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Evaluating Low-Speed Rear-End Impact Severity and Resultant Occupant Stress Parameters

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ABSTRACT: Automotive Systems Analysis, Inc. (ASA) and Lowell Hicks, Inc. (LHI) have developed a ground-up set of sensor instrumentation and recording method to document vehicle-artifact/occupant-stress parameters occurring from a continuing series of low-speed rear-end multi-vehicle impact tests (≈ 2 to 8 MPH). This work has four goal areas: 1) calculate impacted vehicle (TARGET) barrier equivalent velocity (BEV) from isolator Artifacts; 2) correlate calculated BEV' to occupant stress; 3) calibrate injury potential of occupant stress impulse; 4) compare occupant stress with everyday volunteer activities.

The test collision series now includes several different vehicle pairs with varying impact/escape speeds, weight ratios, and parallel parameters from a driver side manikin and passenger side volunteer.

Observable physical vehicle isolator artifacts (piston stroke scrapes) were compared with computer-recorded linear sensor time traces, and these data were fitted to a 'calculated BEV' worksheet/algorithm. The worksheet/algorithm method shown here was found to be reasonably repeatable, per vehicle model and series tested.

Next, manikin and volunteer occupant stress data, measured along with TARGET vehicle BEVs, were charted and compared with injury-threshold-impulse criteria referenced in the literature.

Lastly, the occupant-stress impulses were compared with sample stress impulses for various volunteer physical activities, as a practical calibration of vehicle occupant stress.

KEYWORDS: engineering, low-speed impacts, rear-end impacts, lower back pain, cervical strain, whiplash

Nomenclature

GLOSSARY OF TERMS USED IN ASA LS-IMPACT TESTS

Acronym	Description	Units
ACHn	Analog Data Channel #n Part of Data Acquisition Data Word	

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BULLET	Impacting Vehicle	
BULFPDX	Bullet Left Front Piston Displacement—X	cm
BURFPDX	Bullet Right Front Piston Displacement—X	cm
BU_MPH	Bullet Veh Velocity	MPH
BEV	Barrier Equivalent Velocity	MPH
	Equivalent of hard infinite-weight barrier impacting vehicle	<KPH>
	{also called Equiv Barrier Speed (EBS) Barrier Equiv Speed (BES)	
cm	Unit of Distance Measure	Centimeters
CTRX	Cervical-Thoracic Rotation, X Axis	Degrees
CTAX	Cervical-Thoracic Acceleration, X Axis	Gs
CTAY	Cervical-Thoracic Acceleration, Y Axis	Gs
CTAZ	Cervical-Thoracic Acceleration, Z Axis	Gs
G	Acceleration of Gravity 32.2 ft/sec/sec	
HDAX	Head Acceleration, X axis	Gs
HDAY	Head Acceleration, Y Axis	Gs
HDAZ	Head Acceleration, Z Axis	Gs
in	Unit of Distance Measure	inches
KPH	Unit of Velocity Measure	Kilometers per hour
LBF	Pounds Force	Pounds
LSAX	Lumbar-Sacral Acceleration, X Axis	Gs
LSAY	Lumbar-Sacral Acceleration, Y Axis	Gs
LSAZ	Lumbar-Sacral Acceleration, Z Axis	Gs
LSFZ	Lumbar-Sacral Axial Force, Z Axis	LBF
LSFZalt	Lumbar-Sacral Axial Force, Z Axis Achieved with seat bottom sensor under manikin/volunteer	LBF
mm	Unit of Distance Measure	millimeters
MPH	Unit of Velocity Measure	miles per hour
TARGET	Impacted Vehicle	
TGAX	Target Veh Acceleration, X Axis	Gs
TGAY	Target Veh Acceleration, Y Axis	Gs
TGAZ	Target Veh Acceleration, Z Axis	Gs
TG_CUMFT	Target Veh Cumulative Feet Roll	Feet
TG_MPH	Target Veh Velocity	MPH
TGLRPDX	Target Left Rear Piston Displacement—X	cm
TGRRPDX	Target Right Rear Piston Displacement—X	cm
sec	Unit of Time	second
SMPL	Sample = Data Acquisition Data Word Usually 20 Channel Values @ indicated time period	
VSS	Vehicle Speed Sensor LR = Left Rear, RF = Right Front, etc.	

Background

Lowell Hicks, Inc., (LHI) has been conducting reconstruction analysis for approximately 35 years. In 1992, LHI started receiving numerous requests for analysis of low-speed multi-vehicle rear-end impacts with seemingly little vehicle damage, and seemingly implausible claims of lumbar, cervical or head injury. LHI has documented vehicle artifacts and data from more than 100 of these cases since that time.

In September 1992, LHI asked ASA to see if a standard form of data and analysis could be found, or collected, to help evaluate, these injury claims with respect to the artifacts from the related low-speed rear-end collisions. Most of these collisions were barely able to mark, or only partially stroke, the target vehicle bumper and/or its isolator systems.

Tests of low-speed multi-vehicle rear-end collisions extend back to early work by Severy et al. in the mid-1950's [*1*]. Among the references:

some identify BULLET vehicle speed before impact, and TARGET exit speed, but not isolator stroke nor TARGET rollout after impact;

some identify BULLET speed and TARGET isolator stroke but not TARGET exit speed nor occupant stress; and

some identify TARGET speed impacts with fixed object, and corresponding cost-to-repair, but not isolator stroke nor occupant stress.

It seemed difficult, using commonly available technology and literature, to correlate TARGET isolator artifacts to TARGET exit speed, to corresponding TARGET rollout, and to a corresponding occupant stress impulse (Σ accel × time, etc.).

Test Plan and Methodology

It was decided to proceed to collect this data ourselves, and that only actual real-time data from multi-vehicle rear-end impact test runs would be used in this study. The vehicle pair impacts consisted of a BULLET (BU), released to free-roll down a gravity ramp, into a stationary TARGET (TG) (Neutral gear, brakes off). Ascending collision speeds [≈ 2, 4, 6, 8, MPH] were incorporated to characterize the particular isolator pairs, with vehicles generally conforming to the 2 ½ MPH or 5 MPH bumper impact protection standard CFR 49.581 [*2*].

The impact magnitude reference was chosen to be barrier equivalent velocity (BEV) imparted to the TG, since this represents the result of the impact impulse (Σ force × time), whether obtained as the result of another vehicle front isolator system, or an infinite mass barrier imparting the energy (classic definition). The use of TG BEV allows direct comparison of ASA data to literature references where TG BEV is identified.

In these tests, both BU and TG velocities were continuously recorded before impact, and through full (unpowered) TG rollout. TG accelerations, isolator deformations, occupant stress parameters were recorded for approximately 1 s after the BU tripped an advance synchronizer wand (approximately 2 ft). This allowed data observation of the very first contact and piston stroke, and is important because occupant stress is related to the 'impulse' value of certain parameters (Σ force/accel × time), not just the peak value.

The data were captured on proprietary twin data acquisition systems; low speed (LS ≈ 9 sample-words/s) for continuous pre/post impact BU/TG velocities, and high speed (HS ≈ 1000 sample-words/s) for all stress and displacement parameters. Each HS sample-word contains 21 parameters (acceleration, force, displacement, etc.). The systems were synchronized and connected to the test vehicles, manikins and volunteers via HS and LS umbilicals. Data were appropriately filtered, recorded and then charted, with annotation, using Harvard Graphics^R.

Tri-axial accelerometers were rigidly affixed to the TG front center floorboard, and volunteers were fitted with sensors on waist, chest, shoulder and head harnesses. TG (and sometimes BU) isolators were fitted with linear potentiometers to record real time displacements. Both BU and TG bumpers were fitted with conductive foil contacts to record vehicle contact.

Figure 1 shows a high level layout schematic of the HS and LS systems and their vehicle umbilicals. Figure 2 shows the placement of sensors, by acronym, on vehicles, manikin and volunteers.

