THE APPLICATION OF AEROSPACE TECHNIQUES TO AUTOMOTIVE CRASH TEST INSTRUMENTATION

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Summary The ultimate proof test of compliance with government safety standards for automobile "passive" occupant crash protection is obtained by crashing a test vehicle, occupied by instrumented anthropometric test dummies, into a concrete barrier. Each test of this type costs a minimum of $10,000, and much more if the vehicle is a prototype. The data that are obtained from the test dummies during such tests are the proof of compliance with the government safety standards and, therefore, must be highly reliable. Many aerospace techniques, such as a Metrology Laboratory, Quality Control, and redundancy can be adapted and utilized to maximize the reliability of the barrier crash data. These techniques are described and some early results are summarized. The early results show a marked improvement in data reliability compared to previous tests.

Introduction The field of automotive crash testing is one of the latest beneficiaries of aerospace technology, both in some of the instrumentation hardware being used and in the test techniques described in this paper. Aerospace type instrumentation hardware has been of invaluable assistance in early development work on so-called "passive" occupant crash protection systems. These crash protection systems, employing so-called "air bags," will have to undergo a large amount of testing on high-g accelerators prior to being refined for incorporation into production vehicle designs. However, the ultimate proof test of their performance against the government's requirements is obtained by crashing a test vehicle, occupied by instrumented anthropometric dummies, head-on into a concrete barrier at 30 miles per hour.

The government standard (No. 208) specifies that the 30 mph front-end barrier crash is to be used to test for compliance to the government's so-called "injury criteria." The criteria require the measurement of head and chest accelerations and femur (upper leg) loads in instrumented dummies. The injury criteria portion of safety standard #208 has been suspended because of recent court decisions. However, test programs on passive restraint concepts continue to involve measurement of dummy accelerations and loads, because such restraint systems can be validated only by the barrier crash criteria.

Each 30 mph barrier test destroys the test vehicle, so there is no chance to repeat the test with the same vehicle in the event of an instrumentation failure. Even if a back-up vehicle is available, the test schedule is usually so tight that there is little time available for a retest. Loss of even one dummy data channel could mean a long delay in testing if another engineering prototype vehicle had to be constructed, or worse yet, it could delay the introduction of a new model. It is obvious that the instrumentation data must be as reliable as possible.

Reliability Improvement Program Historically, barrier crash testing at Ford had been geared to development tests, in which instrumentation data reliability was not a prime objective. Development tests, as used herein, mean those tests whose purpose is to obtain crash data on the vehicle itself or on the occupant crash protection systems, but not to measure ability to comply with governmental standards. Data channel failure rates for development tests were higher than the level that was considered acceptable for standards-related testing. An instrumentation reliability improvement program was developed, based on the use of selected aerospace techniques. The following basic aerospace techniques were adapted to the unique environment of crash barrier testing:

- Traceability of the test instrumentation calibrations to the National Bureau of Standards through use of a Metrology Lab.

- Restrictions on the use of critical hardware, limiting its use only to standards-related tests.

- Establishment of a Quality Control Program, tailored especially to the instrumentation requirements of these tests.

- Special systems-level end-to-end tests, including dry run crashes.

- The use of redundancy where possible.

- The development and use of very detailed test procedures to control each step in the test.

Barrier Instrumentation System Figure 1 is a block diagram of the Ford barrier instrumentation system that is presently used for these tests. Dummy head and chest acceleration, vehicle acceleration and femur loads are sensed by bridge-type transducers installed in the dummies and on the vehicle. Figure 2 is a photograph of an anthropometric dummy showing the transducer locations. Signals from the transducers are transmitted through 500-foot drag cables to signal conditioning equipment in the instrumentation van. After being conditioned, the signals are recorded on magnetic tape, both as wideband FM signals and as an FM multiplex, and also on an oscillograph. The peripheral instrumentation equipment includes two speed traps, a timing system and circuits to record the time of initial barrier contact.

Metrology Laboratory Although a Metrology Laboratory has been operated by Ford's Safety and Services Department for several years, its activities were reviewed for their effects on over-all instrumentation data reliability and compliance to Federal specifications. The Metrology Lab provides traceability of all instruments to the National Bureau of Standards. In the event of a government inquiry into data from the Ford crash test programs, such traceability would be invaluable in supporting the accuracy and credibility ofthe teat data.

In order to improve data reliability, the following changes were made in the Metrology Lab's operations:

- A set of formal, approved calibration procedures was written, superseding the less detailed informal procedures previously used.

