SAE International

SURFACE VEHICLE INFORMATION REPORT

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Occupant Restraint System Evaluation - Passenger Cars and Light-Duty Trucks

RATIONALE

This document is not only severely outdated in many areas, but it is also contradictory to what is practiced today with respect to placement of children only in the rear seat. If we simply reaffirm - then we are stating the committee still feels this document is valid. Because of the obsolescence - it is a waste of time to update it. Therefore - the best solution is to stabilize it.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Restraint Systems Standards Steering Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

***Foreword*—**This Document has also changed to comply with the new SAE Technical Standards Board format.

The purpose of this SAE Information Report is to further the development of passenger car and light-duty truck restraint systems. This report should aid that goal by:

a. Describing standardized restraint system testing methods so that results from various test laboratories can be compared.
b. Serving as a guide in the design and development of restraint systems and in the preparation of detailed procedures for testing and evaluating specific types of restraint systems.
c. Providing an orientation for research in human tolerance to impact and for the development of improved human simulators.

The evaluation procedures discussed are presented as an Information Report. Due to continuously evolving instrumentation/measurement systems, collision simulation, and data on human tolerance to impact, this report will necessarily be subject to continuing review and improvement. Nevertheless, the outlined procedures are intended to form the basis for overall evaluation of any means by which a collision energy exchange between a vehicle and its occupant(s) is measured. Where present knowledge does not allow for rigorous specifications consistent with this broad outlook, an attempt has been made to avoid arbitrary or restrictive statements. The state-of-the-art in testing, engineering judgment, and experience must provide major guidance in restraint system evaluation.

***1. Scope*—**This SAE Information Report discusses the significant factors which measure the effectiveness of the total occupant restraint system in commonly encountered collision configurations. The total system includes the components which affect occupant injury by influencing the manner in which the collision energy management is accomplished. In addition to the elements that contribute to impact attenuation, consideration must be given to factors that encourage maximum use, such as comfort, reliability, appearance, and convenience. Hence, system evaluation necessarily involves consideration of the complete vehicle.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J114—Seat Belt Assembly Webbing Abrasion Performance Requirements
SAE J117—Dynamic Test Procedures—Type 1 and Type 2 Seat Belts
SAE J140—Seat Belt Hardware Test Procedure
SAE J141—Seat Belt Hardware Performance Requirements
SAE J184—Qualifying a Sound Data Acquisition System
SAE J211—Instrumentation for Impact Tests
SAE J247—Instrumentation for Measuring Acoustic Impulses Within Vehicles
SAE J339—Seat Belt Assembly Webbing Abrasion Test Procedure
SAE J800—Motor Vehicle Seat Belt Assembly Installation
SAE J850—Barrier Collision Tests
SAE J885—Human Tolerance to Impact Conditions as Related to Motor Vehicle Design
SAE J972—Moving Barrier Collision Tests
SAE J1211—Recommended Environmental Practices for Electronic Equipment Design
SAE J1368—Child Restraint Anchorages and Attachment Hardware
SAE J1369—Anchorage Provisions for Installation of Child Restraint Tether Straps in Rear Seating Positions
SAE J1460—Human Mechanical Response Characteristics
SAE J1819—Securing Child Restraint Systems in Motor Vehicles
SAE Paper 791026—A Comparison Between Part 572 Dummy and Human Subject in the Problem of Submarining, Leung, Y.C., Tarriere, C., Fayon., A., Mairesse, P., Delmas, A., Banzet, P., In 23rd Stapp Car Crash Conference Proceedings, 1979.
SAE Paper 892440—Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies, Rouhana, S.W., Viano, D.C., Jedrzejczak, E.A., McCleary, J.D., In 33rd Stapp Car Crash Conference Proceedings, 1989.
SAE Paper 902317—Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies: Part II—Development of the Small Female Frangible Abdomen, Rouhana, S.W., Jedrzejczak, E.A., McCleary, J.D., In 34th Stapp Car Crash Conference Proceedings, 1990.

2.1.2 FMVSS PUBLICATIONS—Available from the Superintendent of Documents, U. S. Government Printing Office, Mail Stop: SSOP, Washington, DC 20402-9320.

