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16. Abstract

This report addresses the role which may be played by impact test dummies in developing countermeasures to cope with the high incidence of safety problems related to building structures. Possible roles are discussed in safety problem identification, countermeasure development, and in the preparation of standardized test procedures. The parameters of a test using a dummy are grouped according to: 1. representation of a human victim; 2. representation of the environment in which an injury may occur; 3. the interaction between the victim (dummy) and his environment; and 4. the injuries (transducer or other measurements in the case of the dummy) which occur. Dummies are classified according to sophistication ranging from anthropometric form to impact body blocks and finally to sophisticated anthropomorphic test devices used in automotive safety. Test procedures and data processing are discussed. A bibliography, coded by subject, is also included.

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GUIDEBOOK ON

ANTHROPOMORPHIC TEST DUMMY USAGE

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1.0 INTRODUCTION

This guidebook and report are the result of a project at the University of Michigan entitled, "Anthropometric Test Dummy Usage." The project was initiated in response to the current interest in developing countermeasures to cope with the high incidence of safety problems related to building structures. Human injuries occur during the normal and abnormal usage of common structures such as doors, railings, stairways, floors, and a variety of products utilizing architectural glazing materials. The worker -- construction, maintenance, production, etc. -- is the user of walkways, scaffolds, platforms, construction shoring and other structural assemblages all of which have particular safety problems.

1.1 The Role of the Test Dummy

The role which may be played by test dummies in research, development, and standardization is the primary subject of this report. From the most simplistic point of view, their role is to duplicate the response of man to a particular hostile environment where he may be subject to impact or other types of injury.

The most sophisticated test dummies represent man as a collection of skeletal elements and joints constructed largely of metal. Soft tissues are usually replaced by rubber, plastic, and other polymeric materials. The overall size, shape, and weight of the various body segments are reproduced reasonably well. These sophisticated dummies are most commonly called anthropomorphic test devices. Their construction is based on anthropometric surveys of human populations where measurements have been taken to define the human body and its parts. For the sake of definition, the term "anthropomorphic" generally refers to shape properties and appearance whereas "anthropometric" usually refers to a series of specific physical measurements. These two terms are often confused. It should be noted that the term "anthropomorphic test device" represents a concensus opinion on what to call sophisticated crash test dummies.

Simplified dummies are also often fashioned. They may be used to represent:

- individual body parts (e.g., headforms for helmet testing)
- the whole mass of the body (e.g., the punching bag used in the testing of glazing materials).

Figure 1 shows examples of the various types of dummies. For the purpose of this report both simplified and sophisticated dummies will be lumped together under the term "test dummy."

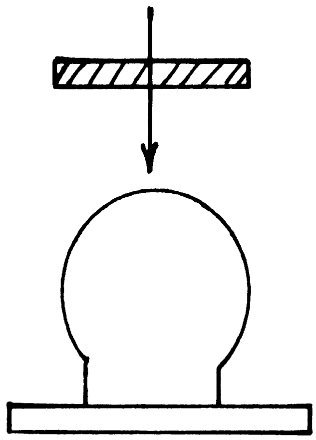
Anthropomorphic test dummies have found their major applications during the last several years in the development of improved hardware for the protection of automobile occupants during crashes.
Their major successful applications have been in the area of attempting to reproduce human motions, velocities, acceleration and gross force interactions with motor vehicle interiors, exteriors, and restraint systems. Up to this time they have not proved useful in duplicating soft tissue injuries such as lacerations and abrasions. Research information on soft organ (brain, lungs, heart, liver, spleen, intestines, etc.) injury due to impact is continually being gathered with inclusion in dummy design specifications as a major objective.

1.2. Definition of a Dummy Test

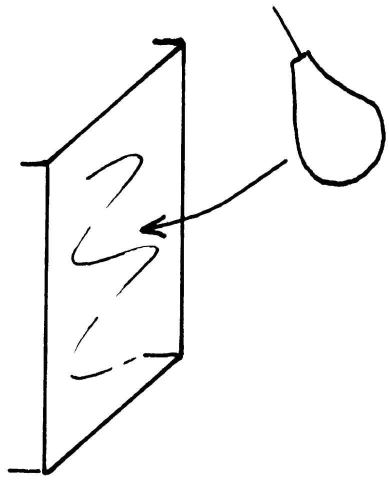
A dummy test is a simulation of the hypothesized physical interaction of a human with his environment where the result is mechanical injury or trauma to the human. Two points should be made at this time.

The first point is that there is a simulated event and a real life event both of which have scenarios with three basic components -- the victim, the environment, and the dynamics of the interaction. Figure 2 is a schematic of the two scenarios.

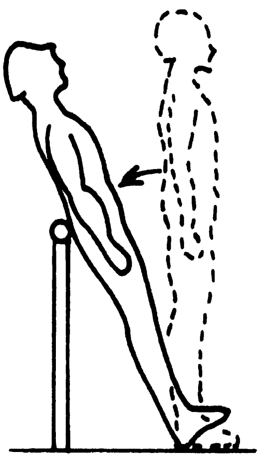
The second point to be noted after reviewing Figure 2 is that there are several obvious potential sources of difference between the simulated and real events. One of these is that the test dummy is not a perfect representation of the engineering physical properties of man. For example, muscle properties are not included and, even in the most sophisticated test dummies available at the present time, the compliance or stiffness of various structural elements is often too great. Although it may be possible to duplicate the environment where the injury took place, another source of difference arises due to the difficulty of duplicating the interaction. A key reason for this is the uncertainty



Individual Body Part (Headform Impact)



Body Mass (Glazing Material Pendulum Test)



Whole Body Linkage (Dummy Railing Test)

Figure 1. Three Examples of Test Dummies.

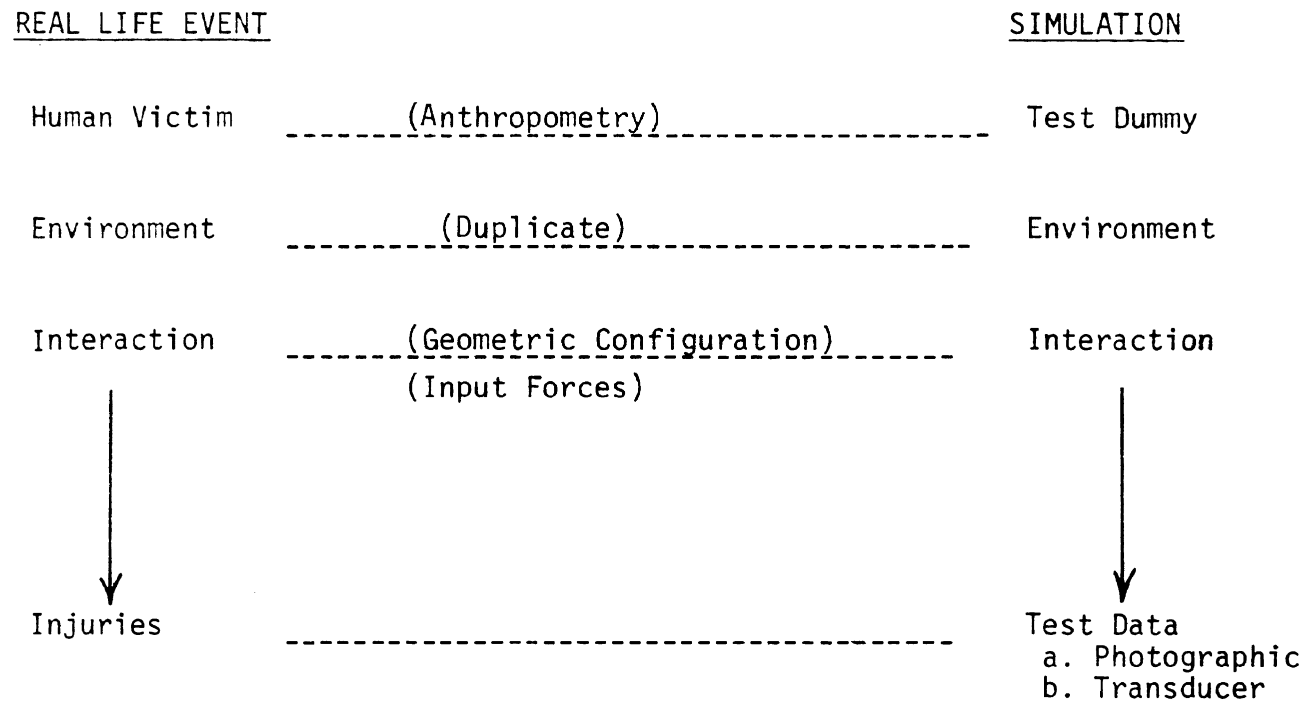


FIGURE 2. Dummy Test Simulates Real Life Injury Event

of human posture at any point in time, a factor which is known to have a strong effect on the dynamics of linkage systems. The last and most important source of differences between test and real life scenarios is that the human suffers an injury (which is only beginning to be defined in quantitative terms based on current research). In contrast, only a variety of physical measurements are possible during a dummy test.

The details and implications of these differences are discussed later in the report.

1.3 Report Contents and Organization

There are three basic sections to this guidebook/report plus an appendix. Part 2 shows the three basic reasons for dummy testing -- safety countermeasure development, compliance testing, and problem identification through accident reconstruction. These reasons are illustrated by examples from practice. Part 3 discusses the details of dummy testing through a comparison of test and real life engineering variables which must be considered. Guidance is given relative to decision-making based on test results. Part 4 provides practical information for the potential user of test dummies. Items discussed are the range of data to be expected and procedures for data acquisition as well as analysis.

The appendix to the report gives a listing and short review of the literature of test dummies. It is organized to give the reader quick access to the type of information he may need. Reference to specific documents is not included in the main text.

2.0 WHY CONDUCT A DUMMY TEST?

This section of the report discusses the overall scenario of activities which may involve safety-related dummy testing. Examples of different types of tests are given.

2.1 The Three Basic Reasons for Dummy Testing

The reasons for dummy testing become clear when they are seen within the framework of all safety-related activity. Figure 3 is a simplified schematic of the types of activity that take place within the safety community.

A particular type of safety activity is initiated on the basis that an injury pattern is observed or supposed in reviewing or gathering accident data. In some cases, the cause of the accident is clear. If so, the problem is quickly identified. If not, a hypothesis is developed for the cause and scenario of the accident. At this point, accident reconstruction and testing may be done to identify the problem. The accident environment is reconstructed in the laboratory and a dummy subject is chosen for use in the test. This has been done successfully in the case of automotive safety (full-scale barrier crash tests) and more recently in the study of guardrails at the Center for Building Technology of the National Bureau of Standards. In most cases of accident reconstruction, the dummy chosen is as sophisticated as can be located, particularly if little is known about the mechanisms of injury causation and the forces and motions which may be involved.

Proceeding down Figure 3, the next type of testing may occur after a problem is identified and countermeasures are proposed for its elimination or attenuation. Especially in those cases where the scenario is altered or attenuated, testing is required to determine countermeasure effectiveness. A great deal of dummy testing is done in this area. New restraint concepts for automobile occupant protection are continually reviewed in this manner by means of impact sled or barrier impact tests using full-scale anthropomorphic test devices. Simple head forms are used to evaluate the performance of protective head

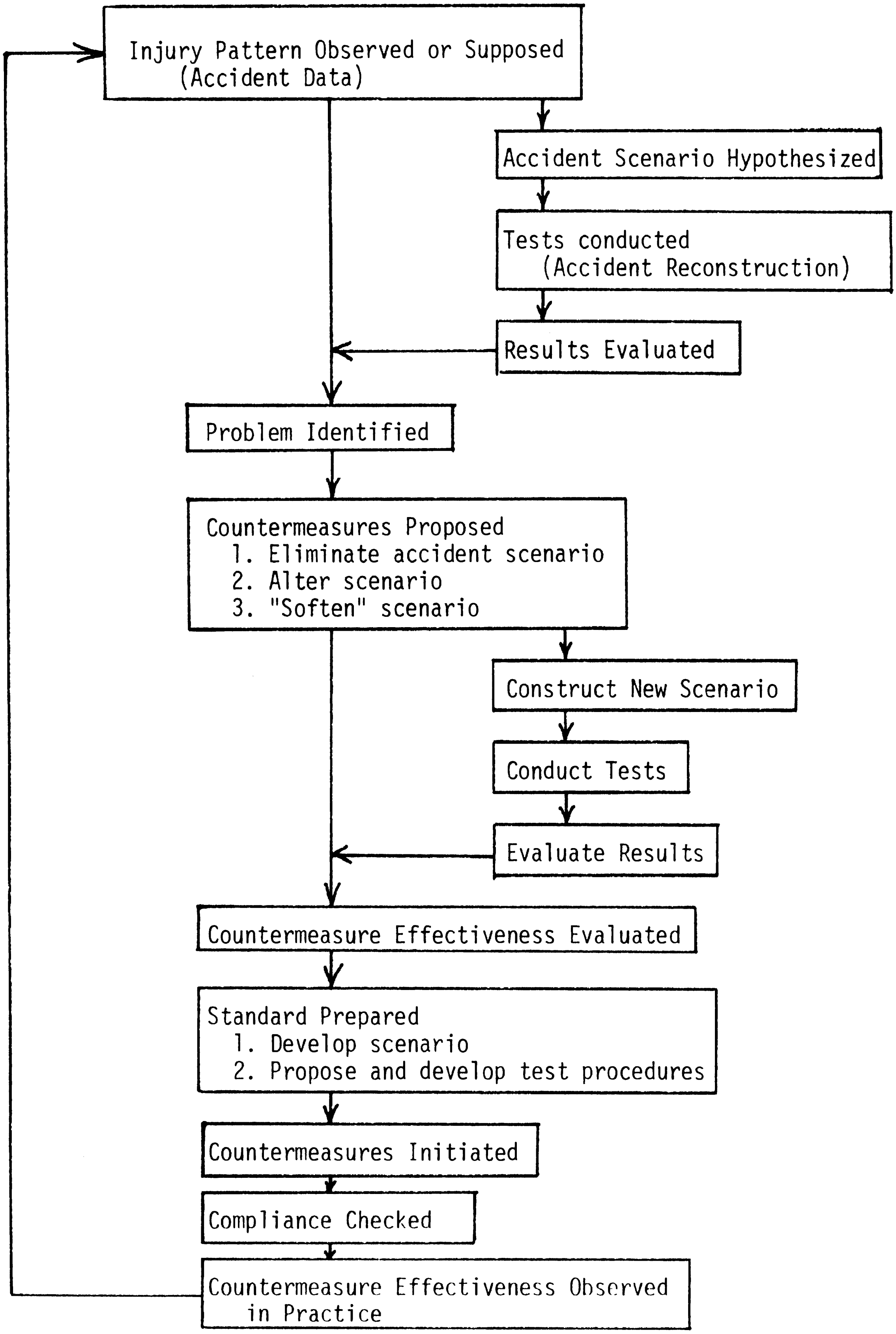


FIGURE 3. Simplified Schematic of Safety Activity

gear and sports equipment as well as automotive windshields. This area of study is the one which usually leads to the development of new and simplified concepts in dummies as the need for specialized information arises. The success or failure of a dummy used in this activity is directly related to whether the parallel between the dummy test and the real world of injuries illustrated in Figure 2 is kept clearly in mind.

