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National Highway Traffic Safety Administration

DEVELOPMENT AND EVALUATION OF A VEHICLE INTERIOR IMPACTOR

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16. Abstract

A vehicle interior impactor was designed and fabricated to permit evaluation of vehicle interior surfaces with regard to their energy absorbing characteristics. This device can evaluate interior surfaces of production vehicles without their modification and at lower cost and in less time than impact sled testing. The impactor is free standing and accomodates action and reaction loads from firing and impact within its own frame. The impactor can accomodate a variety of body forms weighing up to 40.4 kg (89 lbs) and propel these up to 48.3 km/hr (30 mph). It includes fixtures specifically designed for Part 572 dummy head, thorax-abdomen and lower extremities (abdomen and legs); these fixtures can be modified to accept Hybrid III dummy body parts. The impactor is adjustable to permit almost any vehicle interior surface to be targeted.

A series of 135 test runs were made with the impactor to evaluate its performance with all three body forms, each at a variety of velocities. From this data a series of firing curves were made. The firing curves related pressure settings to body form velocities for each body form. Evaluation also included positioning the impactor with the various body forms inside a compact car to assess the range of adjustments and potential target surfaces.

The testing demonstrated the impactor's ability to propel all three body forms in a relatively flat trajectory up to 48.3 km/hr (30 mph) without undesirable rotation. Installing the impactor inside the vehicle showed that it could accomodate the range of positions needed to meet the testing requirements of the NHTSA follow-on program, "Study of Occupant Impact with Vehicle Interior Surfaces."

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INTRODUCTION

This final summary report covers the development, evaluation and installation of the vehicle interior impactor portion of the work conducted under Contract No. DTNH22-80-C-07165 (SwRI Project No. 14-6059) with the National Highway Traffic Safety Administration (NHTSA). As discussed in Modification 2 to this contract, limited funds made only a summary report possible. All areas of development, evaluation and installation have been addressed. Some of the detail discussion concerning development decisions, and a consolidated bill of materials for the drawing package, have been left out. All material requirements for the fabrication of another impactor have been included on the drawings. This summary report, the Operator's Manual (submitted separately), the drawing package (submitted separately) and the impactor (shipped to Calspan ATC) complete this part of the contract.

OBJECTIVE

All effort was directed to develop and evaluate a vehicle interior impactor that could measure the injury producing potential of vehicle interior surfaces. This impactor was to be capable of accurately accelerating and propelling a wide range of instrumented anthropomorphic (human-like) dummy forms, from small head forms up to torso forms weighing 40.4 Kg (89 lbs), at velocities up to 48.3 km/h (30 mph). The impactor was to be designed for conducting tests within vehicles of a variety of sizes, and so that the body forms could strike almost any contact surface within the occupant compartment. The impactor was also to allow dummy body forms to be instrumented to measure the accelerations, forces, and/or distortions resulting from an impact.

BACKGROUND

High numbers of deaths and serious, disfiguring injuries continue as a result of vehicle accidents on the nation's highways. Many of these deaths and injuries could be avoided if vehicle occupants were wearing their safety belts. Because very few accident victims wear belts, the vast majority of victims are impacting the interior of vehicles during crashes. In a sense, these people are using vehicle interior surfaces as their safety restraints, and so there is a need to improve the energy absorbing characteristics and reduce the injury producing potential of these surfaces. This is not to say that interior surfaces could provide protection equal to a properly designed and fitted safety belt or air cushion. However, these surfaces can be improved over those available in most cars produced today.

Existing Federal Motor Vehicle Safety Standards (FMVSS) 201 and 222 address this concern for automobile and school bus interiors, respectively. They are, however, in each case limited to a simulated head impact.

In addition, there have been other efforts to develop devices to evaluate vehicle interior surfaces. The most notable of these is a device developed by General Motors Corporation (GMC) and described in a progress report issued by them in October 1981. Their efforts were in response to the NHTSA notice regarding side impact protection. The GMC device mounts outside the vehicle and as such does not rely on the vehicle structure. It is designed to propel a headform weighing 5.1 kg (11.3 pounds) up to 30 km/hr (18.3 mph) into a wide range of interior surfaces. It is constructed so that the headform is guided along its trajectory.

INITIAL CONCEPT

The first concept proposed responded to requirements for a device that would propel headforms into the instrument panel of vehicles. It would include the capability to use either the 15 pound FMVSS 201 spherical headform or the FMVSS 222 bispherical headform. It would be designed primarily to propel the headforms forward with limited ability to perform lateral or oblique impacts. It also would guide the headform during its trajectory so that lateral motion was resisted, and penetration and rebound velocity was accurately measured. There are advantages to the guided approach versus an unguided approach and these advantages are particularly true when propelling a light compact geometrically shaped headform. The ability to measure penetration and rebound velocity means that the change in kinetic energy and the energy absorption characteristics of the impacted surface can be accurately assessed. A protocol and costs were developed for this approach.

SECOND APPROACH

After the first approach was drafted, test capabilities were revised. This led to the second concept which, while similar to the first, considered propelling bodyforms up to a complete dummy less arms and legs. The design was similar to the previous one in that it relied on the test vehicle's structure, primarily the B pillars, to support the test device and handle the impactor firing reaction forces. The design proposed to propel a headform similar to the previous approach, that is, with a guiding feature. It proposed to propel other larger bodyforms with an unguided or free flight approach.

FINAL APPROACH

When calculations of forces and stresses were considered, in the second approach, it was realized that the vehicle structure would not handle the reaction forces of propelling the larger bodyforms. As a result of this and the assignment of new personnel to the design team, a new approach was formulated that did not rely on the test vehicle body structure for support. A conceptual drawing is shown in Figure 1. An exploded view of the impactor is shown in Figure 2. Basically, this device has a frame onto which the test vehicle is driven and secured. A single arm supporting the accelerating cylinder and the mechanisms with which to orientate it are inserted through the door opening of the vehicle. The test body forms are mounted to the piston rod of the accelerating cylinder.

The basic features of this final design and a discussion of other considered design features were as follows:

1. The principal impactor components are designed for long life.

2. The actuator is mounted on an arm, which extends through the door opening. The arm is mounted to a pedestal that is outside the vehicle.

3. The vehicle is supported and secured on a frame that is part of the pedestal that supports the actuator.

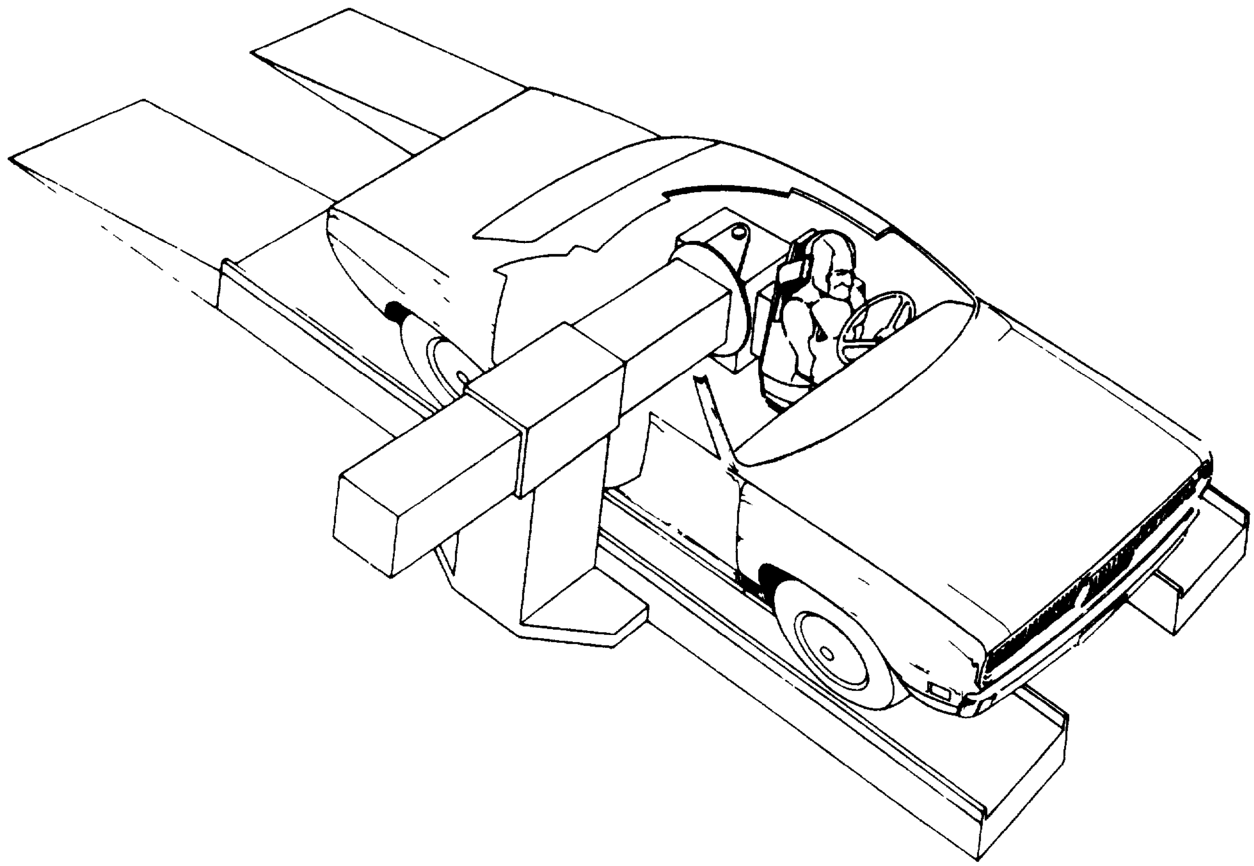


FIGURE 1. VEHICLE INTERIOR IMPACTOR CONCEPTUAL DESIGN

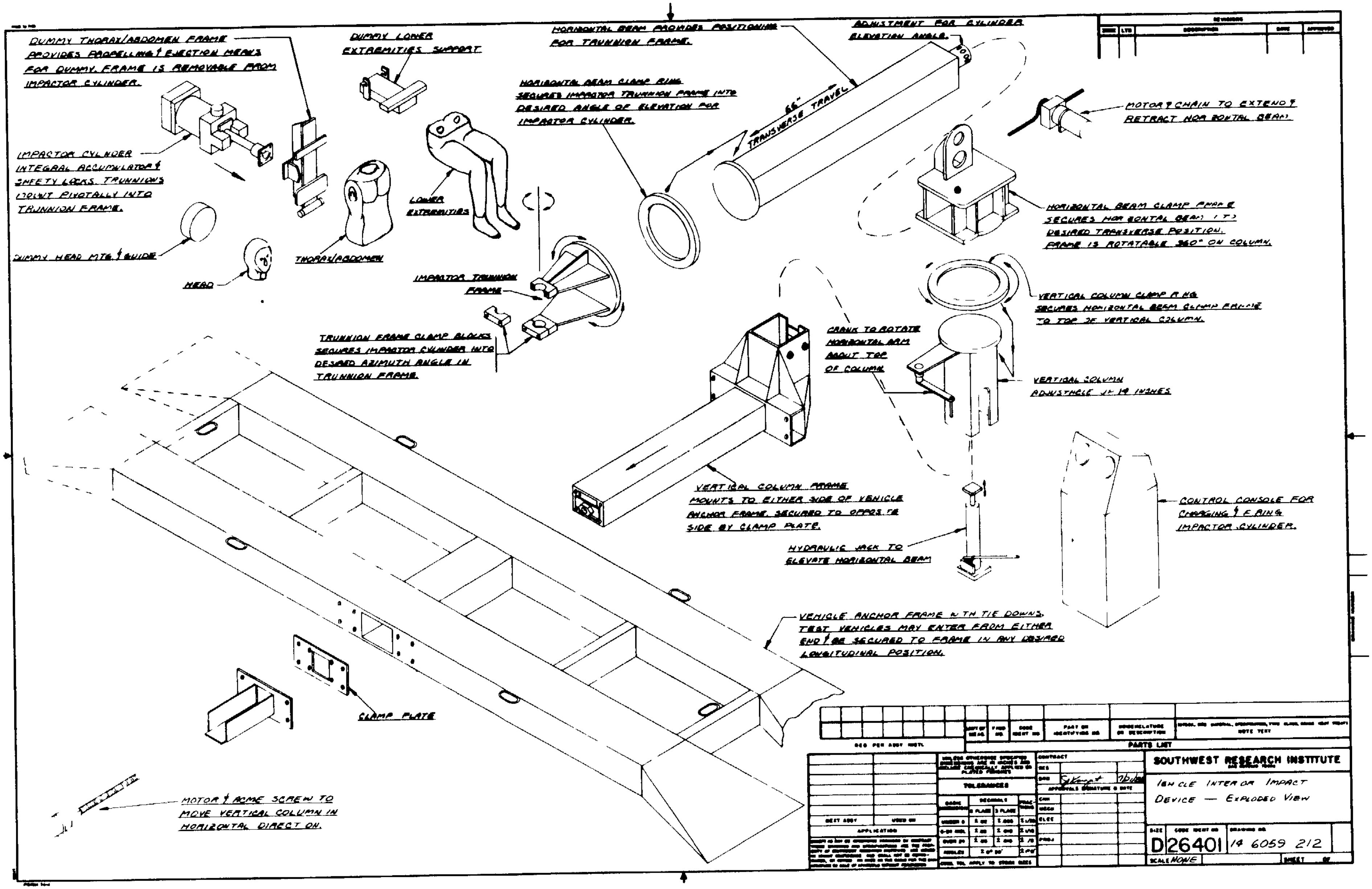


FIGURE 2. EXPLODED VIEW OF VEHICLE INTERIOR IMPACTOR

4. Adjustment is provided to extend and retract the arm over a 72 inch span so that the impactor's lateral position within the vehicle can be changed to any position from full left to full right inside the vehicle. The arm also rotates about its vertical mount on the pedestal to permit the actuator's initial distance from the instrument panel or other surface to be varied. The height of the arm above the frame or its height relative to the interior of the vehicle is continuously adjustable through 12 inches by raising or lowering the arm on the pedestal.

