EXAMPLES OF STAGED COLLISIONS IN ACCIDENT RECONSTRUCTION

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ABSTRACT

A summary of data associated with 16 staged collisions involving unmodified passenger car vehicles is reported. The data include pre-impact, impact and post-impact information. These data will aid accident reconstruction specialists in their interpretation of actual highway crashes and in the comparative test and development of reconstruction algorithms that model the impact and trajectory of accident-involved vehicles.

NOMENCLATURE

a	- acceleration
C_1, C_2---C_6	- six measurements of damage depth profile; spaced equidistant over the length, L (Fig. 2)
D	- location of center of damaged area relative to center-of-mass (Fig. 2)
$\bar{F}$	- force vector
L	- length of damage area in plan view (Fig. 2)
m	- vehicle mass
T	- pulse width or duration in milliseconds of impact between vehicles
u, v	- center-of-mass velocity components in vehicle centered reference frame
U, V	- center-of-mass velocity components in space-fixed reference frame
$\bar{V}$	- velocity vector
X, Y	- space-fixed coordinates (Fig. 1)
x, y	- vehicle centered coordinates (Fig. 1)

$\Delta \bar{V}$ - change in velocity during impact; $V_{SEPARATION} - V_{IMPACT}$

Ψ - angular measure CW from X-axis

θ - angular measure CW from x-axis

ω - angular velocity of vehicle

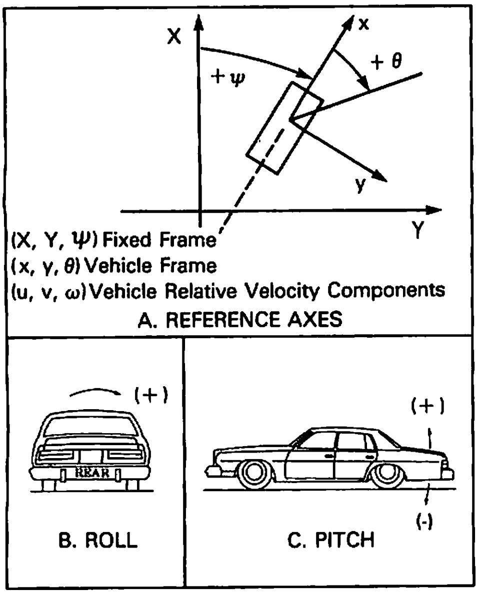
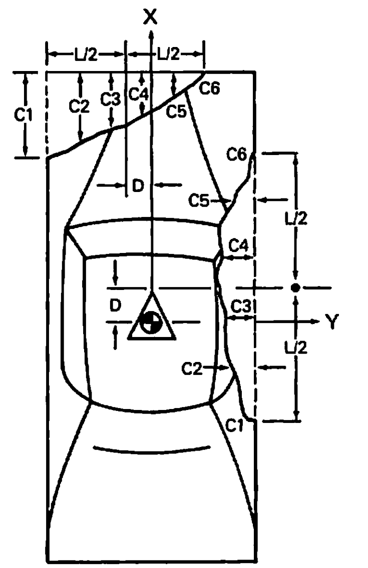


FIG. 1 COORDINATE CONVENTIONS



FRONTAL DAMAGE: D>0 RIGHT OF CENTERLINE
SIDE DAMAGE: D>0 FORE OF C.G.

FIG. 2 DAMAGE DIMENSIONS

INTRODUCTION

Motor vehicle accidents are undesirable events, which upon close examination are usually found to be complicated combinations of many events or factors. Practice has led to the definition and identification of harmful events, such as an impact with another vehicle or pedestrian, a vehicle rollover, or a vehicle fire, to name a few examples. Indeed many accidents involve more than one harmful event.

Accident reconstruction is the determination, based on available post-accident information, of the events immediately before, during and subsequent to the undesirable or harmful event(s) in the accident. Such reconstruction can be motivated by many purposes, such as determining the causal factors involved, determining the pre-accident traveling speed and determining the forces or trajectory experienced by the vehicle. Our interest in discussing herein the subject of staged collisions and their contribution to accident reconstruction, tends towards the area of vehicle dynamics and motions. The causal factor interest is not addressed in this discussion; however, its relation to vehicle dynamics and velocity such as when combined with driver reactions and roadway demands would be served by this discussion. We also exclude those spontaneous events such as fire or explosion and motor vehicle defects that suddenly manifest themselves in a loss of vehicle control.

Having excluded some extraordinarily interesting possibilities for discussion, there nevertheless remains for consideration the overwhelmingly greatest proportion of accidents, those harmful events involving impacts with other vehicles and objects. Indeed, data reported in the Fatal Accident

Reporting System (FARS) (1) indicate that 72 percent of all fatal accidents excluding motorcycles and pedestrians involve a motor vehicle striking another motor vehicle or some fixed object.

A common example of a staged collision is that used in the enforcement activities associated with the Federal Motor Vehicle Safety Standards. These collisions are often barrier impacts, including fixed-rigid and movable barriers whose utility is grounded in their simplicity and the repeatability of their impact configuration. Although these staged collisions are useful for their purposes in standards enforcement, they are not good surrogates for modeling the dynamics, kinematics and trajectory of vehicle-to-vehicle collisions. Obviously it is desirable to use two moving vehicles to accomplish the most realistic staged collision of actual on-the-road events. In the past years numerous such staged collisions have been conducted by contractors of the Federal government in support of the research in motor vehicle crashworthiness and accident reconstruction. Much of the crashworthiness research utilizing staged collisions involves structural-modified vehicles intended to test a new concept in vehicle crashworthiness. These are excluded in this discussion because they do not model any actual on-the-road vehicles. Many other staged collisions have included post-impact vehicle arrest systems to avoid the potential of an out-of-control vehicle striking other test equipment in the vicinity of the impact area. These too must be excluded here because the trajectory itself is one of the most valuable sources of information in accident reconstruction. Independent of these limitations, we have begun to accumulate well-documented staged collision data useful for accident reconstruction. The purpose of this discussion is to call these data to the attention of the accident reconstruction community and to indicate some of the features we have observed. (Undoubtedly other researchers will observe many additional interesting features as they examine the detailed results of these staged collisions.)

OBSERVABLE FEATURES IN STAGED COLLISIONS

Beginning with the impact itself, three areas of interest or features can be identified in these staged collisions. They are the post-impact trajectory and velocity, the vehicle damage and the vehicle dynamics during the impact.

Post-Impact Trajectory

Usually the involved vehicles separate and proceed to a final rest position in rolling and skidding motions with no driver steer inputs and under the action of tire-ground forces. All of the cases we discuss make the assumption that the driver has been divorced from vehicle brake, steer or acceleration inputs by the forces of the impact. Of course this is not always true in an actual collision and the true driver inputs become a difficult matter of conjecture that can confound even well-documented trajectory evidence.

One interesting feature of this post-impact trajectory occurs particularly in side impacts and offset frontals. This is the introduction of strong vehicle rotational velocity and the combined action of vehicle tires undergoing both rolling and skidding motion. We adopt here a simple concept of skidding to mean examples where the tire slip angle is sufficiently great that the side force developed is saturated or at its peak value. When such skidding occurs in contrast to rolling, the increased friction between the tire and dry road surface quickly heats the tire sufficiently to result in tire markings that are visible after the accident. Of course hard or panic brake application also results in tire markings, as does extraordinarily large tractive torques. The distinguishing features of these various tire markings are explained in Baker's text on accident investigation (2). The roll and pitch of the vehicle further confounds the tire markings because this action results in individual tires being off the ground surface at interim periods of the trajectory. Nevertheless, the existence of tire markings is a valuable aid to reconstruction because it provides information on the path of the vehicle between impact and final rest. In the data reported, tire markings, braking forces, steer effects and other phenomena that influence the tire-ground interface forces are identified. Braking forces are estimated in the tabular data summaries herein by expressing the force as a decimal portion of wheel lock-up. In this nomenclature, a figure of 1 indicates a locked wheel. A figure of 0.2 indicates a level of drag or braking generally produced by vehicle transmission drag, and is 20 percent of the force produced by locked wheels.

Vehicle Damage

The observation and measurement of the resultant damage is helpful in two ways to the reconstruction. First, by comparing the available evidence from the two impacting vehicles, an estimate of their impact orientation and subsequent relative motion during impact can be obtained. Inspection of the damage to both vehicles also yields an estimate of the average force direction that caused the damage. This force is actually an average in time (over the impact duration) and in space (over the area of damage).

$$\overline{F} = \frac{1}{T} \int_0^T \left(\int_A \overline{f} dA \right) dt \tag{1}$$

where

$\overline{F}$ = average force during impact

T = duration in time, t, of the impact

$\overline{f}$ = impact force per unit contact area

A = contact area between impacting vehicles

Of course $\overline{F}$xT is the impulse from the impact. Momentum considerations, Eqn. (2), dictate that the direction of $\overline{F}$ is, neglecting tire forces, the same as the direction of the velocity change during impact.

$$(\overline{F} + \overline{F}_{TIRE})\ T = m\Delta\overline{V} = m\ (\overline{V}_{SEPARATION} - \overline{V}_{IMPACT}) \tag{2}$$

This directional property of the average force can be quite helpful in reconstructing separation and impact velocities.

A second piece of information offered by the damage is the estimation of the energy expended in deformation. This is possible to estimate if the deformation profile is obtained and if the stiffness--(impact force per unit area per unit depth of deformation) is known. Although the stiffness differs among vehicles and differs within a vehicle structure according to front, side or rear damage, and even depth of damage, general or approximate values for stiffness have been tabulated by the NHTSA in support of the CRASH (Calspan Reconstruction of Accident Speeds on the Highway) accident reconstruction code (3).

The deformation is usually quantified by measuring its length and location along the front, rear or side and by four or six measurements of damage depth (see Fig. 2). Experience dictates that the damage depth measurements be made from an undeformed position to the deformed position of the same point. The profile itself is usually based on the maximum deformation; however, if extreme underride or override occurs, profiles in more than one horizontal plane are justified.

Vehicle Impact Dynamics

The impact phase of the accident, whether involving another vehicle or an object such as a utility pole, is characterized by an extraordinarily large vehicle acceleration and associated impact force. This acceleration occurs over only a 100-200 millisecond period of time, depending largely upon the stiffness properties of the impacting vehicles and objects. During this period and shortly thereafter an impacted vehicle undergoes the violent change in original motion that results in the so-called "second collision" of the occupants within the vehicle itself and involves these occupants in a great risk of injury. Any study of this crash phase by staged collision or reconstruction is invariably directed at determining vehicle acceleration and motion (translation and rotation.) Velocity and position are then determined by integrating the accelerometer data.

The vehicle acceleration unfortunately is an elusive quantity even in staged collisions. The vehicle itself is undergoing substantial elastic and plastic deformation including both translational and rotational displacements. Consequently the response of accelerometers depends markedly on their location on the vehicle. Structural engineering studies dictate placing accelerometers on deforming panels and other strength members; however, accident reconstruction studies usually dictate consideration of a reference position such as the center-of-mass. Unfortunately there is seldom a structural member located at the center-of-mass on which to place an accelerometer, so a "reasonably" stiff member in near proximity, such as the transmission tunnel, is often chosen. In any event the output of any accelerometer must carefully be reviewed and corrected to eliminate the effects of rotational acceleration and rotational displacement of the center-of-mass coordinates.

We have attempted to achieve necessary corrections to acceleration and velocity data by approximating vehicle rotational velocity and rotation of the reference frame from its orientation at impact, by making reference to multiple accelerometer outputs at different locations on the vehicles and by analysis of high speed photography. For purposes of accident reconstruction the result can be simplifed to the estimation of average acceleration and pulse width, or velocity change and pulse width. (Clearly these quantities are related by the expression, $\overline{a}_{ave} = \Delta\overline{V}/T$.)

Other significant forces exist during the collision. Among these in some cases are the tire forces. When the vehicle motion is largely parallel to the tire plane, and no braking or tractive torques are applied these forces are clearly negligible, for the drag from rolling friction even when the engine is connected mechanically to the drive wheels is seldom greater than approximately 0.25 g's. When compared to average impact forces of 5-10 g's this is not significant; however, in sideways motions occurring in side collisions the tire-ground forces can exceed 1 g, in which case they are of some influence.

Staged Collision Results

A summary of the collision configurations reported herein is given in TABLE 1. A tabular and a graphical presentation of selected details then follows for each case identified in the summary table. Additional details on these collisions can be found in the cited reference material, including accelerometer data. High speed photographic documentation is available on a loan basis from the authors of this paper. The coordinate and measurement systems used in reporting these data are illustrated by Figs. 1 and 2.