The bottom of Figure 3 is concerned with the development of standards and it is here that the final type of testing is accomplished. The purpose of a safety standard is to show that a countermeasure (helmet, restraint system, improved guardrail, etc.) is effective in reducing potential for injury to a clearly defined level. Most often, this implies that the standard addresses a very specific accident scenario with a simple interaction between the victim and his environment. Because of this, it may be possible to simplify the dummy and test procedure for compliance-type tests. Examples of this are the simple headforms mentioned previously and the punching bag impactor used in the ANSI testing of architectural glazing materials. The validity of simplifications of this type must be established through correlation of test results with the real world accident scenario -- a step which has rarely been accomplished in standards development up to the present time.

In summary, three basic reasons have been identified for dummy testing. These are:

1. Problem identification (accident reconstruction),
2. Countermeasure development,
3. Standardization and compliance testing.

2.2 Examples From Research, Development, and Standardization Activities

This section of the report presents brief discussions of nine examples of dummy testing. The examples cover the three basic uses of dummies presented in Section 2.1 as well as the various types of dummies in use for different applications. In each brief discussion, the reason for the test is given followed by a description of the test procedure and results obtained. An evaluation of the test procedure concludes each discussion to provide the reader with some case data to aid in decision-making with respect to feasibility and utility of future dummy tests.

2.2.1 Problem Identification. Child Car Seat Tests. Before the U.S. government issued a standard for the safety performance of children's car seats (1971) little information was available concerning their behavior in a dynamic crash environment. In response to concern in the private and public sector about these devices, test programs were initiated to estimate their safety potential. In most cases, an automotive seat was bolted to an impact sled, a child seat was attached according to manufacturer's directions (if any), and an articulated dummy the size of a three-year-old was positioned as the crash victim. The impact sled was then used to simulate frontal, oblique, side, and rear impacts. The dummy was instrumented with accelerometers in the head and chest and high-speed motion picture cameras were used to record the motions.

These tests demonstrated serious shortcomings in the structural designs of children's car seats as seat hardware failures and undue dummy motions were easily observed. The ability to relate the data gathered to injury patterns was very limited for two reasons. First, there is essentially no human impact tolerance data for children, and second, no correlations have been made between dummy performance and the limited tolerance data which are available. The utility of the dummy test was limited therefore, to two (very important) factors:

1. The dummy delivers a mass load to the product (car seat) representing an approximation of loads which may be expected in practice. This has led to a realistic appraisal of potential (and observed) product failures.

2. Because of its articulation, the dummy was capable of defining a motion envelope not possible in a static test which showed relative motions between body parts and the potential for forcible interactions with the vehicle interior.

Figures 4 and 5 illustrate this type of test. Figure 4 shows four frames from a high speed movie. The upper left photograph shows the position of the subject just prior to the crash sequence. The lower left photo shows the dummy (and seat) moving forward while the simulated vehicle is subjected to a crash deceleration. The upper

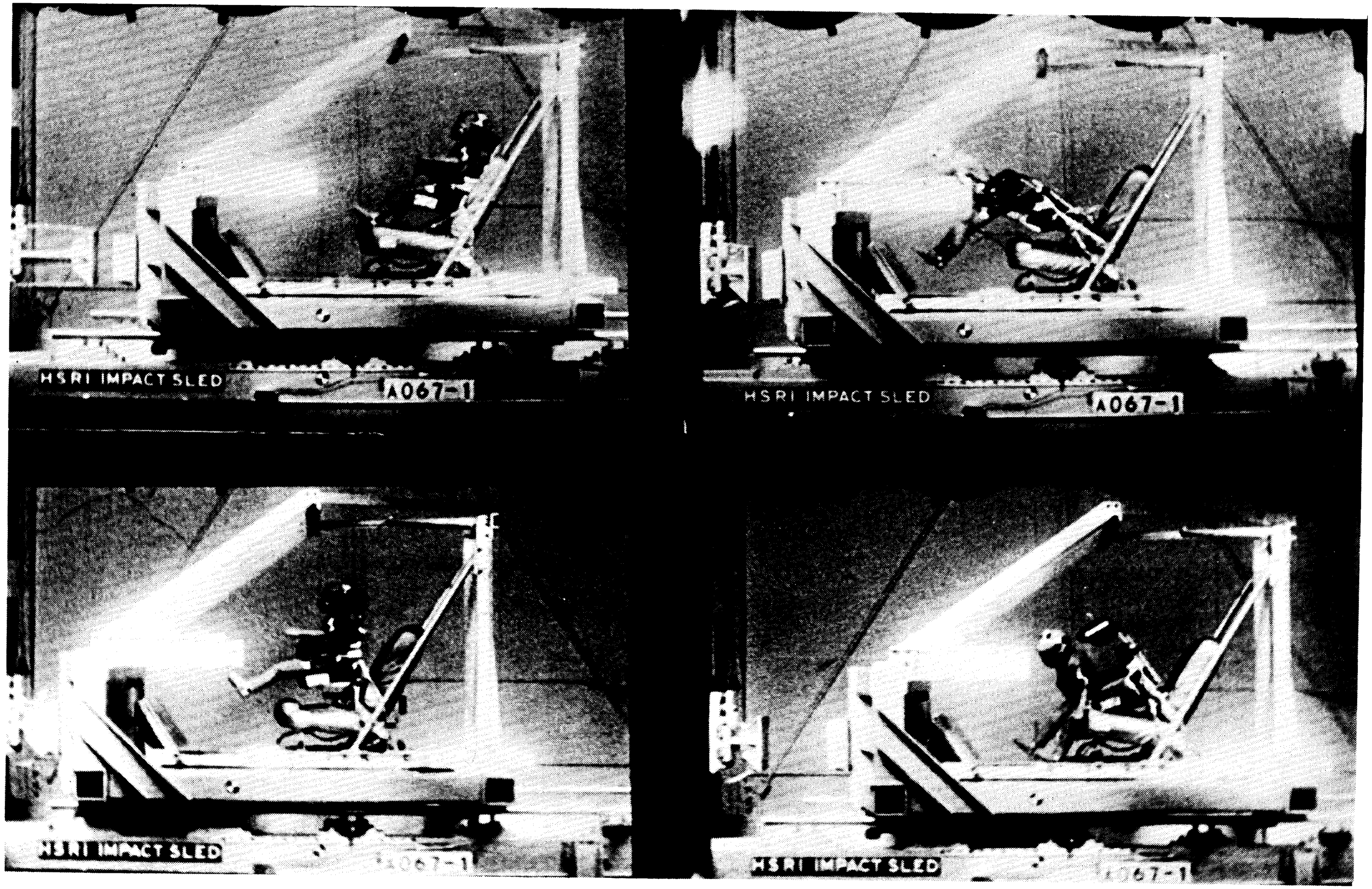


Figure 4. Movie Crash Sequence of Dummy in Child Car Seat.

Figure 5. Post-Test Photograph of Dummy in Child Car Seat.

right photo shows seat collapse and violent interaction of the dummy with windshield and instrument panel areas. The lower right photo shows the post-crash state of rest. Figure 5 shows an engineer examining the test setup following a similar test.

2.2.2 Problem Identification. Architectural Glazing Materials. During technical discussions relating to a standard for architectural glazing materials, two of the issues raised were:

1. How does a human interact with a large glazed panel such as a sliding patio door?

2. Does the punching bag impactor adopted in ANSI Standard Z97.1 relate to the human impacts?

To aid in the discussions, a limited series of tests were initiated where a sophisticated anthropomorphic test dummy and a standard punching bag (simplified one mass dummy) were alternately dropped through glazed panels.

Figures 6-9 show pre- and post-test views of these experiments. Figure 8 shows one of the positions assumed for the dummy. This simple configuration was contrasted with others such as a case where the dummy was presumed to be running with a stiff arm into the panel of glass. It should be noted that the wires running from both the punching bag and the dummy carried accelerometer signals to FM tape-recorders. High speed motion pictures were also made to record the dynamic motions.

It was not possible to answer the questions posed at the beginning of this section on the basis of the project. First, the test did little to define the real world accident scenario. However, it did demonstrate the complexity of the interactions which could occur during an accident of this type (e.g., for a running dummy the knee and hand contacted the glass at about the same time; they both rebounded causing the dummy to straighten out; finally the whole body carried through the panel breaking it). Thorough accident investigations would be required to shed additional light on the real scenario in order to define subject posture and velocity at the time of impact. Second, any injury estimates were impossible. Glass injury usually involves lacerations. The dummy skin has not been designed to produce a laceration injury. Indeed, no indisputable laceration simulator has yet been developed.

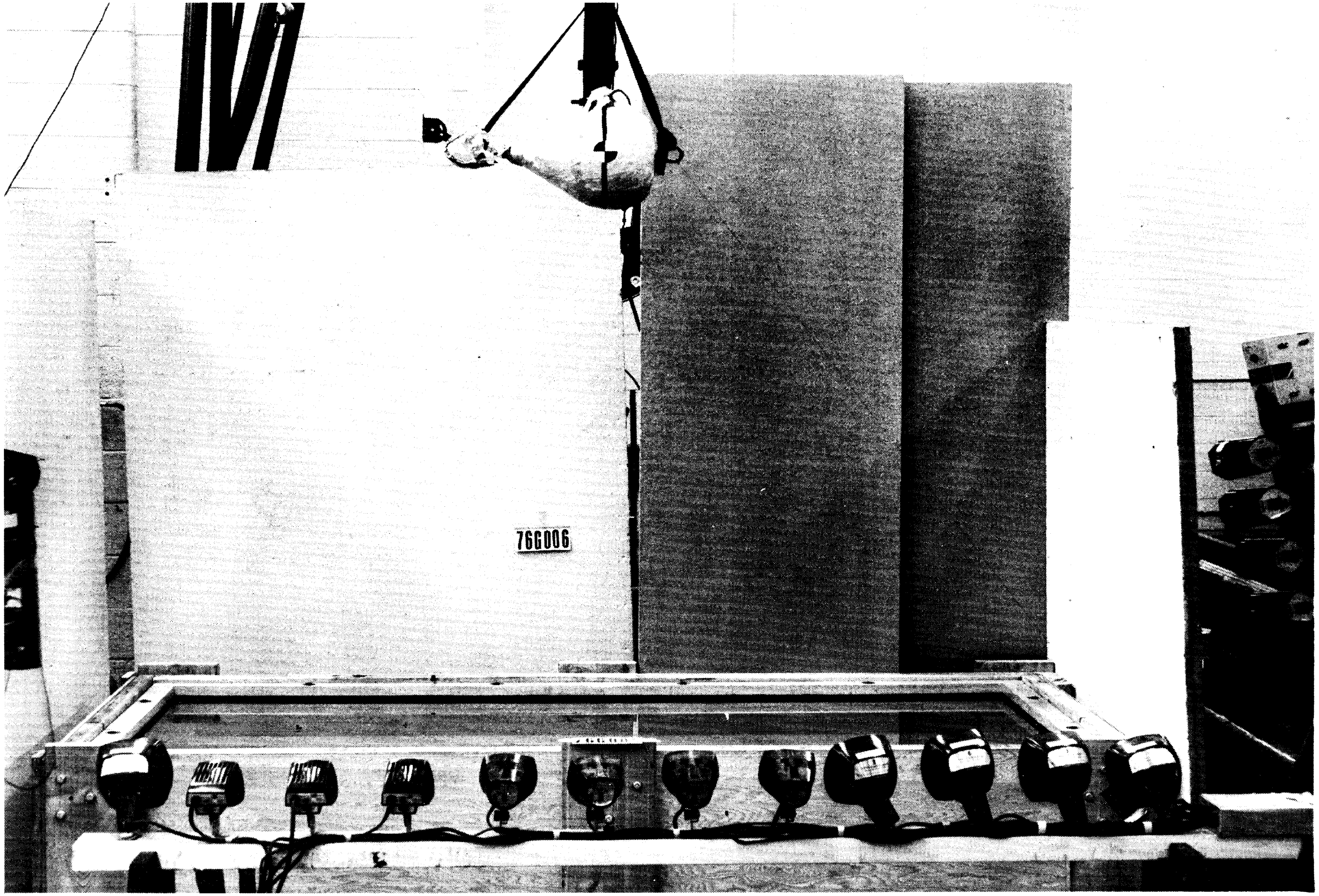


Figure 6. Punching Bag Dummy Drop Test of Architectural Glazing Materials.