FMVSS 208—Occupant Crash Protection
FMVSS 214—Side Impact Protection

2.1.3 U.S. GOVERNMENT PUBLICATIONS—Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

United States Patent 3,841,163: Daniel, R.F.; Test Dummy Submarining Indicator System; October 15, 1974.
49 CFR Part 572: Test Dummy Specifications—Anthropomorphic Test Dummy for Applicable Test Procedures

2.1.4 OTHER PUBLICATIONS

Mertz, H.J.: Anthropomorphic Test Devices In Accidental Injury: Biomechanics and Prevention, Springer-Verlag, 1993.

3. Technical Information

3.1 Design and Testing Guidelines—The following is a suggested checklist for evaluating restraint system characteristics.

3.1.1 COLLISION CONSIDERATIONS

3.1.1.1 *Injury Mitigation*—A restraint system should perform in a manner which applies restraint forces to appropriate areas of the anatomy to help reduce the likelihood or severity of contact with vehicle interior surfaces other than the restraint system(s) to mitigate occupant injury, with consideration of skeletal, internal organ, and soft tissue damage, including disfigurement.

FMVSS considerations include: head acceleration, chest acceleration and compression, and femur loads. Even when numbers recorded by the anthropomorphic test device (ATD or test dummy) are acceptable for FMVSS 208, significant occupant injury is still possible, e.g., by submarining where the forces of restraint are partially channeled into the abdominal region of the occupant. Likewise, some neck injury can occur in situations where the FMVSS 208 conditions are all met. The automotive safety engineer is encouraged to review SAE J885, which deals with such issues in depth.

3.1.1.2 *Kinematics of Restraint*—In evaluating injury reduction, consideration should be given not only to the direct effects of restraining forces but also to the possible consequences of occupant kinematics, such as violent contact between occupants (e.g., head bumping), areas of load concentration on the human body (e.g., loading of the abdomen by submarining), and excessive body motion of one body region relative to another (e.g., head relative to torso as in whiplash).

Submarining occurs when the occupant's pelvis slips under the lap belt which then causes the forces of restraint to be applied to the abdominal region. Although pelvic load bolts, front-of-the-ilium load transducers, and iliac crest load cells can usually detect the occurrence and timing of submarining, until recently there was no way to quantify the risk of abdominal injury when submarining occurred. A new device, the Frangible Abdomen, is available for the Hybrid III small female and mid-size male dummies. It has a more correct mechanical response for low-velocity abdominal belt loading as seen in submarining, and provides some indication of the risk of abdominal injury by measurement of the abdominal penetration. In balancing the benefit of the restraint of the whole body against some risk of abdominal injury, the latter may be acceptable and indeed unavoidable. The Frangible Abdomen may offer an objective, quantitative approach to making these assessments.

Relative motion of major body regions might occur in the case of an occupant interaction with a knee bolster without upper body restraint. In this case, the thorax may move relative to the pelvis, which could cause large shear loads to build up in the lumbar spine. Thus, an attempt to balance loading over the major regions is important.

3.1.1.3 *Injury Criteria*—It should be recognized that the devices specified in 49 CFR Part 572 have no capability to measure simulated human physiological responses. They measure physical parameters which are correlated to probability of injury to the body region in question. In addition, injury criteria and tolerances are developed based on a limited number of tests. Yet, human tolerance to injury is known to be a distribution, that is, there is no single number at which a femur, for example, will fracture regardless of the individual involved in a collision. Tolerance is an individual matter based on a host of physiologic considerations beyond the scope of this document. There are always individuals who are more or less susceptible to injury than the average person. Therefore, care must be exercised when evaluating the data resulting from the use of an ATD in restraint tests. Use of a single number (e.g., HIC = 1000) should be avoided in favor of a balanced approach considering test severity and proximity to the "accepted" tolerance value. Appropriate human tolerances to impact are presented in SAE J885 (JUL86).

3.1.1.4 *Ejection*—Injury potential is generally increased when an occupant is completely or partially ejected from a vehicle during a crash. The relative ability of the restraints to retain the occupant within the body shell is therefore an important criterion of system performance.

3.1.1.5 *Deployment*—A restraint system or component which is stored remotely and moved rapidly into place immediately before or during an impact should to the extent possible not pose a greater hazard to the vehicle occupants or to service personnel than if the system were not present. For example, factors to be considered in these types of systems include: noise, dust, and smoke. However, it is not anticipated that such systems can be entirely free of hazard.