In reviewing and interpreting these results it is observed that the center-of-mass momentum changes associated with each pair of impacting vehicles is not equal and opposite. There are two sources for this circumstance; one, errors in the acceleration measurement and its integration to obtain velocity, and two, the influence of tire forces. The latter contribution to the difference can be illustrated by manipulation of Eqn. 2. Writing Eqn. 2 for each vehicle, adding the two resulting expressions and recognizing that

$$\overline{F}_1 + \overline{F}_2 = 0$$

we obtain

$$(\overline{F}_{TIRE})_1 T + (\overline{F}_{TIRE})_2 T = m_1 \Delta\overline{V}_1 + m_2 \Delta\overline{V}_2 \qquad (3)$$

where subscripts denote vehicles 1 and 2 respectively. The direction and magnitude of the impulse associated with the tire-ground forces can be estimated from the vehicle trajectory, pulse width and tire-ground coefficient of friction. Clearly the tire-ground forces must be zero before the momentum changes are equal and opposite.

Giving due account to this force, it is clear that some error or differences not attributable to tire-ground forces exists in one or both of the velocity changes reported in cases number 10, 12 and 15. The authors have on the basis of film analysis made qualitative judgments that the error resides primarily in poor accelerometer data for one of the two involved vehicles. The reported data noted with an asterisk in cases number 10, 12 and 15 are believed to be in error. We have refrained from correcting them as the only basis for correction is Eqn. 3 itself. Such correction, if deemed necessary by the reader, can be applied using estimated tire forces.

SUMMARY

A brief reporting of the results of 16 documented staged collisions has been presented. The collisions reported include examples of unmodified production vehicles in car-to-car impacts modeling side, rear-end and head-on highway configurations. These results and the collisions on which they are based represent the initial efforts of the agency to document staged collision evidence, including vehicle and trajectory information, through a selected and continuing program in accident reconstruction.

REFERENCES

1 Fatal Accident Reporting System, National Highway Traffic Safety Administration, "1978 Annual Report," U.S. Government Printing Office, Washington, D.C. 20402.

2 Baker, J. S., Traffic Accident Investigation Manual, 1975, The Traffic Institute, Northwestern University, Evanston, Illinois.

3 McHenry, R. R., "Extensions and Refinements of the CRASH Computer Program, Part II, User's Manual," DOT-HS-801-838, February 1976, NTIS No. PB 252116.

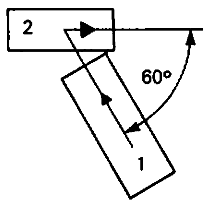
4 James, M. E., Ross, H. E., and Whittington, C., "Improvement of Accident Simulation Model and Improvement of Narrow Object Simulation," DOT-HS-803-620, April 1978.

5 Shoemaker, N. E., "Research Input for Computer Simulation of Automobile Collisions," Vols. 2, 3 and 4, DOT-HS-805-038, 039, 040.

6 Shaw, L. M., "Countermeasures for Side Impact," Final Report for Contract DOT-HS-9-02177, to be published.

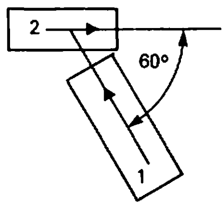
7 "Collision Deformation Classification," SAE J224b, Recommended Practice, Society of Automotive Engineers.

CASE NO. 1



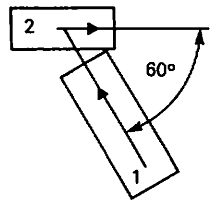
SIZES: #1, I; #2, S
SPEEDS: #1, 31.7 #2, 31.7

CASE NO. 2



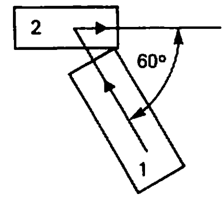
SIZES: #1, I; #2, S
SPEEDS: #1, 50.4 #2, 50.4

CASE NO. 3



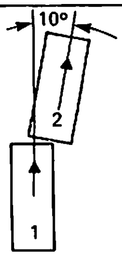
SIZES: #1, I; #2, S
SPEEDS: #1, 34.4 #2, 34.4

CASE NO. 4



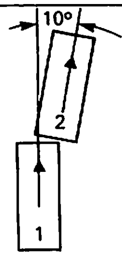
SIZES: #1, I; #2, S
SPEEDS: #1, 46.6 #2, 46.6

CASE NO. 5



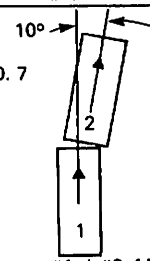
SIZES: #1, I; #2, S
SPEEDS: #1, 33.9 #2, 0.0

CASE NO. 6



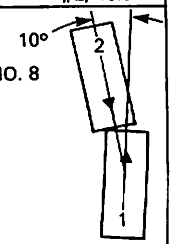
SIZES: #1, I; #2, S
SPEEDS: #1, 61.9 #2, 0.0

CASE NO. 7



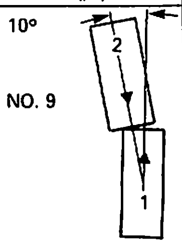
SIZES: #1, I; #2, M
SPEEDS: #1, 63.5 #2, 0.0