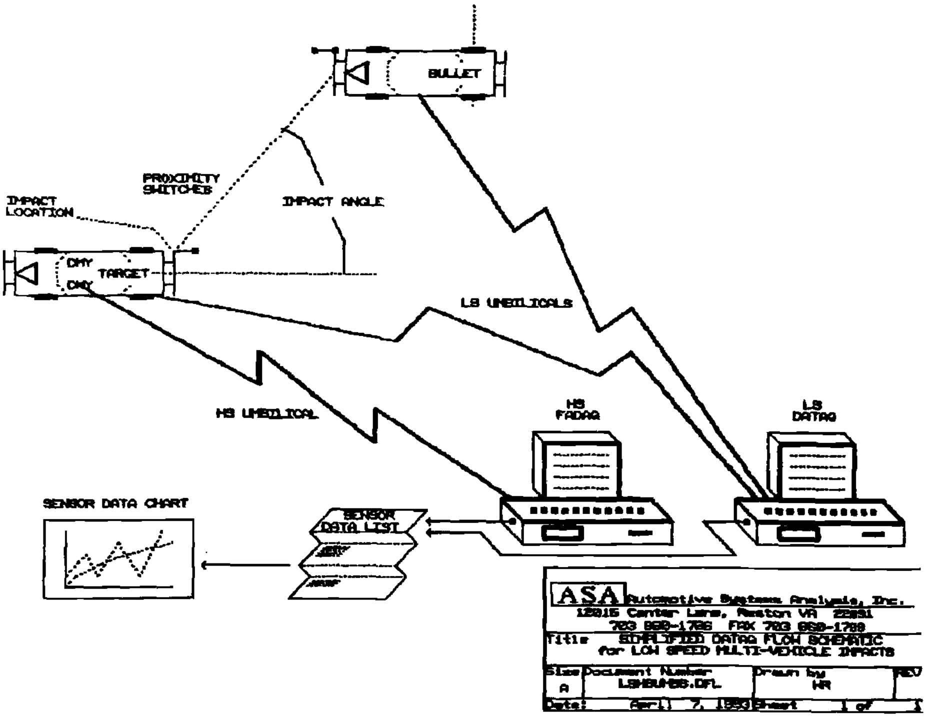


FIG. 1—*Simplified DATAQ flow schematic for low speed multi impacts.*

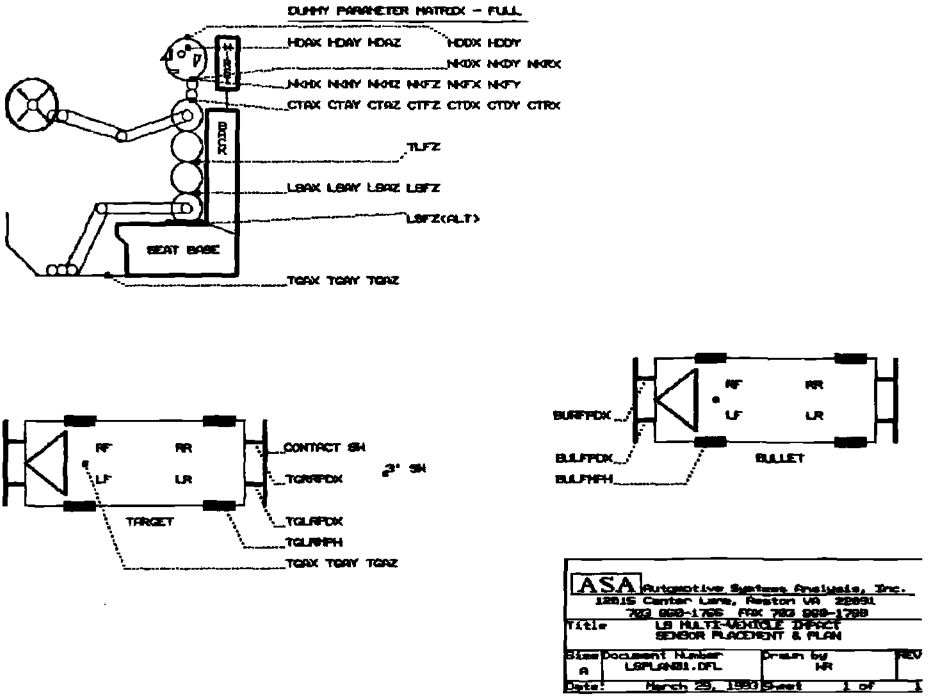


FIG. 2—*LS multi-vehicle impact sensor placement and plan.*

FIG. 3—*Bullet and target vehicles with instrumentation and umbilicals.*

Figures 3, 4, 5 are photographs of the vehicle sensors in typical installations, and Fig. 6, 7, 8 are photographs of manikin/volunteer sensors in typical installations.

Aside from reasonably standard accelerometers and linear axis potentiometers, two unique sensors were fabricated.

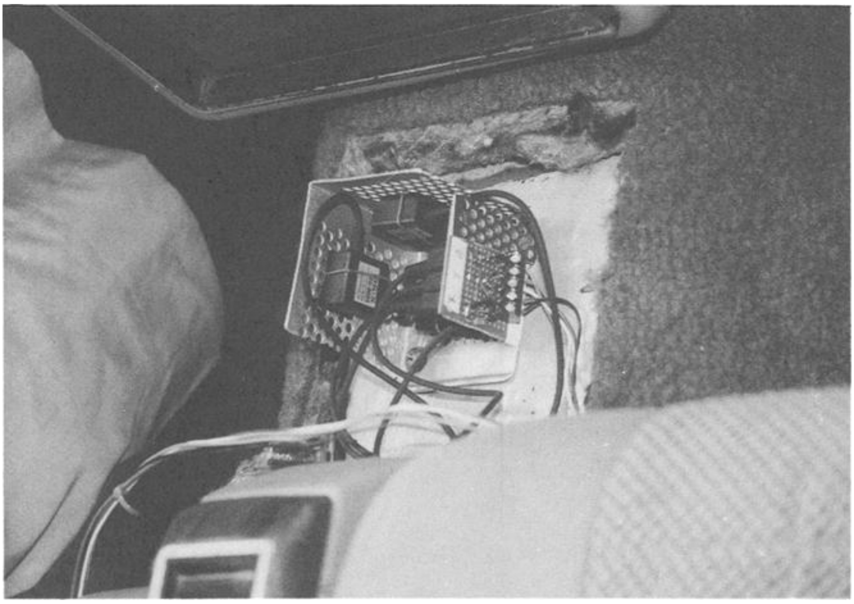


FIG. 4—*Floorpan mounted tri-axial target vehicle accelerometers.*

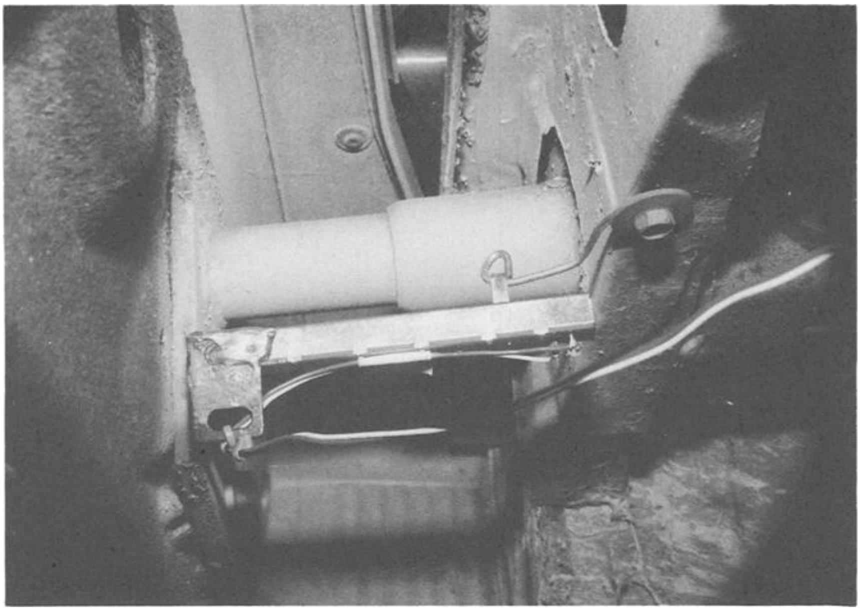


FIG. 5—*Typical piston isolator displacement sensor.*

Neck flexion/extension angle was recorded by a linear rotary position sensor affixed to the manikin/volunteer right shoulder. This parameter, CTRX, represents the angular deflection of the head vs the torso in degrees, in real time. Figure 7 shows this sensor on a volunteer L. H.

Lumbar-sacral (inferior/superior) weight variation on the seat bottom was recorded by a platform sensor, embedded into the seat bottom cushion. This parameter, LSFZalt, represents the weight variance in pounds force, on the seat bottom, in real time. Figures 8, 9, 10 show this sensor and typical installations.

Test Activities

To date a series of six vehicle pairs and two volunteer activities have been recorded.

Test Date	Test Series ID	Vehicle Pair		Manikin/Volunteer
930325	LS001 BU 80	Rabbit	⇒ TG 82 Accord	ASA-SAE J944/M
930331	LS002 BU 82	Accord	⇒ TG 80 Rabbit	ASA-SAE J944/M
930623	LS003 TG 83	LTD	⇒ TG 81 Citation	Alderson C95/M
930705	DW001 TG 83	LTD	⇒ TG ASA Sled	ASA-SAE J944/M
930715	LS004 BU 81	Citation	⇒ TG 83 LTD	Alderson C95/M
930807	LS005 BU 83	LTD	⇒ TG 80 Rabbit	Alderson C95/M Volunteer LH Volunteer JJR
930918	LS006	Parking Lot Speed Bump & Curb Drop Tests	87 Toyota P/U	Volunteer LH

Goal 1: Calculating BEV from Isolator Artifacts

Approach—The Goal 1 objective was to develop a dependable way to correlate real time isolator artifacts to BEVs. From our test runs, known BEV/Isolator data was then tabulated

FIG. 6—*Side by side volunteer and manikin instrumentation.*

and fitted to an empirical algorithm/worksheet. On each worksheet we evaluated our 'calculated BEV' versus the known (recorded) BU→TG impact exit velocity. This 'prediction variance' was the % difference between our calculated BEV and the known (recorded) BEV.

Data Examples—Table 1 summarizes and identifies BEV and isolator stroke data for our test runs. It also shows that manufacturer-dependent thresholds and safety margins must be determined individually, unless one uses factors more conservative than all examples.

Table 1 also identifies the test runs and associated data, showing worksheet calculations, TG BEVs (LS data), TG isolator strokes and TGAXs (HS data). Representative data charts and worksheets (shown by a * before the data line) are included here, but all data charts and worksheets are available from the authors.

Figure 11 is an example photograph of a 2.3 cm isolator stroke artifact from Test #005D, corresponding to the dynamic isolator stroke data of data chart HS005D1 (and used in worksheet 80RBBT35).

FIG. 7—*CTRX sensor.*

We also determined the 'stroke threshold' parameter for the vehicle having the most impacts, the 1980 VW Rabbit. Figure 12 (Chart PDX80RBT), tabulating the result of six Rabbit rear impacts, shows the isolator stroke threshold to be approx 0.8 MPH, and that, within the isolator range, the total stroke is linearly proportional to TG BEV (MPH). The 0.8 MPH threshold value was used in the 80RBBT.. algorithm/worksheet examples.

Figure 12 also shows that a frame TGAX less than 0.8G, can result without observable isolator stroke.

Calculation Method—In our algorithm/worksheets, the observed (and data recorded) L & R piston stroke was compared with the max piston stroke to determine an aggregate actuation ratio (over both pistons).

The FMVSS CFR 49.581 [2] base requirement (per model years) was then adjusted for engineering safety factor, and stroke threshold. This determined a net dynamic capability.

The net dynamic capability × the actuation ratio then determined the dynamic actuation product.