3.1.1.6 *Durability*—Restraint system components should be tested to evaluate their ability to provide acceptable performance throughout their service life. This may require real time or accelerated exposure to such factors as aging, use, sunlight, corrosion, and dirt. (See SAE J114, J117, J140, J141, J339 and J800 for specific tests applicable to seat belt assemblies.)

3.1.1.7 *Component Installation*—Restraint system components should be installed in the vehicle in such a manner that they do not themselves constitute a significant impact hazard.

3.1.1.8 *Ambient Conditions*—A restraint system should provide performance which remains acceptable throughout the range of ambient conditions to which it can reasonably be expected to be exposed during its service life. Since it is not usually feasible to vary these conditions during crash tests, it may be necessary to conduct component tests which are supplementary to and more controllable than the complete system tests specified in 3.4.1.

3.1.1.9 *Egress*—The restraint system should not cause excessive difficulty or delay in exiting from the vehicle after a collision, with or without outside assistance. Consideration should also be given to the occurrence of a user suspended in an overturned vehicle.

3.1.1.10 *Unusual Conditions*—While it is obviously desirable that a restraint system provide a high level of protection for all occupants in all accident conditions, the broad spectrum of occupant sizes, the large distribution of occupant tolerances, and the statistical nature of collision casualties must be recognized. A system which provides generally good protection is not necessarily rendered unacceptable by its performance under some extreme set of circumstances which will rarely be encountered.

3.1.2 ACCEPTABILITY CONSIDERATIONS—The following characteristics affect the probability of acceptance and proper use of the total restraint system so that its performance potential can be realized. These factors should therefore be weighed heavily in the overall evaluation of a system.

3.1.2.1 *Comfort*—The restraint system should embody as far as possible those features which contribute to occupant comfort. For those elements which usually contact the occupant, particular care should be paid to avoiding pressure points, rubbing, and similar sources of annoyance which discourage consistent and proper use. Measures taken to assure occupant comfort should be evaluated with respect to their effect on system performance.

3.1.2.2 *Convenience*—Restraint system convenience includes consideration of potential interference with normal driving functions (e.g., vision, steering, etc.), and optimizing the use, removal, adjustment, and storage of components, particularly in darkness or without reference to written instructions. These needs are best met by minimizing occupant participation or effort.

3.1.2.3 *Adjustability*—Restraint system adjustability concerns address the spectrum of different occupant sizes and include consideration of feasible measures to "tune" the restraint system for optimum comfort, fit, and occupant protection across this range.

3.1.2.4 *Child Seat Compatibility*—The restraint system should allow secure placement of child restraint devices as specified in SAE J1368, J1369, and J1819. Where inflatable restraints or non-bench seats are present, consideration should be given as to the appropriateness of such seating positions for child restraint use. Considerations should include, but are not limited to, possible interactions between the child restraint and the inflatable restraint, ability to secure the child restraint, compatibility with the belt system, etc.

3.1.2.5 *Appearance*—The attractiveness of system components, both in use and stored, and their effect on occupant clothing should be considered to encourage use.

3.1.2.6 *Ingress*—The restraint system should not impede progress nor damage the clothing of an occupant entering the vehicle.

3.1.2.7 *Noise*—Noise from shakes and rattles should be minimized for each type of restraint system in its stowed or non-deployed position, and for belt restraints when in use. Consideration should be taken of the noise produced by restraint systems which are deployed by pyrotechnic, mechanical, or other means as in SAE J184 and J247.

3.1.2.8 *Durability*—In addition to the retention of system performance specified in 3.2.1.4, it is important to ascertain that the factors which influence acceptability will not deteriorate throughout the service life of the system to an extent which would constitute a significant deterrent to maximum use. For example, consideration should be given to the effect of vibration on system acceptability as in SAE J1211.

3.1.2.9 *Maintenance*—The responsibilities of the user with regard to establishing and maintaining proper use should be kept to the feasible minimum and should be documented in clearly written instructions.