5. The cylinder is mounted to the arm so that it can be rotated about vertical and horizontal axes. These adjustments permit the impact angle of the body form to be adjusted to simulate oblique impact or rotation of an occupant about some lateral axis such as the "H" point. All adjustments are such that the cylinder can be secured rigidly in its final position to maintain accurate aiming while the impactor is being fired.

6. All adjustments are designed to be accomplished as quickly and as easily as possible. This permits setups to be made and changed in a minimum amount of time. Motorized adjustments are provided for column horizontal movement relative to the frame and movement of the horizontal arm relative to the top of the column.

7. Some growth potential in terms of increased velocity and mass are inherent in the design.

8. The accumulator is large in volume compared to expanded cylinder volume to minimize the variation in cylinder pressure as the piston moves. The accumulator is also concentric with the cylinder to minimize the actuator length.

9. The cylinder is designed with a seal about the center at the piston head. The area inside the O-ring is directly exposed to the high pressure of the accumulator. The accumulator is charged to a preset pressure, based on the desired velocity of the linear actuator. The annular area of the piston

outside the seal is not exposed to the high pressure until the piston displaces. The piston is kept in its retracted position by a lower pressure exposed to the annular area around the piston rod on the rod side. The cylinder is fired by shunting pressurized air from the accumulator through a solenoid valve to the clearance volume on the piston cap end. The piston displaces once the balance of forces on each side of the piston is in favor of the cap end. As soon as the piston moves, the seal unseats and the entire piston head is exposed to the high pressure from the accumulator. The piston is then accelerated rapidly until the pressure on the rod end side increases and provides sufficient force to decelerate the piston to a stop.

10. Acceleration of the linear accelerator piston occurs over approximately five to six inches of its stroke. The body form is then free to translate forward at the velocity reached at the end of this stroke. The piston is decelerated over approximately three inches of its stroke by pressure over the cylinder rod end.

11. Provision for guiding a headform has been considered. All four cylinder clamping bolts are hollow and any two diagonal bolts can accommodate rods extended from the back of the headform to resist lateral motion and rotation about the cylinder axis. This is admittedly a simple approach, but it is potentially viable and it was included at little additional cost. A more effective approach would be to use linear bearings with the headform sliding on a shaft concentric with the piston rod. However, a new cylinder would have to be designed to accommodate this concept.

12. The method for accelerating the bodyform is to accelerate it to the desired velocity and leave it free to translate into the target surface. The location of the impact and the orientation of the modified dummy body form is controlled by the fixture, mounted to the piston rod; this fixture supports the body form so that undesirable motion does not occur during acceleration. The body form rebounds unconstrained.

13. Constraining the bodyform was considered impractical for two reasons. First, it would impose large bending and torsional loads on the linear accelerator, making stored energy and its release in the linear accelerator structure a consideration in analyzing the data. There also may be a need to complicate and increase the cost of the linear accelerator structure to decrease deflections and their effects to an acceptable amount. Second, the kinematics of the bodyform and its change in velocity (and therefore change in kinetic energy) would be reduced if it is constrained on rebound and significant energy is introduced and stored in the accelerator structure. Stored energy could also be high enough to cause the bodyform to impact the interior a second time.

14. The introduction of a ball joint, between the piston rod and dummy support fixture, was also considered less desirable than the approach discussed in paragraph 12 for two reasons. First, there would be an undesirable effect on dummy kinematics on rebound. While the torsional resistance would be negligible due to the swivel action of the ball joint, the lateral resistance would still load the accelerator structure and affect the change in velocity as the dummy rebounds. Second, the ball joint will compromise the accuracy of the initial dummy positioning and introduce variation in impact location and direction since rotation is likely under acceleration. While some means to resist motion at the ball joint under acceleration was possible, adequate resistance to prevent rotation would have yielded system performance somewhere between a free ball joint and a rigid coupling.

15. An optional firing approach was investigated using an explosive squib to fire the impactor. A supplier was asked to assess the feasibility of this approach, its cost and the variance in velocities that may be expected. Variability in speed and mass could have been accommodated by variable sized charges. A few different sized charges should have been sufficient to accelerate the headform or the partial dummy to several different velocities. There were several potential advantages to this approach over the pneumatic method:

- The initial cost should have been lower because the accumulator, hoses, valves and stored gas cylinders (or compressor) were n t required. The squib would be fired from an external current source.

- The cylinder would be smaller and, as a result, easier to fit into more positions and into smaller vehicles.

- The upkeep costs would be less because fewer components (valves in particular) would be used.

After discussions with the NHTSA CTM, this approach was rejected becaus of the unfamiliar technologies and the potential safety problems that may have resulted.

DESIGN DETAILS

Use of Analytical Methods

Final design details were worked out using a computer model of the proposed system to assure correct sizing of the piston, accumulator and orifice. Stress analysis was performed on critical parts, particularly in the fixture components which are highly stressed. Deflection analysis was performed on critical structural parts to assure that excessive cylinder motion and hence, deviation from the impact target would not occur. Dummy component weights were analyzed to determine the loads that would be placed on the fixtures and cylinder during firing.

Dimensional Analysis

Dimensional analysis of the conceptual design using interior envelope dimensions of U.S. compact and foreign subcompacts was performed. This was done to assure that the device could be used in vehicles of this size. A dimensional analysis was also done on the width, length, wheelbase, and ground clearance of selected vehicles to properly size the impactor components and to enable the vehicles to be driven onto the frame. Dimensions were obtained from the Motor Vehicle Manufacturer's Association (MVMA) and directly from vehicles.

Dummy Body Form Fixtures

Fixtures were designed, fabricated, and provided as part of the completed impactor to propel the dummy head only, or the thorax-abdomen assembly and the lower extremities (legs and abdomen). In addition, another fixture was designed to propel the head-thorax-abdomen assembly. All fixtures were designed for Part 572 dummy body parts.

The head fixture consists of a single flat plate that mounts directly to the piston rod. The head is held in place by a rigid structural polyurethane foam that is cast using the head and a fixture before mounting. The head orientation relative to the piston rod for a particular test can be set during the casting procedure so that it will be correct when mounted. The head is held in place before testing with paper tape. A complete description of the fixture, its preparation and use is included in the Operator's Manual.

The fixture for the thorax-abdomen body form was designed to mount this assembly in a forward facing position with adjustments to move it vertically and to rotate it about a lateral axis relative to the piston rod. The thorax-abdomen body form is mated to this fixture with a guide that is mounted in place of the standard pelvic accelerometer cover. The guide is adjustable to suit the angle of the fixture.

This fixture was designed with an extension so that a head support could be added and the head-thorax-abdomen fired as an assembly.

The lower extremities use the thorax-abdomen fixture with a support to hold the legs prior to firing. The support, which attaches to the thorax-abdomen fixture, drops away when the impactor is fired, allowing the lower extremities to translate freely.

A complete description of the use of these fixtures is included in the Operator's Manual along with a list of design considerations that were used in developing the fixtures. These design considerations should be reviewed prior to the development of any new fixtures.

Body Form Impact Velocity Measurement

A number of velocity measurement concepts were considered. The system finally used consisted of a rack with a series of evenly spaced holes attached to the body form fixture. The attachment was such that the rack would translate with the fixture as it accelerated and translated forward approximately 50 mm at the point of fixture maximum velocity when the fixture started to decelerate. The rack was constrained so that it translated only in a forward direction. The portion of the rack with a series of holes slid through a housing that contained an LED on one side and a light sensitive transistor on the other. These two components were in a line intersected by the rack with the holes. A digital signal was produced from the associated electronics that varied as the holes passed the LED and light sensitive transistor. A time based measurement of the circuit condition could be converted to maximum fixture or body form velocity by dividing the time of one cycle at the point of maximum velocity. This method proved reliable and reasonably accurate given adequate resolution of the time base. A circuit schematic is shown in Figure 3.

The accuracy of the velocity signal was checked by two methods. First, it was checked approximately by measuring the bodyform speed on high-speed film. Second, it was checked by comparing it to the first integral of the piston rod acceleration. This was a more accurate measure of velocity and proved consistent in comparison with the velocity measured with the photo transistor circuit.

It should be mentioned that velocity of the body form measured with the photo transistor circuit is relative to the cylinder. Though rearward movement of the cylinder is slight, it does introduce a possible error in the velocity value. To overcome this, the attachment of the photo transistor circuit housing to the cylinder was designed so that it could move slightly parallel to the axis of the cylinder. It was fitted with a threaded hole into which a rod end could be fastened and an extension could be attached to the rod end and through a second rod end to a plate that is anchored to the test vehicle. This means that, while the cylinder supports the housing, the housing is connected to the vehicle along an axis parallel to cylinder motion during firing.

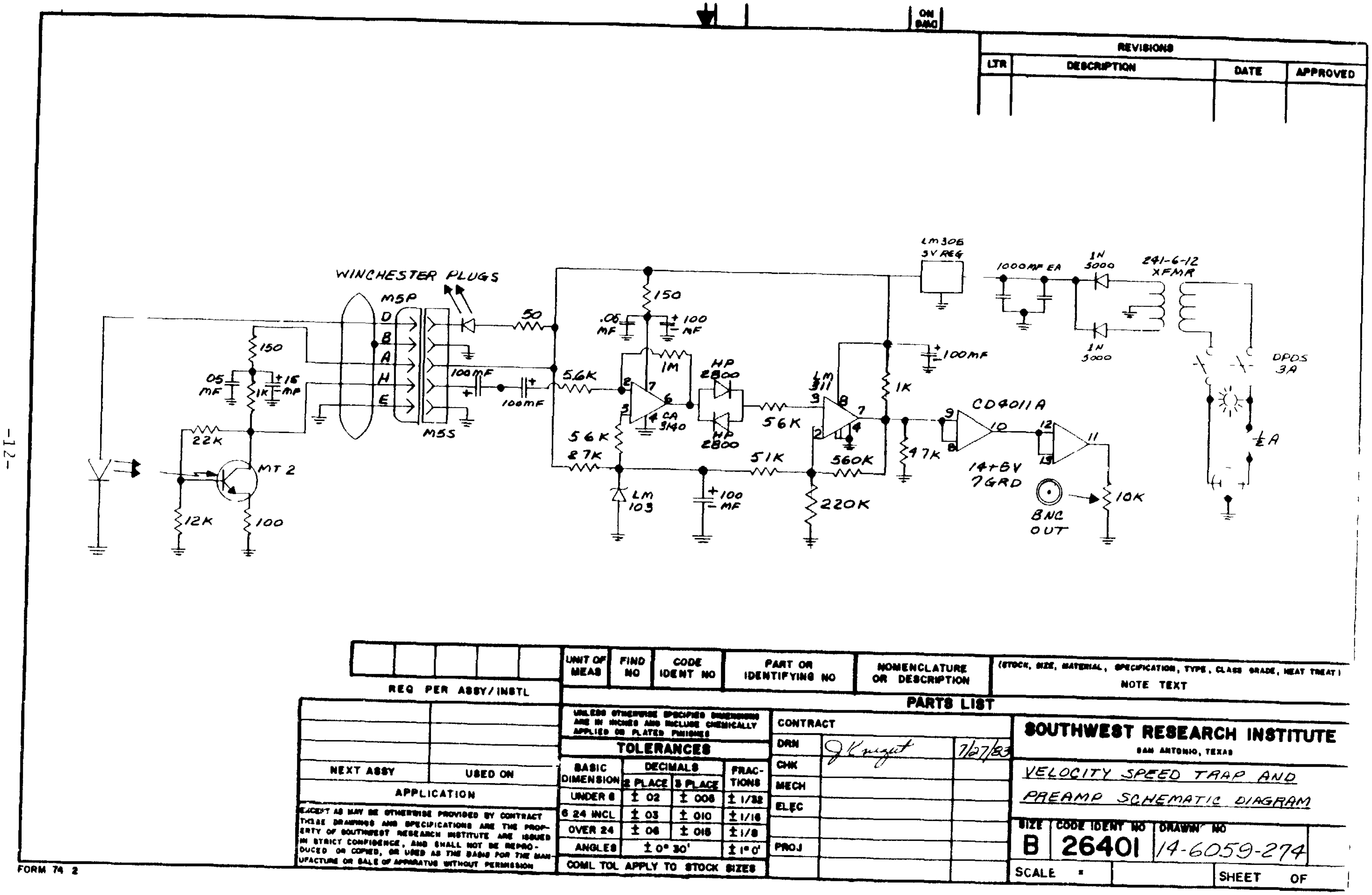


FIGURE 3. VELOCITY SPEED TRAP AND PREAMP SCHEMATIC

CONTROLS AND ACTUATION

Compressed nitrogen of at least 8268 kPa (1200 psig) is used as a source to propel the dummy form. Its requirements are discussed in detail in the Operator's Manual and a schematic of the circuit is shown in Figure 4. A low pressure supply that is either nitrogen or compressed air at 689 kPa (100 psig) is required to actuate the safety pins. A 115 VAC power supply is needed for the electric motors that adjust the horizontal arm, the horizontal motion of the vertical column and the console. The console electrical schematic is shown in Figure 5.