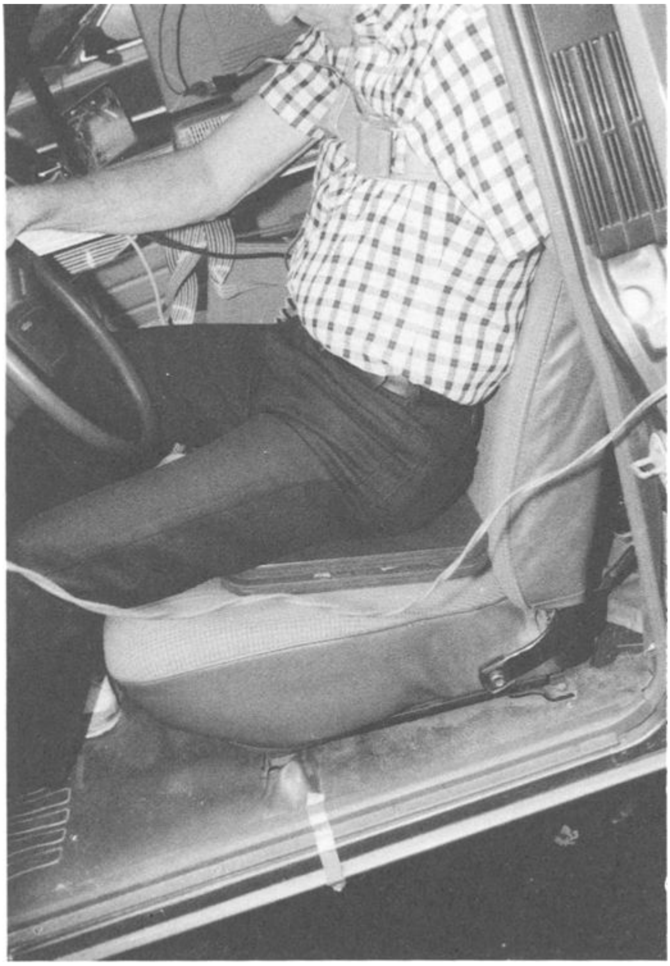


FIG. 8—*LSFZ force sensor.*

The dynamic actuation product, added to the stroke threshold becomes the 'calculated BEV'.

This 'calculated BEV' was then compared with the measured BEV to determine a prediction variance. Table 1 summarizes these comparisons. It can be seen that the tracking, per make and model in our tests, is very acceptable. It also shows that manufacturer-dependent thresholds and safety margins must be determined individually, unless one uses factors more conservative than all examples.

Goal 2: Correlating 'Calculated BEV' to Occupant Stress Parameters

Several low-speed-impact references [*3–7*] show real time vehicle frame stress parameters [Gs}] correlated to real time manikin occupant stress parameters, and their associated phasing, attenuation and amplification factors. We recorded and compared our data with these references, where appropriate BEVs could be determined. This was valuable as a consummate check on the integrity and calibration of our sensors and data system, and to confirm special artifacts such as chassis-ringing (the 'gong effect') and variously observed

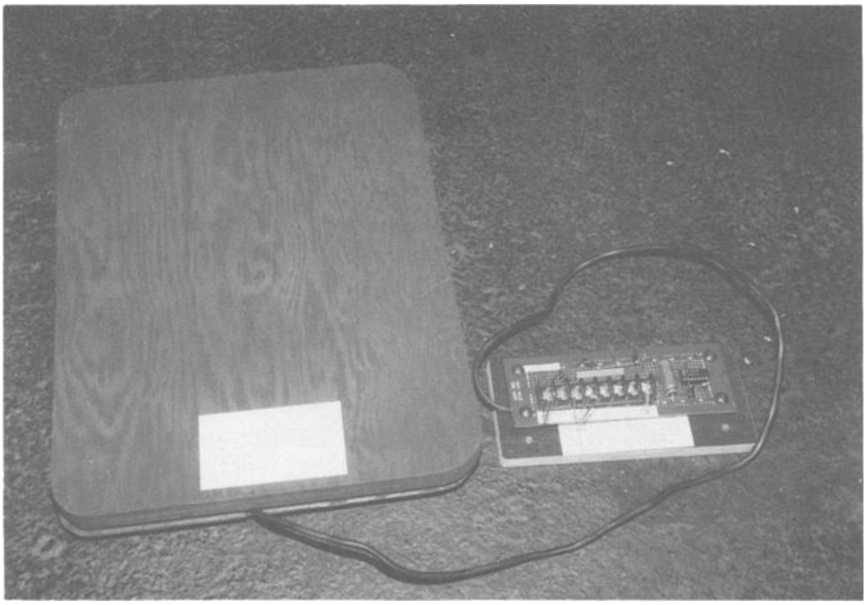


FIG. 9—*LSFZ sensor and signal conditioning circuit.*

occupant stress amplification (HDAX >> CTAX >> LSAX/TGAX). Our results were in conformance with the usable references, and confirmed the calibration of our sensors and data system.

An example of chassis ringing ('gong effect') and appropriate filtering is shown in Figure 13.

An example of comparative G-Amplifications, occurring in two actual rear-end impacts (#5005D - Vol LH & #5005E - Vol JJR), is shown in Figures 14A, 14B & 14C. Further documentation is shown in Table 2. The reader should note that G-Amplification in rear end impacts was first noted by Severy in the mid 1950s [*1*].

Because most references use peak LBF & G values as a measure of stress, for the sake of comparison, we also tabulated these items.

However, true occupant stress is measured by the 'impulse value' of such parameters. References [*8–13*] confirm that various 'injury thresholds' occur when the time summation of a force *x* time product exceeds an identified threshold value. As an example of the evaluation of the injury potential of one particular test stress data, we used a measured head acceleration pulse (Fig. 15A), calculated the neck shear stress accruing from that acceleration pulse (Fig. 15B) and overlayed that data on an accepted neck shear injury-threshold reference (Fig. 15C).

Additionally, it has been suggested that certain soft tissue injuries are related to extension/compression rates and cycles, rather than simple stress magnitudes. Because of this, and because low-speed injury allegations typically involve soft tissue complaints, not discernable with X-rays etc., we instrumented and recorded CTRX and LSFZ, two parameters thought to be meaningful to lower-back and neck complaints. Figure 16 compares CTRX for the manikin vs volunteer LH in test run #005C. Figure 17 compares LSFZ for the manikin vs volunteer in test run #005D.

Table 2 presents a summary of various stress parameters experienced by both manikin and volunteers in several ASA test runs.

FIG. 10—*LSFZ sensor embedded in 1980 Rabbit seat.*

Table 2 and previous data chart examples, show various peak G values, however, the effective G-impulse value is not intuitively apparent.

Figure 18 displays three superimposed TGAX data traces (Test Runs #005D, 005E & 005F) and shows the calculated equivalent impulse for each run. Data box windows then compare peak vs average vs impulse values for each run. The impulse value has units of G-seconds (Σ accel 3 time). The G-impulse and/or the force-impulse values are the most appropriate parameters to use when comparing impact injury potential to established injury envelopes.

It must be noted that the peak to impulse correlation is strong in this example because the same vehicle pairs were used in all tests. Different vehicles would likely produce more varied waveforms and thus lesser correlations.

Goal 3: Assessing The Injury Potential of Occupant Stress Impulses

The primary purpose of collecting the Goal 1 and Goal 2 data was to calibrate the likely occupant stress exposure resulting from similar low-speed impacts. A corollary use of Goal 2 data was the evaluation of volunteer reactions to their exposures.

TABLE 1—*Summary of 'calculated BEVs' and prediction measures.*

				Assumptions		Isolator					Reference Figures		
Figs Incl	Test Date	Test Series	Target Vehicle	Isol Thresh MPH	Mfr Safety Margin	L + R Max cm	Stroke Meas cm	Calc BEV MPH	Meas BEV MPH	Calc Predictn Variance	Test BEV MPH	Test Displ mm	Calc BEV Worksht
	930325	LS001B	TG 82 Accord	1.00	100%	11.0	2.77	3.27	3.23	+0.8%	LS001B	HS001B1	82ACRD32
*	930325	LS001E	TG 82 Accord	1.00	100%	11.0	5.24	5.29	5.23	+1.1%	LS001E	HS001E1	82ACRD51
	930623	LS003C	TG 81 Citation	0.80	90%	29.0	7.52	3.06	2.68	+14.0%	LS003C	HS003C1	81CITN27
	930623	LS003D	TG 81 Citation	0.80	90%	29.0	8.89	3.47	3.97	−12.7%	LS003D	HS003D1	81CITN39
	930807	LS005A	TG 80 Rabbit	0.80	40%	12.0	2.37	2.02	2.05	−1.2%	LS005A	HS005A1	80RBBT20
*	930807	LS005C	TG 80 Rabbit	0.80	40%	12.0	7.60	4.73	4.84	−2.3%	LS005C	HS005C1	80RBBT48
*	930807	LS005D	TG 80 Rabbit	0.80	40%	12.0	5.79	3.79	3.54	+7.1%	LS005D	HS005D1	80RBBT35
*	930807	LS005E	TG 80 Rabbit	0.80	40%	12.0	5.76	3.78	3.82	−1.2%	LS005E	HS005E1	80RBBT38
	930807	LS005F	TG 80 Rabbit	0.80	40%	12.0	3.08	2.39	2.70	−11.4%	LS005F	HS005F1	80RBBT27

NOTE: Representative test run data charts and worksheets (shown by a * before the data line) are included here, but all data charts and worksheets are available from the authors.