3.2 Equipment

3.2.1 ANTHROPOMORPHIC TEST DEVICES (ATDS)—For the impact tests specified in 3.4, restraint systems should be evaluated with the aid of an anthropomorphic test device which conforms to 49 CFR Part 572, Subpart E (Test Dummy Specifications--Hybrid III Test Dummy) for frontal and rear impact tests, and 49 CFR Part 572, Subpart F (Test Dummy Specifications--Side Impact Dummy 50th Percentile Male or equivalent) for side impact tests. Other test devices not specified in 49 CFR Part 572, may nevertheless be useful qualitative tools in reaching evaluation judgments (BIOSID, Hybrid III with additional instrumentation, etc.). Attention is called to the following general considerations and limitations which apply to ATDs.

3.2.1.1 *Size*—The test device which conforms to 49 CFR Part 572, Subpart E is representative of the 50th percentile adult male. Hybrid III devices are now available which represent occupants of other sizes. In general, the restraint system should exhibit sufficient performance to provide comparable protection for the range of occupant sizes for which it is intended.

3.2.1.2 *Articulation*—Test devices conforming to 49 CFR Part 572, Subpart E provide a representative range of motion for the major body members, although the articulation is necessarily somewhat less sophisticated than that of the human being. In general, motions of the test device will be reasonably adequate for severe impact conditions but less reliable for low-energy impacts, where such factors as muscular forces and internal damping can have a proportionately larger influence on the relative displacement of body elements during the collision event.

3.2.1.3 *Clothing*—Frictional forces between the test device and components of the vehicle can have important effects on relative motion of the test device. Body elements likely to be in substantial contact with the seat, vehicle interior, or restraining devices should therefore be clothed in material which will provide friction coefficients representative of typical occupant clothing. In the absence of special considerations, cotton is recommended. While it is recognized that loose, multiple-layer clothing can affect friction, form-fitting stretch garments are recommended to minimize interference with photographic analysis.

3.2.1.4 *Dynamic Compliance*—Correlation work is ongoing between static and dynamic compliance of ATDs and human response data of the type contained in SAE J1460. While these test devices can generally be used to make quantitative predictions of human injury, the response of some body regions is either unknown or not accurately reproduced in the ATD. There are many reasons for this, such as the multiplicity of conditions under which the human tolerance data have been obtained, the scarcity of such data, and the difficulty of developing mechanical parts which have the same dynamic properties as the human body. Impact data measured by using such a test device can nevertheless be of considerable value in evaluating restraint systems because of considerations such as the following:

a. Where possible, the evaluation desired should be relative to some similar restraint system whose performance with the same test device is known or can be determined. The relative performance is thus less likely to be obscured by differences between the test device and the human being.
b. If typical crash loads are to be kept within human tolerance limits, the dynamic deflections of restraining elements will usually have to be quite large relative to the involved elements of the human body. Under these conditions, inaccuracies in the compliance rates of the test device will have only a relatively minor effect on the loads developed, since these devices are usually the stiffer elements in the interaction with the restraint system or the vehicle interior.

It is, however, important to inspect test information closely in order to detect misleading results due to details of the construction of the test device which are significantly different from those of the human body (for example, metal edges which might cut restraint devices).

3.2.1.5 *Instrumentation*—Many different physical parameters can currently be measured using the ATD specified in 49 CFR Part 572, Subpart E including, but not limited to: acceleration of the head, chest, and pelvis, forces and moments on the upper and lower neck, compression of the chest, and loads on the femur and tibia. In addition, instrumentation specifically developed to address occupant submarining under belt systems is available (pelvic load bolts, frangible abdomen, front-of-the-ilium load transducers, and iliac crest load transducers). Careful consideration should be given to the instrumentation used in the ATD for a particular test.

3.2.1.6 *Occupant Kinematics*—While instrumentation on the dummy provides the engineer with useful information, reliance should not be placed only on the numbers generated by the dummy's transducers. The kinematics (motion) of the dummy during the test should be monitored using high-speed photography or videography. The images thus provided may enable the engineer to evaluate how test-to-test variation might affect the numbers generated by the transducers (for example, if minimal differences in excursion might allow the dummy to contact some part of the vehicle interior).