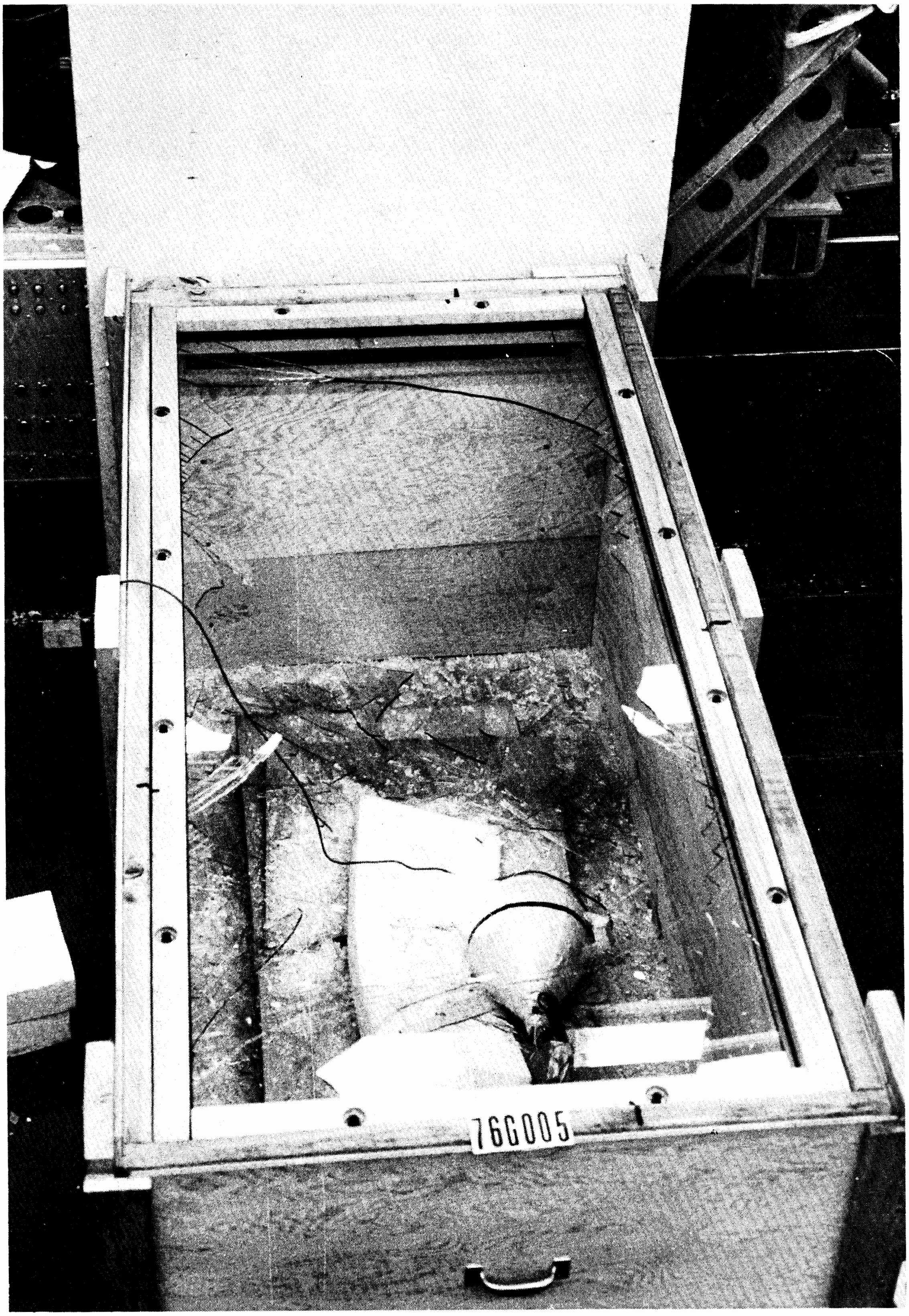


Figure 7. Post-test View of Punching Bag Dummy Drop Test.

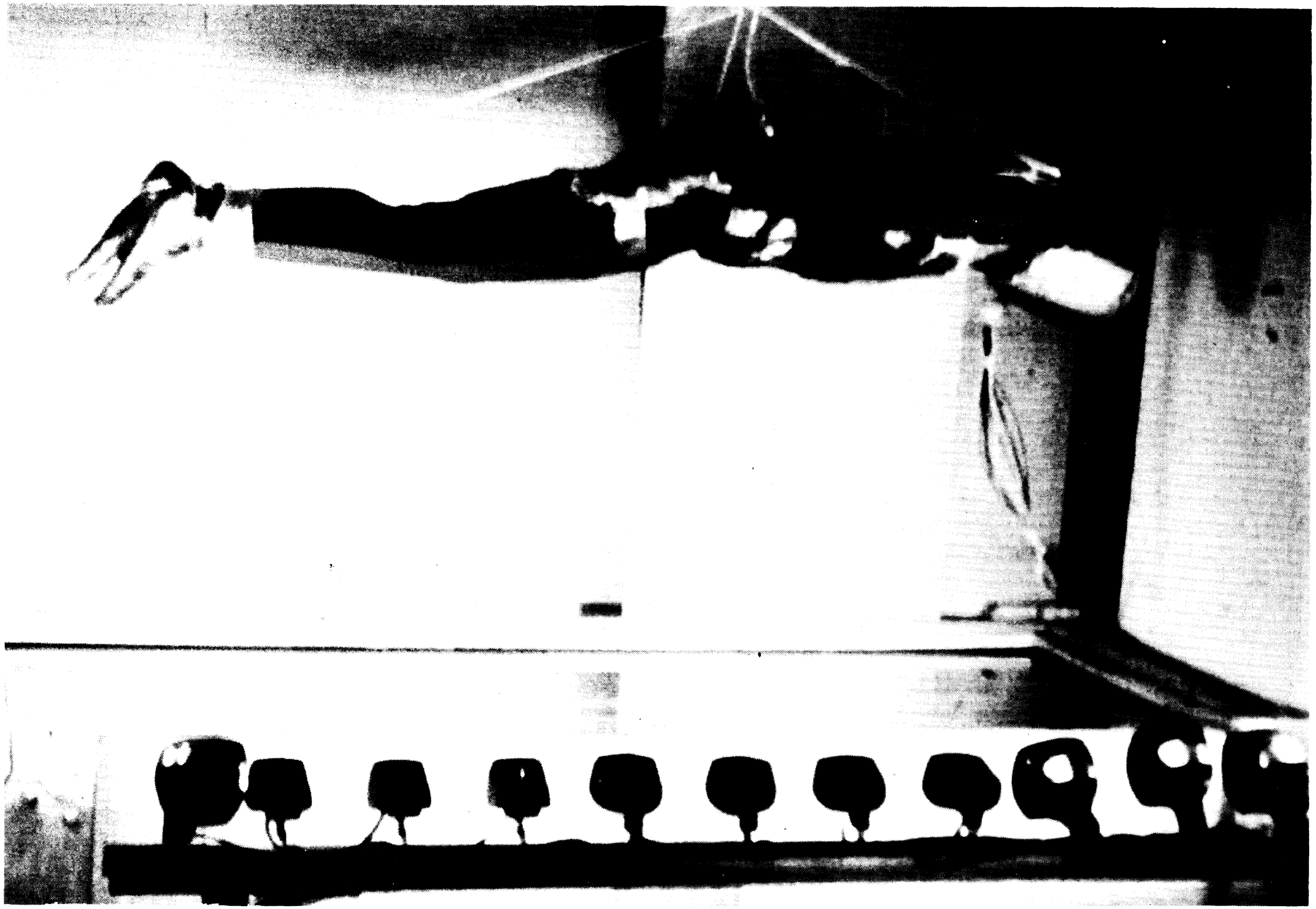


Figure 8. Anthropomorphic Dummy Positioned for Drop onto Glass Panel.

Figure 9. Post-test View of Dummy After Drop Through Glass Panel.

Third, because of the lack of a clear definition of the real accident scenario, it was also impossible to relate the punching bag drop test to human injury causing impact events.

2.2.3 Countermeasure Studies. Guard Rails. In reviewing work-surface accidents and falls, it has been found that a significant number are guardrail-related. A test program was initiated at the NBS Center for Building Technology which involved dynamically loading various guardrail structural assemblages using an anthropomorphic test dummy. As a result of these tests and others, a proposed criterion was developed for guardrail height. A schematic for one of the test conditions is shown in Figure 10.

The dummy properties which are of relevance to the study are body mass, geometry and articulation. It should be recalled from Figure 3 that the first of the types of countermeasures listed is elimination of the accident scenario. Here, the concern is fall prevention. Body mass and geometry of a dummy define human body center of gravity with a fair degree of accuracy. The tests are thus particularly appropriate for defining guidelines with respect to railing heights. Insofar as it is possible to estimate or put an upper bound on the velocity of impact or force of loading of the accident victim on the guardrail structure, it is also possible to develop strength requirements from tests such as these.

2.2.4 Countermeasure Studies. Protective Helmets. Protective helmets for motorcycle riders, race car drivers, athletes, construction workers, miners, etc., have been the subject of standardization activities for many years. Helmets are known to reduce injury incidence but their effectiveness and usage still is an area of great controversy. The primary reasons for this are threefold:

1. What is the accident scenario? (Size, velocity and direction of the impactor)

2. What is human tolerance to head blows? (A major research problem in itself, the data available must be clearly relatable to the test procedure adopted for a standard).

3. What dummy or hardware should be used in the test (Headform mounted rigidly or on an articulated neck).

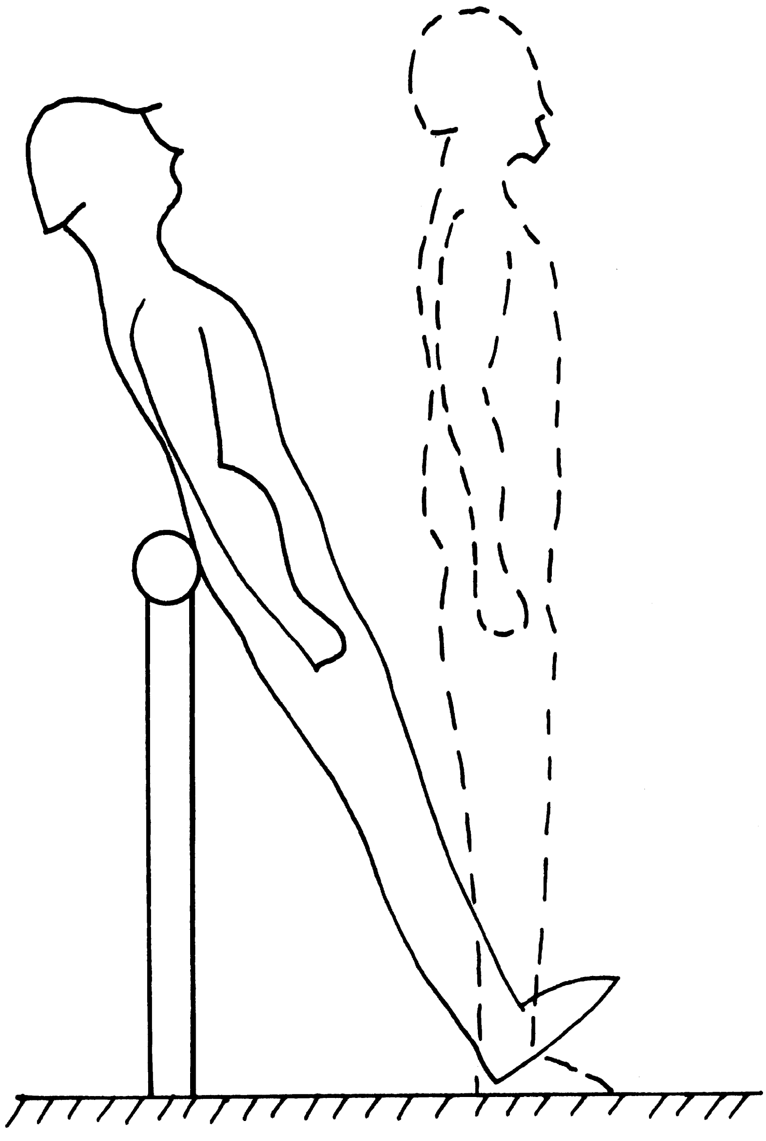


Figure 10. Schematic of Test Dummy Falling Against Guardrail Structure.