FIG. 11—*23 mm stroke artifact from test run #005D.*

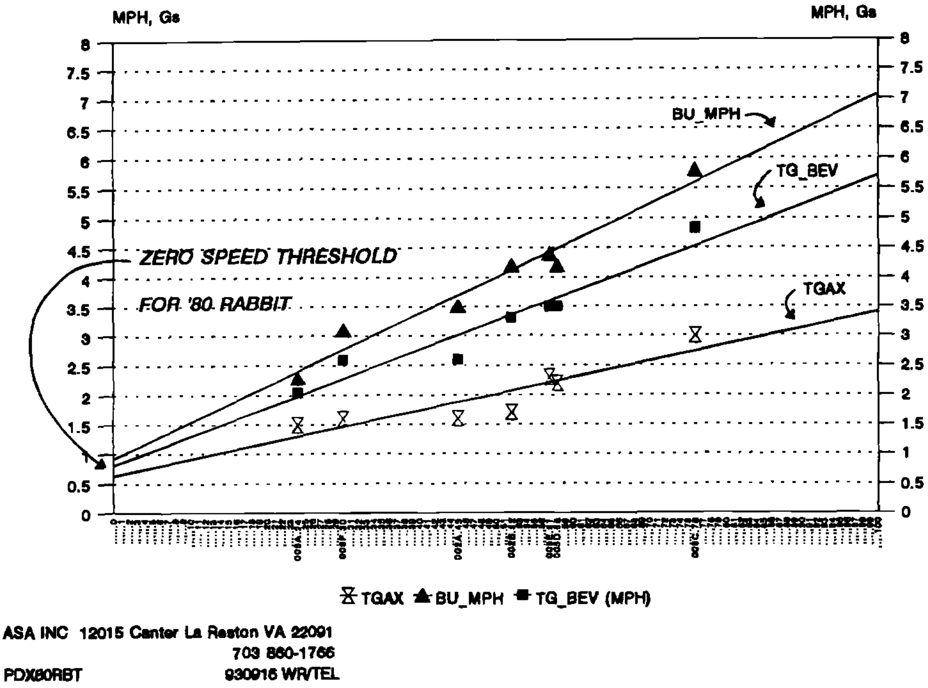
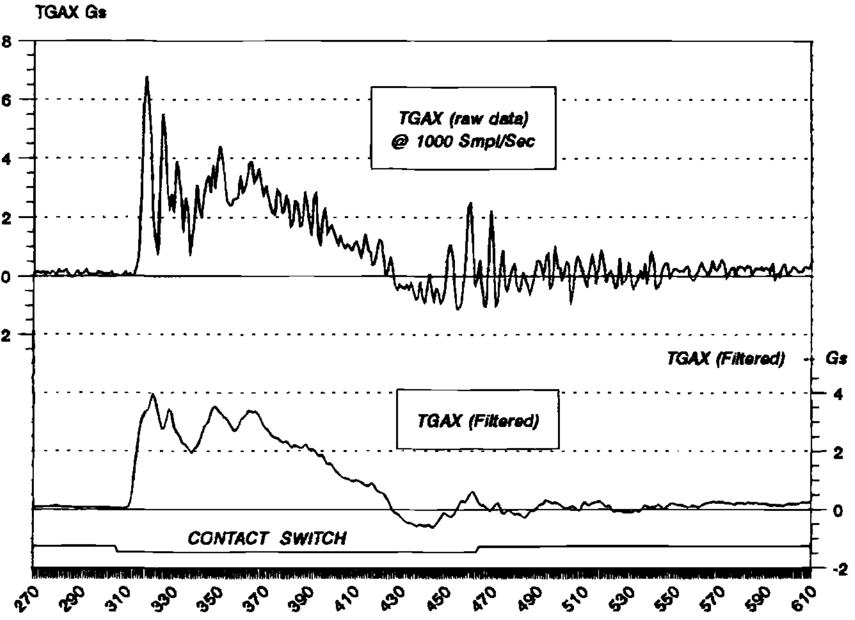


FIG. 12—*80 Rabbit total isolator displacement (LR + RR mm) vs TG BEV by test run.*



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0.0009978 Sec/Smpl 1002.135 Smpl/Sec 703 860-1766
93-HS005CTC 931101 TEL

FIG. 13—*TGAX, raw data w/chassis ringing vs filtered data.*

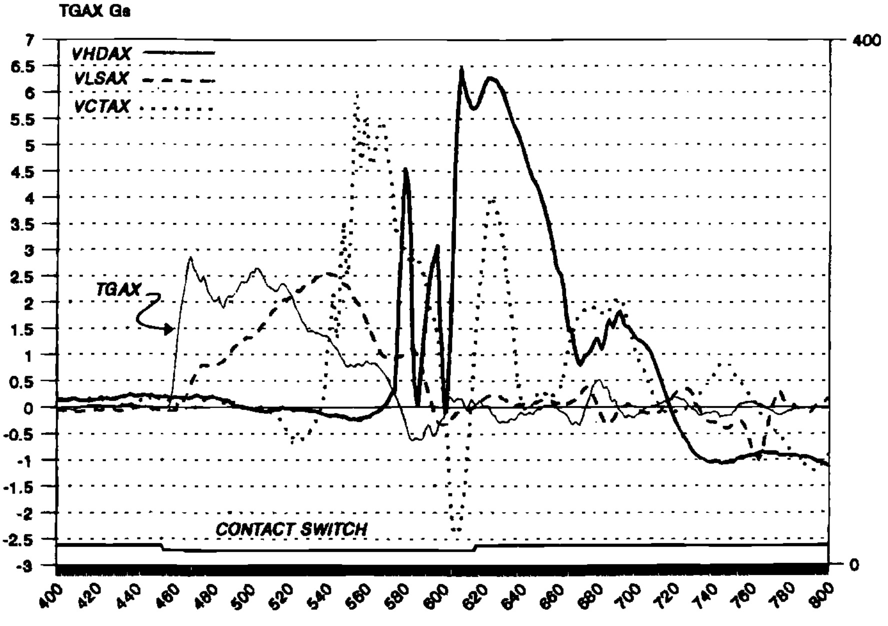

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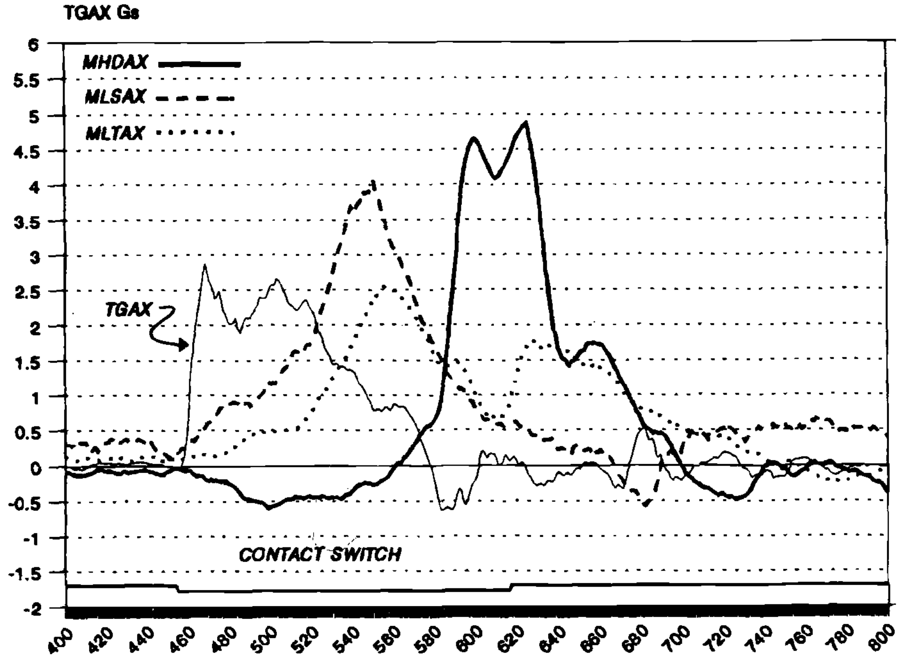
FIG. 14a—*Example of G-amplification, Run E, volunteer JJR.*



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93-HS5EMANX 931022 WR/TEL

FIG. 14b—*Example of G-amplification, Run E, manikin.*

Corollary Goal 2 data, Goal 4 data, and the balance of the biomechanical references, form the basis of evaluating whether the likely occupant stress was below/at/above various referenced and understood injury thresholds.

Almost all injury threshold criteria are defined in terms of the impulse value of a force, moment or acceleration [Σ stress-parameter × time]. So, the only meaningful use of a peak value, as shown in the tables, occurs when the peak value is less than the long-duration minimum stress-parameter value (and thus all possible stress is below all injury potential).

Examples of such impulse thresholds and injury criteria are shown in Mertz [*11*], Lau [*8*] and Melvin [*13*].

Figure 15C provides an example of how a measured ASA test data impulse is compared to a reference injury threshold (Mertz [*11*], neck shear force injury envelope).

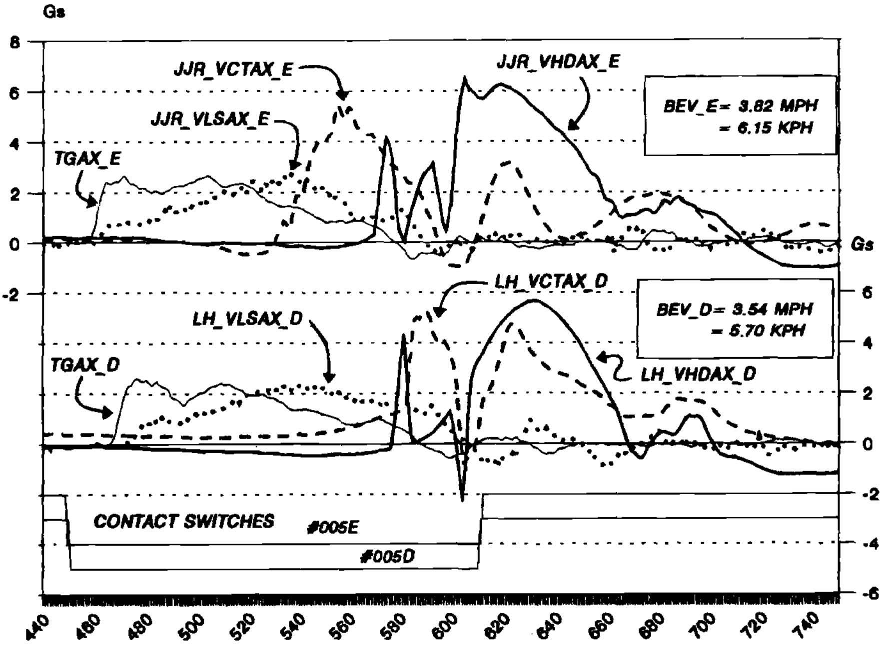
Additional validation of permissible stress was obtained from ASA test volunteers, subjected to multiple test exposures, who reported no discernable lingering physical effect due to repeated stress exposures, up through 4.8 MPH <7.8 KPH> BEV. The volunteers were polled post-event, +2 hours, +12 hours and +24 hours.