The console contains controls for adjusting pressures to the cylinder and for actuating the safety pins and firing the impactor. It is attached to the cylinder by an umbilical which permits the operator to station himself a safe distance from the cylinder and provide flexibility in locating himself so that the impact may be observed. The controls for the electric motors that adjust the horizontal arm extension and the horizontal motion of the column are contained on a separate umbilical so that the person actuating them can position himself to view the adjustment.

SAFETY FEATURES AND CONSIDERATIONS

The design requirements of the impactor necessitate the ability to store large amounts of energy in the form of compressed gas. It is also capable of driving the piston rod of the impactor at velocities exceeding 30 mph when a bodyform is mounted and at much higher velocities when no mass is mounted. In addition, the component structures of the impactor which support the cylinder and move to permit adjustment are by design heavy to withstand firing stresses and minimize deflection. The high mass of these moving components makes them potentially hazardous when they are not secured.

The Operator's Manual discusses safety in detail. It stresses the need for proper operation to eliminate the possibility of serious injuries or fatalities that could result from improper use. Safety is discussed in four areas which are detailed in the following paragraphs.

Pressures - The cylinder has been provided with two safety pins that engage the piston rod when it is fully retracted. The pins will retain the piston rod even if the

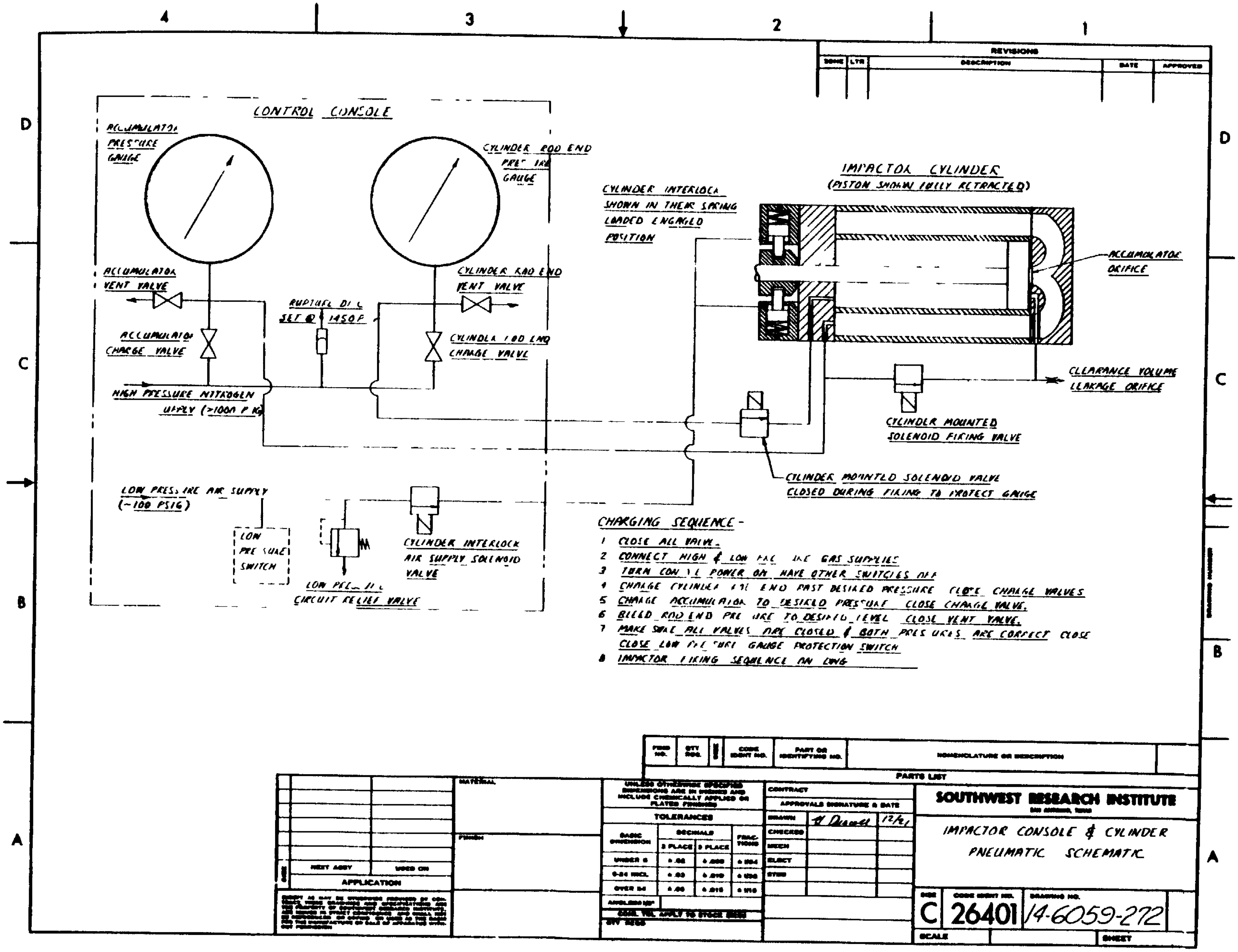


FIGURE 4. IMPACTOR CONSOLE AND CYLINDER PNEUMATIC SCHEMATIC

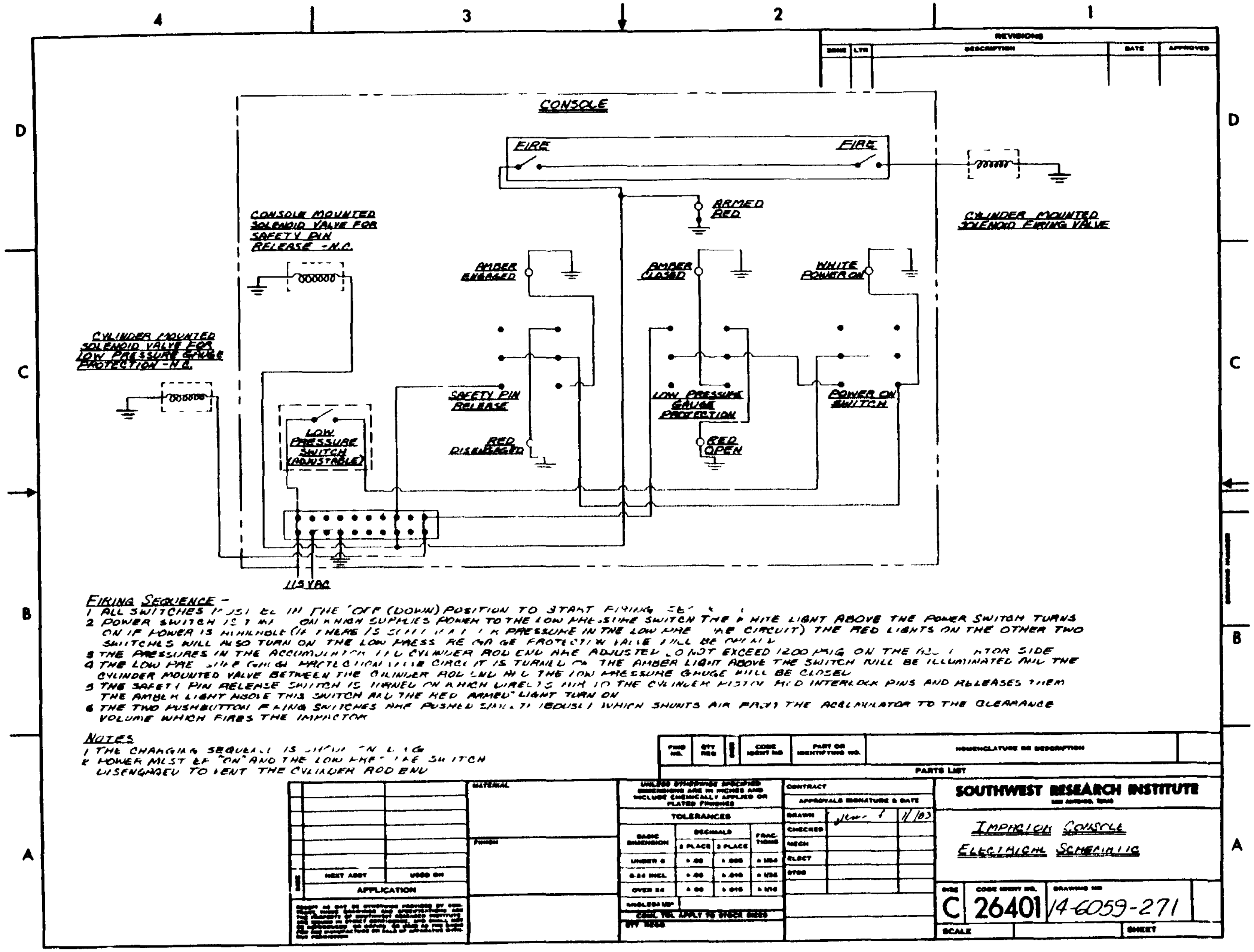


FIGURE 5. IMPACTOR CONSOLE ELECTRICAL SCHEMATIC

pressures are such that the piston would otherwise be unseated or if a malfunction occurred that permitted the firing circuit to be energized. These pins are engaged in the piston rod under spring pressure and released by actuating the low pressure air circuit. The switch to actuate these pins is located on the front of the control panel.

The maximum pressure allowed in the cylinder is 8268 kPa (1200 psig). This limit is labeled on both the control panel and on the cylinder. To assure compliance with this limit by the control panel operator and to eliminate the possibility of overcharge due to the charge valve being left open, a regulator should be attached to the high pressure cylinder and adjusted to 8268 kPa (1200 psig) or to a lower pressure that reflects the maximum working pressure expected. A rupture disc is included in this circuit to prevent pressures from exceeding 9991 kPa (1450 psig).

The maximum pressure in the safety pin actuation circuit is 689 kPa (100 psig). A regulator should also be provided in the circuit to assure that the pressure does not exceed this amount. A relief valve is included in the circuit to prevent pressure from exceeding 689 kPa (100 psig).

Adjustments - The impactor adjustments made with the electric motors require actuation of two switches for any motion. The motor direction toggle switch is first actuated, then a push button engaged to actuate the motor. The motors will stop as soon as the push button is released.

Actuation of the impactor adjustment inside the vehicle should be made only when no personnel are inside the vehicle. Actuation of the various adjustments should be made with great care as substantial masses are being moved. All adjustments should be locked except for the one being moved to eliminate unexpected movements of the various impactor parts.

Procedures - The use of a checklist similar to that provided in Appendix B will assure that the proper order of events for firing takes place and that personnel safety is observed.

Firing - The actuation of control panel switches should be called out in the sample checklist and in the order provided from left to right. Actuation should be immediately before firing except for the power switch. Two push button switches must be actuated simultaneously to fire the impactor. The red light between these two indicates that the system is ready for firing.

No one should be in the vehicle or near the cylinder when it is being pressurized or when firing. A safety zone should be marked or at the very least observed around the anchor frame and vehicle when pressurizing or firing.

MAINTENANCE

Minimal maintenance is required for the impactor. Two areas that require attention are discussed in detail in the Operator's Manual. The cylinder internal seals and bearings require periodic lubrication as do the moving parts of the assembly. The specific procedures and types of lubricant are included in the Operator's Manual.

FIRING

The Operator's Manual discusses the firing procedure. It is recommended that a written protocol be followed to assure adherence to safety concerns as well as assuring that the proper test setup is followed, test documentation is obtained and all test instrumentation is properly activated. The importance of a well developed and properly followed firing protocol cannot be overemphasized. It assures safe operation as well as testing that yields a high percentage of successful results.

TESTING

Testing was conducted on the completed impactor to confirm its structural and stiffness adequacy under use, as well as its safety and practicality. In addition, its performance was measured to assure that it met design goals. Evaluations were conducted in the areas discussed in the following paragraphs.

Installation of Test Vehicle on Impactor Frame - Several test vehicles were installed on the impactor frame to assure that vehicles of the size they represented could be driven on and off as well as positioned so that the horizontal arm could be extended through either the front or (if equipped) rear door. A full size 1979 Chevrolet Impala, a compact 1978 Ford Fairmont, a compact 1981 Buick Skylark, and a subcompact 1978 Toyota Corolla were used to test dimensions. After minor changes to the inner tire guides on the impactor frame to permit vehicle chassis clearance, all of these cars could be accommodated.

Installation of Impactor Inside Vehicle - The impactor was installed inside the 1978 Fairmont and the 1981 Skylark to evaluate its range of adjustments and the ease of making adjustments on the impactor. A detailed set of instructions to install the cylinder and adjust it inside the test vehicle is included in the Operator's Manual. The range of cylinder adjustments inside the Skylark are shown in the figures included in Appendix A. The following basic firing positions and bodyforms were evaluated:

Body Form	Target
Head-Face	Windshield
Head-Face	A-Pillar
Head	Roof Edge
Head	Windshield Header
Head	B-Pillar
Head-Face	Steering Wheel
Head-Face	Instrument Panel
Thorax-Abdomen	Instrument Panel
Thorax-Abdomen	Steering Wheel
Lower Extremities	Instrument Panel

This list was derived from the RFP entitled "Study of Occupant Impact with Vehicle Interior Surfaces" (RFP No. DTNH22-82-R-07364). Though some minor limitations were noted with the headform, all firing positions could be obtained. It should be noted that the headform requires the greatest range of adjustment and the least amount of energy to propel. The cylinder, which is designed to propel at least a 40 Kg (89 lbs) payload is over-designed for accelerating the headform. A smaller cylinder exclusively for accelerating the head could be designed and used allowing further flexibility in aiming the cylinder.