CASE NO. 8

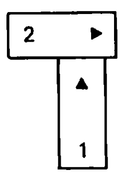


SIZES: #1, S; #2, I
SPEEDS: #1, 32.6 #2, 32.6

CASE NO. 9

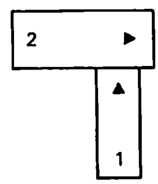


SIZES: #1, S; #2, I
SPEEDS: #1, 50.4 #2, 50.4



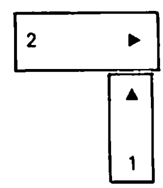
CASE NO. 10

SIZES: #1, I; #2, I
SPEEDS: #1, 33.2 #2, 33.2



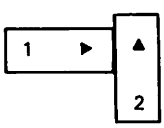
CASE NO. 11

SIZES: #1, M; #2, I
SPEEDS: #1, 33.9 #2, 33.9



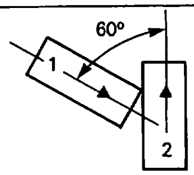
CASE NO. 12

SIZES: #1, M; #2, I
SPEEDS: #1, 53.2 #2, 53.2



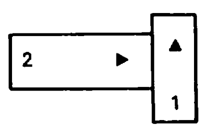
CASE NO. 13

SIZES: #1, I; #2, I
SPEEDS: #1, 41.0 #2, 42.4



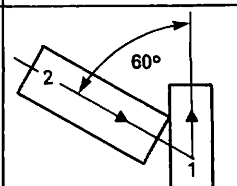
CASE NO. 14

SIZES: #1, I; #2, I
SPEEDS: #1, 61.6 #2, 42.4



CASE NO. 15

SIZES: #1, M; #2, I
SPEEDS: #1, 32.5 #2, 64.3



CASE NO. 16

SIZES: #1, M; #2, I
SPEEDS: #1, 24.6 #2, 48.3

SIZES: M-MINICAR, S-SUBCOMPACT, I-INTERMEDIATE

SPEEDS: KILOMETERS PER HOUR

TABLE 1. STAGED COLLISION ORIENTATIONS

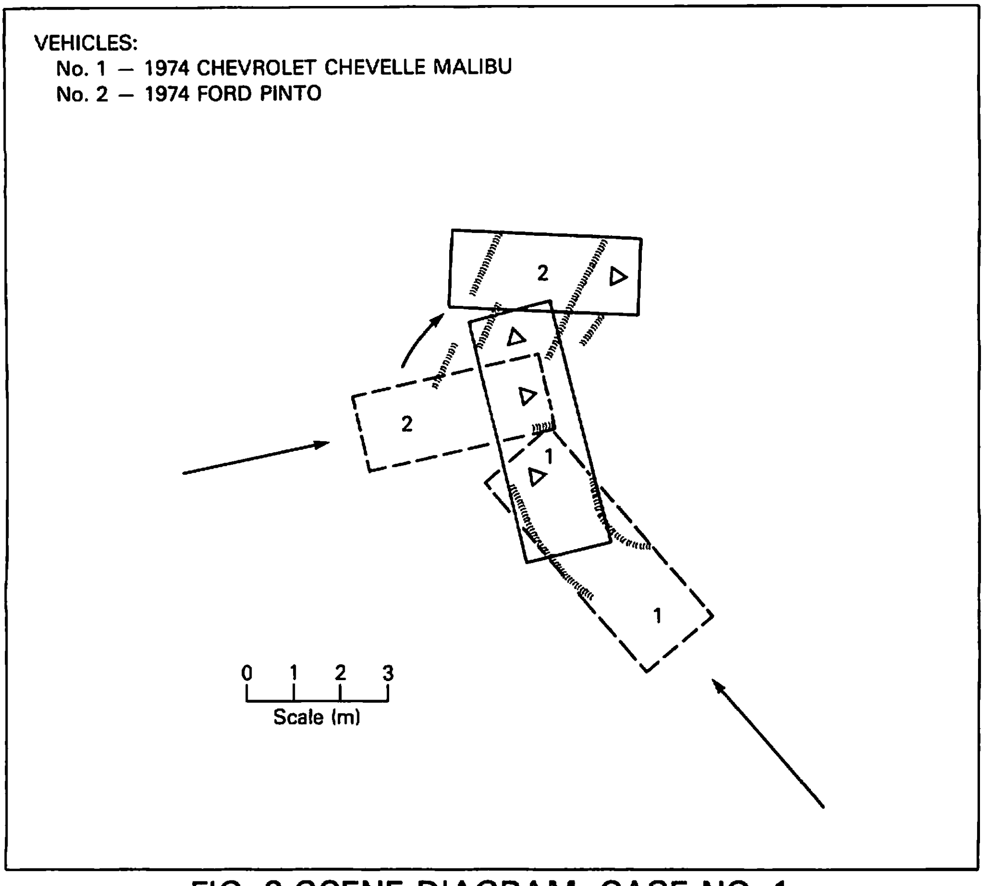


FIG. 3 SCENE DIAGRAM, CASE NO. 1

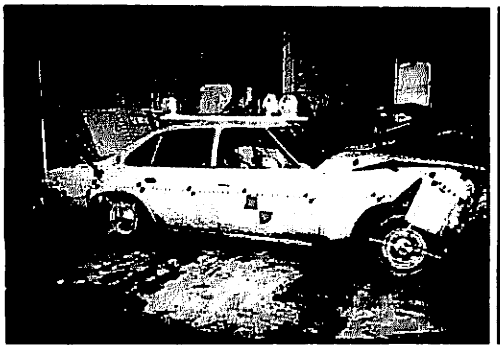


FIG. 4 CASE 1, V1 POST TEST

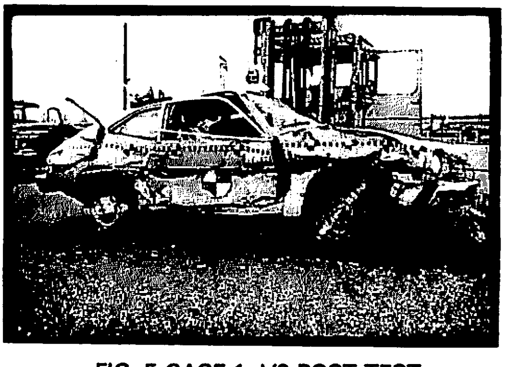


FIG. 5 CASE 1, V2 POST TEST

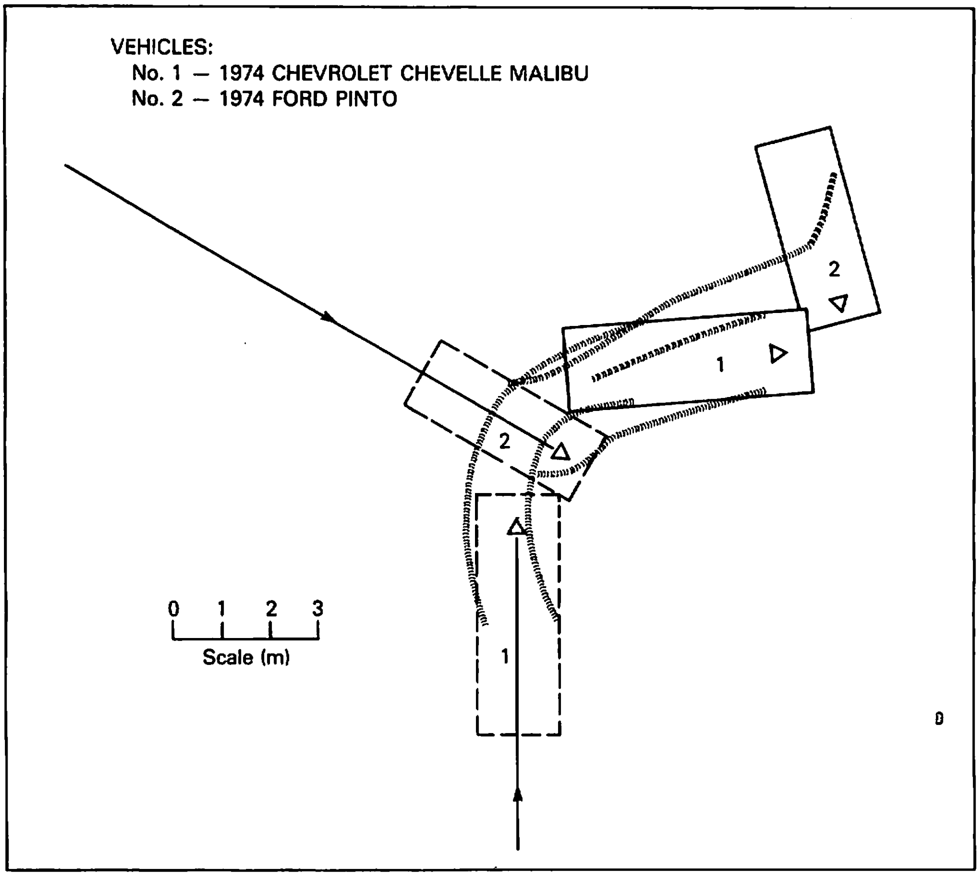


FIG. 6 SCENE DIAGRAM, CASE NO. 2

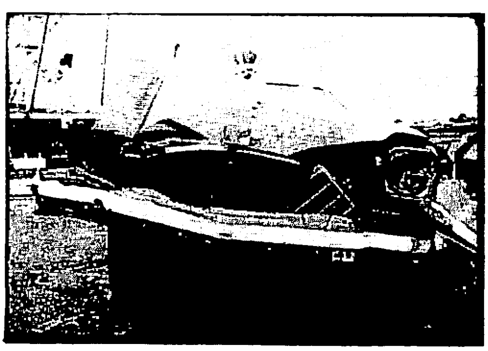


FIG. 7 CASE 2, V1 POST TEST

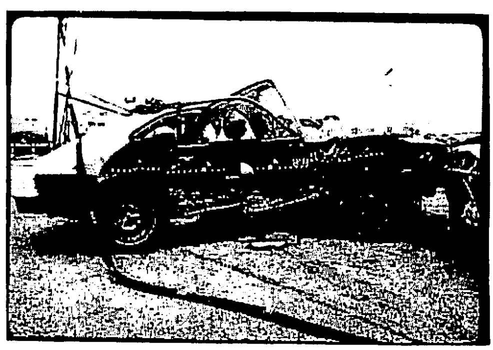


FIG. 8 CASE 2, V2 POST TEST

	60° FRONT-TO-SIDE	
CASE NO. 1 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Chevelle	74 Ford Pinto
TEST MASS (KG)	2109	1411
IMPACT SPEED (KM/HR)	31.7	31.7
VELOCITY CHANGE (KM/HR) Δu	−17.0	−19.4
Δv	9.6	−15.7
ANGLE (DEG)	−29	39
PULSE WIDTH (ms)	225	225
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(−3., −0.3, −30)	(0., −1.7, 90°)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(−0.7, −0.3, −1.5)	(2.3, 0.7, 105)
ROTATION (DEGREES) − COLLISION PHASE	15	0
− POST-COLLISION	14	15
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	90	0
PITCH (DEGREES)	3 max	−5 max
ROLL (DEGREES)	8 max	−15 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	10 max	10 max
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	11FZEW2	01RDEW3
DAMAGE MEASUREMENTS (MM) L	1168 46	2878 113.3
D	363	554
C_1	102	13
C_2	140	305
C_3	178	269
C_4	259	300
C_5	307	229
C_6	376	104

TABLE 2 DATA SUMMARY, CASE NO. 1

	60° FRONT-TO-SIDE	
CASE NO. 2 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Malibu	74 Ford Pinto
TEST MASS (KG)	2136	1479
IMPACT SPEED (KM/HR)	50.4	50.4
VELOCITY CHANGE (KM/HR) Δu	−26.4	−37.9
Δv	16.8	−26.6
ANGLE (DEG)	−32	35
PULSE WIDTH (ms)	225	225
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(−3.4, 2.6, −30)	(0., 0., 90)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(3.4, 2.9, 55)	(7.2, 3.8, 134)
ROTATION (DEGREES) − COLLISION PHASE	18	−9
− POST-COLLISION	67	44
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	150	90
PITCH (DEGREES)	4 max	−4 max
ROLL (DEGREES)	−8 max	−20 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.5	.02
LF	.02	.02
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	−7 max	4 max
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	11FDEW2	02RDEW4
DAMAGE MEASUREMENTS (MM) L	1918 75.5	3010 118.5
D	0	348
C_1	13	173
C_2	61	579
C_3	94	597
C_4	175	541
C_5	305	254
C_6	419	0

TABLE 3 DATA SUMMARY, CASE NO. 2

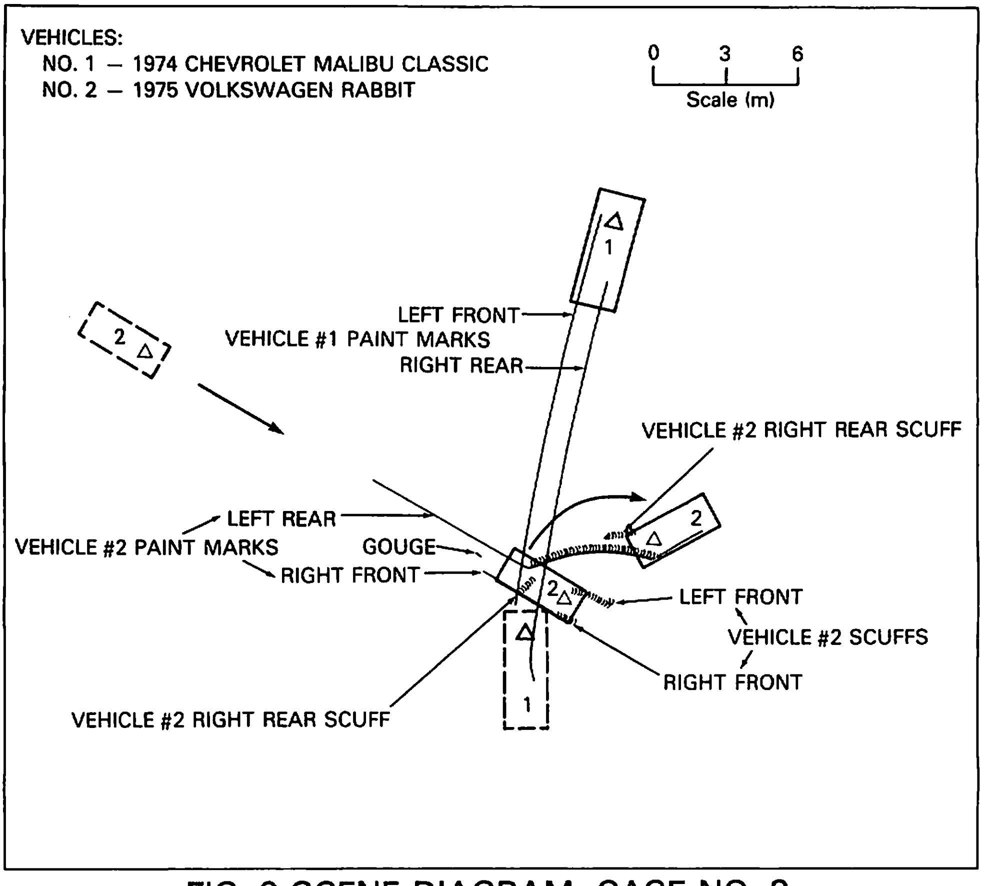


FIG. 9 SCENE DIAGRAM, CASE NO. 3

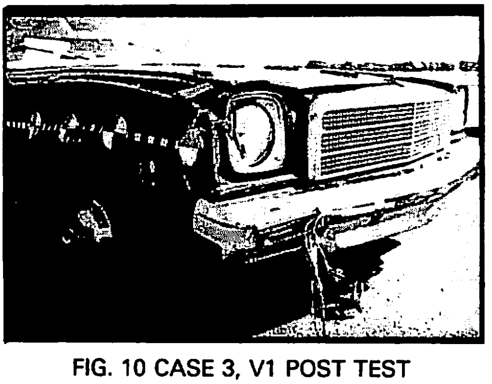


FIG. 10 CASE 3, V1 POST TEST

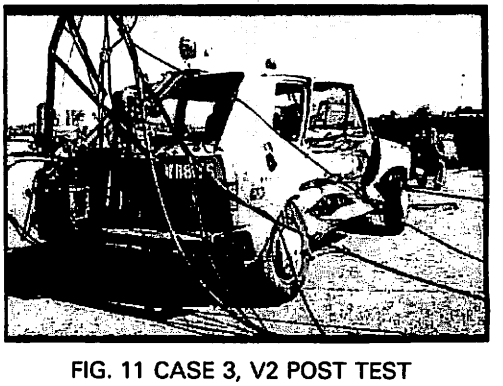


FIG. 11 CASE 3, V2 POST TEST

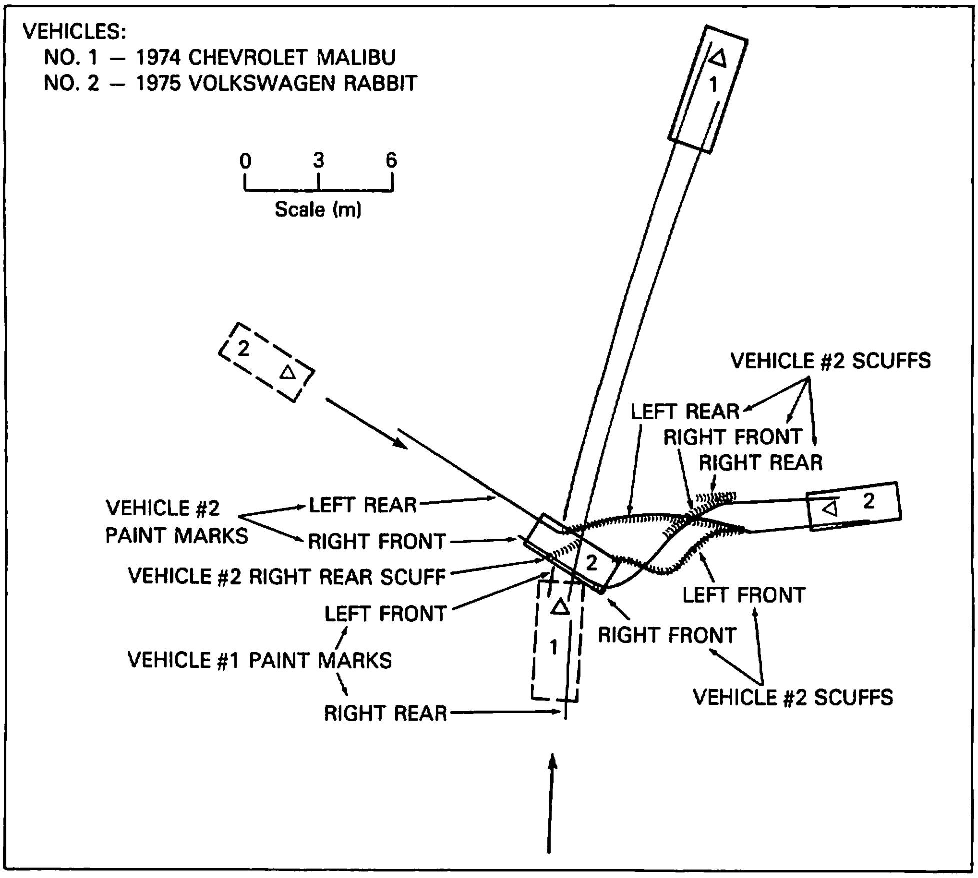


FIG. 12 SCENE DIAGRAM, CASE NO. 4

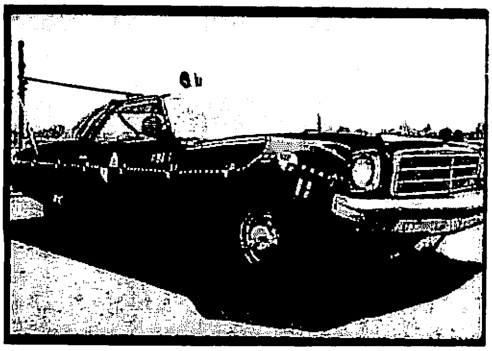


FIG. 13 CASE 4, V1 POST TEST

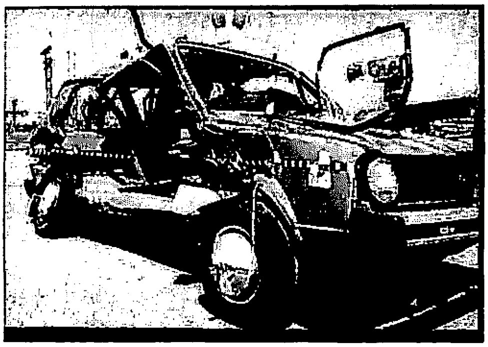


FIG. 14 CASE 4, V2 POST TEST

CASE NO. 3 (REF. 5)	60° FRONT-TO-SIDE VEHICLE #1	60° FRONT-TO-SIDE VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Chevelle	75 VW Rabbit
TEST MASS (KG)	1955	1198
IMPACT SPEED (KM/HR)	34.4	34.4
VELOCITY CHANGE (KM/HR) Δu	−13.6	−20.5
Δv	4.8	−13.8
ANGLE (DEG)	−19	34
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(0., 0., 0.)	(3.4, 0.8, 120)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(18.3, 3.4, 15)	(6.1, 6.4, 242)
ROTATION (DEGREES) – COLLISION PHASE	5	20
– POST-COLLISION	10	102
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	30	180
PITCH (DEGREES)	3 max	−10 max
ROLL (DEGREES)	3 max	−20 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW >0)	−3 max	13 max
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	11FZEW1	02RDEW3
DAMAGE MEASUREMENTS (MM) L	1384	1956
D	249	−84
C_1	13	102
C_2	13	305
C_3	33	452
C_4	38	490
C_5	46	432
C_6	58	211