Lastly, several volunteer common-activities, causing no discernable lingering physical effect due to repeated exposures were recorded.

These volunteer common-activities are documented in Figs. 19 through 24.

Figure 19 shows a 7-year-old female volunteer skipped rope to generate the triaxial head acceleration data in Fig. 20. This is contrasted with a 28-year-old female volunteer who skipped rope to generate the triaxial data in Fig. 21.

Figure 22 shows a 1987 Toyota pickup truck during to parking lot speed bump and curb drop-off tests. The data synchronizer wand can be seen in the foreground at the driver side



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.0010014 Sec/Smpl 998.581 Smpl/Sec 703 860-1766
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FIG. 14c—*Example of G-amplification comparing vol. LH, Run D, and vol. JJR, Run D.*

of the truck. Comparative vehicle vs volunteer data from a speed bump test is shown in Fig. 23, and comparative vehicle vs volunteer data for a curb drop-off test is shown in Fig. 24.

Table 3 summarizes key parameters from these volunteer common-activities.

The volunteer common-activity data can be used as part of a set of quantitative comparison standards for assessing the occupant stress and injury likelihood for actual case investigations.

Additional validation of permissible stress was obtained from ASA test volunteers, subjected to multiple test exposures, who reported no discernable lingering physical effect due to repeated stress exposures, up through 4.8 MPH <7.8 KPH> BEV.

Lastly, several common volunteer activities, causing no discernable lingering physical effect due to repeated exposures were recorded. The volunteers were polled postevent, +2 hours, +12 hours and +24 hours.

Summary

The test runs and activities produced a wealth of data and much practical knowledge in a short time. Days of setup and calibration, one hour test runs, followed by days of data analysis and charting, were the norm.

At the one-year point in our experience, we were able to provide a tested quantitative methodology to:

1. Evaluate accident impact artifacts to quantify a 'calculated BEV' [for piston isolators].

TABLE 2—*Partial summary of occupant stress parameters obtained in ASA tests.*

Run ID {manikin} {volunteer}	IMPACT MPH BU/TG pre/post MPH/MPH ⟨KPH⟩	TGAX peak Gs	LSAX peak Gs	CTAX peak Gs	HDAX peak Gs	LSAZ peak Gs	HDAZ peak Gs	LSFX peak LBF	LSFZ peak LBF −/+	CTRX peak deg −/+
LS003, 930623										
93-LS003B	4.5/3.0	BU 83 LTD ⇒ TG 81 Citation								
93-HS003B	⟨7.2⟩/⟨4.8⟩	3.2								
BEV =	⟨4.8⟩									
LF={Alderson C95/M, 157#}			2.8	2.5	6.7	0.9	1.4	x.x	x.x/x.x	−3/+8.8
LS004, 930715										
93-LS004A	4.4/2.2	BU 81 Citation ⇒ 83 LTD								
93-HS004A	⟨7.1⟩/⟨3.5⟩	2.7								
BEV =	⟨3.5⟩									
LF={Alderson C95/M, 157#}			1.4	1.5	3.0	0.8	0.8	x.x	−60/+0	−19/+1.2
LS005, 930807										
93-LS005A	2.3/2.0	BU 83 LTD ⇒ 80 Rabbit								
93-HS005A	⟨3.7⟩/⟨3.3⟩	1.7								
BEV =	⟨3.3⟩									
LF={Alderson C95/M, 157#}			1.5	0.9	2.8	1.0	x.x	x.x	−71/+1	−1.2/+0.5
RF={Vol LH, Male, 63, 160#}			1.2	1.6	3.0	x.x			−31/+0	−0.3/+17
93-LS005C	5.9/4.8	BU 83 LTD ⇒ 80 Rabbit								
93-HS005C	⟨9.6⟩/⟨7.8⟩	4.0								
BEV =	⟨7.8⟩									
LF={Alderson C95/M, 157#}			5.4	3.1	6.8	1.2	x.x	x.x	−92/+195	−0.4/+7
RF={Vol LH, Male, 63, 160#}			3.3	8.0	8.6	x.x			−68/+33	−0.6/+34
93-LS005D	4.4/3.5	BU 83 LTD ⇒ 80 Rabbit								
93-HS005D	⟨7.1⟩/⟨5.7⟩	2.8								
BEV =	⟨5.7⟩									
LF={Alderson C95/M, 157#}			3.8	2.2	4.7	0.9	x.x	x.x	−93/+31	−5/+6
RF={Vol LH, Male, 63, 160#}			2.4	7.4	6.1	2.3			−54/+4	−0/+22
93-LS005E	4.5/3.8	BU 83 LTD ⇒ 80 Rabbit								
93-HS005E	⟨7.2⟩/⟨6.2⟩	2.9								
BEV =	⟨6.2⟩									
LF={Alderson C95/M, 157#}			4.7	2.8	5.1	1.0	x.x	x.x	−98/+97	−4/+5
RF={Vol JJR, Female, 55, 120#}			2.7	7.0	7.1	x.x			−47/+42	−21/+9

2. Determine probable occupant-stress as a function of the 'calculated BEV' {*f* (calc BEV)}.
3. Evaluate the likelihood of injury or lingering physical discomfort for that probable occupant-stress {*f* (calc BEV)}.
4. Corroborate injury likelihood evaluations with firsthand experience of ASA test volunteers, subjected to multiple stress exposures in the ranges of subject collision probable occupant-stress {*f* (calc BEV)}.
5. Compare probable occupant-stress {*f* (calc BEV)} with volunteer common activities.

The test series is continuing with other vehicle pairs, so that we can extend our experience with additional piston isolator types, as well as honeycomb and deformable isolator components.

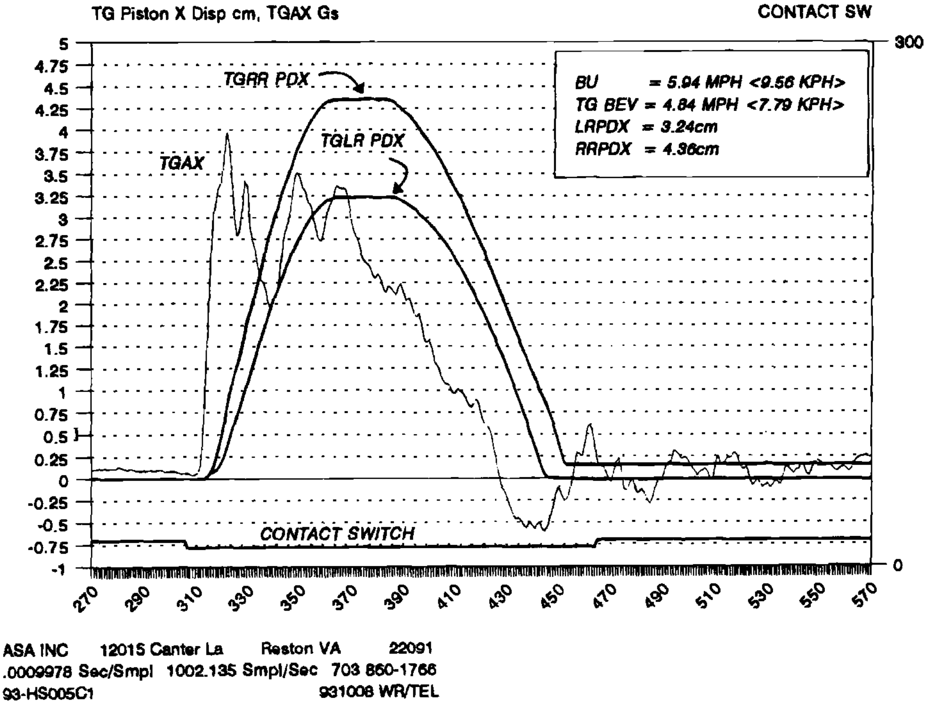
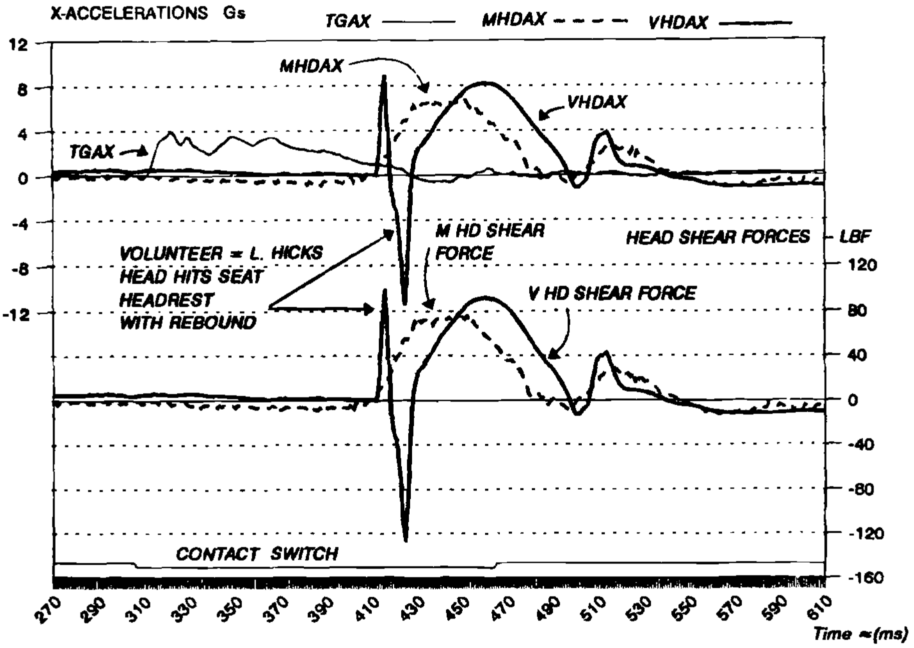
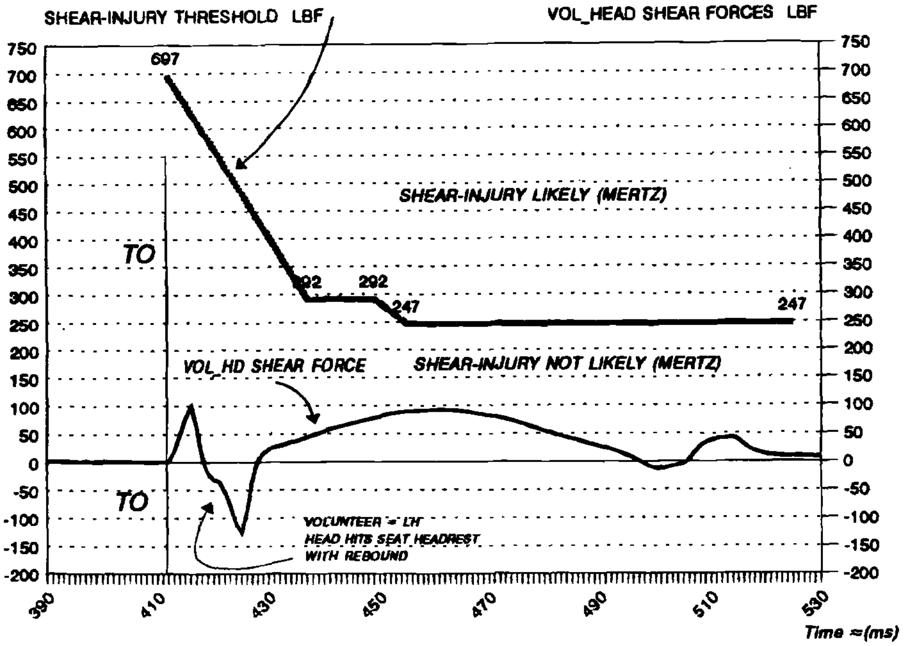