In the process of developing countermeasures for protective head gear, a variety of activities must take place simultaneously in response to all three of these questions. With respect to the dummy, a variety of headforms may be used. Figure 11 shows several which are constructed to different anthropometric standards. Some are metal; some are plastic. Some are solid; some are hollow. In countermeasure development, it is possible to try various impact directions, dummy configurations, and instrumentation in order to better duplicate or reconstruct accident scenarios. Figures 12 and 13 show the pretest setup for two hard hat experiments conducted at HSRI. One involves the dangerous vertex impact (Fig. 12) while the other involves a less common but equally dangerous impact from the side. The procedure shown here is somewhat more sophisticated than the usual tests found in current standards. First, the headform is mounted on a flexible neck and torso. Second, the blow delivered by the controlled pneumatic ram impactor is registered as forces and accelerations both in the head form and in the impactor. Third, high speed motion pictures record the head/impactor interaction.

Tests such as this demonstrate that a period of varied and sometimes sophisticated testing often precedes and supplements development of new standardized testing procedures. Much of the reason for this is that countermeasure development often requires more instrumentation and detail in order to assure measurement of all the important engineering variables.

The procedures adopted for use in standards should tend to be as simple as possible without losing sight of the engineering objective. In the case of protective helmets, the procedure adopted in standards has been to use only the head from more sophisticated dummies and assume that coupling of impact loads with the neck and torso can be ignored. This procedure has come into question as has the problem of where on the helmet to deliver the impact.

2.2.5 Countermeasure Studies. Simplified Dummy for Automotive Side Impact Testing. Two problems with anthropomorphic crash test dummies have led to development of the device shown in Figures 14 and 15 by the Transportation Road Research Laboratories (TRRL) in England. The problems were that existing dummies were unrealistically stiff

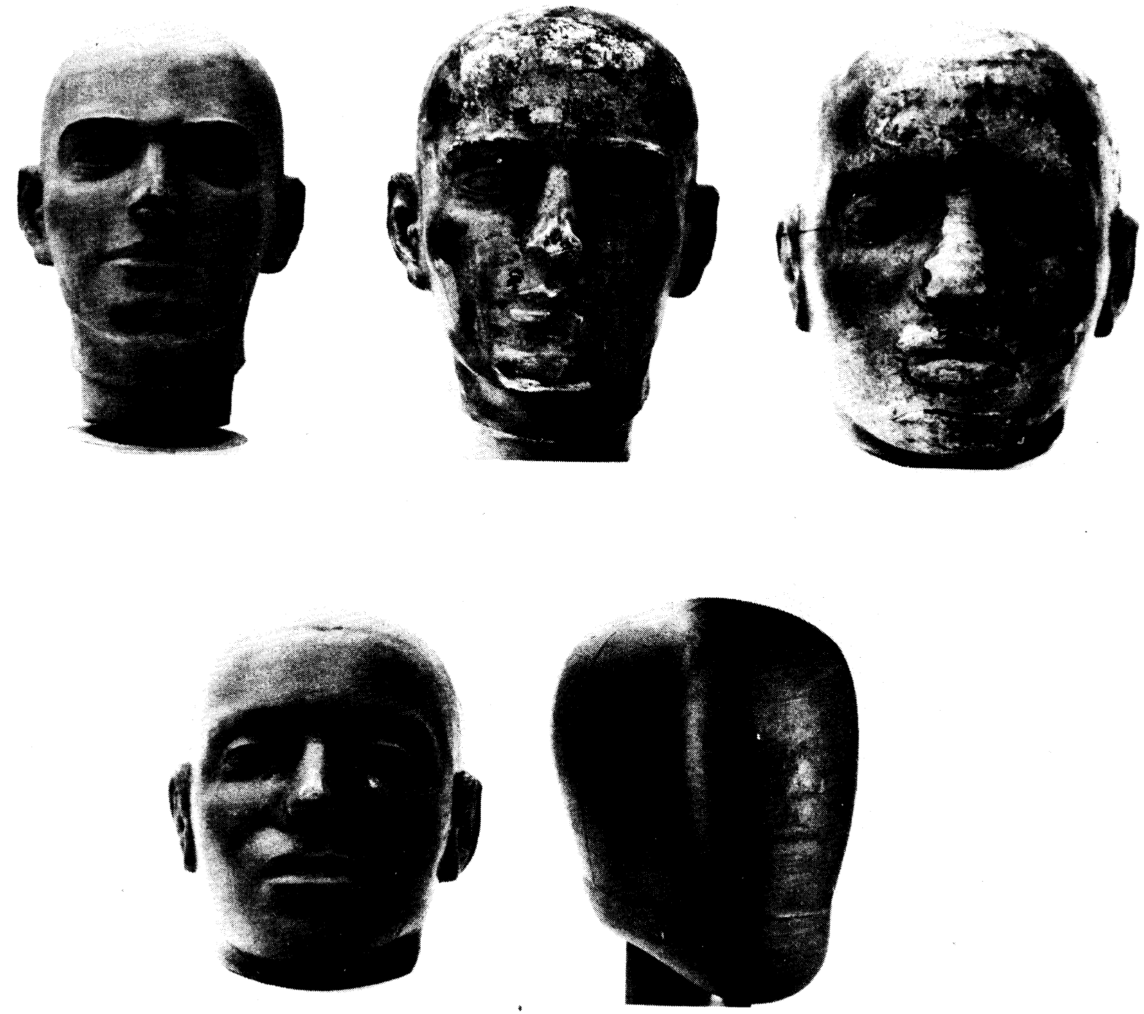


Figure 11. Dummy Head Forms.

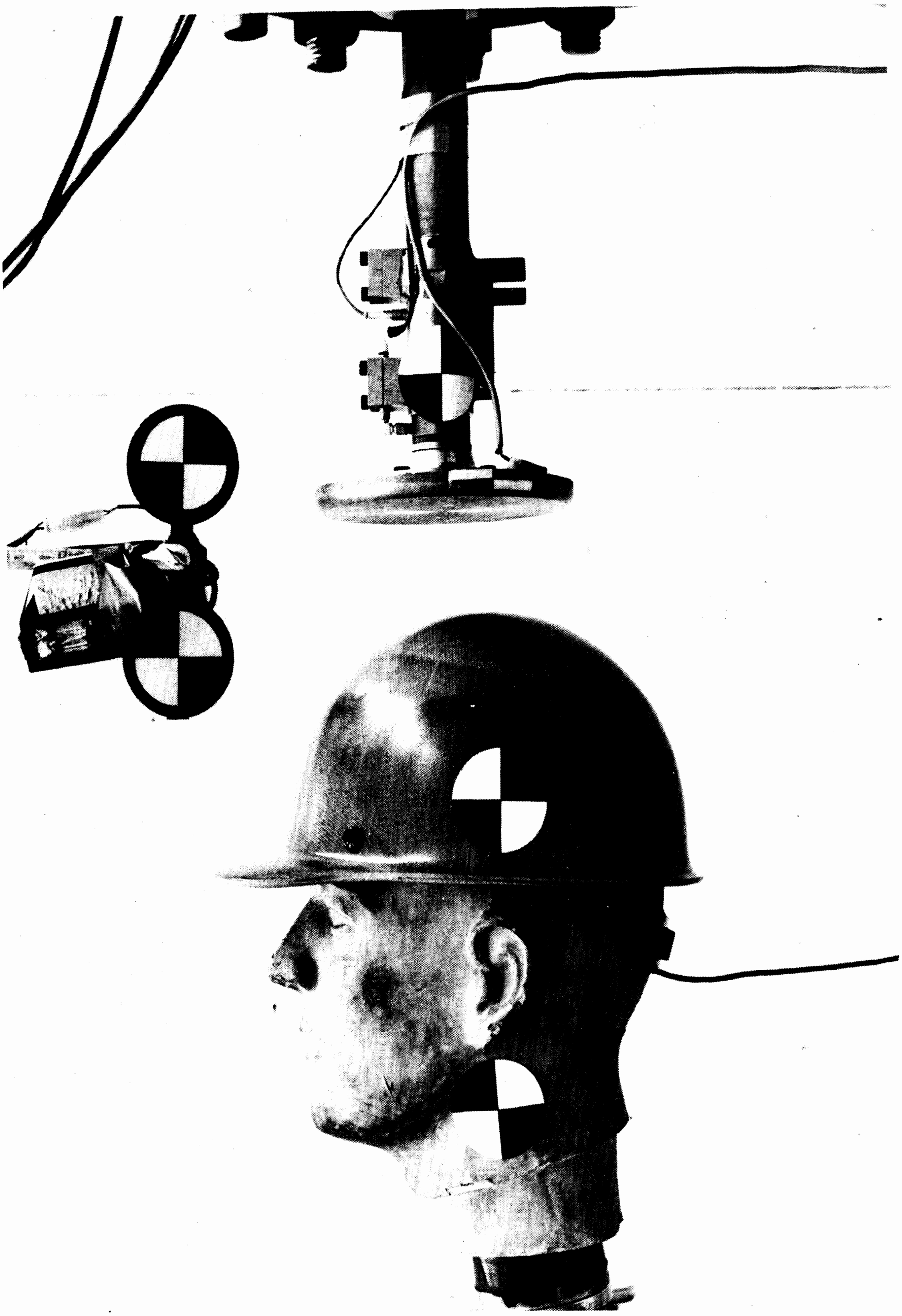


Figure 12. Protective Helmet Test. Vertex Impact.

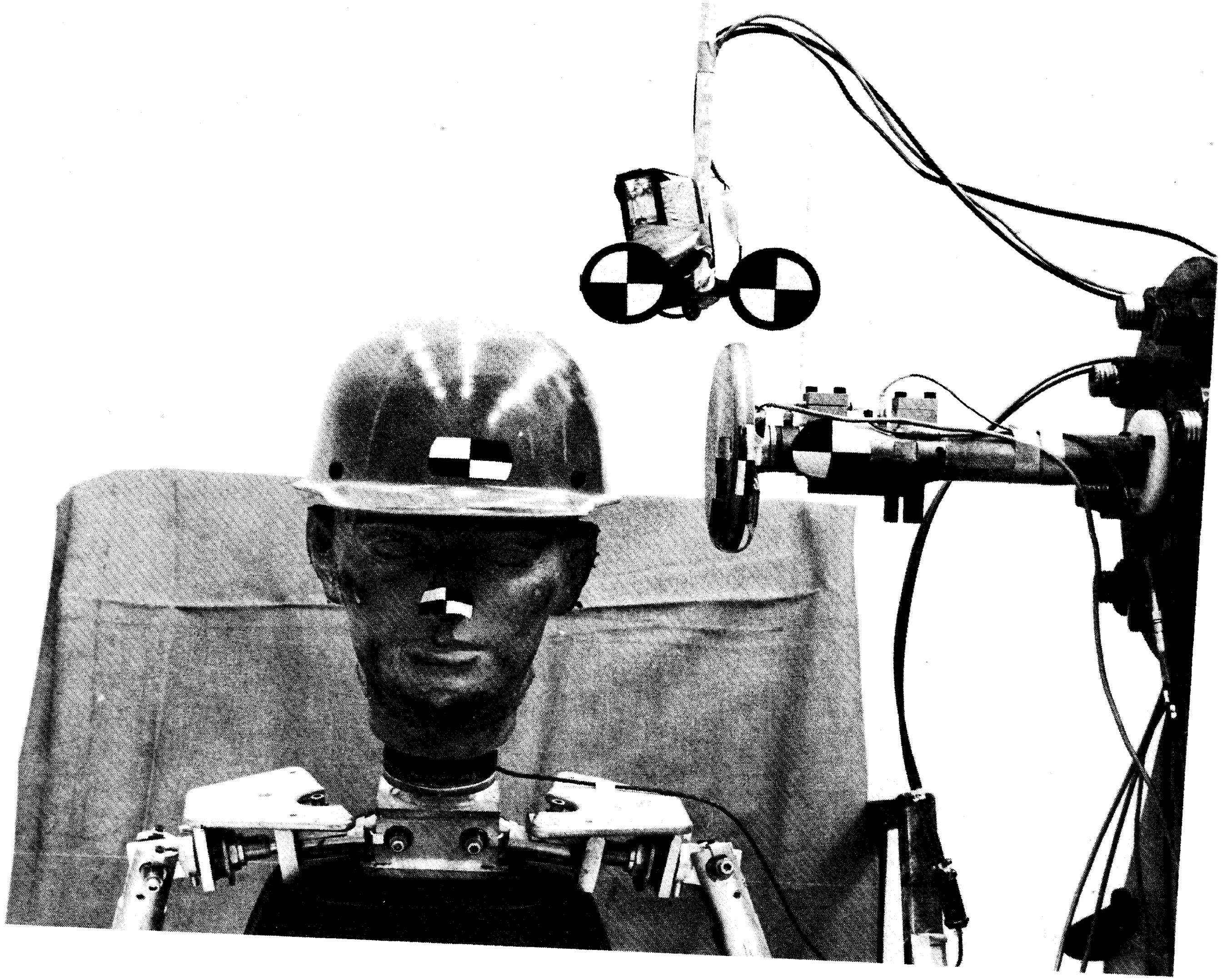


Figure 13. Protective Helmet Test. Side Impact.

