Automotive Collision Impact Phenomena

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A discussion of what happens to occupants of an automobile during a collision is presented on the basis of findings from a series of controlled car crashes. In order to cover a broader range as well as provide maximum severity of load to components undergoing test, cars were impacted into a barrier in addition to the car-to-car crashes. Items such as deceleration of passenger compartment, seat belt loads, occupant decelerations, etc., are reported graphically as they vary with impact velocity.

● THE words "automobile collision" are used repeatedly to describe how approximately 100 people in this country become statistics, and how another 6,000 receive injuries every day. The time, during which the decelerations and forces generated in a collision are of sufficient magnitude to cause a fatality, is very short. In fact, the total time consumed in a whole day involves less than thirty seconds to produce all these fatalities, and only about thirty minutes to inflict this multitude of injuries. It is with these seconds and minutes of impact that the authors have been concerned during the past year, and upon which they would like to shed some light in this paper.

The desire to decrease the injury-producing potential of the present day automobile introduced numerous specific questions and problems. Answers could not be supplied from available data and a study project was initiated in the Ford Motor Company Engineering Research Department to explore and analyze impact phenomena.

Normally, the research engineer can simulate in the laboratory the conditions imposed on a particular system under investigation and with little difficulty eliminate or isolate the effects of selected parameters. The foregoing statement holds true, however, only when considerable information concerning the system is available and its reduction and subsequent analysis can be undertaken without violating the general characteristics of the system. After detailed consideration of possible laboratory collision simulators, it became apparent that the information necessary to design a simulator, largely embraced all the information that ultimately would be gained by its use. Design factors, such as deformations, decelerations, stopping distance and time, could be determined only by staging full-scale collisions.

Since it was impossible to simulate the infinite number of possible accident situations and conditions, two general categories of controlled collisions were studied, car-to-car and barrier. The car-to-car type was selected because it accounts for the largest percentage of injuries. The barrier collision was used to establish the maximum deceleration and force conditions for any given impact velocity.

The purpose of these full-scale crash tests is to study the kinematics of passengers, determine the forces and decelerations acting on both the vehicle and the passengers, and to evaluate various safety features incorporated into the vehicle.

General Description

The full-scale crashes, so far conducted, have been accomplished by towing an instrumented test car toward a stationary car or barrier. The vehicle is towed at the desired velocity and released just before impact. A mobile instrumentation van is driven beside the test car, (Figures 1 and 2). Anthropomorphic dummies are variously positioned in the moving and stationary vehicles. Typical barrier and car-to-car impacts are demonstrated in Figures 3 and 4. Various 1952 through 1955 models of Ford, Mercury and Lincoln vehicles have been used in these tests.

The test car and the towing vehicle are displaced 11 ft laterally and 34 ft in the direction of motion. Towing in this manner is made possible by the use of a bridle on the towing cable (Figure 5) and setting the front wheels of the test car to a negative camber. The steering mechanism is centered by trial towing and then held in a neutral position with spring tension applied to the steering wheel. A quick release mechanism, Figure

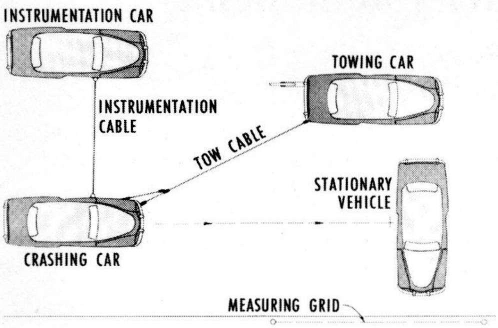

Figure 1. Schematic of vehicle arrangement for full scale crash tests.

6), is actuated manually from the towing vehicle. Table 1 charts towing distance as a function of velocity. These distances are for a Thunderbird, with automatic transmission, operating at full throttle while towing a 4,000 lb test car.