FIG. 15A—*LS multi-vehicle rear impact test #005C BU 83 LTD ⇒ TG 80 Rabbit.*



ASA INC 12015 Canter La Reston VA 22091
0.0009978 Sec/Smpl 1.002.135 Smpl/Sec 703 860-1766
09-HS005CHF 931026 WR/TEL

FIG. 15B—*Run LS005C X-accelerations and manikin/volunteer head/neck shear forces.*



ASA INC 12015 Canter La Reston VA 22091
0.0009978 Sec/Smpl 1002.135 Smpl/Sec 703 860-1766
09-HS05CHF2 931026 WR/TEL

FIG. 15C—*Run LS005C vol_ head/neck shear force vs shear-injury threshold.*

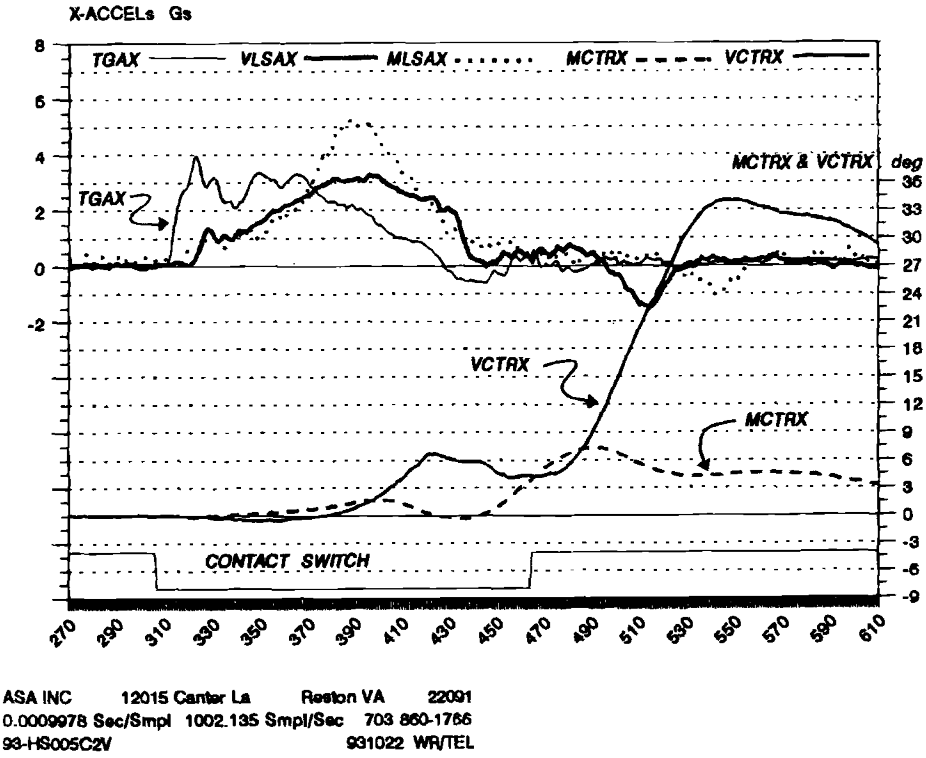
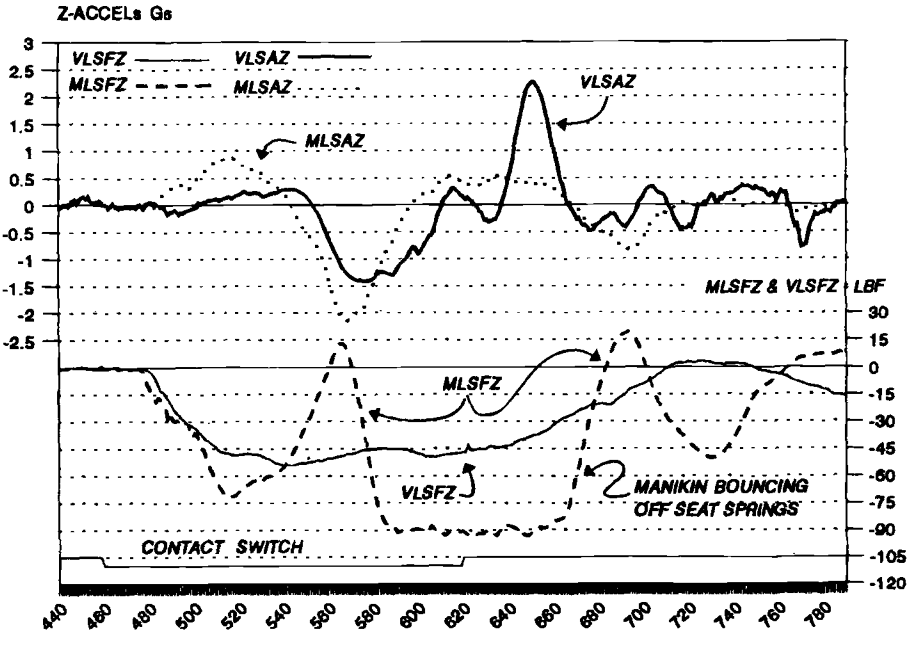


FIG. 16—*X-accelerations vs impact BU 83 LTD ⇒ TG 80 Rabbit w/ASA-002 L. Hicks.*



ASA INC 12015 Canter La Reston VA 22091
0.0010014 Sec/Smpl 998.581 Smpl/Sec 703 860-1766
93-HS005D3 931022 WR/TEL

FIG. 17—*Low Speed Test #005D BU 83 LTD⇒ TG 80 Rabbit w/ASA-002 Manikin Volunteer LH.*

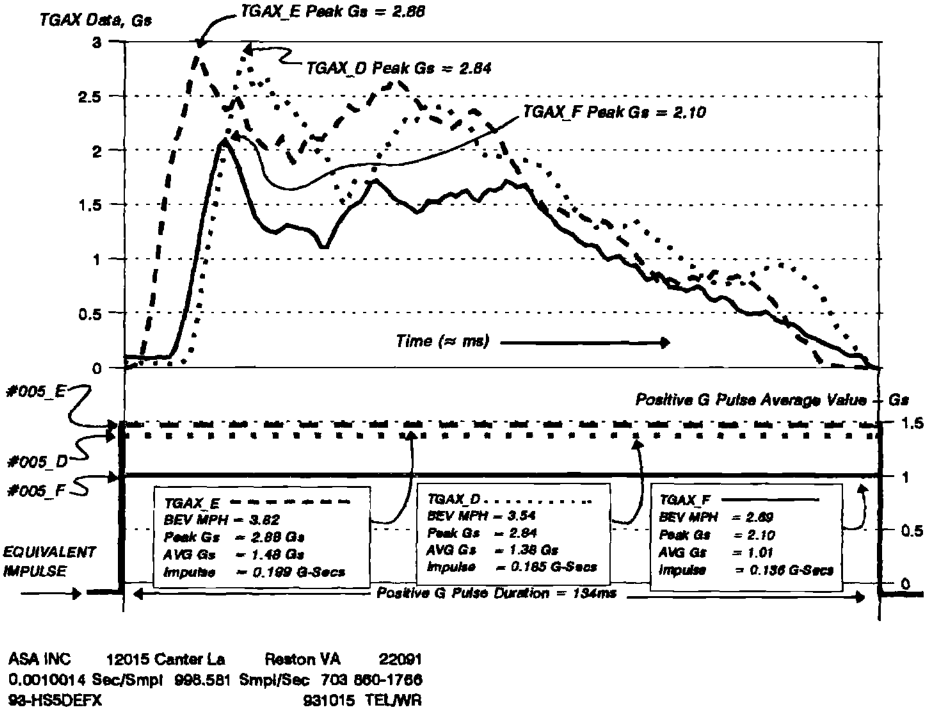
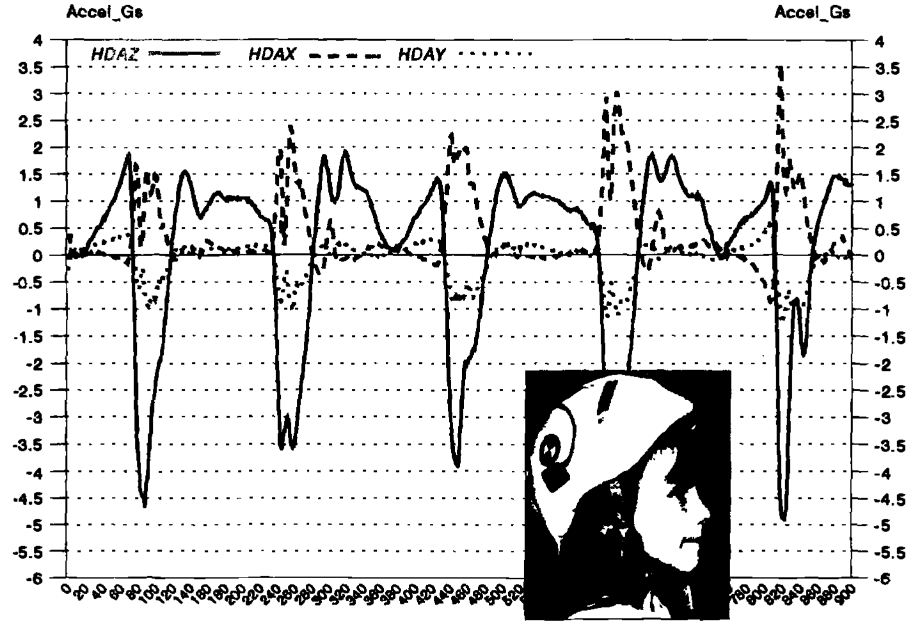