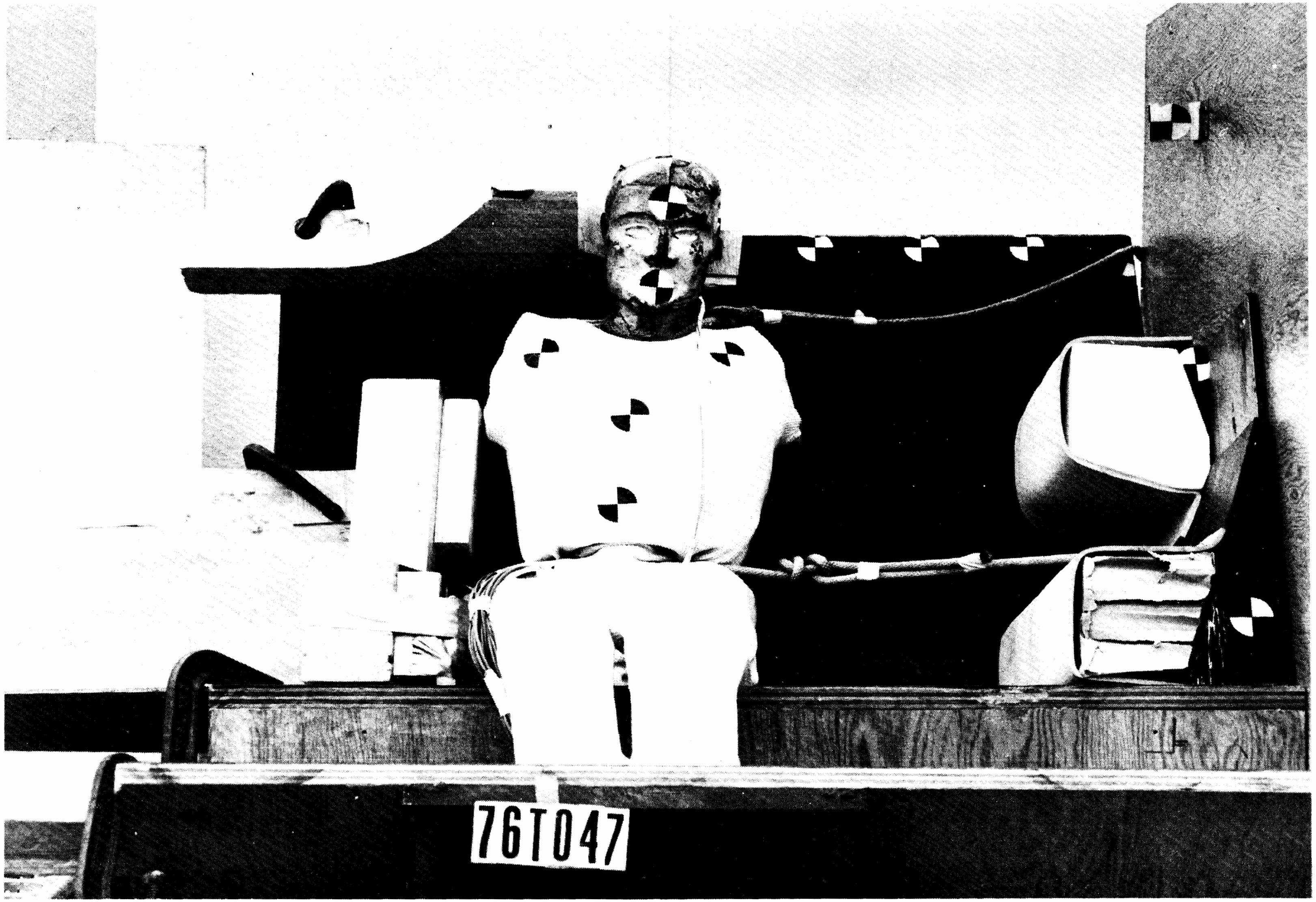


Figure 14. TRRL Side Impact Dummy Prior to Test of Vehicle Side Structures.

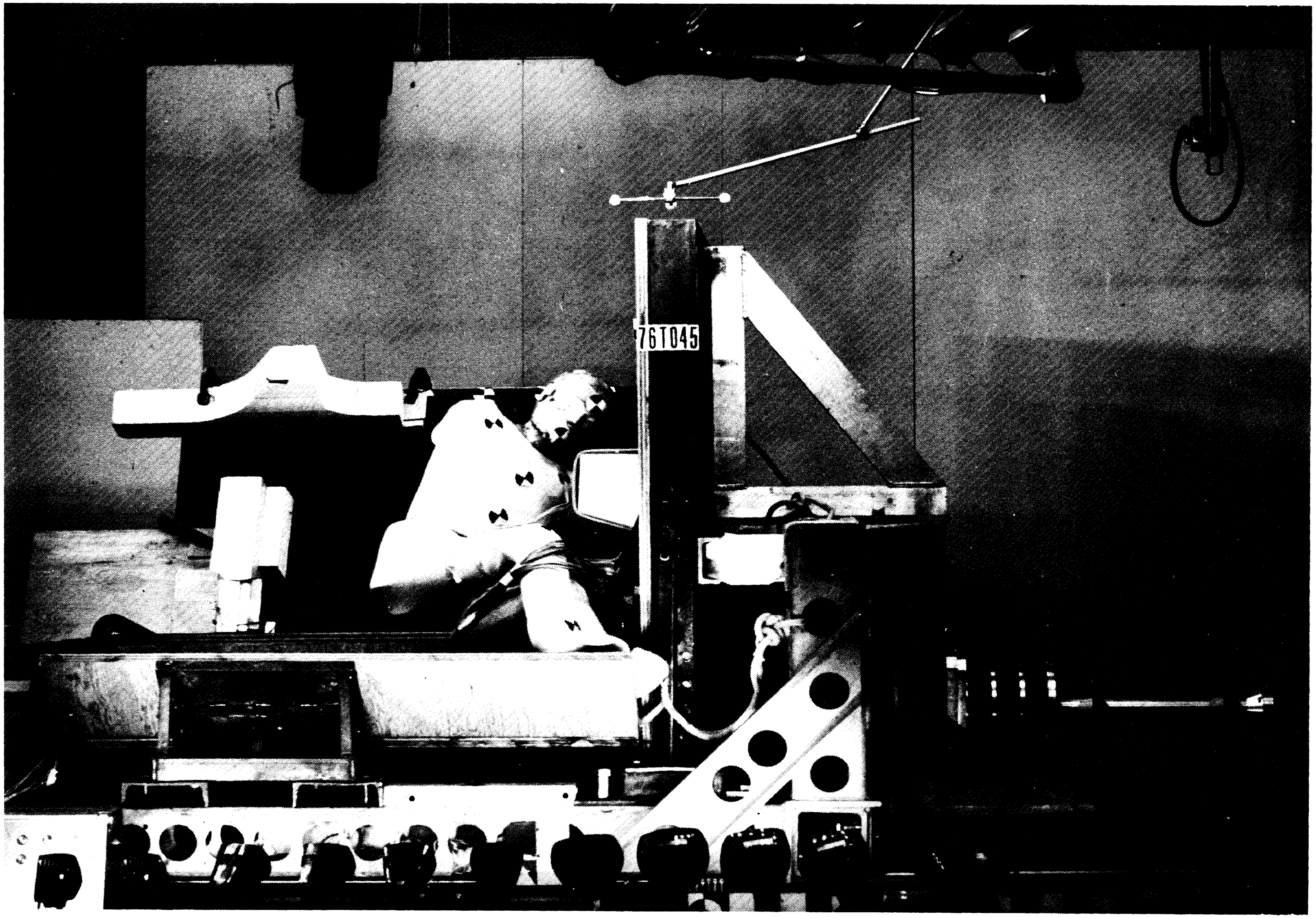


Figure 15. TRRL Side Impact Dummy After Dynamic Test.

when subjected to side impact and that there was no known relation between test data derived from these dummies and human injury. Then TRRL set out to develop a specialized side impact dummy which reproduced vehicle interior damage caused by the human crash victim. In turn, the vehicle interior damage had been correlated with injury. The developers then correlated accelerometer and force transducer data from the pelvis, shoulder and ribs of the dummy with the injuries to produce human impact tolerance corridors for the specialized impact.

The example shown in Figures 14 and 15 involve impact sled tests of prototype energy-absorbing vehicle side door structures. Figure 14 shows the initial position of the dummy. In Figure 15, the dummy has slid into the door structures and rebounded to his final resting place. These test results have been correlated with test data using standard anthropomorphic test dummy and human cadaver subjects with the data most resembling the cadaver results, particularly the motions of the head and thorax. This dummy is very important for one primary reason. The reason is that a direct link has been established between observed injuries and a well-defined data gathering system built into the dummy. It is the opinion of the author that this should be the goal of all laboratory test dummies to be used in any of the three applications set forth in this report. However, there are some cautions which also should be noted. The dummy has been designed for direct vehicle side impacts strongly limiting its potential test environment. The injury data base also is limited to the same type of crash environment.

2.2.6 Countermeasure Studies. Inflating Occupant Restraint Systems. A classic case of the use of test dummies for studying countermeasures involves their use in the development of inflating occupant restraint systems or airbags. In early testing the system exhibited reasonable performance for dummies positioned with good posture in an upright seated position. However, objections immediately arose about this limited definition of the accident scenario. After all, people, especially passengers, assume a variety of positions in a car. What happens then? Figure 16 shows four set-up photographs from an early airbag test series conducted at HSRI indicating a few of the

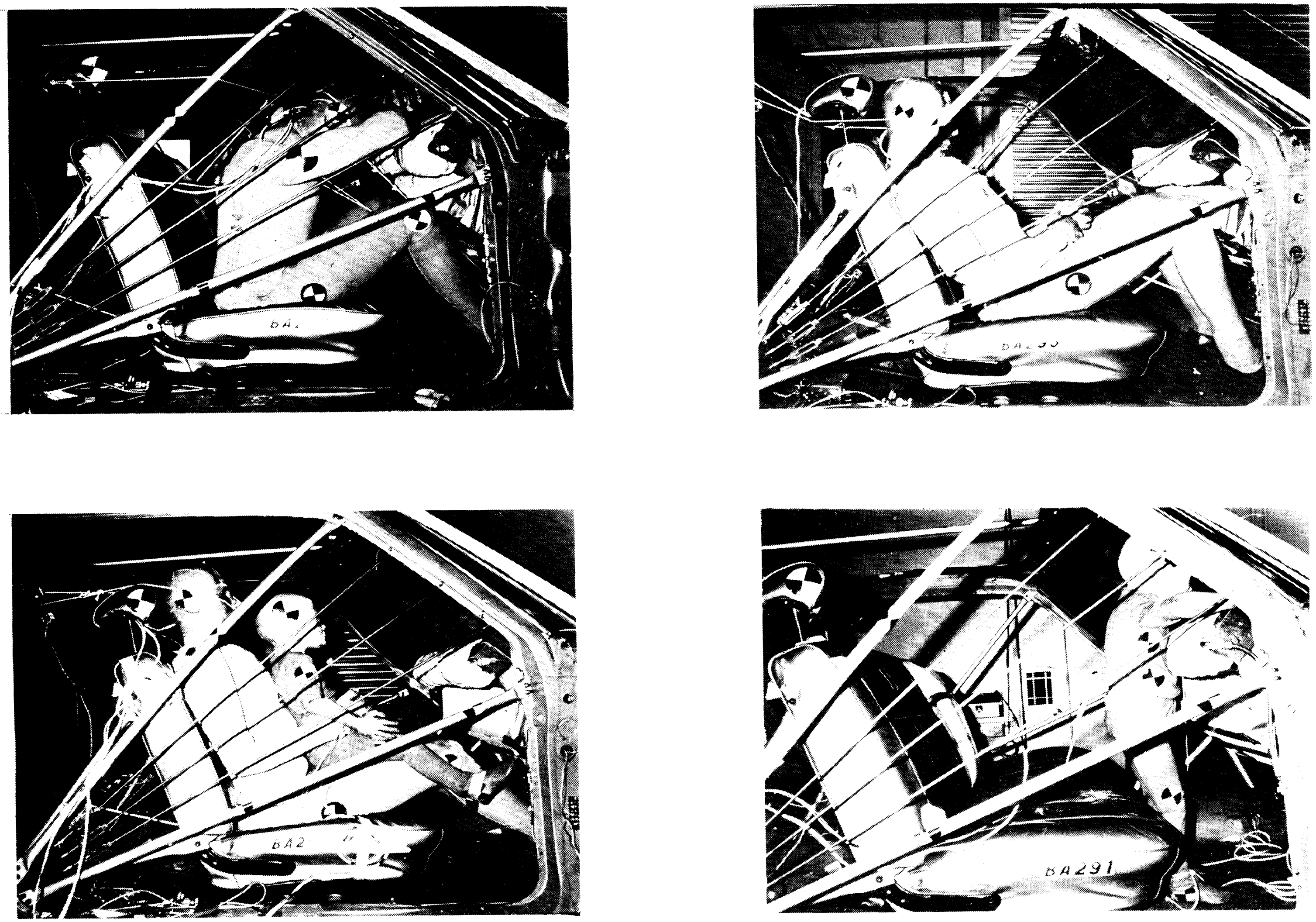


Figure 16. Four Test Setup Photographs for Impact Sled Tests Involving Inflating Occupant Restraint Systems.

occupant positions which were examined in the course of the development of the airbag system as a safety countermeasure. The positions are:

1. Dummy passenger leaning forward on the instrument panel.
2. Dummy slouched in seat.
3. Child dummy on lap of adult dummy.
4. Child dummy standing with chest against airbag.

The anthropomorphic dummies were instrumented with the usual complement of triaxial accelerometer clusters in head and chest. More often than not, the level of protection was estimated to be degraded when the occupants were out of the "usual" erect seated position.

The important point to be noted with respect to this example is again the importance of accident scenario definition. Countermeasure testing should encompass the variety of situations likely to be encountered in practice in order to assure that simplified standard test procedures which may evolve cover the necessary range of performance requirements.