3.2.2 TEST VEHICLE OR EQUIVALENT—The dynamic response of vehicles to a given impact can vary widely due to such factors as vehicle weight, structural design, body style, and engine size and location. These variations have significant effects on the performance of occupant restraining elements. Though it is not possible to test for all conceivable crash conditions, it is instructive to include the whole vehicle in the impact testing of a restraint system, or to use an adequately verified simulation of the complete vehicle, such as a sled buck with similar interior trim, subjected to a similar acceleration pulse. Exclusive of test devices and instrumentation, the vehicle should be tested at curb weight. It is also necessary to take into account any significant effects which optional equipment might have on the structural crush characteristics of the vehicle. (Adjustment for the weight of any equipment required for this reason is covered in 3.3.2.1.)

3.2.3 INSTRUMENTATION—Instrumentation appropriate for measuring accelerations, velocities, penetrations, distances, forces, and event timing is described in SAE J211 (OCT88). For correlation, acceleration data from the anthropomorphic test device should be recorded at 1000 Hz. However, to aid in the interpretation of results, it is recognized that some filtering of recorded data may be needed.

Complete high-speed video or photographic coverage is an integral part of a restraint system test program. It will frequently be advisable to remove a door or other section of the vehicle body to permit better photographic coverage, in which case struts should be employed as needed to make the structural integrity representative of the complete vehicle and to restore equivalent lateral restraint.

3.3 Test Preparation

3.3.1 INSTALLATION OF RESTRAINT SYSTEM COMPONENTS—Restraint system components should be installed, employed, and adjusted as they are intended to be used (in accordance with the manufacturer's recommendations).

Where seat belts of the types covered by SAE J114, J117, J140, J141, J339, and J800 form a part of the restraint system, belts should be adjusted to a pre-load of approximately 9 to 18 N (2 to 4 lb) per anchor. For manually adjustable shoulder belts, pre-load is obtained with a 76.2 mm (3 in) cube between the belt and the sternum, which is removed before the test is run. If a locking type retractor is present, the tension that results from the retractor's internal spring should be used for a pre-load tension setting. Belts and test devices should be jostled about during the tightening process so as to minimize the effects of friction on the pre-load reading.

3.3.2 INSTALLATION OF ANTHROPOMORPHIC TEST DEVICES

3.3.2.1 *Number of Occupants*—Occupant restraint conditions should be evaluated for each designated seating position. However, the dynamic response of a vehicle will vary with load and with the manner in which the load is restrained. In addition, a full complement of anthropomorphic test devices makes good photographic coverage quite difficult, and conditions of symmetry or previous experience may make it unnecessary to test all seating positions simultaneously.

With these and similar considerations in mind, the test vehicle should be loaded to 270 kg ± 25 kg (600 lb ± 50 lb) above curb weight including all test devices, instrumentation, optional equipment, and ballast for a vehicle with four, five, or six designated seating positions. This load should be reduced by 70 kg (150 lb) for vehicles with less than four seating positions and increased by 70 kg (150 lb) for vehicles with more than six seating positions.

3.3.2.2 *Occupant Placement*—With an anthropomorphic test device normally occupying the driver's position, consideration should be given to additional devices located at any appropriate seating position to evaluate restraint conditions and to bring into play any interaction between occupants. Adjustable seats and seatbacks should be at the seat position appropriate for the size dummy used. Tests at other seat adjustment positions should also be considered if engineering judgment determines or predicts that the seat position has a significant effect on the manner in which the occupant engages the restraints.

3.3.2.3 *Posture*—Details of the restraint system and vehicle being tested should be considered together with the vehicle manufacturer's instructions for proper use in order to select from the range of normal seating postures and positions those which appear to be most appropriate for evaluating the system. To the extent possible, the test results should then be examined to assure that the system has exhibited a sufficient margin of performance to cover other reasonable postures and positions.

In the absence of considerations specific to the particular vehicle and restraint system, the driver should be centered on the center of the steering wheel with the hands on the wheel rim at the horizontal centerline. Where the space provided for other outboard occupants is similar to the driver space, these dummies should be located approximately the same distance from the vehicle centerline as the driver. Test devices in center seats should be on the car centerline except that where the front seat foot well area is effectively divided into two compartments, both feet should be in the passenger's portion of the foot well. Passengers' arms should be placed on the lap with the hands overlapping.