TABLE 4 DATA SUMMARY, CASE NO. 3

CASE NO. 4 (REF. 5)	60° FRONT-TO-SIDE VEHICLE #1	60° FRONT-TO-SIDE VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Malibu	75 VW Rabbit
TEST MASS (KG)	1955	1184
IMPACT SPEED (KM/HR)	46.6	46.6
VELOCITY CHANGE (KM/HR) Δu	−18.4	24.6
Δv	5.6	−22.7
ANGLE (DEG)	−17	43
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(0., 0., 0.)	(3.3, 1.1, 120)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(25.8, 5.6, 16)	(7, 12.6, 262)
ROTATION (DEGREES) – COLLISION PHASE	12	22
– POST-COLLISION	4	220
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	30	192
PITCH (DEGREES)	−2.5 max	−8 max
ROLL (DEGREES)	5 max	−7 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW >0)	3 (max); 1 (ave.)	2 (ave.)
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	11FDEW1	01RDEW4
DAMAGE MEASUREMENTS (MM) L	1676	2756
D	102	−216
C_1	0	0
C_2	33	279
C_3	51	452
C_4	97	533
C_5	127	541
C_6	160	185

TABLE 5 DATA SUMMARY, CASE NO. 4

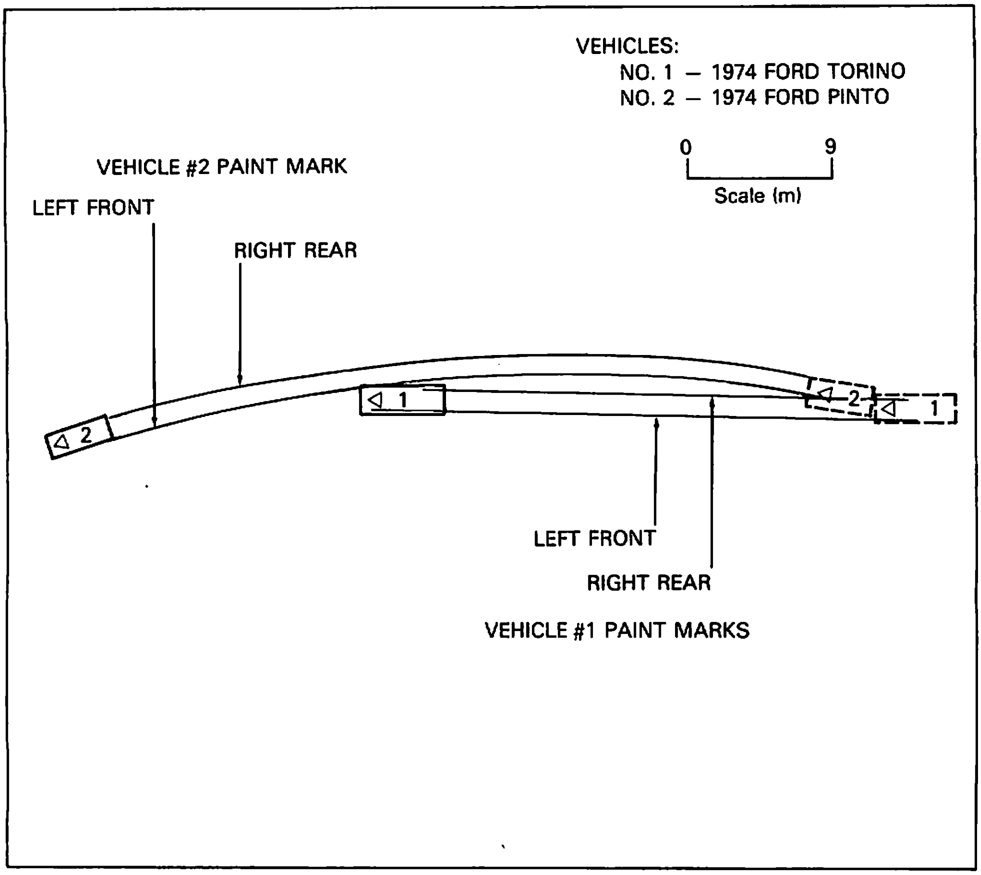


FIG. 15 SCENE DIAGRAM, CASE NO. 5

FIG. 16 CASE 5, V1 POST TEST

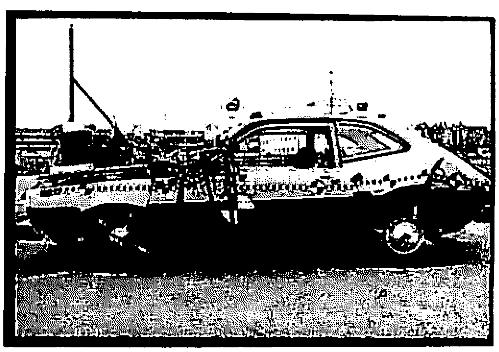


FIG. 17 CASE 5, V2 POST TEST

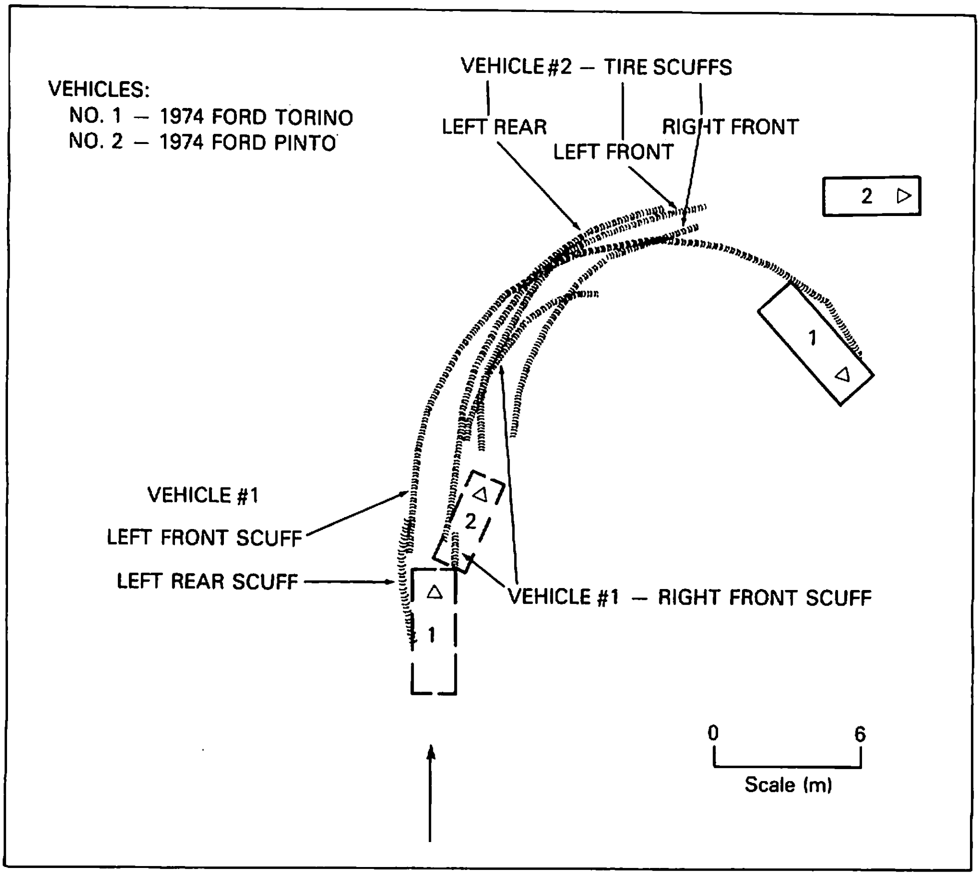


FIG. 18 SCENE DIAGRAM, CASE NO. 6

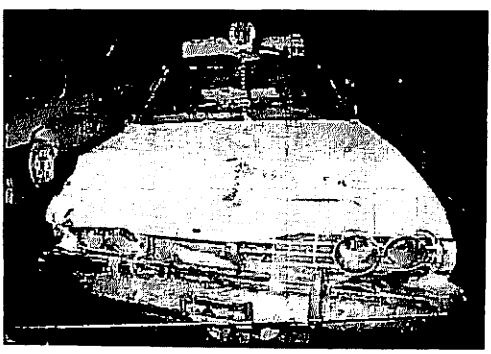


FIG. 19 CASE 6, V1 POST TEST

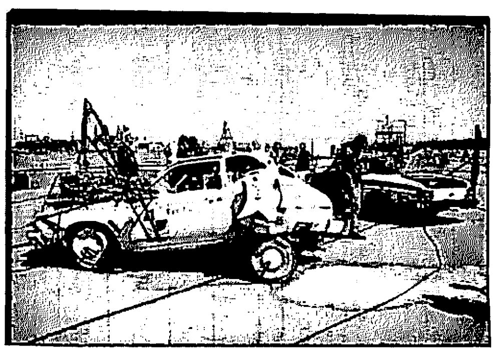


FIG. 20 CASE 6, V2 POST TEST

	10° OFFSET FRONT-TO-REAR	
CASE NO. 5 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Ford Torino	74 Ford Pinto
TEST MASS (KG)	2259	1424
IMPACT SPEED (KM/HR)	33.9	0
VELOCITY CHANGE Δu	−15.2	25.3
(KM/HR) Δv	−0.6	−0.3
ANGLE (DEG)	2.4	179
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(0., 0., 0.)	(4.6, 0.7, 10)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(34.0, 0.6, −4)	(55.3, −2.0, −19)
ROTATION (DEGREES)		
− COLLISION PHASE	1	0
− POST-COLLISION	−5	−29
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	15	0
PITCH (DEGREES)	<2.5 max	−17 max
ROLL (DEGREES)	< ± 2.5	−10 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.1	.1
LR	.1	.1
STEERING DATA (POST-IMPACT) (DEG;CW>0)	−2 max	<1 (ave.)
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	12FZEW1	06BZEW1
DAMAGE MEASUREMENTS (MM) L	762	762
D	559	127
C_1	51	165
C_2	51	173
C_3	38	147
C_4	46	127
C_5	51	97
C_6	58	76

TABLE 6 DATA SUMMARY, CASE NO. 5

	10° OFFSET FRONT-TO-REAR	
CASE NO. 6 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Ford Torino	74 Ford Pinto
TEST MASS (KG)	2259	1447
IMPACT SPEED (KM/HR)	61.9	0
VELOCITY CHANGE Δu	−29.9	35.5
(KM/HR) Δv	0.6	4.5
ANGLE (DEG)	−1.2	187
PULSE WIDTH (ms)	275	275
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(0., 0., 1)	(5.0, 1.0, 10)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(13.0, 16.6, 138)	(19.5, 19.1, 88)
ROTATION (DEGREES)		
− COLLISION PHASE	−	−
− POST-COLLISION	−	−
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	37	30
PITCH (DEGREES)	−2 max	−7 max
ROLL (DEGREES)	−7 max	± 8 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	20 max	12 max; 7 ave.
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	12FZEW3	05BYEW5
DAMAGE MEASUREMENTS (MM) L	1054	1062
D	409	231
C_1	160	914
C_2	198	808
C_3	249	737
C_4	318	610
C_5	376	495
C_6	465	376