Firing the Impactor - A series of test firings were conducted on the impactor to evaluate its performance, develop a firing protocol, develop velocity versus pressure firing curves and develop protocols for using the three bodyforms.

Initial testing showed some problems with seal leakage which was corrected through redesign. The cylinder was tested to a maximum pressure of 8268 kPa (1200 psig). It was designed for 20,670 kPa (3000 psig).

A firing protocol was developed and this was included in a test protocol which was provided as a checklist in the Operator's Manual.

The head, the thorax-abdomen and the lower extremities were all fired from the lowest practical speed to 49 km/h (30 mph) to evaluate their respective supporting fixtures and to assess their trajectory performance. Evaluation of fixture and trajectory performance was done with high-speed photography. Lateral views were taken with a Photosonic 16mm-1B camera operating at 1000 FPS and with an 8mm Ilex lense. The films permitted a detailed view of the fixture body form during firing, and fixture and body form deformation and body form rotation about its lateral or vertical axes. Tests were conducted with a target surface as close as 250mm (10 inches) to the extended impactor piston rod to assess the impactor in a condition similar to that inside a vehicle and as far away as two meters (∿6.5 feet) to assess the body form trajectory.

Instrumentation used to evaluate impactor performance consisted of an accelerometer mounted to the impactor cylinder rod, an accelerometer in the chest mount of the thorax-abdomen assembly and the piston rod velocity measurement equipment. This instrumentation was used along with the high-speed film to determine relative motion between the body form and the fixture, and static and dynamic deformation of the body form. Relative motion between the body form and fixture can best be minimized by adequately supporting the body form where it extends over the fixture and by preloading it to the fixture with tape before firing. Static and dynamic deformation is only a concern with the thorax-abdomen. From analysis of the high-speed films it was found that a minimum distance of 229 mm (9 inches) should be made available between the body form and the target surface with the piston rod fully retracted when firing at 49 km/h (30 mph) to assure that body form excitation has adequately decayed and that the abdomen shape has fully recovered. The Operator's Manual gives complete information for minimum distances relative to firing velocity.

The instrumentation was also used to establish the firing curves. These are the relationships between accumulator and rod end pressures and the bodyform velocity for each of the three body forms evaluated. Copies of these curves are included in Appendix B.

A record of all firings, including a description of the body forms and maximum velocities, was made. A copy of this log is included in Appendix C.

OPERATOR'S MANUAL

An Operator's Manual was drafted and sent to NHTSA and CALSPAN. Its contents include a description of the impactor; detailed installation, operating and maintenance instructions; safety features and procedures; pneumatic and electrical schematics; firing curves; and a suggested firing protocol. An attempt was made to include much of the operating experience that had been gained over the 135 firings that had been made during development and evaluation of the impactor.

DELIVERY OF HARDWARE AND FOLLOW-UP ASSISTANCE

After evaluation of the impactor was completed, the impactor was loaded on a flatbed trailer for delivery to CALSPAN Corporation in Buffalo, New York. Copies of the Operator's Manual were sent separately. After the impactor was received, SwRI personnel visited CALSPAN to assist in its assembly and to instruct CALSPAN personnel on its operation. Several follow-up telephone conversations were made with CALSPAN personnel to answer questions they had about the impactor operation.

DRAWING PACKAGE

A complete set of reproducibles and all drawings was made and forwarded to NHTSA under separate cover. Each drawing has a bill of materials. The entire package was reviewed by the designer and the project manager to assure that it was complete and correct prior to shipment.

FURTHER INVESTIGATION

Further refinement of hardware is possible and could best be accomplished after experience from firing the impactor is gathered during the first test program.

One of the purposes of the impactor is to be able to assess the energy absorbing characteristics of vehicle interiors without resorting to the expense of full scale or sled tests. It would be desirable to compare the results of impactor testing on an impact sled using the same interior surfaces and full or partial anthropomorphic dummies. This comparison is necessary to either validate the impactor results or to provide a baseline to which impactor test results can be compared.

APPENDIX A

PHOTOGRAPHS OF THE IMPACTOR

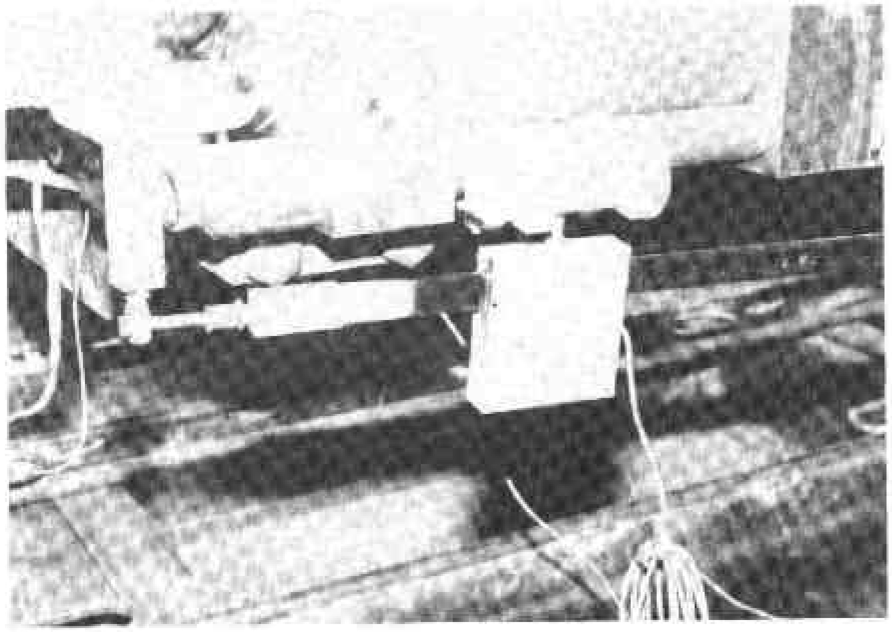


FIGURE A1. VELOCITY MEASURING MECHANISM SHOWING HOUSING MOUNTED TO CYLINDER THAT GUIDES SLIDING ROD AND CONTAINS PHOTOTRANSISTOR CIRCUIT. SLIDING ROD IS FREE TO SLIDE THROUGH HOUSING AND CONSTRAINED TO SLIDE APPROXIMATELY 50mm THROUGH ROD END ATTACHED TO PISTON ROD AFTER MAXIMUM VELOCITY IS REACHED.

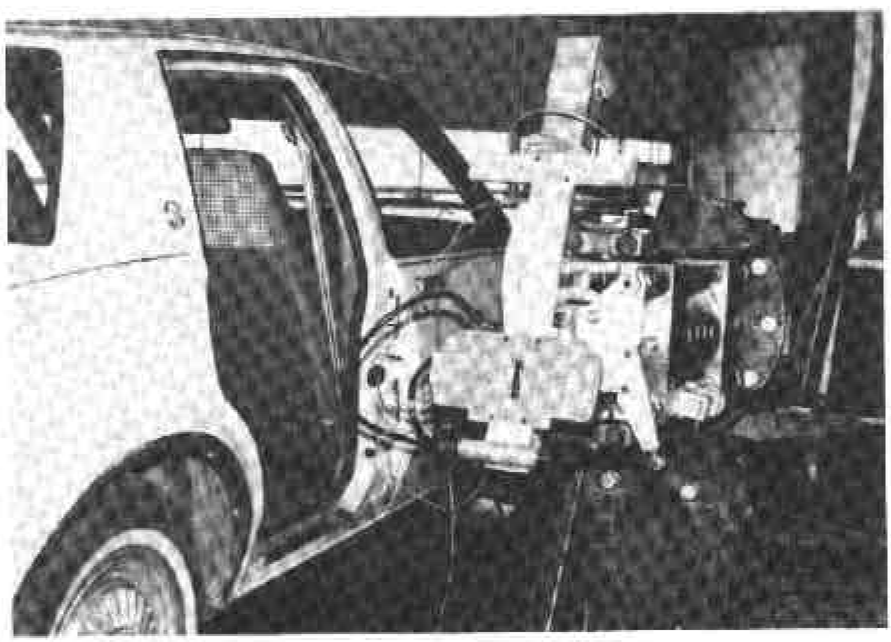
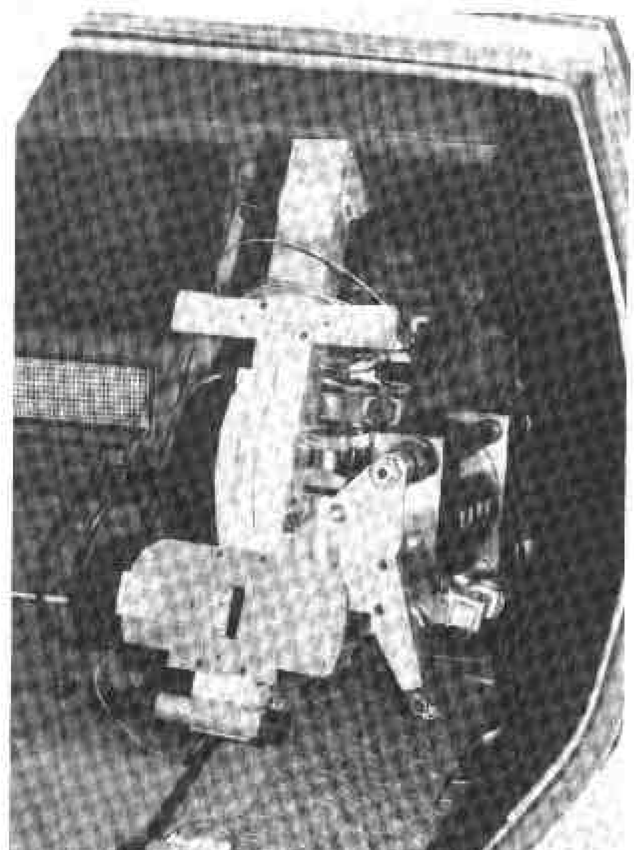


FIGURE A2. TEST CAR MOUNTED ON FRAME WITH REAR DOOR REMOVED AND HORIZONTAL ARM PIVOTED TO CLEAR VEHICLE.

FIGURE A3. HORIZONTAL ARM INSERTED THROUGH REAR DOOR OPENING.

FIGURE A4. CYLINDER WITH FIXTURE ATTACHED INSERTED THROUGH TEST VEHICLE REAR DOOR OPENING.



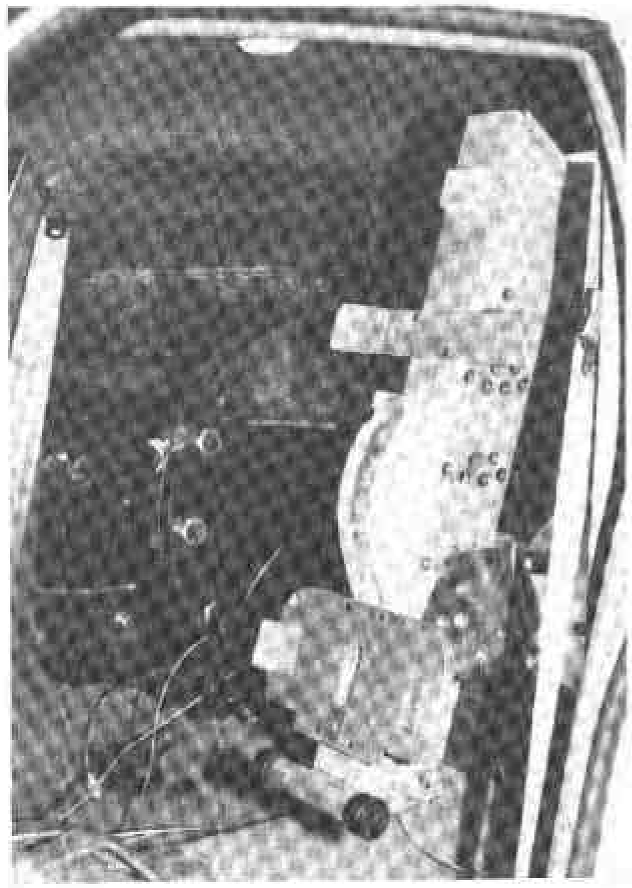


FIGURE A5. CYLINDER TURNED SO THAT FIXTURE FACES FORWARD BEHIND STEERING. BODY FORM CAN NOW BE MOUNTED ON FIXTURE.