2.2.7 Standard Test Procedure. Architectural Glazing Materials. The Consumer Product Safety Commission has been involved in the development of a standard for architectural glazing materials. To a large extent the effort has concentrated on a simple pendulum test where a lead-filled punching bag swings into a vertically mounted panel of glazing material (See Figure 17 for a schematic of the test). The 100 pound punching bag is a simple, idealized test dummy representing a running boy. The energy of the impact is determined by the height of the bag as it is released and has been established at a maximum of 400 ft. lb. (ANSI Standard Z97.1). The interaction being modeled, thereby, is a boy running at a brisk rate into a large glazed panel. If the panel does not break, the laceration injury scenario, which is the usual form of injury from this class of product, does not develop. If it does break, there are limitations on the size and shape of the hole and the fragments of material which result, again attempting to avoid the assumed accident scenario.

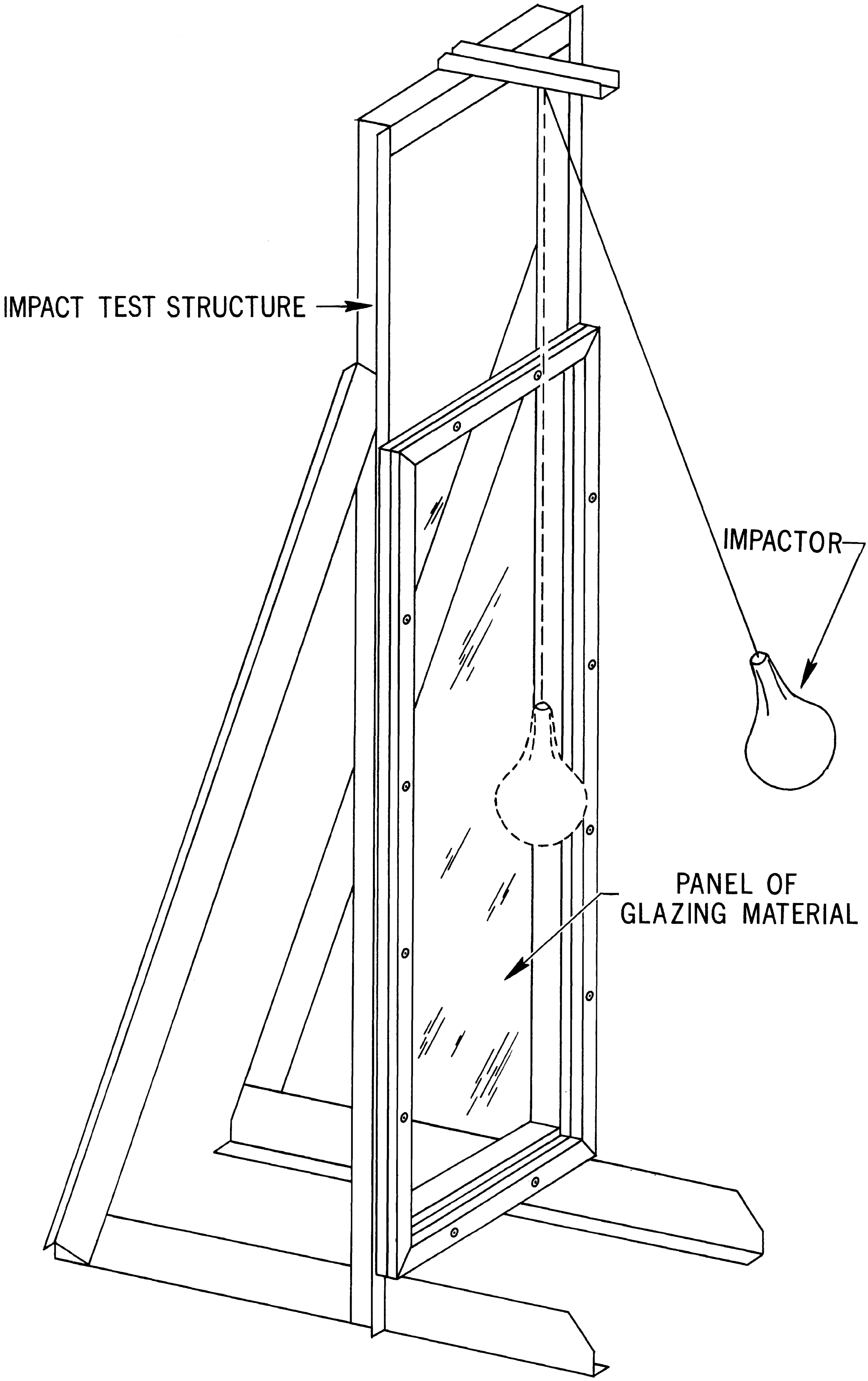


Figure 17. Pendulum Test for Architectural Glazing Materials.

This standard test procedure, by avoiding or eliminating the primary anticipated injury scenario, can be judged successful as a strength measure of glazed panels. Some of the issues which are avoided are:

1. Insufficient accident scenario definition with respect to what parts of the human contact the panel;
2. Unknown impact energy levels;
3. Sequence of events leading from panel breakage to laceration injury is undefined.

It should be stressed that standards such as this which are intended to use a test dummy to prove avoidance or elimination of an injury scenario are usually more tenable than those which strive to attenuate injury. The obvious reasons are the added need for biomechanical data relating injuries to measurable engineering parameters and a clearly documented, statistically based accident scenario definition.

2.2.8 <u>Standard Test Procedure. Part 572 Dummy.</u> The most sophisticated simulation of human form, articulation, and mass which has been incorporated into a standard is the Part 572 anthropomorphic test device (See CFR, Title 49, Part 572). Its use is called for in the Motor Vehicle Safety Standard 208 of the National Highway Traffic Safety Administration in the evaluation and certification of passive automobile occupant restraint systems. In testing, the dummy is positioned either in the driver or passenger seat according to a complex placement procedure. The car is then subjected to a series of crash events consisting of a 30 mph front solid barrier crash, a lateral barrier impact, and a rollover. The restraint system being tested is not in compliance when the transducers in head, chest, and legs of the dummy exceed certain values which to the extent possible are based on biomechanical data. For the head, the head injury criterion (H.I.C.) cannot exceed 1000. Its computation is based on a special integral of the resultant head acceleration. The resultant chest acceleration is limited to 60 G's for intervals exceeding 3 milliseconds. Loads in individual femurs cannot exceed 1700 lb.

This standard, not yet fully implemented, duplicates real crash scenarios to the extent that a crash barrier duplicates the variety of objects contacted during automotive accidents and the

Part 572 dummy represents human dynamic response. The standard has had a controversial history not only due to the fact that passive restraint systems are controversial but also because of the level of development of crash test dummies. Of particular concern have been reproducibility of test results and the biofidelity of the dummy (the degree to which its predictions reflect human response). Title 49, Part 572 was prepared to improve and clarify the properties of the dummy and the test procedures for its use. Figure 18 is a photograph of a Part 572 anthropomorphic test device prior to an impact sled test of a belt restraint system.

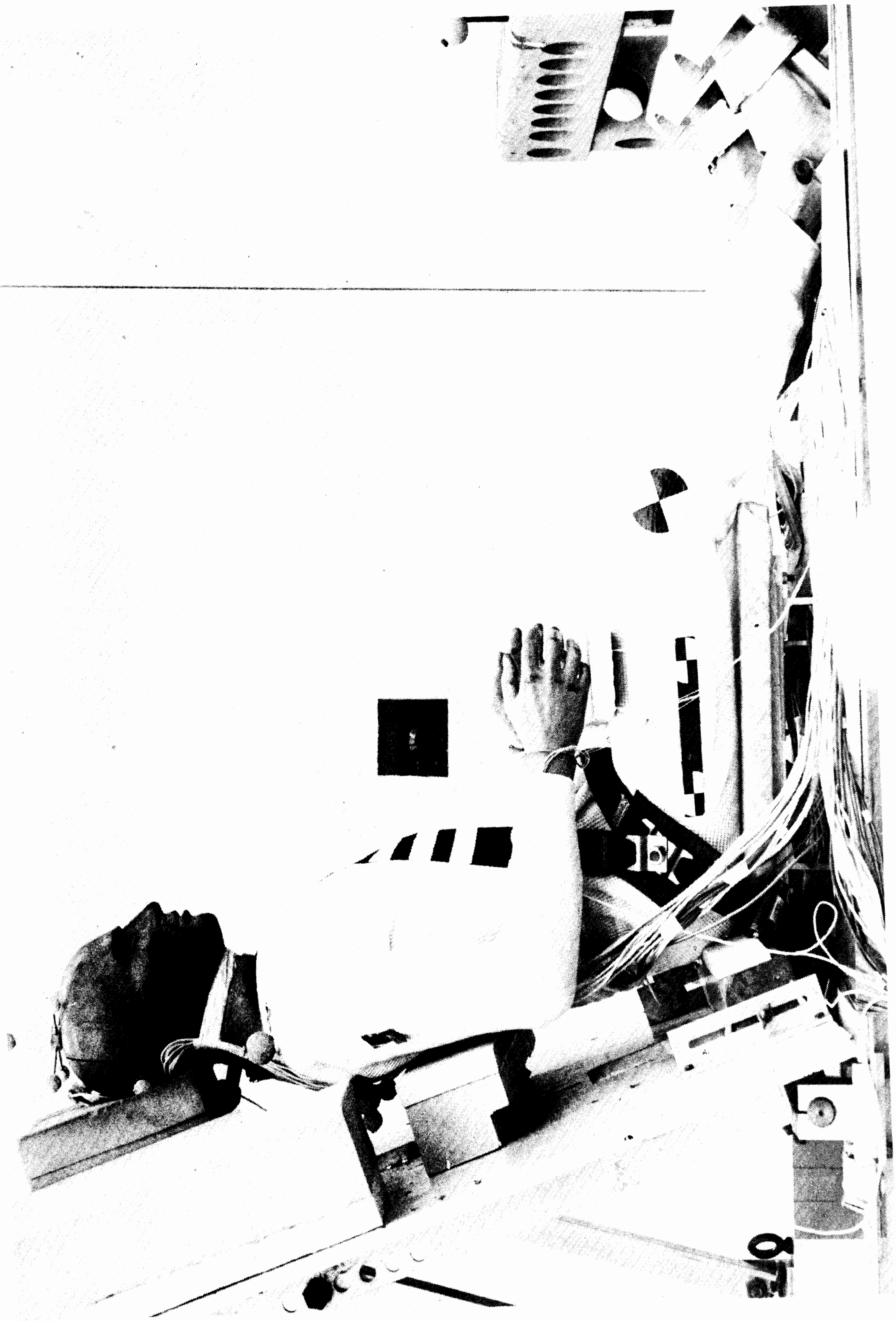


Figure 18. Part 572 Anthropomorphic Test Device.

3.0 WHAT IS A DUMMY TEST?

In the introduction to this report, a dummy test was defined as the hypothesized physical interaction of a human with his environment where the result is mechanical injury or trauma to the human. Two points were made briefly:

- The accident scenario has three basic components which are the victim, the environment, and the dynamics of interaction.
- There are potential sources of differences between the simulated and real events which can be discussed in terms of engineering parameters of the problem.

The purposes of this part of the report are to discuss the engineering parameters of dummy testing, describe the state of knowledge with respect to them, and indicate what types of decisions may be possible based on dummy test results.

3.1 Engineering Parameters in Dummy Testing

The parameters of dummy testing can be organized into four groups. The first three deal with the three components of the accident scenario while the fourth deals with accident (or test) results. Table 1 lists parameters with similarities between victim and test dummy and also those parameters where differences exist or where there may be problems. The list shows that the best data are probably available for describing the weight and shape of the human body and its component parts. A problem exists as these data have been implemented into hardware for only a few sizes representing average and large males as well as a small female, infant, three year old, and six-year old children. Little controversy surrounds the definition of an average or 50th percentile male but non-controversial anthropometric definitions have not yet been developed for the other sizes. The parameter problem is illustrated graphically in Figure 19 which shows a diasassembled child dummy.