TABLE 7 DATA SUMMARY, CASE NO. 6

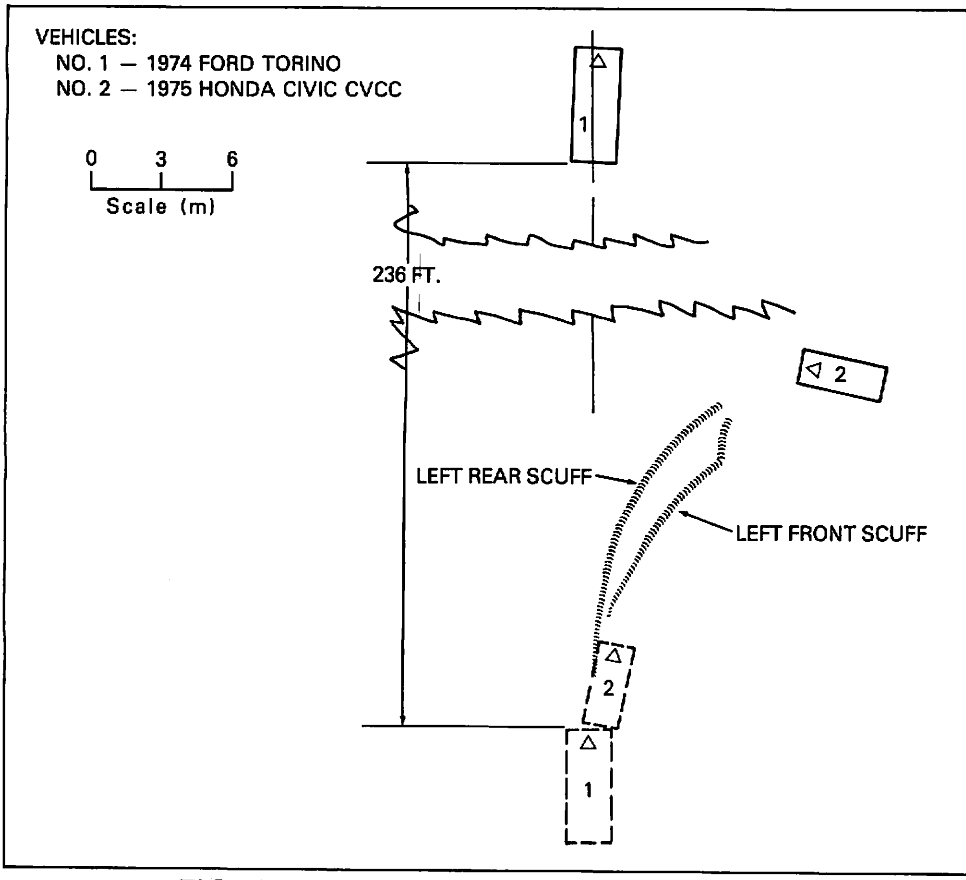


FIG. 21 SCENE DIAGRAM, CASE NO. 7

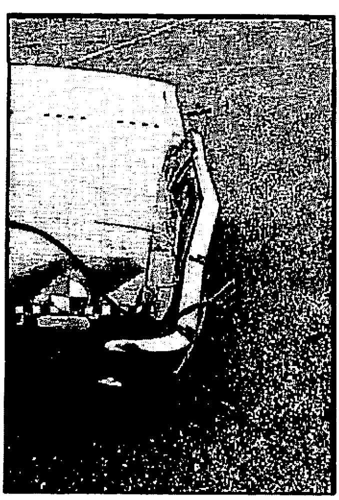


FIG. 22 CASE 7, V1 POST TEST

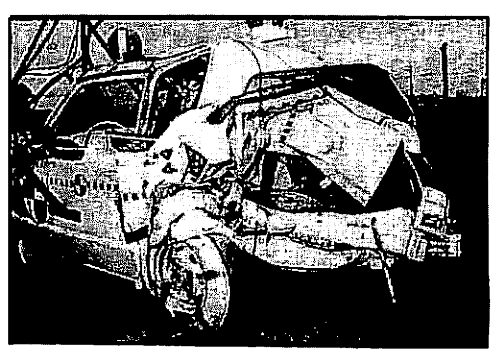


FIG. 23 CASE 7, V2 POST TEST

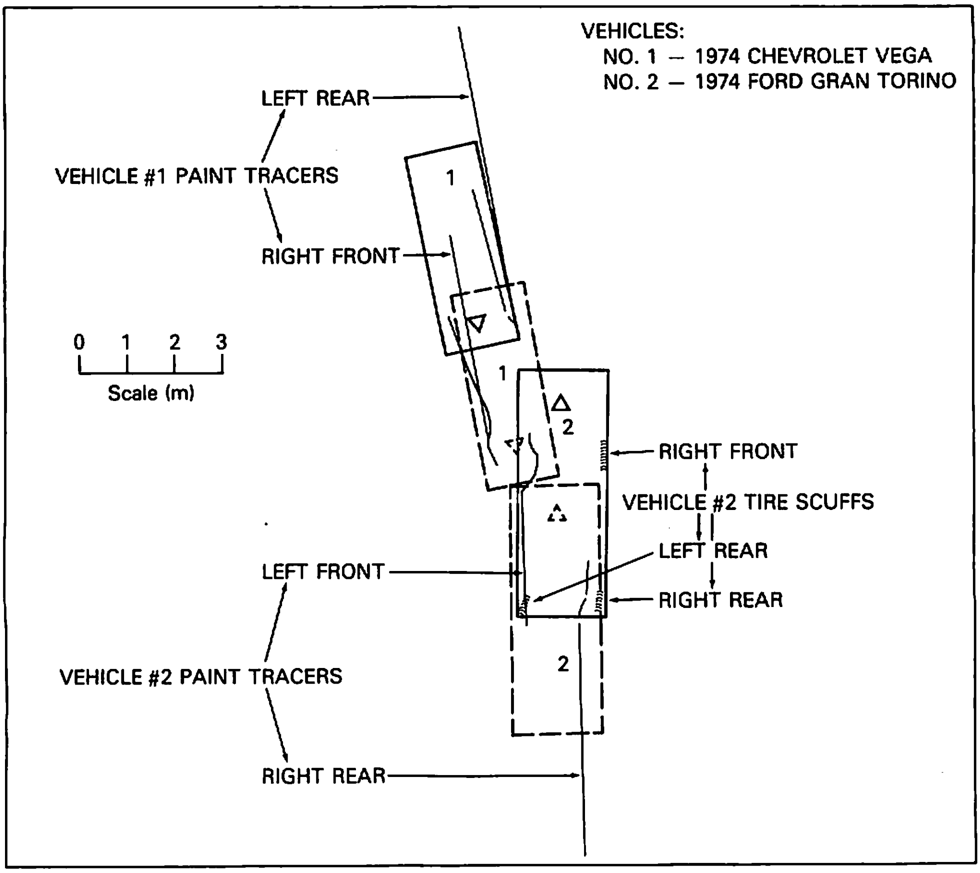


FIG. 24 SCENE DIAGRAM, CASE NO. 8

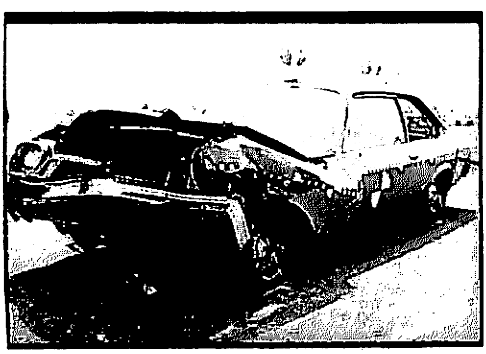


FIG. 25 CASE 8, V1 POST TEST

FIG. 26 CASE 8, V2 POST TEST

CASE NO. 7 (REF. 5)	10° OFFSET FRONT-TO-REAR VEHICLE #1	10° OFFSET FRONT-TO-REAR VEHICLE #2
YEAR/MAKE/MODEL	74 Ford Torino	74 Honda Civic
TEST MASS (KG)	2091	1150
IMPACT SPEED (KM/HR)	63.5	0
VELOCITY CHANGE (KM/HR) Δu	−26.1	40
Δv	0.3	−2.9
ANGLE (DEG)	−1	175
PULSE WIDTH (ms)	250	250
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(0., 0., 0)	(4.5, 1.0, 10)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(73.8, 0., 3)	(17.3, 11.9, 282)
ROTATION (DEGREES) – COLLISION PHASE	5	–
– POST-COLLISION	–	–
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	12	70
PITCH (DEGREES)	3 max	12 max
ROLL (DEGREES)	−4 max; 6 max	−12 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	−12 @ 250 ms	−3 max
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	12FZEW1	05BDEW8
DAMAGE MEASUREMENTS (MM) L	851	1346
D	516	−41
C_1	36	914
C_2	36	927
C_3	51	800
C_4	53	584
C_5	58	338
C_6	74	152

TABLE 8 DATA SUMMARY, CASE NO. 7

CASE NO. 8 (REF. 5)	10° OFFSET FRONT-TO-SIDE VEHICLE #1	10° OFFSET FRONT-TO-SIDE VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Vega	74 Ford Gran Torino
TEST MASS (KG)	1388	2214
IMPACT SPEED (KM/HR)	32.6	32.6
VELOCITY CHANGE (KM/HR) Δu	−38.4	−25.0
Δv	1.3	3.2
ANGLE (DEG)	−2	−7.3
PULSE WIDTH (ms)	225	225
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(4.8, -1.2, 171)	(0., 0., 0.)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(7.8, −2., 170)	(2.6, 0.1, 0)
ROTATION (DEGREES) – COLLISION PHASE	−6	0
– POST-COLLISION	5	0
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	−30	0
PITCH (DEGREES)	−8 max	−5 max
ROLL (DEGREES)	−5 max	11 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	2 ave.	6 max ; 4 ave.
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	12FYEW3	12FYEW3
DAMAGE MEASUREMENTS (MM) L	826	820
D	−71	−328
C_1	559	749
C_2	513	668
C_3	470	584
C_4	427	475
C_5	381	363
C_6	318	279