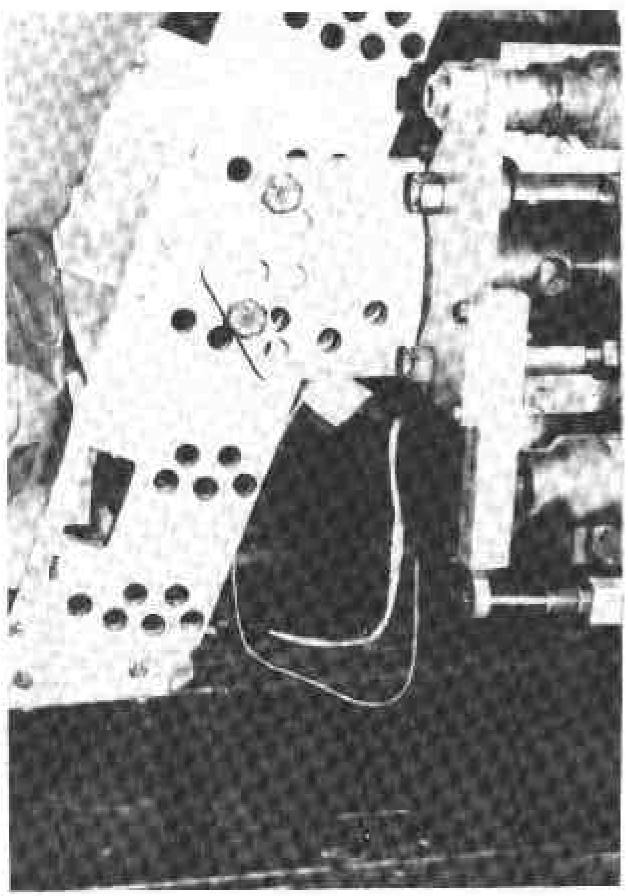


FIGURE A6. CLOSE UP OF THORAX - ABDOMEN FIXTURE ATTACHED TO THE PISTON ROD BY TWO BOLTS. THE UPPER BOLT IS THE PIVOT BOLT THAT ALWAYS USES THE SAME HOLE. THE LOWER BOLT USES ONE OF THE REMAINING HOLES THAT PERMIT THE PITCH ANGLE OF THE FIXTURE TO BE ADJUSTED IN 50° INCREMENTS.

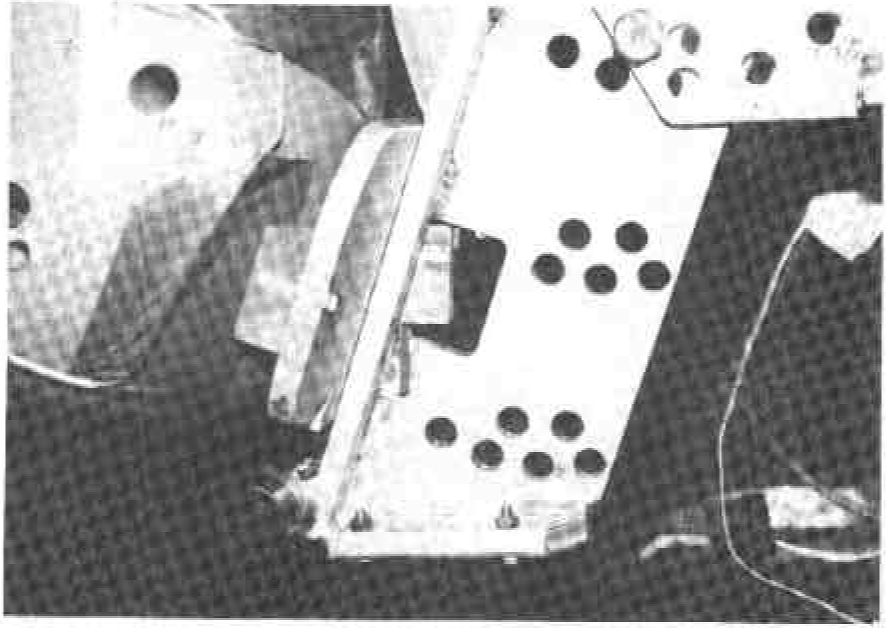
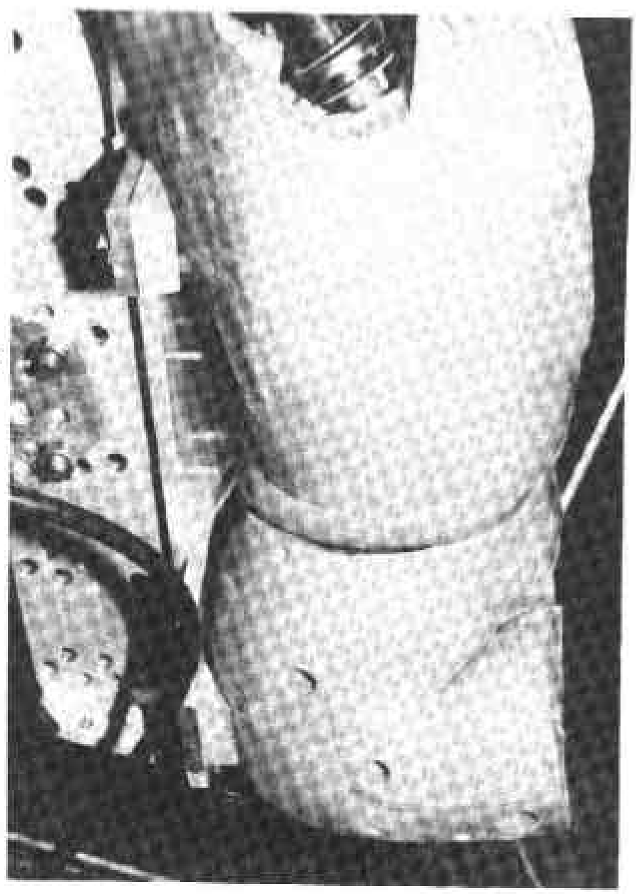


FIGURE A7. VIEW OF LOWER THORAX-ABDOMEN FIXTURE WITH GUIDE ATTACHED TO THE PELVIC ACCELEROMETER MOUNT ON THE BODY FORM INSERTED THROUGH THE FIXTURE.

FIGURE A8. THORAX-ABDOMEN MOUNTED ON FIXTURE WITH SUPPORTS AT BUTTOCKS, SHOULDERS AND SPINE TO RESIST SPINE DEFLECTION AND BODY FORM ROTATION UNDER ACCELERATION



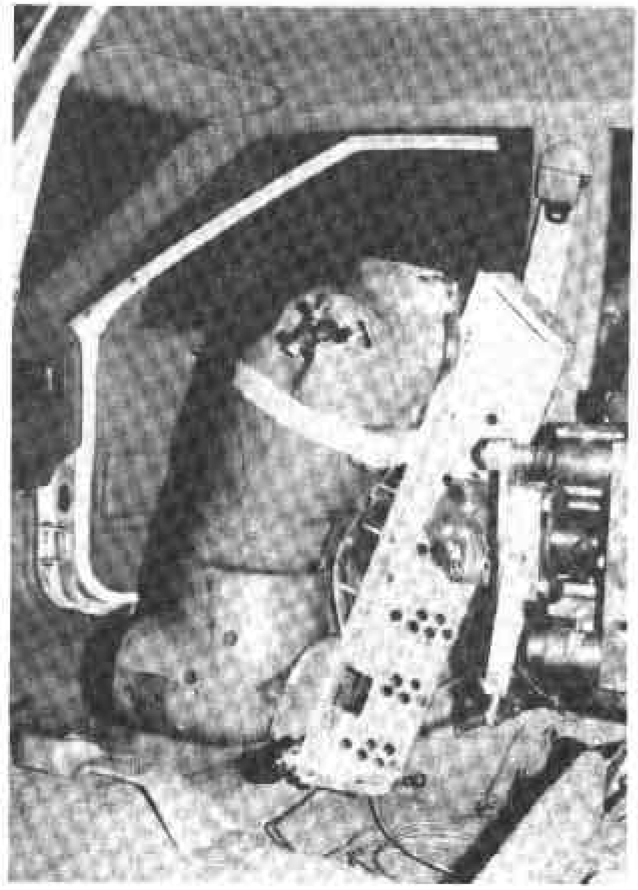


FIGURE A9. THORAX-ABDOMEN MOUNTED ON FIXTURE AND LOCATED TO IMPACT PASSENGER SIDE OF INSTRUMENT PANEL.

FIGURE A10. LEFT SIDE VIEW OF THORAX-ABDOMEN IN DRIVERS POSITION LOCATED TO IMPACT STEERING WHEEL.

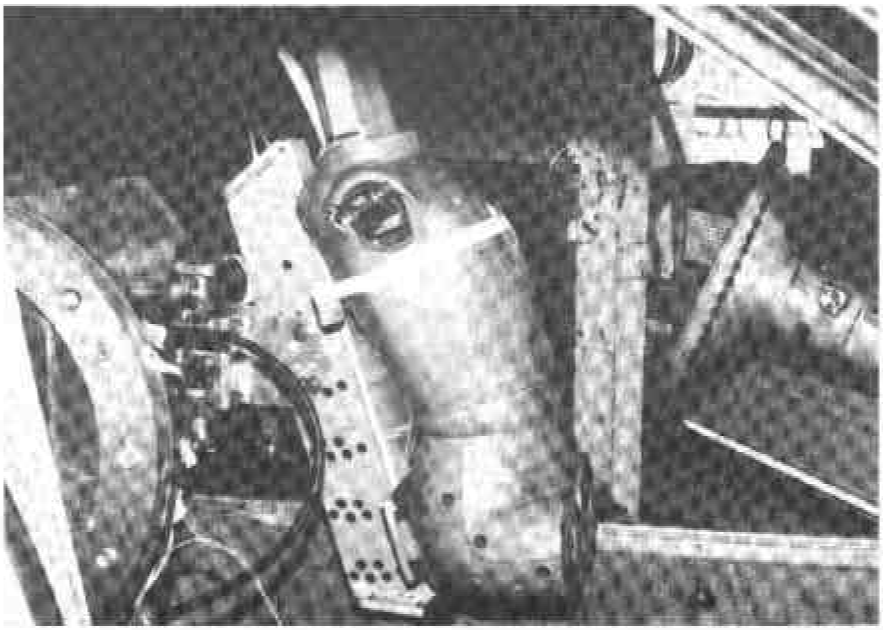


FIGURE A11. RIGHT SIDE VIEW OF THORAX-ABDOMEN IN DRIVER'S POSITION LOCATED TO IMPACT STEERING WHEEL.

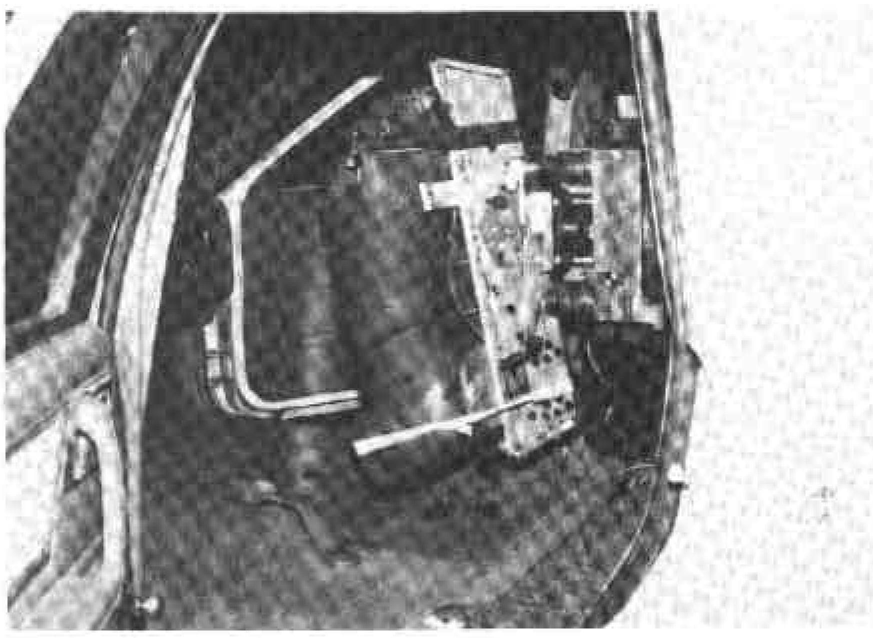


FIGURE A12. THORAX-ABDOMEN PITCHED FORWARD ON FIXTURE, LOCATED TO IMPACT PASSENGER SIDE OF INSTRUMENT PANEL.

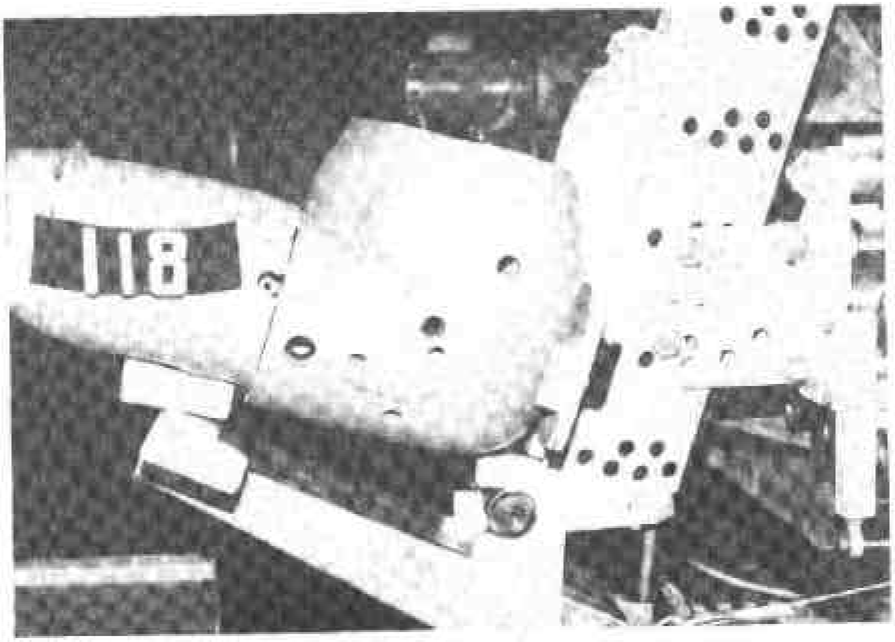


FIGURE A13. CLOSE UP VIEW OF LOWER EXTREMITIES MOUNTED ON FIXTURE WITH LEG SUPPORT. THE PELVIC GUIDE ENGAGES THE THORAX-ABDOMEN FIXTURE WHILE THE LEG SUPPORT HOLDS THE DUMMY LEGS UP PRIOR TO FIRING AND DROPS AWAY AS THE PISTON ROD EXTENDS.