- Calibration intervals for the transducers used for standards-related tests were shortened. All accelerometers and femur load cells were calibrated before each of these tests. The normal calibration interval had been 6 months for accelerometers and 3 months for load cells.

- The recall of instruments overdue for calibration was made mandatory for these tests. The use of an overdue instrument is permitted at the discretion of the site personnel for development tests, but for standards-related tests the use of overdue instruments is not allowed.

Limitations on Equipment Usage As in aerospace programs, documented control of critical hardware is an essential part of a reliability improvement program. Transducers and cables were selected as the most critical items in the barrier instrumentation system, and the required number were reserved for use only on critical tests. Ideally, the whole instrumentation system should have been tested and reserved for use only on these high reliability tests, but this was impractical because of the need to use this equipment for development tests. Closer physical control was maintained on the selected set of transducers and cables, and a better test history was developed. At the time the program originated, the selected transducers and cables were simply obtained from the normal inventory, but as the reliability requirements became more widely accepted, funds were allocated to procure new transducers and cables solely for restricted use. This was a major departure from past practice.

Quality Control Program Another major step in the improvement of data reliability was the establishment of an Instrumentation Quality Control Program, to be used for standards-related tests. This Quality Control Program, the essentials of which were adapted from aerospace programs, includes the physical control of critical hardware, visual inspections of hardware, particularly connectors and cables, and verification that all procedures are properly performed. This too was a major change from past practice, which had been to rely primarily on the ability and judgment of the engineers and technicians conducting the tests. Under the new program, quality control personnel perform the following tasks for standards-related tests:

- Maintain physical control of transducers and cables.
- Conduct visual inspections of transducers, connectors, cables and other instrumentation hardware.
- Review the transducer calibration data and the system set-up documents for correctness of entries.
- Verify that the instrumentation test procedure is correctly followed and provide an independent judgment in the event of problems.
- Maintain records to provide equipment traceability for each data channel.
- Document the problems that occur during the crash tests.

Systems Level Tests Each component in the crash barrier instrumentation system was selected so that the total system met the static and dynamic accuracy requirements of governing regulations, including SAE Recommended Practice J211, which is referenced in safety standard #208. However, just as aerospace programs rely heavily on systems tests to demonstrate over-all system compatibility and conformance to specifications, three systems level tests were initiated to demonstrate systems compliance. The first, called the Technical Compliance Tests, was a one-time end-to-end test to prove the static and dynamic accuracy of the system. The second, a systems frequency response test, is performed prior to every standards-related test. The third, a filter verification test, is performed just prior to computer processing the final crash data for a standards-related test.

The Technical Compliance Test was conducted at the Metrology Laboratory, with the instrumentation van and the cables and transducers that were to be used for standards-related tests. Known accelerations were applied to the accelerometers and known force loads to the load cells, using the laboratory’s vibration shaker and load test machine. The data was recorded on magnetic tape in the instrumentation van, then taken to the computer center where it was tabulated and plotted by the computer. The final computer output was compared with the known input that had been applied. The comparison accuracy for the single-point static accuracy test was well within the in-house limits of ± 3%. A frequency response test was made by applying a swept frequency to The amplifier signal input at the transducer. Other parts of the Technical Compliance Test included a check for noise, a DC linearity test, and an accelerometer mount resonance test. Each of these tests showed compliance with SAE J211.

The frequency response requirements of SAE J211 are considered to be among the most important requirements that the instrumentation system must meet. There are four different frequency response classes, 1000 Hz, 600 Hz, 180 Hz, and 60 Hz, each of which applies to a different type of data such as head accelerations, femur loads, etc. Figure 3 shows the limits for class 1000, which is used for dummy head accelerations. Note that the channel class designates the frequency range over which the response is essentially flat, not the -3dB point.

In order to assure that the frequency response requirements of SAE J211 are met, a frequency response test is conducted prior to each standards-related test, using the transducers, cables and signal conditioning that will be used for that specific test. The data from this test is reviewed for compliance to SAE J211 prior to the final set-up for the crash test, and a go/no go decision is made, based upon this review.

The third special test, the filter verification test, is also related to the frequency response requirements of SAE J211. This test, which is conducted at the computer center just prior to processing the final crash data, consists of computer processing a special frequency sweep for each data channel. This data is also examined for compliance with J211 frequency response and is intended to give positive proof that the computer center's analog filters were set properly for each channel.