TABLE 9 DATA SUMMARY, CASE NO. 8

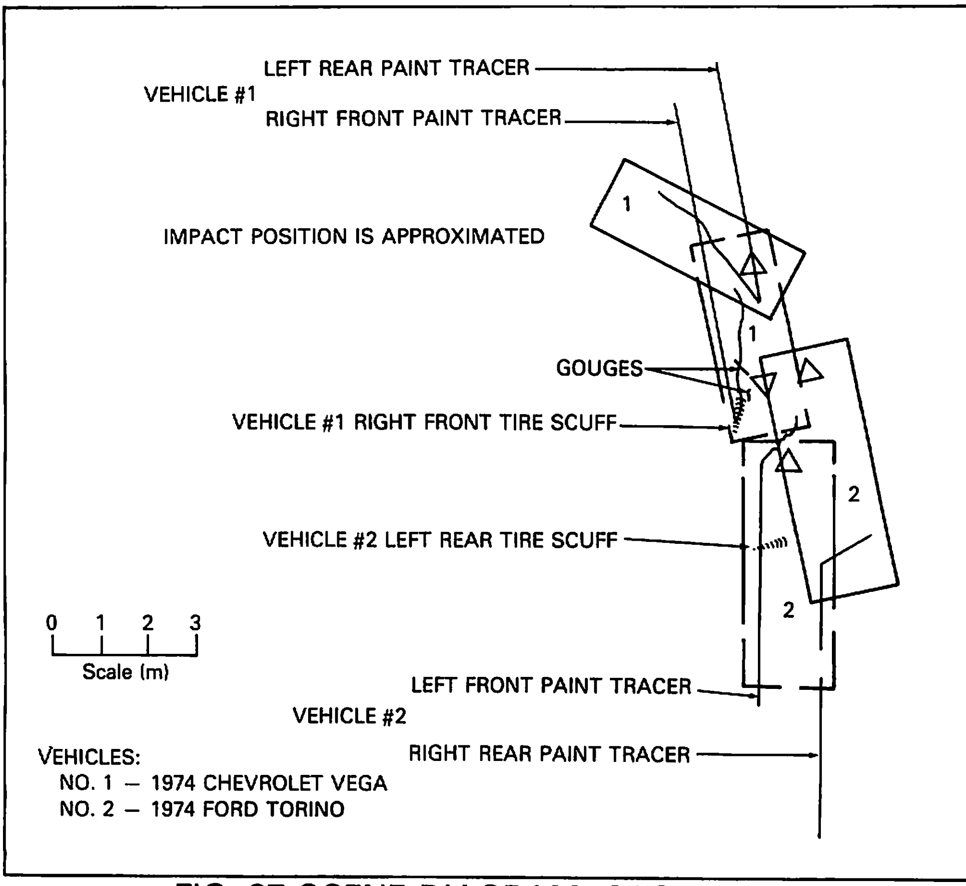


FIG. 27 SCENE DIAGRAM, CASE NO. 9

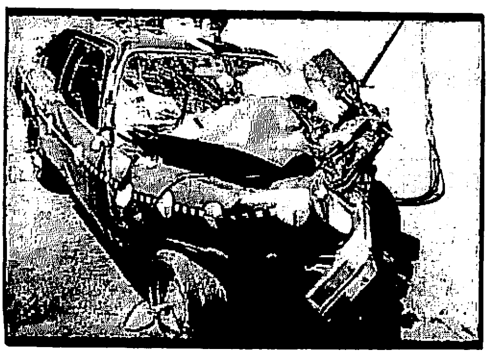


FIG. 28 CASE 9, V1 POST TEST

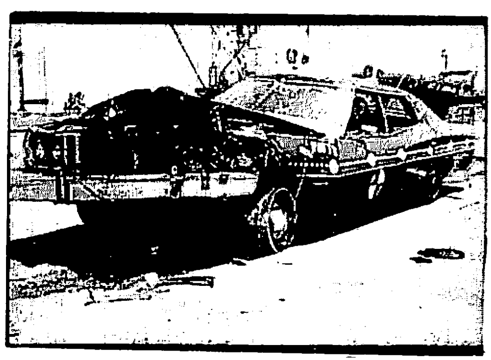


FIG. 29 CASE 9, V2 POST TEST

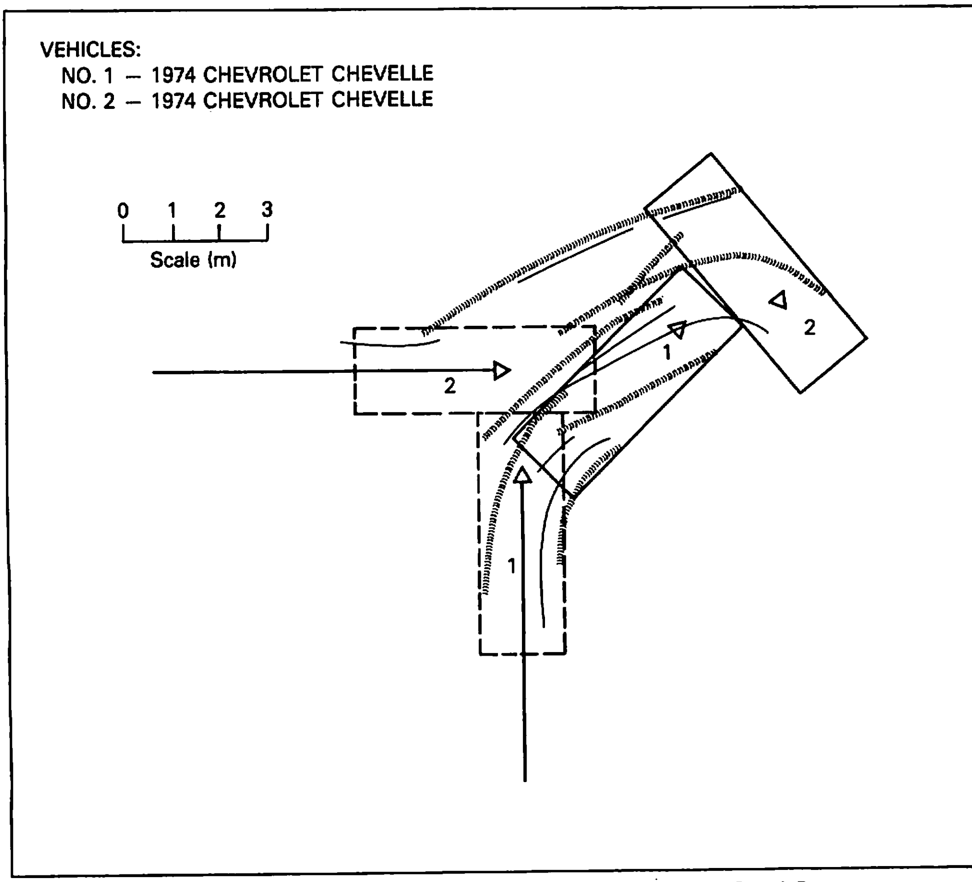


FIG. 30 SCENE DIAGRAM, CASE NO. 10

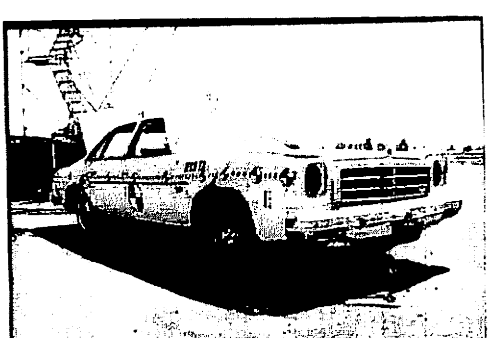


FIG. 31 CASE 10, V1 POST TEST

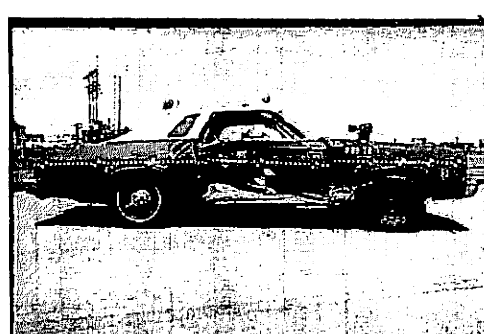


FIG. 32 CASE 10, V2 POST TEST

CASE NO. 9 (REF. 5)	10° OFFSET FRONT-TO-FRONT VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Vega	74 Ford Torino
TEST MASS (KG)	1429	2059
IMPACT SPEED (KM/HR)	50.4	50.4
VELOCITY CHANGE (KM/HR) Δu	−66.4	−41.6
VELOCITY CHANGE (KM/HR) Δv	3.5	7.7
ANGLE (DEG)	−3	−11
PULSE WIDTH (ms)	225	225
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(4.8, −1.2, 171)	(0., 0., 0.)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(6.8, −1.7, 118)	(2.1, 0.8, −12)
ROTATION (DEGREES) — COLLISION PHASE	−10	−2
ROTATION (DEGREES) — POST-COLLISION	−53	−12
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	−90	−60
PITCH (DEGREES)	−10 max	−6 max
ROLL (DEGREES)	−23 max	16 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	45 (constant)	2 (constant)
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	12FDEW4	12FYEW4
DAMAGE MEASUREMENTS (MM) L	813	719
D	71	−269
C_1	980	1003
C_2	879	838
C_3	749	732
C_4	660	605
C_5	498	488
C_6	363	381

TABLE 10 DATA SUMMARY, CASE NO. 9

CASE NO. 10 (REF. 5)	90° FRONT-TO-SIDE VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Chev. Chevelle	74 Chev. Chevelle
TEST MASS (KG)	2032	2136
IMPACT SPEED (KM/HR)	33.2	33.2
VELOCITY CHANGE (KM/HR) Δu	−20.8	−11.5
VELOCITY CHANGE (KM/HR) Δv	13.8*	−12.8*
ANGLE (DEG)	−33	48
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(−3.3, 1.0, 0)	(0., 0.6, 90)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(−0.2, 3.4, 46)	(2.0, 33.6, 141)
ROTATION (DEGREES) — COLLISION PHASE	15	0
ROTATION (DEGREES) — POST-COLLISION	31	51
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	114	18
PITCH (DEGREES)	0	0
ROLL (DEGREES)	7 max	−15 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW>0)	12 max	17 max; 12 ave.
TIRE-TERRAIN FRICTION COEFFICIENT	0.87	0.87
COLLISION DEFORMATION CLASSIFICATION	11FDEW1	02RYEW1
DAMAGE MEASUREMENTS (MM) L	1854	2146
D	0	381
C_1	69	157
C_2	91	211
C_3	–	234
C_4	–	150
C_5	–	112
C_6	–	20