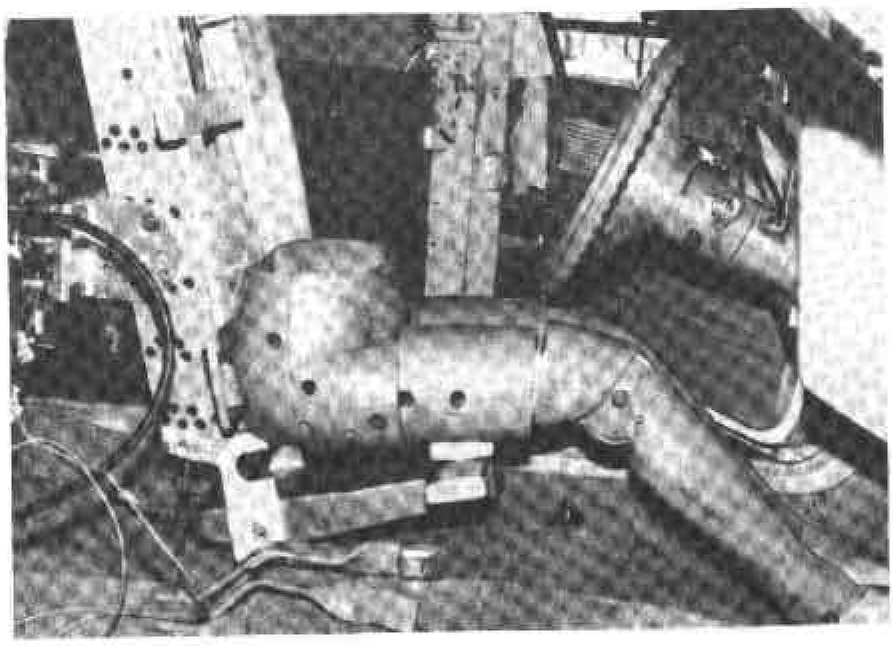


FIGURE A14. RIGHT SIDE VIEW OF LOWER EXTREMITIES MOUNTED ON FIXTURE AND LOCATED BEHIND STEERING WHEEL.

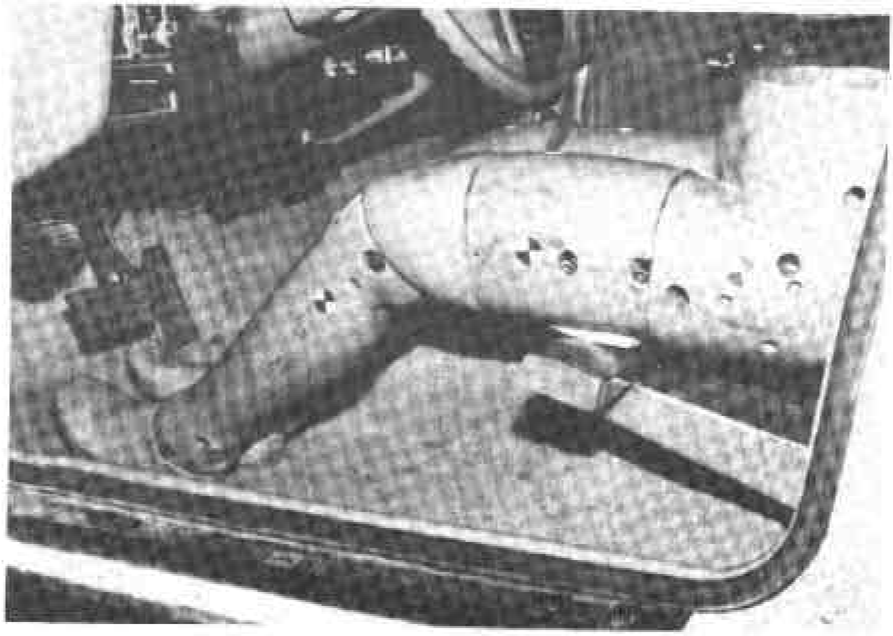


FIGURE A15. LEFT SIDE VIEW OF LOWER EXTREMITIES MOUNTED ON FIXTURE AND LOCATED BEHIND STEERING WHEEL.

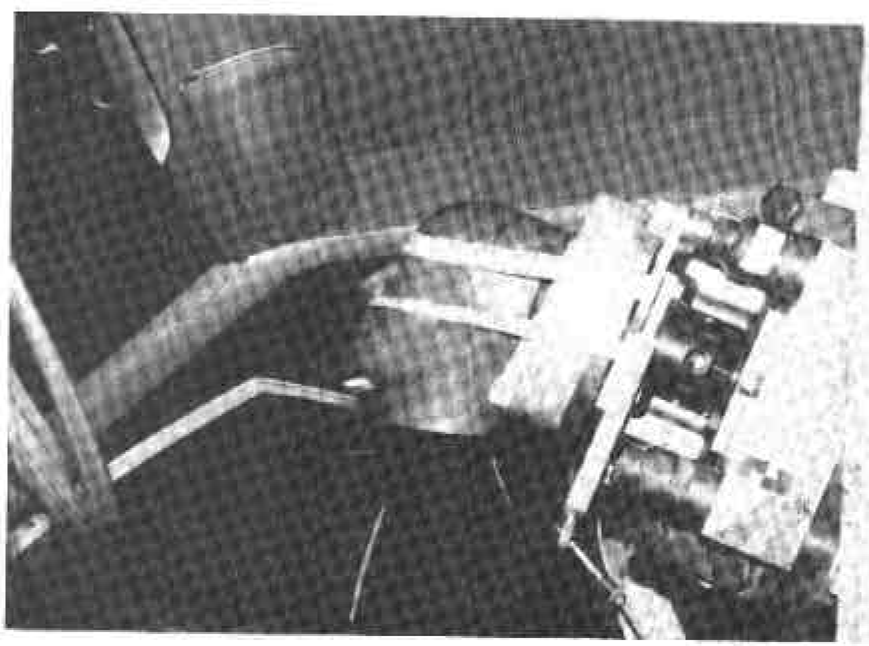


FIGURE A16. HEAD MOUNTED TO ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE VEHICLE WINDSHIELD.

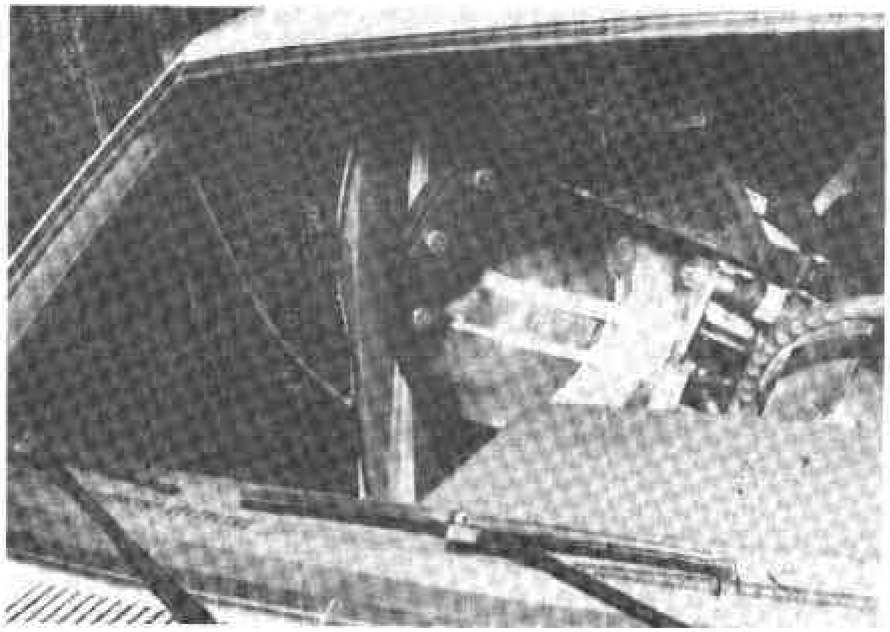


FIGURE A17. HEAD MOUNTED TO ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE RIGHT SIDE "A" PILLAR.

FIGURE A18. HEAD MOUNTED ON ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE LEFT SIDE "A" PILLAR.

FIGURE A19. HEAD MOUNTED ON ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE ROOF OVER THE DRIVER SIDE DOOR.

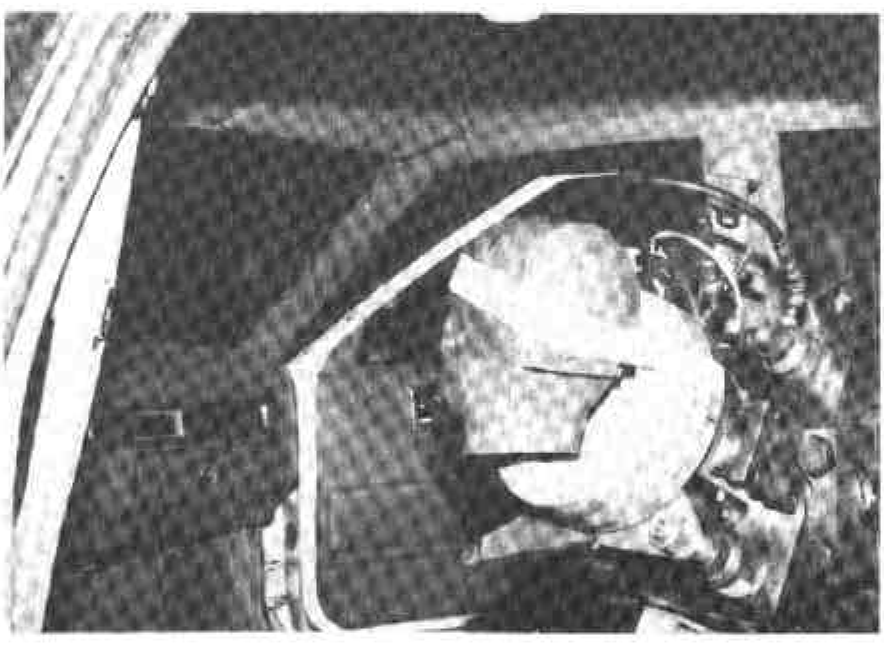


FIGURE A20. HEAD MOUNTED ON ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE DRIVER SIDE "B" PILLAR.

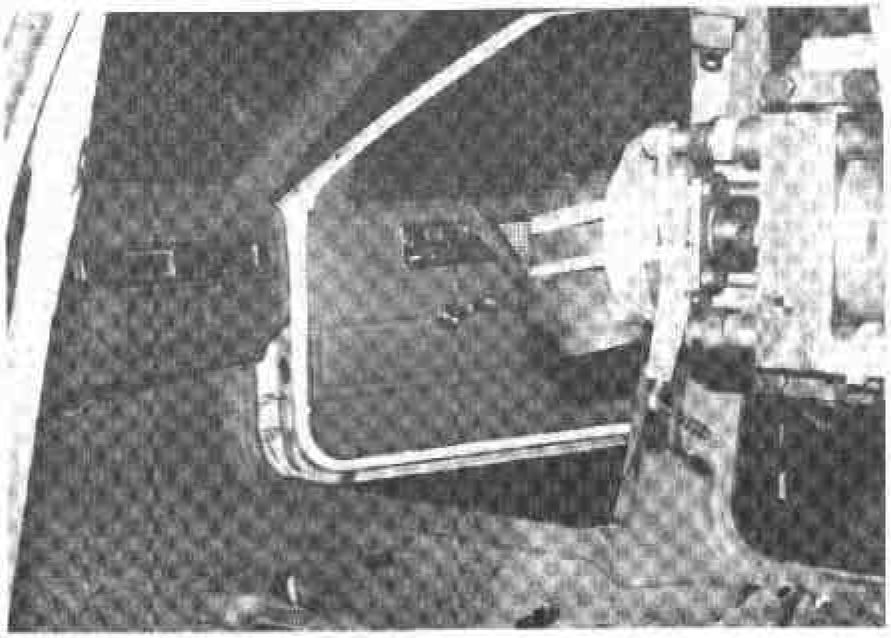


FIGURE A21. HEAD MOUNTED ON ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE PASSENGER SIDE INSTRUMENT PANEL.