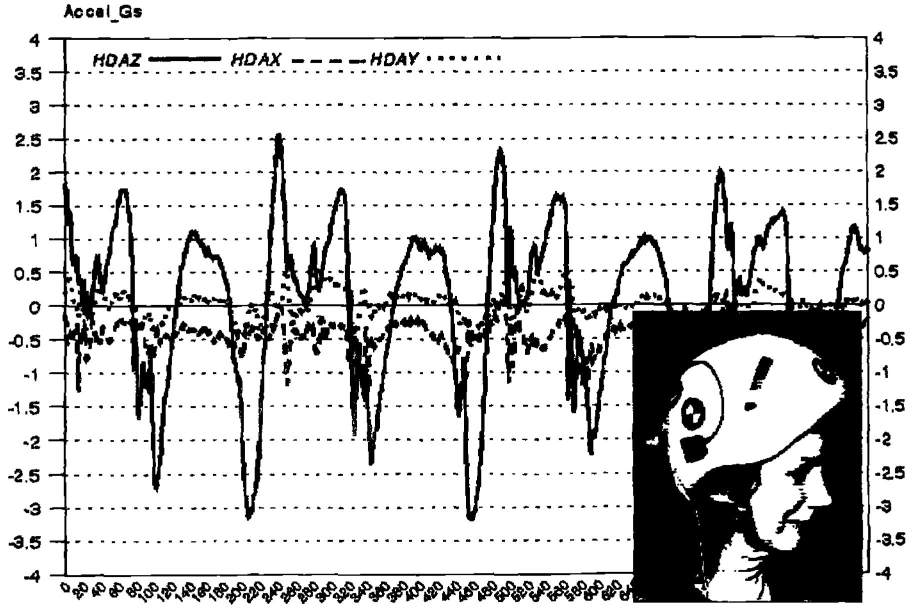
FIG. 18—*Comparison of TGAX AVG-G impulse to TGAX data trace, runs #005D, E, F.*

FIG. 19—*Skip rope trials, Racheal DeHart, 7-year-old female, 51#, 4′ 4″.*



ASA INC 12015 Canter La Reston VA 22091
0.00203 Sec/Smpl 492 Smpl/Sec 703 860-1766
92-LSC24CAQ 931101 WR/TEL

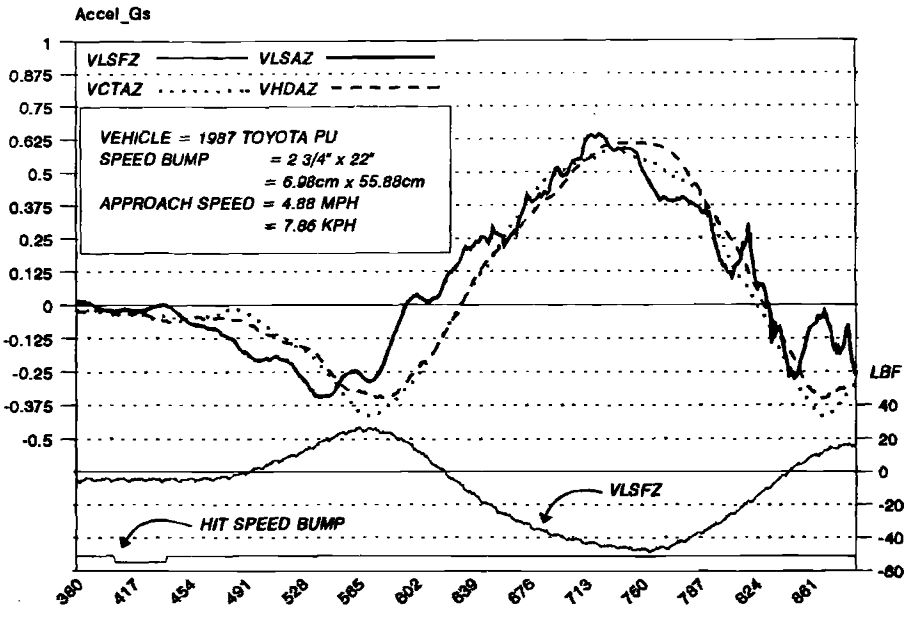
FIG. 20—*Skip rope trials, Racheal DeHart, 7-year-old female, 51#, 4' 4".*



ASA INC 12015 Canter La Reston VA 22091
0.00357 Sec/Smpl 280 Smpl/Sec 703 860-1766
92-AMYC20BQ 931101 TEL/WR

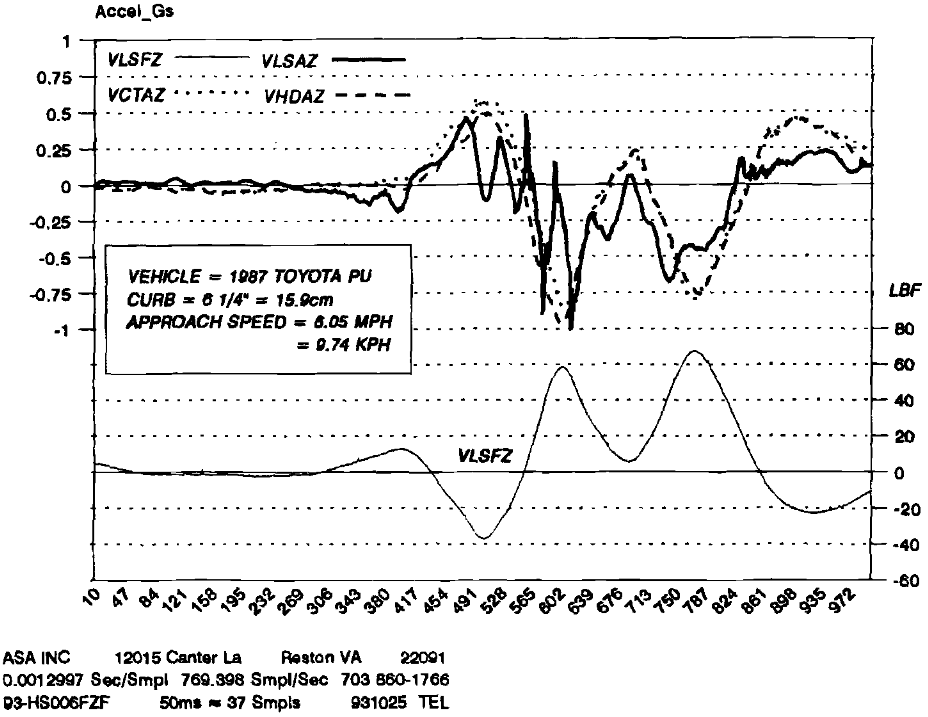
FIG. 21—*Skip rope trials, Amy Wallace, 27 years old, 130#, 5' 6".*

FIG. 22—*1987 Toyota pickup truck preparatory to curb roll-off tests. Note: HS FADAQ synchronizer wand in foreground.*



ASA INC 12015 Canter La Reston VA 22091
.001289 Sec/Smpl 775.757 Smpl/Sec 703 860-1766
93-HS006AZF 50ms = 37 Smpls 931025 TEL

FIG. 23—*Low-speed test #006A parking lot speed bump impacts.*



VEHICLE = 1987 TOYOTA PU
CURB = 6 1/4" = 15.9cm
APPROACH SPEED = 6.05 MPH
= 9.74 KPH

ASA INC 12015 Canter La Reston VA 22091
0.0012997 Sec/Smpl 769.398 Smpl/Sec 703 860-1766
93-HS006FZF 50ms ≈ 37 Smpls 931025 TEL