TABLE 11 DATA SUMMARY, CASE NO. 10

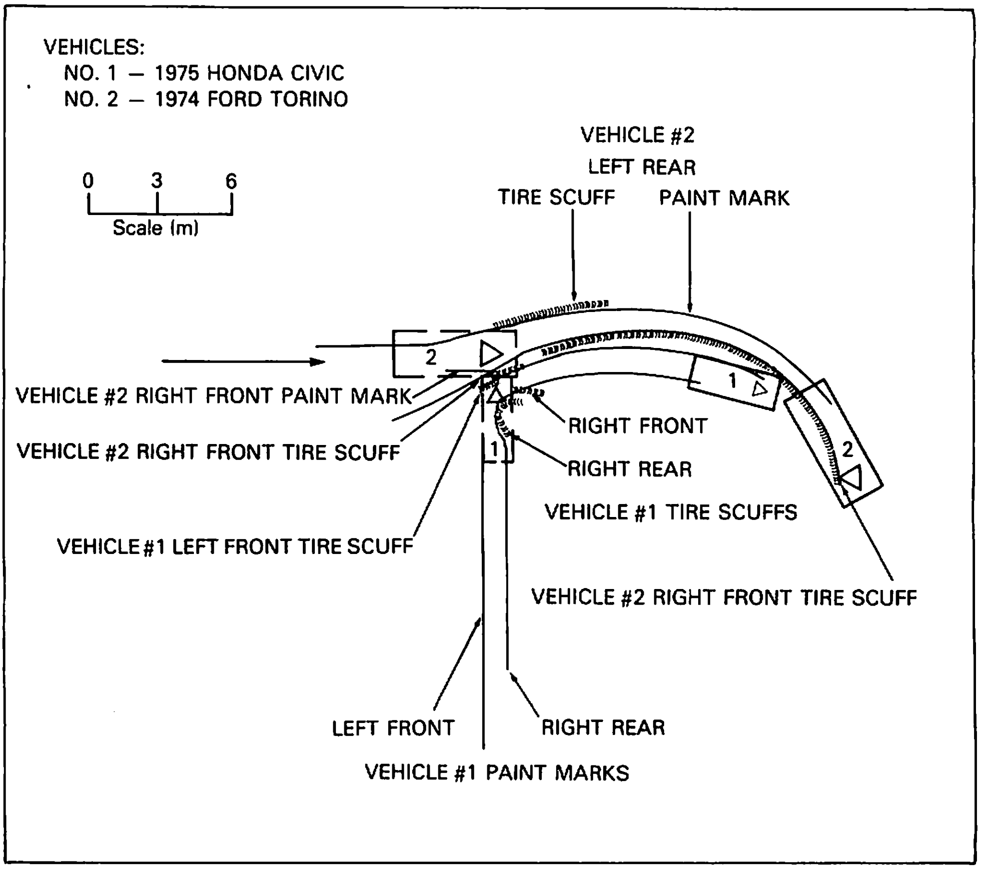


FIG. 33 SCENE DIAGRAM, CASE NO. 11

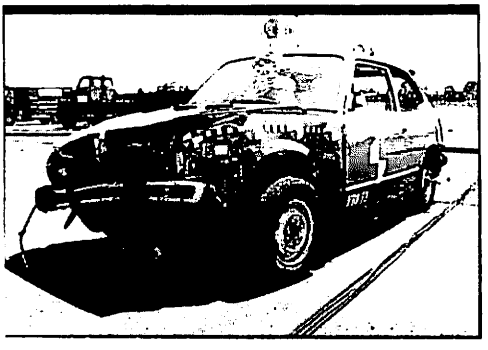


FIG. 34 CASE 11, V1 POST TEST

FIG. 35 CASE 11, V2 POST TEST

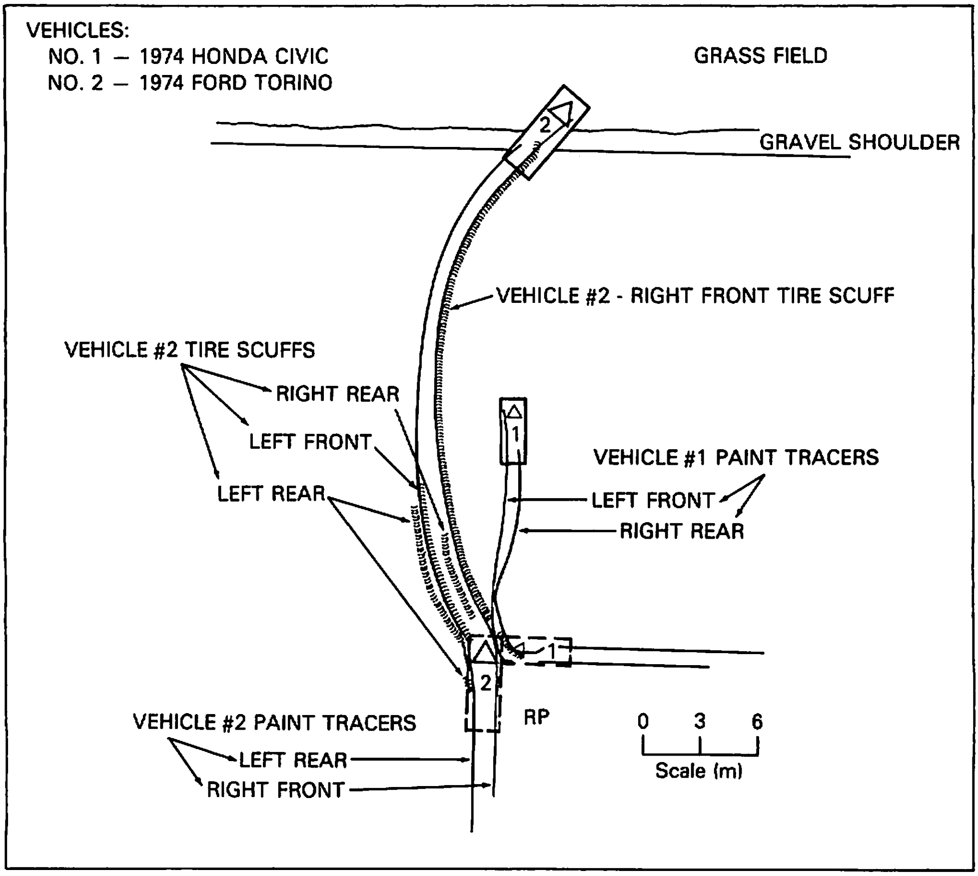


FIG. 36 SCENE DIAGRAM, CASE NO. 12

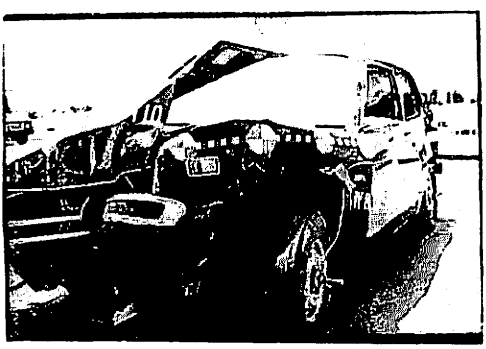


FIG. 37 CASE 12, V1 POST TEST

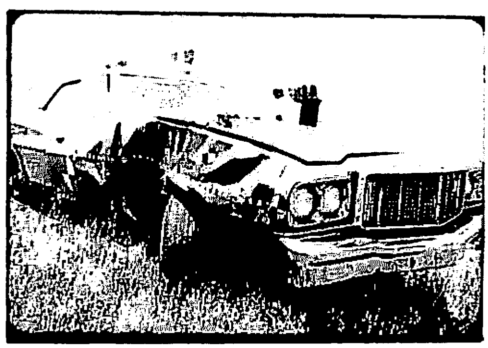


FIG. 38 CASE 12, V2 POST TEST

	90° FRONT-TO-SIDE	
CASE NO. 11 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Honda Civic	74 Ford Torino
TEST MASS (KG)	1030	2236
IMPACT SPEED (KM/HR)	33.9	33.9
VELOCITY CHANGE (KM/HR) Δu	−28.3	−8.0
Δv	15.8	−11.8
ANGLE (DEG)	−29	56
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(0., 0., 0.)	(2.6, -1.8, 90)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(1.2, 10.8, 104)	(−1.5, 15.1, 152)
ROTATION (DEGREES) – COLLISION PHASE – POST-COLLISION	27	−10
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	180	−45
PITCH (DEGREES)	−5 max	7.5 max
ROLL (DEGREES)	−6 max	2.5 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.1
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW >0)	11 max	−6 ave.
TIRE-TERRAIN FRICTION COEFFICIENT	0.87	0.87
COLLISION DEFORMATION CLASSIFICATION	11FDEW2	02RFEW2,03RPEW1
DAMAGE MEASUREMENTS (MM) L	1265	1384
D	41	38
C_1	127	198
C_2	147	117
C_3	318	122
C_4	191	97
C_5	191	71
C_6	241	38

TABLE 12 DATA SUMMARY, CASE NO. 11

	90° FRONT-TO-SIDE	
CASE NO. 12 (REF. 5)	VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	74 Honda Civic	74 Ford Torino
TEST MASS (KG)	1052	2155
IMPACT SPEED (KM/HR)	53.2	53.2
VELOCITY CHANGE (KM/HR) Δu	−43.7 *	−14.1
Δv	25.6 *	−17.6
ANGLE (DEG)	−30	51
PULSE WIDTH (ms)	200	200
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)	(0., 0., 0.)	(2.6, -1.8, 90)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)	(1.5, 13.1, 87)	(0., 30.3, 129)
ROTATION (DEGREES) – COLLISION PHASE – POST-COLLISION	55	−12
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	300	−72
PITCH (DEGREES)	−7 max	−4 max
ROLL (DEGREES)	8 max	−8 max
DECIMAL PORTION OF WHEEL LOCK-UP RF	.01	.01
LF	.01	.01
RR	.2	.2
LR	.2	.2
STEERING DATA (POST-IMPACT) (DEG;CW >0)	−22 max	−10 max
TIRE-TERRAIN FRICTION COEFFICIENT	.87	.87
COLLISION DEFORMATION CLASSIFICATION	11FDEW2	02RFEW2
DAMAGE MEASUREMENTS (MM) L	1207	1346
D	−71	1689
C_1	178	234
C_2	259	165
C_3	350	155
C_4	226	135
C_5	178	114
C_6	229	13

TABLE 13 DATA SUMMARY, CASE NO. 12

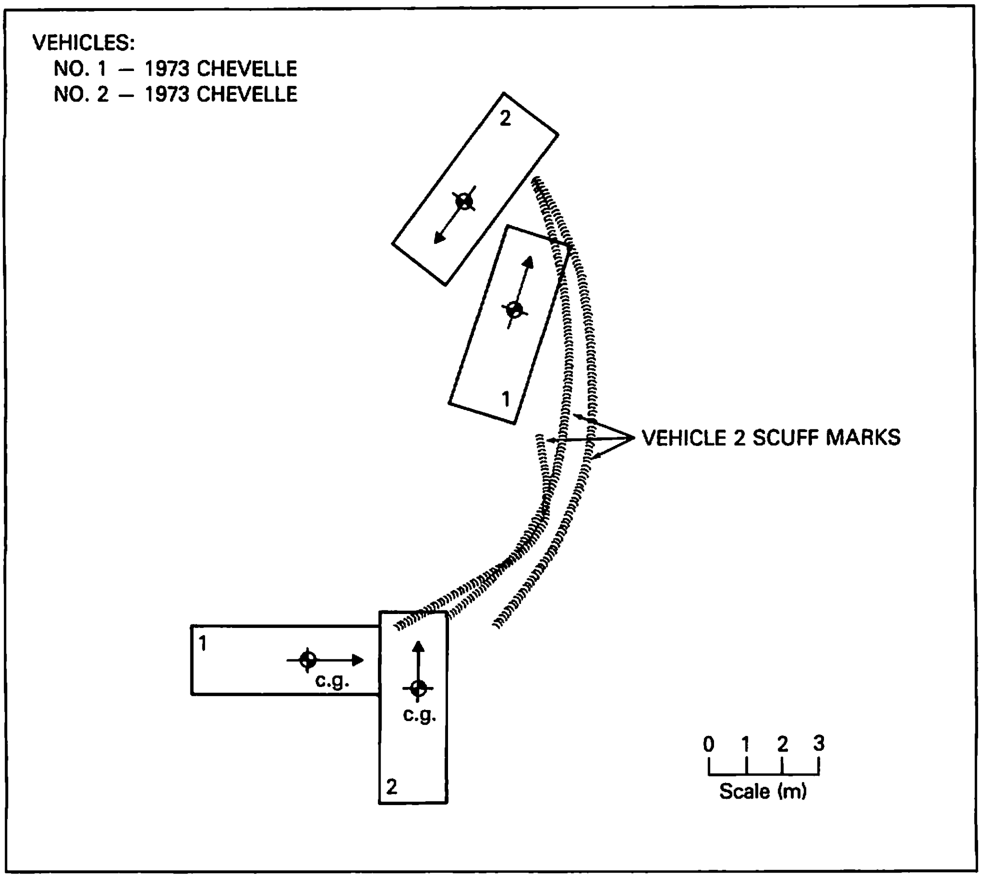


FIG. 39 SCENE DIAGRAM, CASE NO. 13

Vehicle Photos Unavailable

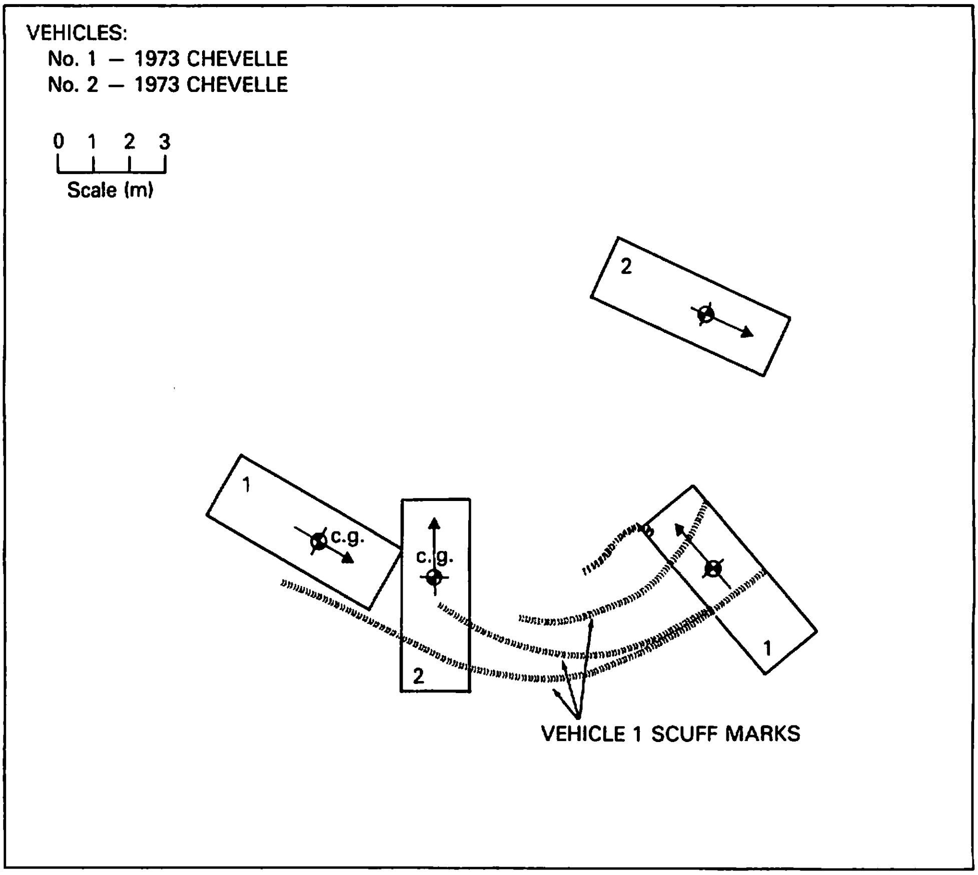


FIG. 40 SCENE DIAGRAM, CASE NO. 14

Vehicle Photos Unavailable

CASE NO. 13 (REF. 4)	90° FRONT-TO-SIDE VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	73 Chev. Chevelle	73 Chev. Chevelle
TEST MASS (KG)	1732	1741
IMPACT SPEED (KM/HR)	41.0	42.4
VELOCITY CHANGE (KM/HR) Δu	−21.8	−12.0
Δv	−4.3	22.9
ANGLE (DEG)	11	−62
PULSE WIDTH (ms)	160	160
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(2.4, 0., 90)	(1.5, 3.0, 0)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(15.1, 4.3, 18)	(12.3, 5.8, −140)
ROTATION (DEGREES) – COLLISION PHASE	−10	–
– POST-COLLISION	−62	−140
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	−150	−40
PITCH (DEGREES)	–	–
ROLL (DEGREES)	–	–
DECIMAL PORTION OF WHEEL LOCK-UP RF	.05	.05
LF	.05	.05
RR	.1	.1
LR	.1	.1
STEERING DATA (POST-IMPACT) (DEG;CW > 0)	–	–
TIRE-TERRAIN FRICTION COEFFICIENT	.75	.75
COLLISION DEFORMATION CLASSIFICATION	01FDEW3	10LYEW3
DAMAGE MEASUREMENTS (MM) L	1951	2642
D	−305	254
C_1	229	0
C_2	152	76
C_3	127	76
C_4	127	254
C_5	127	254
C_6	152	0