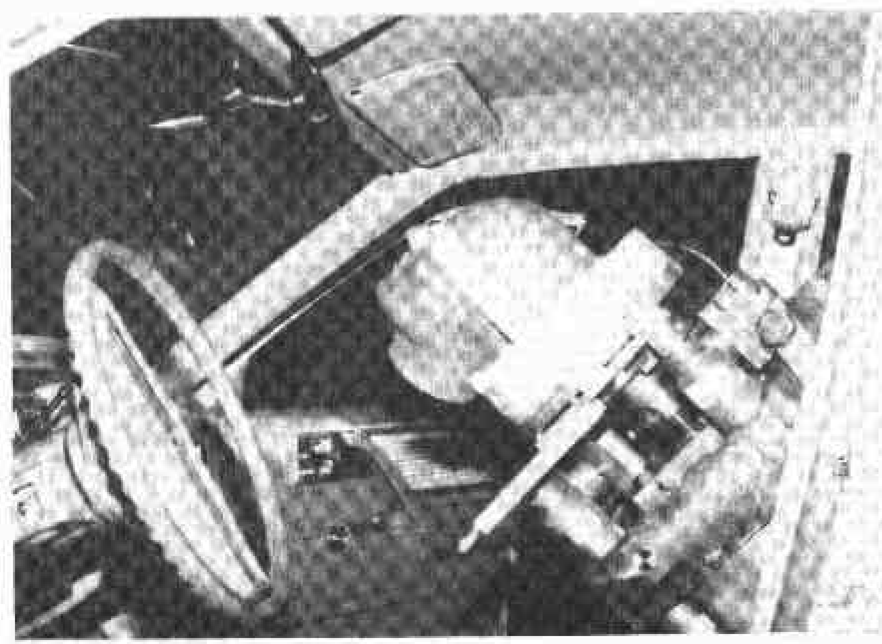
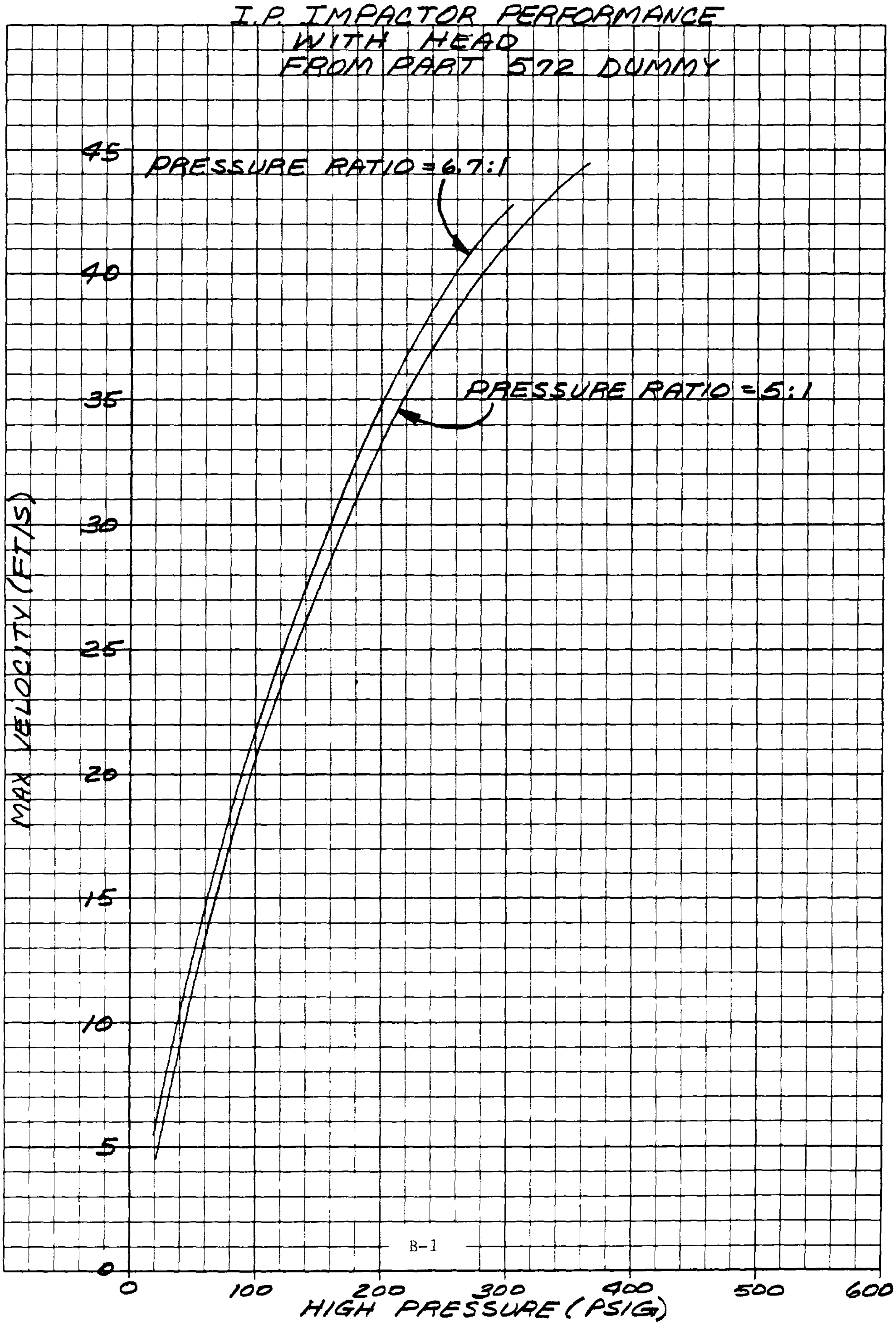
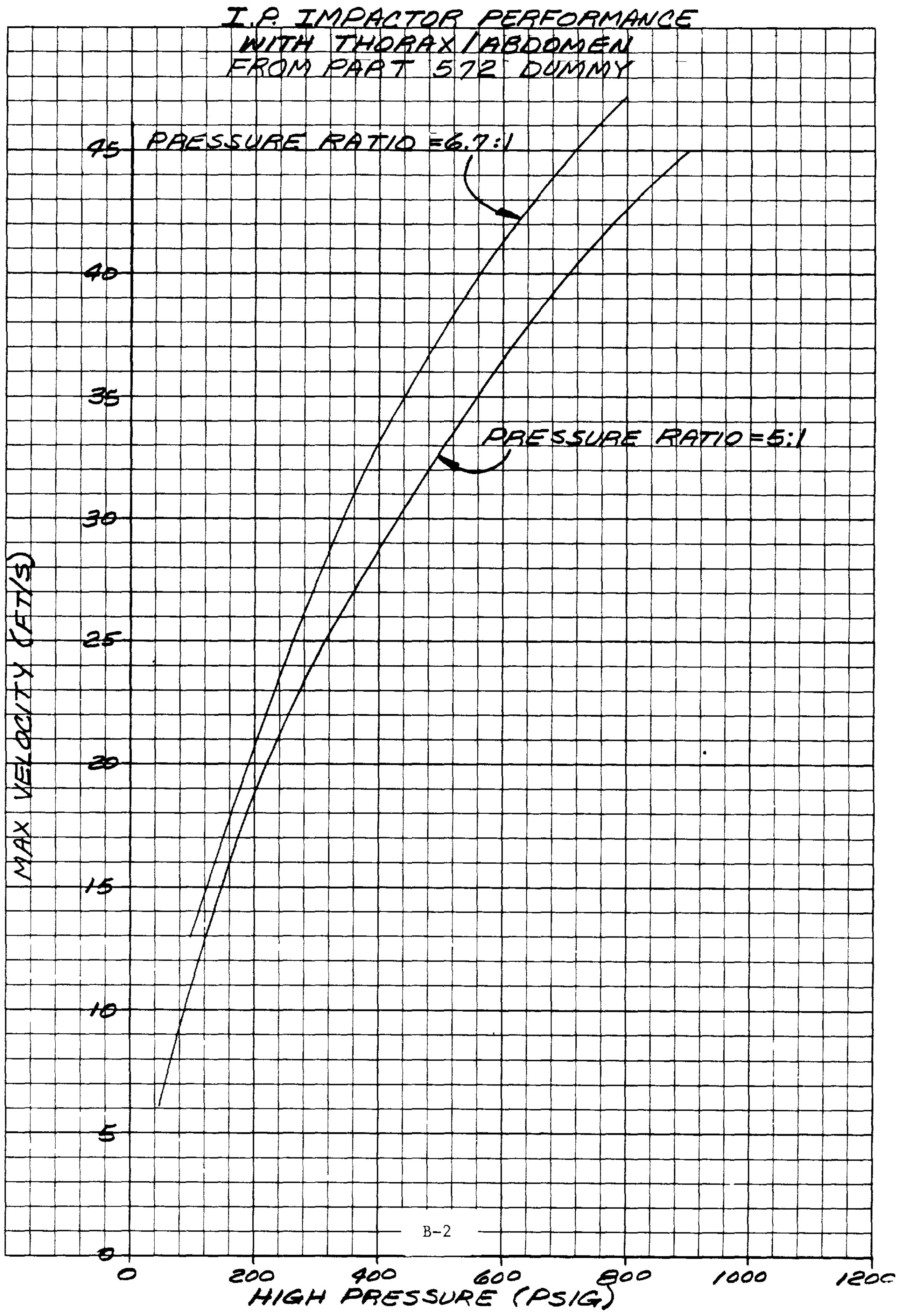


FIGURE A22. HEAD MOUNTED ON ITS FIXTURE AND CYLINDER AIMED FOR IMPACT TO THE WINDSHIELD LEADER.

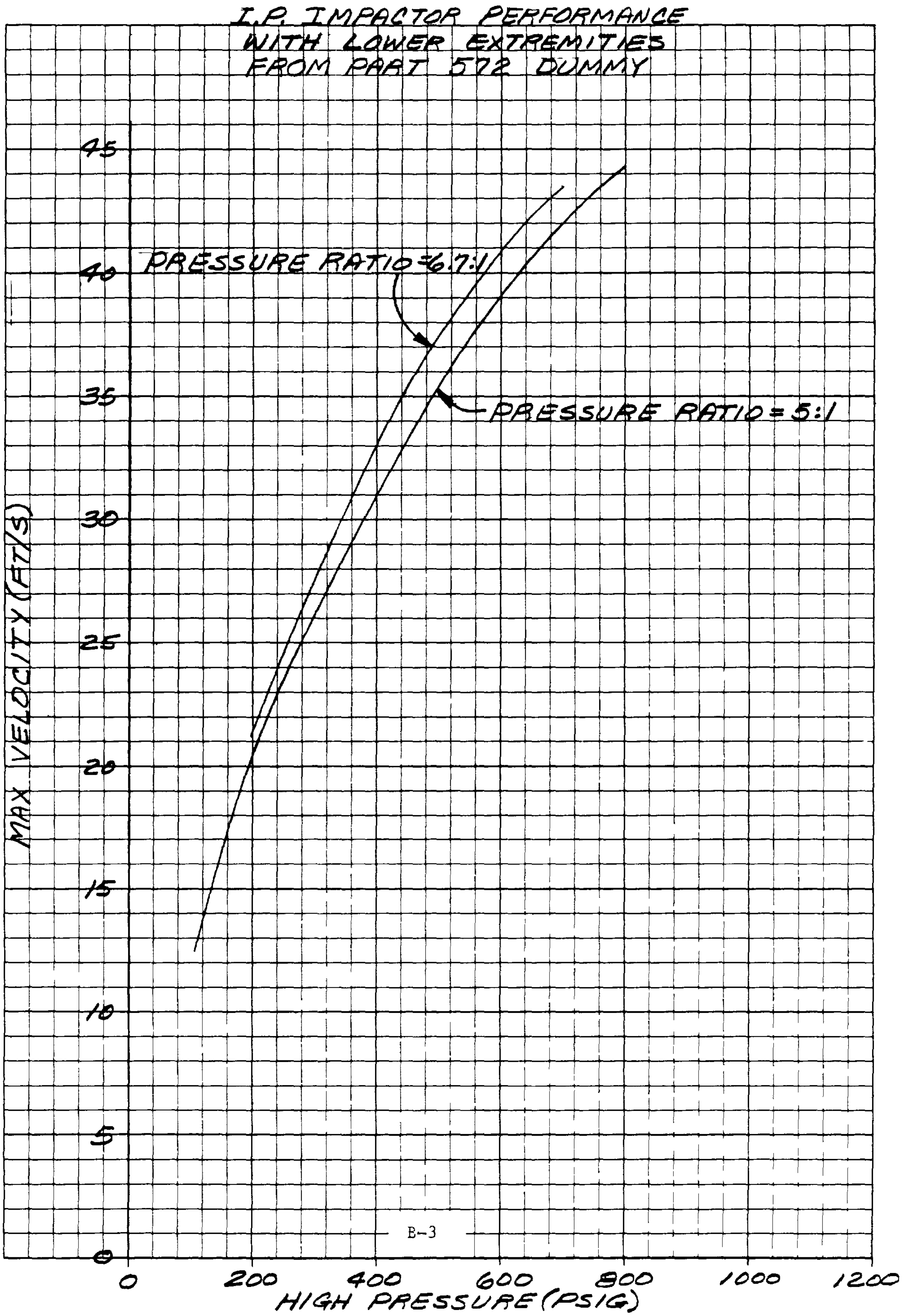
APPENDIX B

FIRING CURVES FOR EACH BODY FORM


I.P. IMPACTOR PERFORMANCE
WITH HEAD
FROM PART 572 DUMMY
PRESSURE RATIO = 6.7:1
PRESSURE RATIO = 5:1
MAX VELOCITY (FT/S)
HIGH PRESSURE (PSIG)
0
5
10
15
20
25
30
35
40
45
100
200
300
400
500
600



I.P. IMPACTOR PERFORMANCE
WITH THORAX/ABDOMEN
FROM PART 572 DUMMY
PRESSURE RATIO = 6.7:1
PRESSURE RATIO = 5:1
MAX VELOCITY (FT/S)
0
5
10
15
20
25
30
35
40
45
0
200
400
600
800
1000
1200
HIGH PRESSURE (PSIG)


I.P. IMPACTOR PERFORMANCE
WITH LOWER EXTREMITIES
FROM PART 572 DUMMY
PRESSURE RATIO=6.7:1
PRESSURE RATIO=5:1
MAX VELOCITY (FT/S)
HIGH PRESSURE (PSIG)
0
5
10
15
20
25
30
35
40
45
0
200
400
600
800
1000
1200