Redundancy The use of redundancy wherever possible was also judged to be necessary to obtain significant reliability improvement. Through past experience it was determined that the most probable failures would occur in the drag cables or tape recorders. Using redundant drag cables was impractical, but redundant recorders and recording techniques were feasible. Figure I shows these redundant recorders as presently implemented. one recorder records all data channels by means of three FM multiplexes, recorded on three tape tracks. The other two tape machines record each channel individually using wideband FM. An oscillograph is used as another backup recorder and for quick-look purposes.

Redundancy is used on two other parts of the barrier instrumentation system, the speed traps and camera timing. Two speed traps are used, with each one connected to a separate electronic counter. The camera timing system furnishes two different timing signals to each camera, IRIG-A time code and 1000 pps. Either one could be used for time correlation of all cameras.

Detailed Test Procedures The instrumentation test procedures used for development type crash testing were very brief, checklist documents, which placed a heavy emphasis on the individual technician's ability to remember and perform all necessary tasks. An aerospace type procedure was judged to be the only way all the required set-up steps could be accomplished reliably and consistently. This test procedure, which includes all instrumentation activities from dummy preparation to post-crash data verification, is presently a fifty-page document. It is written in an easy-to-follow checklist type format and contains space for technician and Quality Control sign-off. Except for critical steps, it does not tell specifically how to do each step, but is written in sufficient detail so that each required step is called out. Figure 4 shows a page from this procedure. The completed copy of the procedure for each test is kept on file as a permanent test record.

Special test countdown was also developed, with the intention of smoothing the test flow and providing a quick means of telling the status of testing. The countdown starts on the day scheduled for the crash. It calls out the start and finishing time of the major test steps, particularly those which delay another step if not completed on time. The countdown differs from many aerospace countdowns in that the estimated crash time is arbitrary. A hold simply means that the crash might be delayed, not scrubbed.

Dry Run Crash Tests Three dry run crash tests were conducted to exercise the entire instrumentation system and to prove the workability of the procedures. All the special preparations previously described were used for these dry runs, for which a development test car was prepared and crashed. A selected team of engineers and technicians was used, so that the dry runs could be part of their training for "live" standards-related tests. These dry runs proved to be invaluable in detecting problem areas, in finalizing the test procedure and in training personnel.

Summary of Results The reliability improvement program was put into effect on a limited basis for standards-related tests in March 1973. The results from the first eight such tests show a noticeable improvement in data reliability compared to past history. These results, based on eight tests and 184 channels, are summarized below together with the results of a 1972 dummy data study. There is a noticeable reliability improvement, although the statistical data base is small. The improvement is the most marked for the dummy data channels.

DATA CHANNEL QUALITY DISTRIBUTION

	1972 Dummy Data	Standards-Related Tests Dummy Data	All Data
Number of Channels Recorded	1,476	128	184
Class 1 (No Anomalies)	73.9%	96.9%	82.6%
Class 2 (Anomalies But Usable)	21.0%	2.3%	16.3%
Class 3 (Not Usable)	5.1%	0.87	1.1%

In addition to increasing the reliability of standards-related test data, this program has produced important improvements which were applied to development tests. The improvement of cables and the instrumentation grounding system are two of the more tangible results. Other results, such as a general smoothing of development test operations, are less tangible, but still evident.

The results of the reliability improvement program show that aerospace techniques can be successfully adapted and used on automotive crash tests where high reliability data is required. Although these tests are more mundane than a trip to the moon, they affect each of us much more directly, and so deserve the same consideration as our recent trips to the moon.

Acknowledgement The author wishes to acknowledge the efforts of his associates in the Safety and Services Department of Ford Motor Company, who developed and implemented the reliability improvement program, thereby making this paper possible.