An additional problem with articulated test dummies is the lack of biomechanical information describing the physical parameters of human joints. Among the important parameters are stiffness or resistance to motion at the joint. This property reflects lack of data describing the normal and forced range of motion possible at the body joints

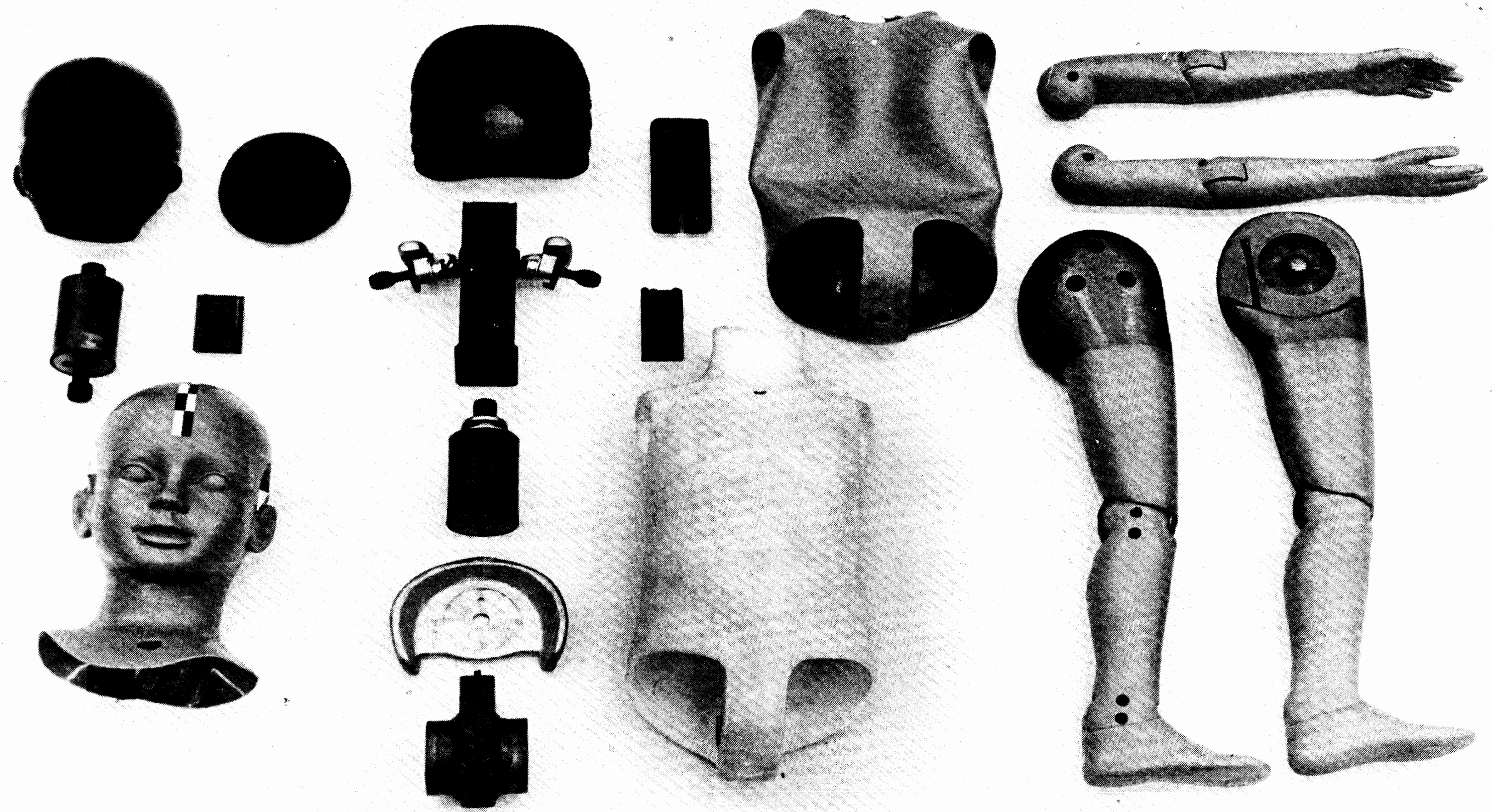


Figure 19. Component Parts of Anthropomorphic Test Device.

TABLE 1. PARAMETERS OF THE VICTIM

Similar Parameters	Problem Parameters
Total body mass	Limited number of body sizes
Weight of body parts	Unrealistic joint properties
Limited anthropometry	No muscle tension
	Flesh inappropriate for superficial injuries
	Not a validated injury indicator.

as well as muscle capability in resisting loads. A good deal of information is available for the arms, torso, and legs to define static lifting strength but the ability to resist surprise dynamic loads is largely unknown. Most of the information on this subject relates to the neck (studies of the whiplash phenomena) and the forearm and elbow.

Other problems with or shortcomings of existing test dummies relate to their ability to register injury. Most of the available injury criteria deal with resistance to blunt impact on the head, thorax, or the femur. Care must be taken that an injury criterion selected for performance evaluation is applicable to the test conditions imposed. For example, head injury criteria are best documented for forehead impact, less-well documented for head side impact, and poor for blows to the vertex or occipital (lower back of the head) regions. Chest injury criteria are best documented for blunt impact to the sternum but are sketchy for blows to the side or back of the chest. Fairly good information is available for blows to the knee/femur complex but do not relate to the twisting and turning of the knee as may occur in a fall. A final problem exists with the flesh or skin of dummies. The flesh provided with anthropomorphic test dummies may be soft and feel somewhat like skin. It may respond somewhat like human flesh when subjected to a blunt impact. However, a good lacerating flesh has yet to be developed.

In those cases where tolerance data is limited or not available, the most that can be expected from a test dummy is a good representation of body mass and form. This representation can aid in countermeasure development or standardization by showing comparative attenuation of dynamic events but cannot be expected to predict a quantified reduction of injury level.

The parameters of the environment where the accident takes place do not present a major problem for laboratory duplication. In so far as is necessary, the structures, surfaces, railings, flying objects, etc. can be reconstructed.

Given a test dummy and an accident environment, however, it is often very difficult to create the correct dynamic interaction between the two. To start with, it is necessary to have a well-defined accident scenario. An example of this problem which has already been discussed in this report concerns hard hats. An obvious problem in defining the interaction is the position in which the victim has his head. Is he looking forward or down? Are his muscles tensed or loose? With respect to this same accident, the possibility for good interaction definition with respect to some parameters also exists. For example, if it is known that an object drops from a certain height, the impact velocity and energy are well-defined. Basically then, parameters of the interaction usually involve the initial position and motions of the victim in the environment. Definition of the interaction can be no more accurate than the ability to position the victim in space, a task which increases in difficulty as the number of articulations in the test dummy increases.

The final class of parameters deals with the comparative results of an accident scenario, an injury to the human and data from a dummy test. Comparisons of the various possible output parameters are given in Table 2. With test dummies it is possible to obtain substantial data describing body motions, applied forces, and kinematic quantities such as velocity and accelerations. The major problems lie in a paucity of information relating injuries to biomechanical human tolerance criteria which can be derived from test dummy data. The appendix to this report gives references on this subject and the other parameters of the injury event.

TABLE 2. OUTPUT PARAMETERS FROM INJURY-CAUSING EVENT

Similar Parameters	Problem Parameters
Gross body motions	No injury measure in test dummy.
Gross forces	No effects of muscle tension possible in dummy.
Gross kinematics	Force and kinematic data available only from dummies.

3.2 Possible Decisions Based on Dummy Test Results

Dummy test results can provide a basis for decision making with respect to each of the three types of tests discussed earlier -- problem identification, countermeasure development, and standardized test procedures. With respect to problem identification, it can be determined that a problem exists, and further, a physical definition of the problem can be made, when a test dummy and a human victim leave the same "imprint" on the environment. If, in addition, the test dummy or environment is carefully instrumented, the injuries or other human responses can be related to engineering variables measured during the test. This is precisely what was done in the case of the TRRL dummy described in Section 2.2.5 and provides a firm foundation for countermeasure development and standards development which may follow.

Countermeasures are developed to eliminate, alter, or soften potential injury-producing scenarios. As a result of testing potential countermeasures, decisions can be reached based on their comparative performance. In other words, answers can be obtained to the question, "Did the countermeasure alter the outcome of the initial scenario in a manner beneficial to the victim on the basis that he feels gentler forces and motion?"

Compliance test procedures can be used in the same manner as countermeasure tests to compare performance of safety countermeasures against standard data and certify their value as safety-protective devices. It is obvious, however, that the standard may be useless or even dangerously misleading unless correlation has been established between the accident and the standardized test procedure.

As a conclusion to this section, a list of three questions is given which should be asked anytime a decision is contemplated relative to any of the three types of dummy tests outlined above:

1. Does the laboratory test scenario reflect all the engineering variables relevant to the injury-causing event?

2. Are the instrumentation and test dummy which have been selected capable of reflecting all the relevant engineering variables?

3. Does the test data which is obtained reflect the potential for injury?

If all these questions can be answered in the affirmative, the dummy test can be a useful tool in decision making relative to safety countermeasures.

4.0 CONDUCTING AN INSTRUMENTED DUMMY TEST

The dummy test as described in this report is a simulation of a dynamic event -- usually an impact. The objective of any instrumentation is therefore to record the parameters of a dynamic mechanical event, that is, motions, velocities, accelerations, forces, and other quantities which may be derived therefrom. It is the objective of this concluding section of the report to outline briefly the range of data which can be expected in this type of test, the equipment utilized in a dummy test laboratory, and typical requirements of data analysis.

4.1 Range of Data to be Expected

There are six groups of variables which are measured during dummy tests. These are:

1. Time
2. Position of objects in three dimensions
3. Linear and angular velocities
4. Linear and angular acceleration
5. Force and moment vector within the dummy or environment
6. Other quantities such as performance indicators which may be derived from the other variables

Time durations in injury production and in dummy tests are brief. The usual unit is the millisecond with total events seldom lasting more than 1/4 second. A common procedure is to digitize time to 0.1 millisecond.

A variety of requirements may be placed on position measurement depending on the particular application. Deformation of a human body or a dummy simulation is usally much less than six inches. Relative motions between adjacent segments of articulated dummies can be said to be limited to any point within a circle within about eight feet of any point on the body. This requirement can stretch the imagination of even the most creative of laboratory specialists as it has in the case of full scale impacts of pedestrian test dummies with an automobile moving at 30 mph. Body segment rotations are also classed as large deformations and may exceed 180° relative to a laboratory fixed coordinate system or even between adjacent body segments in a dummy. The most difficult problem in position measurement is, of course, tracking motion of moving objects in three dimensions. For any rigid body, this requires following three translational and three angular coordinates fixed in the body.

Accelerations measured in dummy tests most often do not exceed 100 G's. Sometimes they may be as great as 500 G's for head impact. Frequency response of accelerometers and other transducers mounted in test dummies generally is not required to exceed 1000 Hz. For anthropomorphic crash test dummies, a Society of Automotive Engineers specification (J211) recommends 1000 hz. for head-mounted instrumentation, 180 hz. for the chest, and 600 hz. for the legs.

Force measurements seldom reach 5000 lbs. Most bony structures in the human body can bear in excess of 1000 lbs. Although test dummies should be designed conservatively to far exceed this requirement, it is not customary to greatly exceed the levels expected of the human during testing. The human femur can ordinarily withstand loads up to 1700 lbs. while the thorax can be expected to resist 2500 lb. if it is well-distributed over the front of the chest.

4.2 Data Acquisition

There are basically two types of data which must be recorded -- visual and transducer. Acquisition of visual data requires the use of high speed motion picture cameras with frame rates generally in the range of 500 to 3000 pictures per second. Transducer data is most often recorded on an FM tape recorder with a frequency capability flat from 0 to 10000 hz.

The key to position measurement is targeting of the subject and the laboratory. The laboratory is targeted to provide a fixed coordinate system against which environmental or victim motions can be measured. Figure 12 illustrates a simple targeting arrangement for a two-dimensional motion study. At the left center are two targets fixed in the laboratory. Targets are also placed on the impactor ram in order to monitor its position as a function of time. Finally, targets are on the helmet and the dummy head to compare their motions with the laboratory-fixed system or with each other.

It is implied in this discussion that position is determined as a function of time from a movie analysis. This requires that the frame rate of the camera in pictures per second is known precisely. The usual procedure is to record time markers directly on the film either using a clock in the field of camera view or, better, imposing a time marker on the edge of the film from a signal generator. Using this procedure it is possible to synchronize visual and transducer data by also recording the time base signal on the FM tape.

Direct three-dimensional motion measurement is a more difficult problem. An example of a system used to track a rigid body in space is shown schematically in Figure 20. Here a test dummy is seated on a moving impact sled. A target cluster of five small balls is rigidly attached to the head of the dummy defining a moving coordinate system in the head. Orthogonal (not a necessity) cameras record the motion from two directions with respect to a laboratory fixed system shown at the left of the figure. Five balls are used to insure that at least three are visible in both cameras at all points in time. This requirement is based on the fact that location of three noncollinear points in a rigid body can be used to define its position in space.

Acceleration measurement is usually accomplished through the use of linear accelerometers mounted singly or in groups of two or three for multidimensional kinematic data acquisition. For test dummy applications, the most commonly used accelerometers are the miniature piezoresistive type. They couple small size with accuracy, sensitivity, and a wide range of frequency responses. The piezoelectric type requiring a change amplifier may cause problems of drifting because many of the impact situations require relatively long response cycles greater than 100 milliseconds which is at the edge of the normal low frequency response of these devices. The wire strain gage accelerometers are usually too large and do not have the response for applications of this type.