APPENDIX C

TEST LOG

1 P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODYFORM	FIXTURE	APPROX ATTITUDE (°)	PISTON MAX ACCEL (G)	PISTON MAX. DECEL (G)	ΔV (FT/SEC)
1	3-24-82	50	10	5:1	NONE	NONE	0	20	40	9.6
2	3-24-82	75	15	5:1	NONE	NONE	0	30	75	14.5
3	3-24-82	100	20	5:1	NONE	NONE	0	40	120	19.3
4	3-24-82	125	25	5:1	NONE	NONE	0	55	160	~22.9
5	3-24-82	175	35	5:1	NONE	NONE	0	80	225	29.6
6	3-24-82	250	50	5:1	NONE	NONE	0	115	160	37.0
7	3-24-82	325	65	5:1	NONE	NONE	0	140	220	4[illegible] 0
8	3-24-82	400	80	5:1	NONE	NONE	0	80	ACCEL [illegible]	
9	4-12-82	100	20	5:1	HEAD THIS, ABOD (HTA)	HTA FIXT	0	13	26	~11
10	4-12-82	100	20	5:1	HTA	HTA	0	15	22	
11	4-12-82	100	20	5:1	HTA	HTA	0	15	23	
12	4-12-82	175	35	5:1	HTA	HTA	0	26	50	
13	4-12-83	175	35	5:1	HTA	HTA	0	25	40	13.7
14	4-12-83	300	60	5:1	HTA	HTA	0	45	95	[illegible] 16.7
15	4-12-83	400	80	5:1	HTA	HTA	0	55	130	[illegible] 21.0
16	4-12-83	550	110	5:1	HTA	HTA	0	SEAL FAIL[illegible] IN ADVERTENT FIRING		
17	4-29-83	FIRING W/ SOLENOID ON LOW PRES CYL 100	20	5:1	HTA	HTA	0	SEAL FAILURE FIXED [illegible]		
18	4-30-82	FIRING W/ SOLENOID ON LOW PRES CYL 100	20	5:1	HTA	HTA	0	GAUGE [illegible] TO 0 PSIG LONG DELAY 35	150	
19	4-30-82	100	20	5:1	HTA	HTA	0	16	20	

1 P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODY/FORM	FIXTURE	APPROX ATTITUDE (°)	MAX ACCEL (G)	MAX DECEL (G)	ΔV (FT/SEC)
20	4-30-82	200	40	5:1	HTA	HTA	0	2 SOLENOIDS 2A EXH & TRIGGER 55	95	
21	4-30-82	400	80	5:1	HTA	HTA	0	2 SOL 70	150	~20.8
22	4-30-82	400	60	6.7:1	HTA	HTA	0	80	190	23.8
23	4-30-82	400	50	8:1	HTA	HTA	0	70	2 SOL 197	~32.0
24	4-30-82	400	50	8:1	HTA	HTA	0	2 SOL		
25	4-30-82	400	50	8:1	HTA	HTA	0	2 SOL		
26	4-30-82	400	50	8:1	HTA	HTA	0	2 SOL 65	195	@ 5 in 27.8
27	4-30-82	400	45	8.9:1	HTA	HTA	0	65	200	@ 4.5 in 27.8
28	4-30-82	600	85	7:1	HTA	HTA	0	SEAL LEAKED		
29	4-30-82	600	95	6.3:1	HTA	HTA	0	100	202	31.5
30		400	50	8:1	HTA	HTA	0	FIRED OFF PINS		
31		400	60	6.7:1	HTA	HTA	0	87	280	34.0
32		500	80	6.3:1	HTA	HTA	0	108	340	37.9
33		600	100	6:1	HTA	HTA	0	118	400	38.3? 30.9
34		1000	175	5.7:1	HTA	HTA	0	120	435	44.1? 41.7? @ 5 in
35		1200	215	5.6:1	HTA	HTA	0	w/ CAMERA 125	325	32.0
36		1200	215	5.6:1	HTA	HTA	0	125	320	32.7
37		1000	165	6:1	HTA	HTA	0	126	325	41.7 32.8?
38		1100	180	6.1:1	HTA	HTA	0	127	320	41.7 45.6?

I.P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODYFORM	FIXTURE	APPROX ATTITUDE (°)	MAX ACCEL (G)	MAX DECEL (G)	ΔV (FT/SEC)
39		1100	180	6.1:1	HTA	HTA	0	126	290	33.0
40		1100	175	6.3:1	HTA	HTA	0	130	330	52 → @ 36 6.5in
41		1100	175	6.3:1	HTA	HTA	0	NO DATA		FILM 47.6
42		1100	175	6.3:1	HTA	HTA	0	125	325	
43		1000	160	6.3:1	HTA	HTA	0	125	335	35
44	5-21-82	1000	160	6.3:1	HTA	HTA	0	125	305	@5.25in 41.7
45	5-21-82	1100	175	6.3:1	HTA	HTA	0	42 4 F/G PER FILM 126	324	@5.25in 43.9
46	5-21-82	1100	175	6.3:1	HTA	HTA	0	39.7 PER FILM 130	324	@5.25 43.9
47	5-21-82	900	135	6.7:1	HTA	HTA	0	125	326	@5.5in 41.7
48	4-26-83	50	10	5:1	NONE	NONE	0			TRIAL
49	4-26-83	100	20	5:1	NONE	NONE	0			TRIAL
50	4-26-83	200	40	5:1	NONE	NONE	0			TRIAL
	4-26-83	500	175	NO FIRE	CHECK	SEALS	HOLDS	PRES OK		
51	5-27-83	100	20	5:1	HEAD	HEAD	0			
52	5-27-83	100	20	5:1	HEAD	HEAD	0			
53	6-9-83	100	20	5:1	HEAD	HEAD	0	~20	~85 G	20.8
54	6-9-83	100	15	6.7:1	HEAD	HEAD	0			22.2
55	6-9-83	200	40	5:1	HEAD	HEAD	0	50	225	31.8
56	6-9-83	200	30	6.7:1	HEAD	HEAD	0			

1 P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODYFORM	FIXTURE	APPROX ATTITUDE (°)	MAX ACCEL (G)	MAX DECEL (G)	ΔV (FT/SEC)
57	6-10-83	200	25	8:1	HEAD	HEAD	0	60	350	37.0
58	6-10-83	200	20	10:1	HEAD	HEAD	0	FIRED OFF PINS		
59	6-10-83	300	60	5:1	HEAD	HEAD	0	80	360	41.7
60	6-10-83	300	45	6.7:1	HEAD	HEAD	0	85	500	42.9
61	6-10-83	300	37.5	8:1	~~W/CAMERA~~ HEAD	HEAD	0	INADVERT... FIR...		[illegible]
62	6-10-83	300	37.5	8:1	W/FILM HEAD	HEAD	0	[illegible]		[illegible]
63	6-10-83	360	72	5:1	HEAD	~~W/ FILM~~ HEAD	0	120	470	44.5
64	6-10-83	360	54	6.7:1	HEAD	HEAD	0	110	660	49.7
65	6-13-83	80	16	5:1	H	H	0	15	55	16.8
66	6-13-83	60	12	5:1	H	H	0	15	30	13.4
67	6-13-83	40 *	8	5:1	H	H	0	10	16	9.3
68	6-13-83	20	4	5:1	H	H	0	4	6	4.6
69	6-13-83	60	9	6.7:1	H	H	0	15	38	14.1
70	6-13-83	20	3	6.7:1	H	H	0	5	5	5.4
71	6-13-83	200	30	6.7:1	HEAD	HEAD	0	60	30[illegible]	RO... VEL
72	6-13-83	200	30	6.7:1	HEAD	HEAD	0	55	280	34.0
73	6-13-83	40	6	6.7:1	H	H	0	16	35	10.4
74	6-13-83	40 *	8	5:1	H	H	0	~~22~~	~~29~~	9.9
75	6-13-83	40 *	8	5:1	H	H	0	20	30	9.9

P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODYFORM	FIXTURE	DRAGON ATTITUDE (°)	MIN ACCEL (G)	MAX ACCEL (G)	ΔV (FT/SEC)
76	6-13-83	200**	40	5:1	H	H	0	50	215	32.5
77	6-13-83	200**	40	5:1	H	H	0	50	208	31.6
78	6-13-83	100	20	5:1	THOR/ABD	THIX [illegible]	6	10	25	11.2
79	6-13-83	100	15	6.7:1	T/A	T/A	0	15	30	12.9
	dummy hung @ pelvis support									
80	6-13-83	50	10	5:1	T/A	T/A	0	5	10	6.1
81	6-13-83	200	40	5:1	T/A	T/A	0	37	75	18.8
82	6-13-83	200	30	6.7:1	T/A	T/A	0	35	95	20.8
83	6-13-83	300	60	5:1	T/A	T/A	0	45	125	24.3
84	6-13-83	300	45	6.7:1	T/A	T/A	0	60	160	27.5
85	6-14-83	100	12.5	8:1	T/A	T/A	0	20	40	12.7
86	6-14-83	200	25	8:1	T/A	T/A	0	35	115	20.8
87	6-14-83	200 (R87)	25	8:1	T/A	T/A	0	35	100	20.6
88	6-14-83	300	37.5	8:1	T/A	T/A	0	50	180	27.8
89	6-14-83	500	100	5:1	T/A	T/A	0	100	200	32.9
90	6-14-83	500	75	6.7:1	T/A	T/A	0	100	300	36.6
	[illegible] seal [illegible] by firing									
100	6-14-83	700	140	5:1	T/A	T/A	0	165	310	39.5
101	6-14-83	300	45	6.7:1	T/A	T/A	0	65	165	26.0
	[illegible]				[illegible] brake					
102	6-14-83	700	105	6.7:1	T/A	T/A	0	150	420	43.5
103	6-15-83	700	120	6.7:1	T/A	T/A	0	160	500	50.0

I.P. IMPACTOR LOG

PG ___

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODYFORM	FIXTURE	APPROX ATTITUDE (°)	MAX ACCEL (G)	MAX DECEL (G)	ΔV (FT/SEC)
104	6-15-83	700	180	5:1	T/A	T/A	0	145	430	45.0
105	6-15-83	700 R100	140	5:1	high speed film, stiff fixtures, rotation T/A [illegible]	T/A [illegible] high	0	DUMMY MTD 2.65G PK	ACC @ T2+20ms	38.9
106	6-15-83	700 R100	140	5:1	T/A	T/A	0	DUMMY MTD ACCL = 300G MAX; V_{max} @ T2+70 ms		38.9
107	6-15-83	300 R87	45	6.7:1	high speed film T/A	T/A	0	DUMMY MTD ACCL - 540G		28.1
108	6-15-83	300 R84	45	6.7:1	T/A	T/A	0	DUMMY MTD ACCEL - 340G		28.7
109	6-16-83	500 R90	75	6.7:1	T/A	T/A	0	DUMMY MTD ACCEL - 350G; 30 ms TO DECAY		34.4
110	6-16-83	400	60	6.7:1	T/A	T/A	0	DUMMY MTD ACCEL 130G; 29 ms TO DECAY		29.1
111	6-16-83	100 R79	15	6.7:1	T/A	T/A	0	DUMMY MTD ACCL 50G; 0 ms TO DECAY		12.6
112	6-16-83	moved fixture down [illegible] take off, track cap platform; 475	71	6.7:1	T/A	T/A	0 w/ film	90	255	32.8
113	6-16-83	300 R84	45	6.7:1	T/A	T/A	0	55	150	25.1
114	6-16-83	300 R84	45	6.7:1	T/A	w/ film T/A	0	65	150	24.2
115	6-17-83	50	10	5:1	LOWER EXTREM	LOWER EXTREM	0			?
116	6-17-83	100	20	5:1	moved cylinder LE	to ¢ of tire trough LE	0	8	25	12.5?
117	6-17-83	100	20	5:1	LE	w/ film LE	0	15	25	12.5
118	6-17-83	200	40	5:1	LE	w/ film LE	0	30	80	20.5
119	6-20-83	100	15	6.7:1	LE	LE	0	10	35	?
120	6-20-83	200	30	6.7:1	LE	LE	0	RAN OUT OF PAPER		
121	6-20-83	200	30	6.7:1	LE	LE	0	23	95	21.1
122	6-20-83	400	80	5:1	LE	LE	0	45	180	29.6

I.P. IMPACTOR LOG

RUN NO.	DATE	HIGH PRES (PSIG)	LOW PRES (PSIG)	PRESSURE RATIO	BODY/FORM	FIXTURE	APPROX ATTITUDE (°)	MAX ACCEL (G)	MAX DECEL (G)	ΔV (FT/SEC)
123	6-20-83	400	327	1.2:1	LE	film LE	0			
124	6-20-83	400	60	6.7:1	LE film	LE	0	50	230	33.3
125	6-20-83	600	120	5:1	LE	LE	0	75	260	39.2 ?
126	6-21-83	600	90	6.7:1	W/O TOE PAN LE	FILM LE	0	100	360	40.2
127	6-21-83	800	160	5:1	LE	LE	0	160	370	46.3
128	6-21-83	700	105	6.7:1	LE FILM	LE	0	90	375	43.5
129	6-30-83	200 R82	30	6.7:1	T/A	T/A	0	—	—	20.0
130	6-30-83	40 R67	8	5:1	HEAD	HEAD	0			? VEL SG INCORRECT
131	6-30-83	40 R67	8	5:1	H	H	0			
132	6-30-83	360 R63	72	5:1	H	H	0			45.5
133	6-30-83	60 R66	12	5:1	H	H	0			13.5
134	6-30-83	200 R118	40	5:1	LE	LE	0			20.7
135	6-30-83	800 R127	160	5:1	LE	LE	0			42.6

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