order for safety standards to be written and used with confidence, greater understanding of the ultimate measure of performance level - human tolerance to impact - must be gained.

APPENDIX

TEST EQUIPMENT SPECIFICATIONS AND CALIBRATION PROCEDURES

A. Equipment Specifications

Transducers

1. Kistler Piezotron Model 818 Accelerometer (Dummy)

   Type: Piezoelectric with integral impedance converter
   Range: ±250 G
   Sensitivity: 10 mv/G
   Freq. Response: 2 to 5000 Hz (±5%)
   Resonant Freq.: 30000 Hz

2. Statham Model A69TC-100-350 Accelerometer (Sled)

   Type: Temperature compensated, unbonded strain gage
   Range: ±100 G
   Natural Freq.: 1800 Hz
   Damping: 0.7 (±0.1) of critical at room temp.

3. Lebow Model 3371 Belt Load Cell

   Type: Strain gage
   Range: 3500 pounds, with 50% overload capacity
   Sensitivity: 2.2906 mv/V/3500 pounds

Signal Conditioners

1. Honeywell Model 120 D.C. Amplifier

   Type: Solid state, direct coupled, wideband differential
   Gain: 10 - 1000
   D.C. Gain linearity: better than ±0.2% of full scale
   D.C. Gain accuracy, calibrated gain ranges: better than ±0.5%
   Freq. Response: ±2% D.C. to 10 KHz

2. Honeywell Model 105 Bridge Balance (Gage Control) Unit

   Freq. Response: ±DC to 10 KHz within ±0.5%

Recorders

1. Honeywell Model 1612 Visicorder Light-Beam Oscillograph

   Galvanometer response:

   M-3300 (15 channels): ±5%, 0 to 2000 Hz
   M-1650 (4 channels): ±5%, 0 to 1000 Hz
   M-1000 (1 channel): ±5%, 0 to 600 Hz

2. Honeywell Model 7600 F.M. Tape Recorder/Reproducer

   Tape speeds: 1 7/8 to 120 ips
   Freq. response: ±1.0 db 0 - 10000 Hz (at recording speed used - 30 ips)
   Harmonic distortion: 1.2%

3. CEC Model VR-3300 F.M. Tape Recorder

   Tape speeds: 1 7/8 to 60 ips
   Freq. response: ±0.5 db 0 - 10000 Hz (at recording speed used - 30 ips)
   Harmonic distortion: 1.5%

B. Calibration Procedures

Transducers: The calibration sensitivites of the transducers are checked to insure that there has been no appreciable deviation from manufacturer's specified sensitivity.

1. Kistler Piezotron Model 818 Accelerometers.

   The sensitivities of these piezoelectric accelerometers, which are used in the crash test dummies, are checked with a Kistler Model 894K Shock Calibration System. This system compares, on peak-reading voltometers, the output of the test accelerometer and an NBS-traceable load cell onto which the accelerometer is dropped. Accuracy of the load cell and associated peak meters is checked against a NBS-traceable standard accelerometer prior to calibration of the test accelerometers.

2. Statham Model A69TC Accelerometer

   This strain-gage accelerometer, used to monitor sled deceleration, is calibrated by comparing its output with that of an NBS-traceable standard accelerometer. The two accelerometers are mounted piggy-back on a common carrier block and impacted. Their outputs are displayed, via the sled umbilical and the signal conditioning system, on the oscillograph. The excitation voltage of the Statham is adjusted until its output agrees with the standard accelerometer. This excitation voltage becomes the standard for subsequent use of the accelerometer.

3. Lebow Seat-Belt Load Cells

   Calibration sensitivity of these load cells is checked by applying a known load to a length of seat belt material on which the cell is mounted. The output signal is compared with that obtained when a shunt resistor is paralleled with one leg of the transducer's bridge. The resistor value is that which has been specified by the manufacturer to produce a transducer output equal to the output produced by a known load.

Signal Conditioning/Recording Systems (Electronics)

1. Kistler Accelerometer Channels

   Referring to Figure 2, a calibrated voltage, equal to the output at a given G-level (10 G's) of the Kistler 818 accelerometer used, is applied at point A, and the input attenuator is adjusted to achieve an output voltage from the Honeywell Model No. 120 amplifier which will drive the associated oscillograph galvanometer to the desired deflection (1" = 50 G's).

   The tape recorder is calibrated, by adjusting its input attenuator, so that the voltage producing the specified 1" galvanometer deflection will also cause 13 1/3% (3" - 150 G = 40%) deviation in frequency of the F.M. carrier of the tape recorder.

2. Strain-Gage Transducer Channels

   Calibration of strain-gage channels is accomplished by introducing shunt resistors across one leg of the bridge of the transducers in question, and checking the excitation required to produce the galvanometer deflection desired. A significant change in the required excitation for any transducer would indicate the need to check the calibration sensitivity of the transducer, or otherwise determine the cause of the change. For the Statham accelerometer channel, the calibration resistors are the internal "Cal I" and "Cal II" calibration resistors of the Honeywell 105 gage unit, and their corresponding G-value and galvanometer deflection were determined at the time of calibration of the transducer itself. In the case of the Lebow belt load cells, a 60 K-ohm resistor is introduced in the transducer cable parallel to one leg of the transducer bridge, and whose corresponding belt load value was specified by the manufacturer.

   Calibration of the tape recorder is accomplished by adjusting its input attenuators to obtain a 40% carrier frequency deviation when the voltage necessary to cause 3" deflections of the oscillograph galvanometers is impressed on the tape inputs.

3. Calibration Frequency

   Calibration of the signal conditioning equipment, oscillograph, and top units is done routinely for each sled test.

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