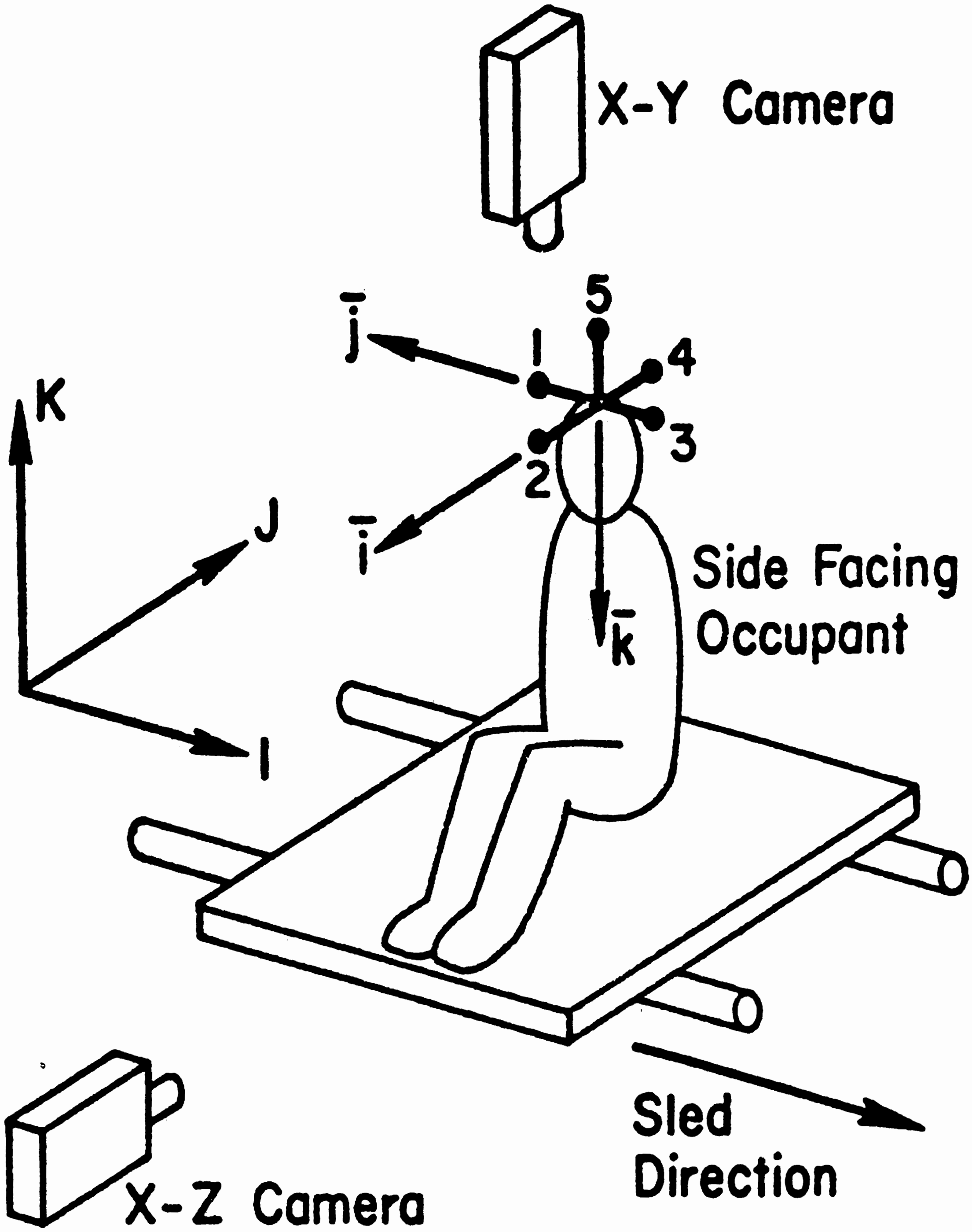


Figure 20. Apparatus for Acquisition of Three-Diminsional Motions of a Rigid Body.

The problem of acceleration measurement in three dimensions has only recently been solved in a practical sense. The technical problem is to measure three linear and three angular accelerations at a point to completely specify the acceleration of any point in a rigid body. The two approaches commonly applied involve either the use of rate gyros or miniature accelerometers. Rate gyros have the advantage of direct access to angular accelerations but the disadvantage of relatively large size and high cost. The approach which seems to be the most widely accepted involves the use of nine linear accelerometers mounted in three triaxial clusters separated by as great a distance as is possible within the constraints of the test. The use of nine accelerometers has been found necessary to avoid stability problems in data analysis which always can be shown to occur when using only the minimum number of six.

Force transduction usually is a less severe problem as force measurements are usually made on a fixed element of the environment eliminating the problem of motion. A variety of satisfactory force links are available usually based on the principal of strain gage sensing of calibrated beam bending. Figure 12 shows an example of typical instrumentation of this type. Above the surface of the impactor is a force link in series with the ram. Because of the motion it is necessary to compensate for the inertia of the ram in order to obtain a correct reading of force applied to the helmet. This is done by measuring ram acceleration (accelerometer mounted just above the force link) and multiplying by ram mass to obtain the compensation due to inertial force of the ram.

The recording of transducer signals is done in two ways. The first, least expensive, and most common is the use of an umbilical carrying the signal directly to a recording device. The second involves telemetering of the signal. This procedure is often limited by frequency response of the system required in recording an impact event. For sophisticated, multi-channel experiments, an FM tape recorder is usually required, especially where the data must be subjected to post-test analysis. Where a single number or data trace is required, a light beam oscillograph or storage oscilloscope are often satisfactory.

4.3 Data Analysis

A schematic of a complete data acquisition, handling, and processing system is shown in Figure 21. This is typical of systems in use in the field of automotive safety which often involves tests acquiring massive amounts of data. There are three data streams in the schematic. The first routes the transducer signals directly through filters onto light beam oscillographs. This is often done as part of the test in order to obtain a quick look at data quality and instrumentation function. The second stream routes the transducer data to an FM tape recorder with a primary goal of detailed post-test analysis. The high speed films are developed and form a parallel data stream. The first step in data processing of the tape is to play back through an analog to digital converter and store the resulting sequence of data points in file storage of a minicomputer. Film analysis has the same goal. Individual frames of the motion picture are projected on one of a variety of film analyzing tables. Point positions are either manually or automatically (or using complex scanning equipment) reduced to digital form and entered into files of the mini-computer.

The second step in data analysis is to assemble, sort, scan, and repair (if necessary) the digitized data from both the transducer and visual (film) data streams on a common basis. This is generally followed by digital filtering using software with the flexibility to allow the user to "design in" his own filter specifications. Graphics plots are often prepared at this point to review the raw but sanitized data.

The third and final step is formal data analysis which may require use of a large digital computer. Typical information desired consists of:

1. Resultant accelerations;
2. Three-dimensional motions and acceleration calculations;
3. Corrections for inertia; and,
4. Computations of performance indicators.

The second and fourth of these may involve use of sophisticated computer software.

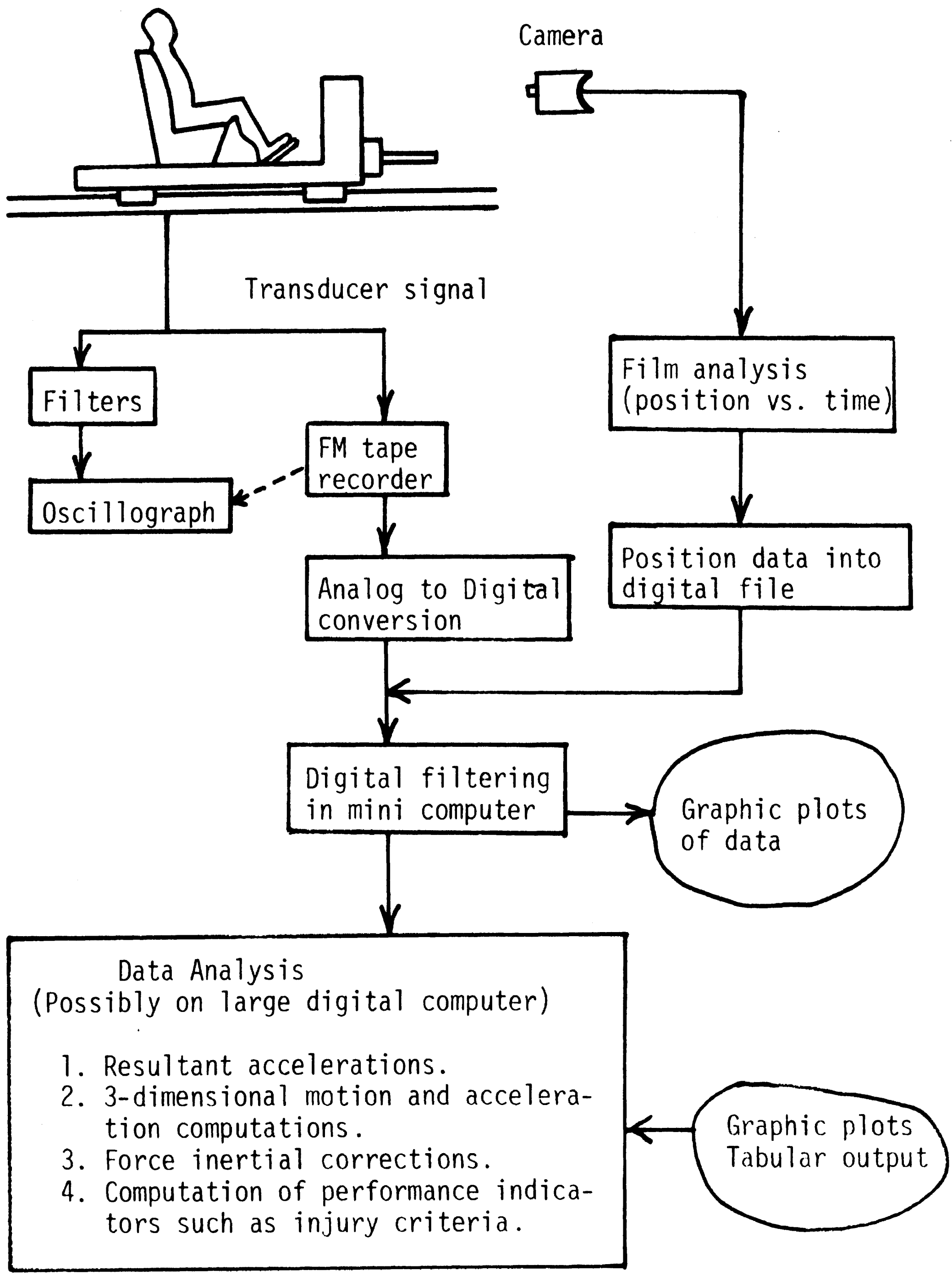


FIGURE 21. Complete Data Analysis System

The data analysis overview which has been presented is intentionally broad and includes the use of sophisticated acquisition, processing, and analysis procedures. It is realized that the objective of most test procedures will be to simplify this system to the greatest extent possible to reduce cost, to eliminate the possibility for error, and to produce minimum but clear data. This is especially true in the development of standardized test procedures. It is also realized that there are times when simplification is not desirable. The procedures which have been presented summarily are in common use (including the software which has been briefly mentioned) and should present few problems to the careful user.

APPENDIX

LITERATURE REVIEW ON TEST DUMMIES AND THEIR USAGE

A.1. INTRODUCTION

To support the work leading to the main text of this guidebook, a literature view was conducted on the general subject of dummy testing. The library at the Highway Safety Research Institute, one of the largest libraries in the world dealing with safety-related issues provided the bulk of the information. No attempt was made to go beyond a first order literature search based on bibliographies included with most of the documents because of limited time and funding. It is known that the literature on many of the sub-categories of this subject includes many thousands of references. Rather, a representative spectrum of literature was included with sufficient depth to aim the user of the Guidebook toward the literature on any topic where he may require further information.

The information gathered was divided into three general categories:

- Dummy Usage
- Dummy Description
- Dummy Testing

Literature falling into the Usage category deals primarily with the various types of applications of test dummies. The dummy description category covers subjects ranging from background data on which to base dummy designs to injury criteria for evaluating dummy test results. Dummy testing documents generally cover the procedures used in testing. Each of the three general categories was further subdivided as shown in Table A-1. An additional category which is included in this list identifies the type of group conducting the work.

A card was prepared for each document which was collected. After review, each was assigned a code word indicating the Table A-1 category. In general the codeword is given as:

Agency - U, D, or T - subheading

It was found that many documents fit primarily into one category but contain information fitting into other categories. On this basis, it was decided to list the literature under the three broad categories given above (U,D, or T) rather than subdividing into shorter lists.

TABLE A-1. CATEGORIES FOR LITERATURE REVIEW

Dummy Usage (U)

1. Accident reconstruction (Problem identification)
2. Countermeasure development
3. Compliance testing

Dummy Description (D)

1. Parameter - anthropometry, mobility (human)
2. Parameter - anthropometry, mobility (dummy)
3. Injury criteria, biomechanics
4. Biofidelity
5. Partial dummies - body blocks
6. Partial dummies - head forms
7. Other simplified dummies
8. Whole body dummies

Dummy Testing (T)

1. Data analysis - photographic
2. Data analysis - transducer
3. Data acquisition and instrumentation
4. Test procedures
5. Test setup and positioning
6. Dummy test performance characteristics (Repeatability, etc.)

Agencies Involved

1. Universities
2. Industries and trade organizations
3. Private laboratories and research-oriented corporations
4. Federal
   a. NHTSA, NBS, DOT, FAA, CPSC, NIOSH, OSHA
   b. DOD, NASA
5. Foreign

Parts A.2, A.3, and A.4 which follow are the three lists, each in alphabetical order.

It will be noted upon review of the literature lists that there is a larger collection of documents in some categories than others (See Table A.2). This is felt to reflect the general state of activity in the dummy test field but also reflects the necessarily cursory nature of the review. In the case of the large relative number of uses in countermeasure studies, the survey is believed to be relatively accurate. This reflects the difficulty of getting a dummy standardized. With respect to testing, the category T-6, which includes the most T-entries, was used for documents of a general nature with much overlapping of the other categories. Several of the D-categories have limited entries and could be expanded. This is particularly true with respect to human anthropometry, biomechanics, and partial dummies.

TABLE A.2. DOCUMENTS IN EACH CATEGORY

Category	Entries
U1	7
U2	61
U3	11
T1	4
T2	10
T3	4
T4	9
T5	7
T6	29
D1	15
D2	29
D3	13
D4	26
D5	4
D6	13
D7	13
D8	36

A.2 DUMMY USAGE

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