TABLE 14 DATA SUMMARY, CASE NO. 13

CASE NO. 14 (REF. 4)	60° FRONT-TO-SIDE VEHICLE #1	VEHICLE #2
YEAR/MAKE/MODEL	73 Chev. Chevelle	73 Chev. Chevelle
TEST MASS (KG)	1732	1741
IMPACT SPEED (KM/HR)	61.6	42.4
VELOCITY CHANGE (KM/HR) Δu	−20.2	−24.0
Δv	−4.4	30.6
ANGLE (DEG)	12	−51
PULSE WIDTH (ms)	150	150
IMPACT COORDINATES (X, Y, Ψ); (M, M, DEG)	(8.0, −0.3, 120)	(6.2, 3.4, 0)
REST COORDINATES (X, Y, Ψ); (M, M, DEG)	(6.7, 11.4, −41)	(14.3, 10.6, 114)
ROTATION (DEGREES) – COLLISION PHASE	−19	−17
– POST-COLLISION	−142	−249
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)	−105	−250
PITCH (DEGREES)	–	–
ROLL (DEGREES)	–	–
DECIMAL PORTION OF WHEEL LOCK-UP RF	.05	.05
LF	.05	.05
RR	.1	.1
LR	.1	.15
STEERING DATA (POST-IMPACT) (DEG;CW > 0)	–	–
TIRE-TERRAIN FRICTION COEFFICIENT	0.75	0.75
COLLISION DEFORMATION CLASSIFICATION	12FDEW4	10LZEW3
DAMAGE MEASUREMENTS (MM) L	1118	2540
D	−498	−879
C_1	1118	0
C_2	610	254
C_3	483	356
C_4	406	381
C_5	305	305
C_6	152	0

TABLE 15 DATA SUMMARY, CASE NO. 14

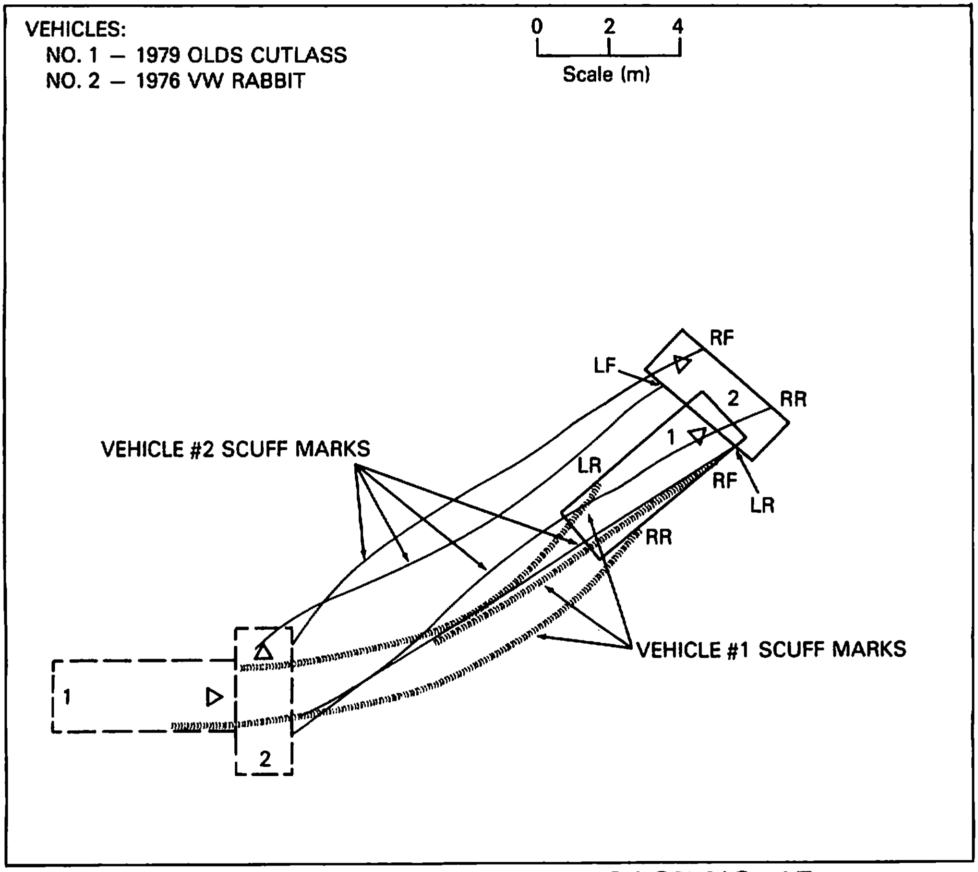


FIG. 41 SCENE DIAGRAM, CASE NO. 15

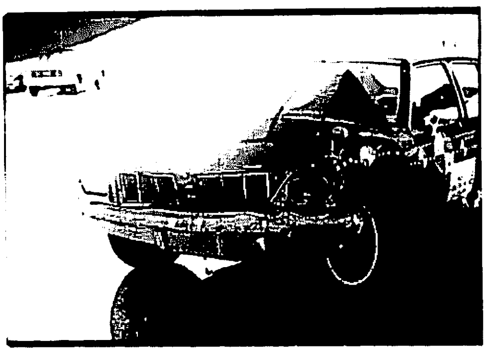


FIG. 42 CASE 15, V1 POST TEST

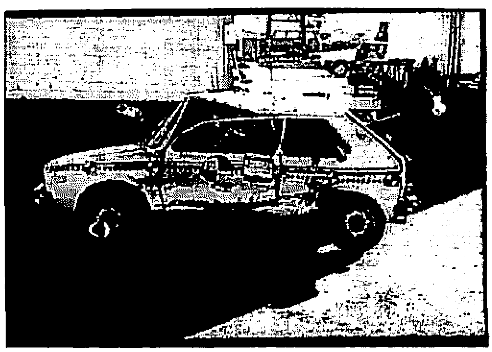


FIG. 43 CASE 15, V2 POST TEST

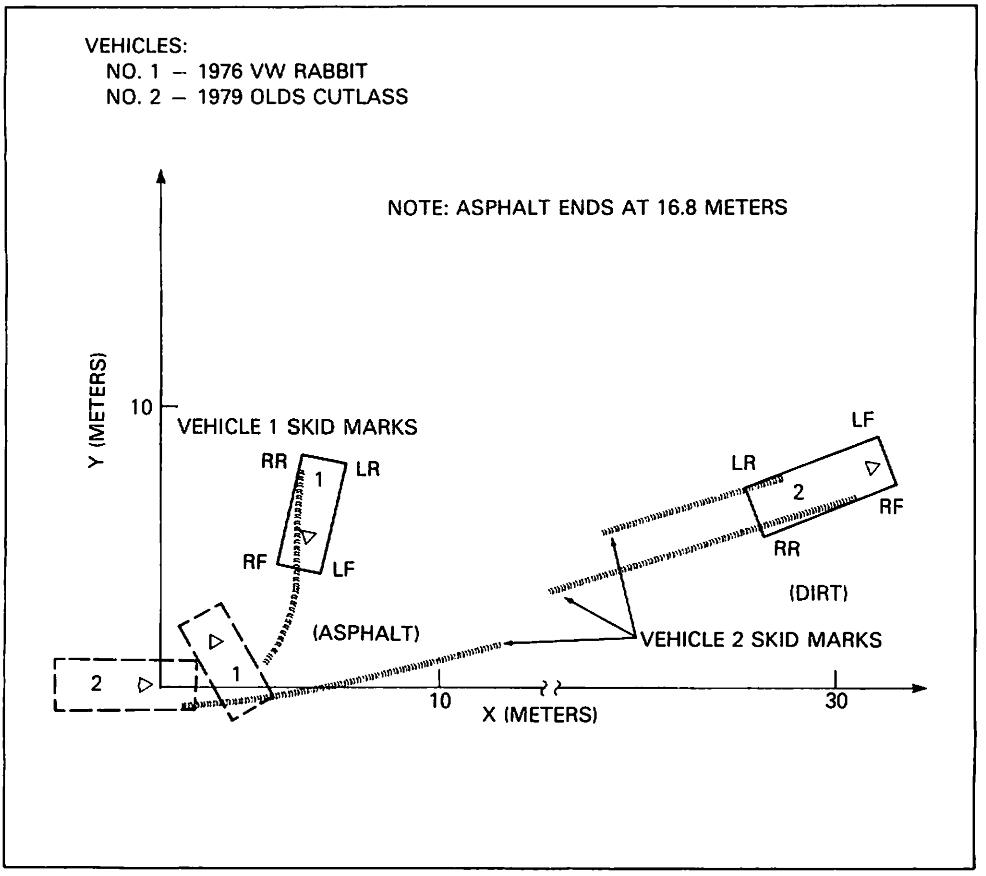


FIG. 44 SCENE DIAGRAM, CASE NO. 16

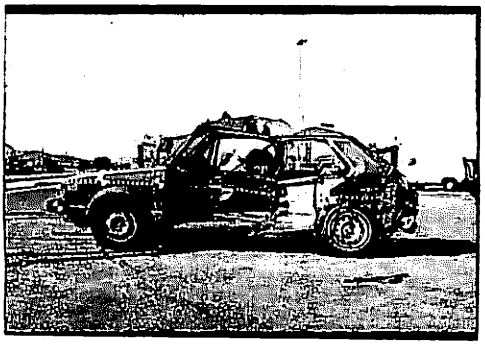


FIG. 45 CASE 16, V1 POST TEST

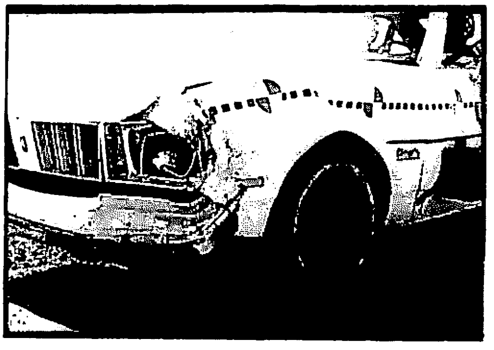


FIG. 46 CASE 16, V2 POST TEST

CASE NO. 15 (REF. 6)		90° FRONT-TO-SIDE VEHICLE #1	90° FRONT-TO-SIDE VEHICLE #2
YEAR/MAKE/MODEL		79 Olds Cutlass	1976 VW Rabbit
TEST MASS (KG)		1474	1051
IMPACT SPEED (KM/HR)		64.3	32.8
VELOCITY CHANGE (KM/HR)	Δu	−29.7	−9.9 *
	Δv	−16.2	37.8 *
ANGLE (DEG)		29	−75
PULSE WIDTH (ms)		145	145
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)		(0., 0., 0.)	(3.1,−0.1, −90)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)		(13.0, −6.0, −41)	(14.4, −8.0, 220)
ROTATION (DEGREES) — COLLISION PHASE		—	—
— POST-COLLISION		counterclockwise	counterclockwise
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)		—	—
PITCH (DEGREES)		—	—
ROLL (DEGREES)		—	—
DECIMAL PORTION OF WHEEL LOCK-UP	RF	.1	.6
	LF	.1	.5
	RR	.1	.8
	LR	.1	.5
STEERING DATA (POST-IMPACT) (DEG;CW >0)		—	—
TIRE-TERRAIN FRICTION COEFFICIENT		.70	.70
COLLISION DEFORMATION CLASSIFICATION		01FDEW2	10LPEW4
DAMAGE MEASUREMENTS (MM)	L	1752	1803
	D	0	−114
	C_1	351	300
	C_2	305	432
	C_3	267	394
	C_4	224	356
	C_5	51	292
	C_6	102	152

TABLE 16 DATA SUMMARY, CASE NO. 15

CASE NO. 16 (REF. 6)		60° FRONT-TO-SIDE VEHICLE #1	60° FRONT-TO-SIDE VEHICLE #2
YEAR/MAKE/MODEL		76 VW Rabbit	79 Olds Cutlass
TEST MASS (KG)		1070	1637
IMPACT SPEED (KM/HR)		24.6	48.4
VELOCITY CHANGE (KM/HR)	Δu	−13.7	16.7
	Δv	27	−5.0
ANGLE (DEG)		−63	17
PULSE WIDTH (ms)		135	135
IMPACT COORDINATES (X, Y,Ψ); (M, M, DEG)		(3.0, −0.9,240)	(0., 0., 0.)
REST COORDINATES (X, Y,Ψ); (M, M, DEG)		(6.3, −5.8, 102)	(30.8, −7.3, −27)
ROTATION (DEGREES) COLLISION PHASE		—	—
POST-COLLISION		counterclockwise	counterclockwise
ANGULAR VELOCITY (ω) AT SEPARATION (DEG/SEC)		—	—
PITCH (DEGREES)			—
ROLL (DEGREES)		—	—
DECIMAL PORTION OF WHEEL LOCK-UP	RF	.1	.1
	LF	.1	.1
	RR	.2	.1
	LR	1.0	.1
STEERING DATA (POST-IMPACT) (DEG;CW >0)		—	—
TIRE TERRAIN FRICTION COEFFICIENT		0.70	0.70
COLLISION DEFORMATION CLASSIFICATION		10LPEW4	01FDEW1
DAMAGE MEASUREMENTS (MM)	L	1638	1422
	D	−470	−330
	C_1	152	152
	C_2	356	127
	C_3	508	81
	C_4	470	51
	C_5	422	38
	C_6	246	13

TABLE 17 DATA SUMMARY, CASE NO. 16