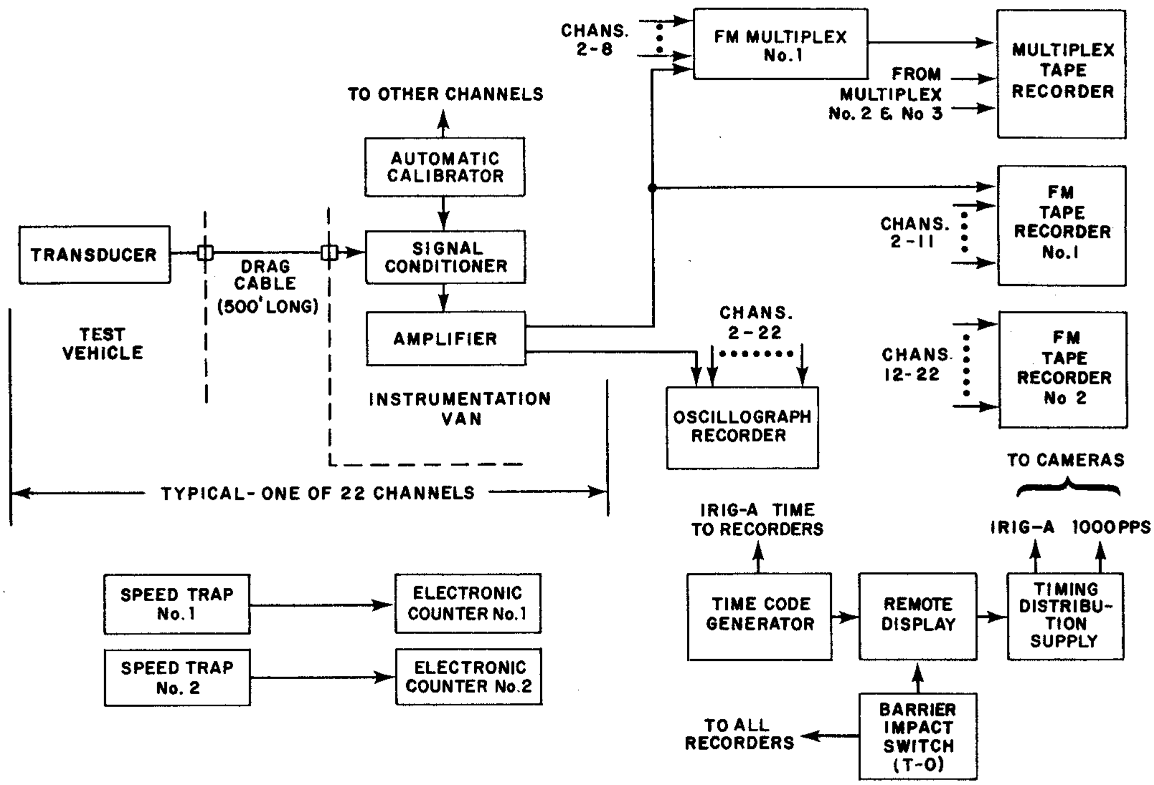

Figure 1. Block Diagram - Barrier Instrumentation System

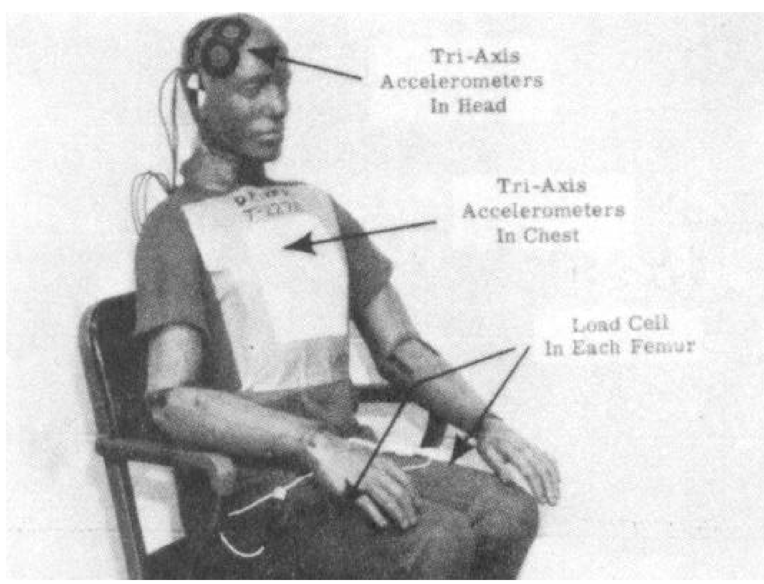

Figure 2. Anthropometric Dummy Showing Transducer Locations

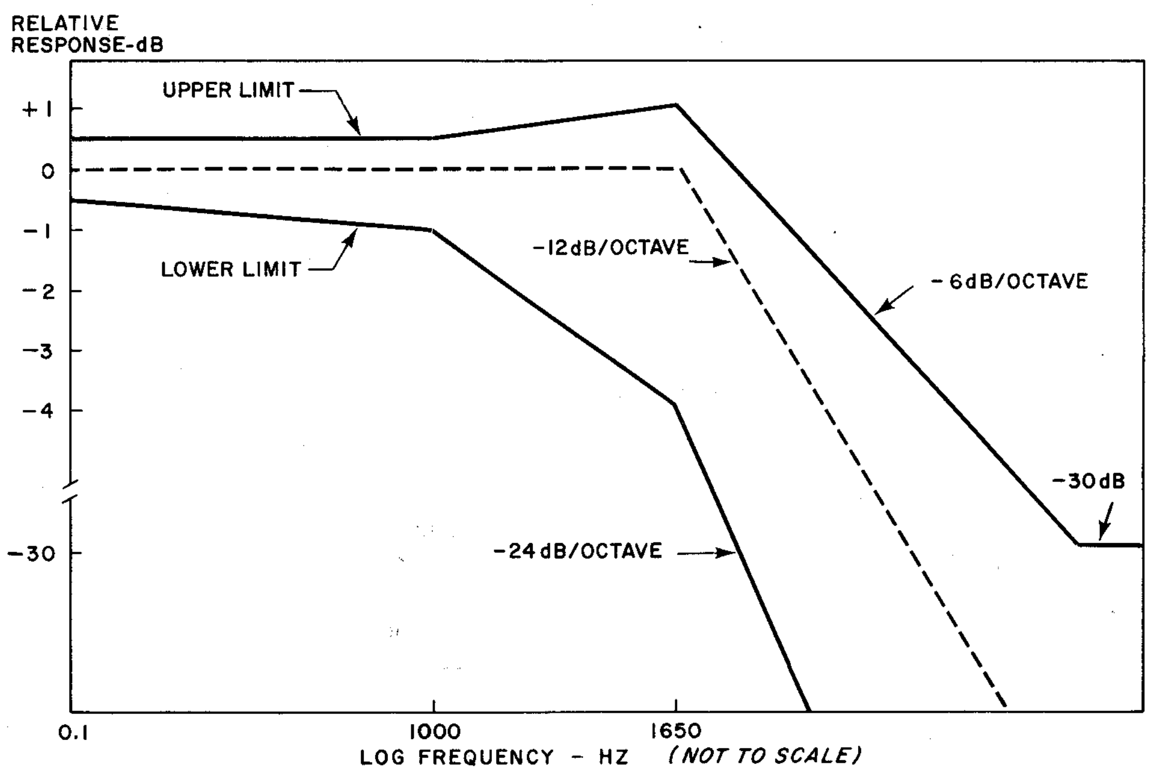

Figure 3. Frequency Response Limits - Class 1000 Channel

Step No.	Procedure	Initials: Tech	QC	Time
	4.3.3 Signal Conditioner Setup			
4.3.3.1	PRELIMINARY EXCITATION SETTING: Set excitation on all channels to about 10 volts.			
4.3.3.2	BANDWIDTH: Set bandwidth on all amplifiers to 100 KHz.			
4.3.3.3	CALIBRATION CARDS: Check piggyback cards for proper values using table 4.3.3-1 below and setup sheet Safety Instr. Van			

CARD	STEP #1	STEP #2	STEP #3	STEP #4
A	80K	40K	20K	10K
B	160K	80K	40K	20K
C	320K	160K	80K	40K
D	640K	320K	160K	80K
E	1.28M	640K	320K	160K
F	2.56M	1.28M	640K	320K
G	OPEN	2.56M	1.28M	640K

Table 4.3.3-1

Step No.	Procedure	Tech	QC	Time
4.3.3.4	WARMUP: Verify at least 30 minutes for system and transducers to warm up.			
4.3.3.5	FINAL EXCITATION VOLTAGE SETTING: Adjust the excitation voltage for all channels being used to 10 ± 0.01 volts.			
4.3.3.6	BALANCE: Balance the output of all signal conditioners to within ±.1 mv of zero.			
4.3.3.7	SENSITIVITY AND POLARITY: Apply cal step 4 and verify that the mv output of all conditioners corresponds to mv sensitivity listed on the QC calibration sheets. Verify correct output polarity, all trnsducers are +.			
4.3.3.8	AMPLIFIER ZERO: With amplifier gain set to 1K, apply a short to the input of the channel 1 amplifier, by removing the input patch jack, and adjust the amplifier output to 0 ± 10 mv.			
4.3.3.9	CAL STEP 4 ADJUST: Remove the short, patch in the signal conditioner, apply cal step 4 and adjust the output of the amplifier to ±20 mv of the voltage found on setup sheet Safety Instr. Van.			
4.3.3.10	RECHECK AMPLIFIER ZERO: Reset the calibrator and again short the input to the amplifier and zero the output to within ±10 mv of zero or better.			
4.3.3.11	FINAL AMPLIFIER ZERO: Again patch in the signal conditioner and balance the amplifier output to within ±10 mv of zero, with the signal conditioner bal. pot.			

Figure 4. Sample Page of Instrumentation Test Procedure