FIG. 24—*Low-speed test #006F parking lot curb roll-off.*

TABLE 3—*Volunteer common activities.*

Run ID {manikin} {volunteer}	APPROACH SPEED MPH ⟨KPH⟩	TGAX peak Gs (1)	LSAX peak Gs	CTAX peak Gs	HDAX peak Gs	LSAZ peak Gs	HDAZ peak Gs	LSFX peak LBF	LSFZ peak LBF −/+	CTRX peak deg −/+
ASA volunteer activities										
Young girl skipping rope, 921224	Racheal DeHart 7-yrs-old				3.5		−4.5			
Young adult woman skipping rope, 921220	Amy Wallace 28-yrs-old				2.5		−3.0			
LS006, 930918										
93-LS006A 93-HS006A	4.88 ⟨7.86⟩	1987 Toyota P/U over 2 3/4" × 22" ⟨7.0 cm × 55.9 cm⟩ speed bump								
LF={Vol LH, Male, 63, 160#} RF={Vol WR, Male, 54, 163#}						+0.63	+0.63		−48/+25	
93-LS006F 93-HS006F	6.05 ⟨9.74⟩	1987 Toyota P/U over 6 1/4" ⟨15.9 cm⟩ curb drop								
LF={Vol LH, Male, 63, 160#} RF={Vol WR, Male, 54, 163#}						−1.00	−0.95		−38/+65	

```
    Automotive Sys Analysis, Inc.                          FILE: 82ACRD51
    12015 Canter La, Reston VA 22091      1                DATE: 931018
    703-860-1766                                           OPER: WR

    Low-Speed Multi-Veh Rear-Impact
    Calc vs Actual—MPH Analysis

INPUT DATA::

RUN ID  :LS001E  BU VEH:   80 RABBIT            TG VEH: 82 ACCORD
DATE    :930325  BU MPH:          7.12          TG MPH:   5.23 BEV (4)
                 BU KPH:         11.46          TG KPH:   8.42
                                  ISOLTR SFTY MRGN: 100.00%    (1)
                                  ISOLATR THRESHLD:   1.00 MPH (3)
                                  M/V
                                         TGAX pk:   2.10 Gs
                                         HDAX pk:        Gs
                                         CTAX pk:        Gs
                                         LSAX pk:        Gs
                                         LSFZ pk:          +LBF  -LBF
                                         CTRX pk:          +Deg  -Deg
TARGET IMPACT ANALYSIS::
        MAX
        ISO-    OBS/DATA  ISOLATOR                                IMPACT (2)
        LATOR   ISOLATOR  ACTUATION                   ISOLATOR    ACTUATION
        STROKE  STROKE    RATIO                       CAPABILITY  PRODUCT
LEFT     5.50    4.00                FMVSS BASE          5.00        MPH
RIGHT    5.50    1.24     ____     ISOLATOR SAFETY
TOTAL   11.00    5.24     0.476      MARGN               5.00        MPH
                                   ISOLATOR GROSS DYN
                                     CPBLTY             10.00        MPH
                                   ISOLATOR STROKE
                                     THRESHOLD           1.00        MPH
                                   ISOLATOR NET DYN                  MPH
                                     CPBLTY              9.00        ____
                                   ACTUATION PRODUCT = A-RAT × NET
                                     DYN                          4.29 MPH
                                   ISOLATOR STROKE THRESHOLD      1.00 MPH
                                   NET IMPCT BEV = S-THRSH + A-PRDCT  5.29 MPH BEV
PREDICTION MEASURE::

                        CALC MPH   5.29
                        -------- = ---- = 1.011 ----->> 1.1 % VARIANCE
                        MEAS MPH   5.23

NOTES:
(1) ENGINEERING SAFETY FACTOR FOR THIS SERIES VEHICLE
(2) IMPACT ACTUATION PRODUCT = STROKE-ACTUATION-RATIO × DYNAMIC-CAPABILITY
(3) MINIMUM IMPACT SPEED TO START ISOLATOR STROKE
(4) BEV = Barrier Equivalent Velocity
```

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Automotive Sys Analysis, Inc.                                   FILE: 80RBBT48
12015 Canter La, Reston VA 22091        1                       DATE: 931017
703-860-1766                                                    OPER: WR

Low-Speed Multi-Veh Rear-Impact
Calc vs Actual—MPH Analysis


INPUT DATA::

RUN ID  :LS005C  BU VEH:   83 LTD                   TG VEH: 80 RABBIT
DATE    :930807  BU MPH:          5.94              TG MPH:   4.84 BEV (4)
                 BU KPH:          9.56              TG KPH:   7.79
                                      ISOLTR SFTY MRGN:  40.00%    (1)
                                      ISOLATR THRESHLD:   0.80 MPH (3)
                                      M/V
                                               TGAX pk:   3.90 Gs
                                               HDAX pk:        Gs
                                               CTAX pk:        Gs
                                               LSAX pk:        Gs
                                               LSFZ pk:          +LBF  -LBF
                                               CTRX pk:          +Deg  -Deg
TARGET IMPACT ANALYSIS::
        MAX
        ISO-     OBS/DATA  ISOLATOR                                         IMPACT (2)
        LATOR    ISOLATOR  ACTUATION                          ISOLATOR      ACTUATION
        STROKE   STROKE    RATIO                              CAPABILITY    PRODUCT
LEFT     6.00    3.24                     FMVSS BASE            5.00           MPH
RIGHT    6.00    4.36      _____     ISOLATOR SAFETY
TOTAL   12.00    7.60      0.633       MARGN                    2.00           MPH
                                     ISOLATOR GROSS DYN
                                       CPBLTY                   7.00           MPH
                                     ISOLATOR STROKE
                                       THRESHOLD                0.80           MPH
                                     ISOLATOR NET DYN
                                       CPBLTY                   6.20        ___MPH
                                     ACTUATION PRODUCT= A-RAT × NET
                                       DYN                                 3.93 MPH
                                     ISOLATOR STROKE THRESHOLD             0.80 MPH
                                     NET IMPCT BEV = S-THRSH + A-PRDCT     4.73 MPH
PREDICTION MEASURE::

                         CALC MPH   4.73
                         -------- = ---- = 0.977 ----->> -2.34 % VARIANCE
                         MEAS MPH   4.84

NOTES:
(1) ENGINEERING SAFETY FACTOR FOR THIS SERIES VEHICLE
(2) IMPACT ACTUATION PRODUCT = STROKE-ACTUATION-RATIO × DYNAMIC-CAPABILITY
(3) MINIMUM IMPACT SPEED TO START ISOLATOR STROKE
(4) BEV = Barrier Equivalent Velocity
```

```
     Automotive Sys Analysis, Inc.                                   FILE: 80RBBT35
     12015 Canter La, Reston VA 22091        1                       DATE: 931017
     703-860-1766                                                    OPER: WR

     Low-Speed Multi-Veh Rear-Impact
     Calc vs Actual—MPH Analysis


INPUT DATA::

RUN ID   :LS005D  BU VEH:   83 LTD                       TG VEH: 80 RABBIT
DATE     :930807  BU MPH:            4.43                TG MPH:  3.54 BEV (4)
                  BU KPH:            7.13                TG KPH:  5.70
                                             ISOLTR SFTY MRGN:  40.00%     (1)
                                             ISOLATR THRESHLD:   0.80 MPH (3)
                                             M/V
                                                     TGAX pk:   1.50 Gs
                                                     HDAX pk:        Gs
                                                     CTAX pk:        Gs
                                                     LSAX pk:        Gs
                                                     LSFZ pk:          +LBF  -LBF
                                                     CTRX pk:          +Deg  -Deg
TARGET IMPACT ANALYSIS::
         MAX
         ISO-     OBS/DATA  ISOLATOR                                    IMPACT (2)
         LATOR    ISOLATOR  ACTUATION                      ISOLATOR     ACTUATION
         STROKE   STROKE    RATIO                          CAPABILITY   PRODUCT
LEFT      6.00    2.34                    FMVSS BASE          5.00          MPH
RIGHT     6.00    3.45      ___       ISOLATOR SAFETY
TOTAL    12.00    5.79      0.483       MARGN                 2.00          MPH
                                      ISOLATOR GROSS DYN
                                        CPBLTY                7.00          MPH
                                      ISOLATOR STROKE
                                        THRESHOLD             0.80          MPH
                                      ISOLATOR NET DYN
                                        CPBLTY                6.20       ___MPH
                                      ACTUATION PRODUCT = A-RAT × NET
                                        DYN                             2.99 MPH
                                      ISOLATOR STROKE THRESHOLD         0.80 MPH
                                      NET IMPCT BEV = S-THRSH + A-PRDCT 3.79 MPH
PREDICTION MEASURE::

                              CALC MPH   3.79
                              -------- = ---- = 1.071 ----->> 7.10 % VARIANCE
                              MEAS MPH   3.54

NOTES:
(1) ENGINEERING SAFETY FACTOR FOR THIS SERIES VEHICLE
(2) IMPACT ACTUATION PRODUCT = STROKE-ACTUATION-RATIO × DYNAMIC-CAPABILITY
(3) MINIMUM IMPACT SPEED TO START ISOLATOR STROKE
(4) BEV = Barrier Equivalent Velocity
```

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Automotive Sys Analysis, Inc.                               FILE: 80RBBT38
12015 Canter La, Reston VA 22091        1                   DATE: 931017
703-860-1766                                                OPER: WR

Low-Speed Multi-Veh Rear-Impact
Calc vs Actual—MPH Analysis


INPUT DATA::

RUN ID  :LS005E  BU VEH:   83 LTD                      TG VEH: 80 RABBIT
DATE    :930807  BU MPH:            4.48               TG MPH:   3.82 BEV (4)
                 BU KPH:            7.21               TG KPH:   6.15
                                         ISOLTR SFTY MRGN:  40.00%    (1)
                                         ISOLATR THRESHLD:   0.80 MPH (3)
                                         M/V
                                                TGAX pk:   1.50 Gs
                                                HDAX pk:        Gs
                                                CTAX pk:        Gs
                                                LSAX pk:        Gs
                                                LSFZ pk:          +LBF  -LBF
                                                CTRX pk:          +Deg  -Deg
TARGET IMPACT ANALYSIS::
         MAX
         ISO-    OBS/DATA  ISOLATOR                                        IMPACT (2)
         LATOR   ISOLATOR  ACTUATION                         ISOLATOR      ACTUATION
         STROKE  STROKE    RATIO                             CAPABILITY    PRODUCT
LEFT      6.00   1.81                 FMVSS BASE               5.00           MPH
RIGHT     6.00   3.95      ____    ISOLATOR SAFETY
TOTAL    12.00   5.76      0.480      MARGN                    2.00           MPH
                                   ISOLATOR GROSS DYN
                                      CPBLTY                   7.00           MPH
                                   ISOLATOR STROKE
                                      THRESHOLD                0.80           MPH
                                   ISOLATOR NET DYN
                                      CPBLTY                   6.20        ___MPH
                                   ACTUATION PRODUCT = A-RAT X NET
                                      DYN                                 2.98 MPH
                                   ISOLATOR STROKE THRESHOLD              0.80 MPH
                                   NET IMPCT BEV = S-THRSH + A-PRDCT      3.78 MPH
PREDICTION MEASURE::

                        CALC MPH   3.78
                        -------- = ---- = 0.988 ----->> -1.15 % VARIANCE
                        MEAS MPH   3.82

NOTES:
(1) ENGINEERING SAFETY FACTOR FOR THIS SERIES VEHICLE
(2) IMPACT ACTUATION PRODUCT = STROKE-ACTUATION-RATIO X DYNAMIC-CAPABILITY
(3) MINIMUM IMPACT SPEED TO START ISOLATOR STROKE
(4) BEV = Barrier Equivalent Velocity
```

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