In car-to-car crashes, brakes are applied after impact to prevent vehicle runaway. The brake master cylinder is actuated pneumatically when a valve, mounted on the fender (Figure 5), is opened by a lanyard attached to the towing vehicle.

The 18 ft wide barrier, (Figures 7 and 8), is constructed to 2-ft diameter green logs 12 ft long which are embedded vertically 6 ft in the ground. A $\frac{1}{2}$-in. steel cable ties the logs together near the top, and a 6-in. slab of concrete binds them just below the surface. The logs are backed by a sand pile retained by planking. The front face of the barrier is provided with replaceable oak boards supported in the log crevices with concrete fill.

Four anthropomorphic test dummies have been used in these tests. These dummies were fabricated to Air Force specifications and, as purchased, are 6 ft tall and weigh approximately 200 lb. The articulation and weight distribution simulates that of a human being. Representative dummies are shown in Figures 9 and 10. The name FERD is an abbreviation for Ford Engineering Research Department. Table 2 gives the measured weight and size of these test dummies. It will be noted that FERD No. 1 has been modified to provide a size range for test purposes.

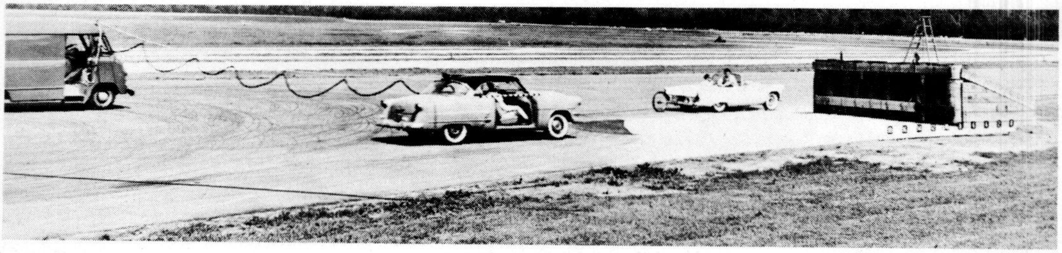

Figure 2. Moving toward barrier.

Instrumentation

Electronic instrumentation is the primary data source utilized in these full-scale crash tests. To augment this electronically recorded information, additional data is obtained from high-speed, motion picture photography and various mechanical measurements, such as, chassis point-to-point measurements before and after each test.

A multichannel recording oscillograph receives suitably amplified signals generated by accelerometers or other transducers which are mounted in the impacting car or test

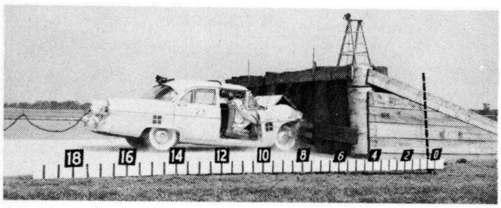

Figure 3. Barrier impact.

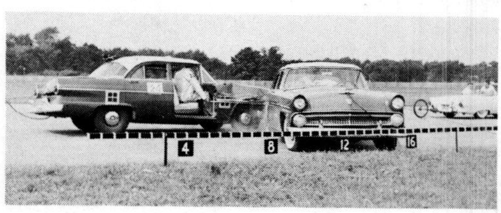

Figure 4. Car-to-car impact.

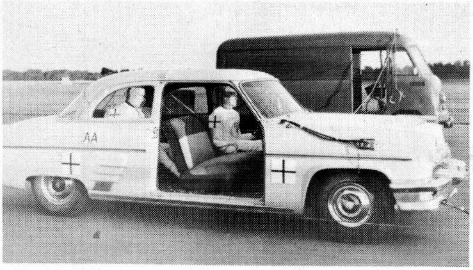

Figure 5. Towing bridle and brake operating valve.

Figure 6. Towing-cable release mechanism.

TABLE 1

APPROXIMATE TOWING DISTANCES FOR VARIOUS IMPACT VELOCITIES

Impact Velocity mph	Towing Distance feet
10	22
20	100
25	150
30	220
35	340
45	615

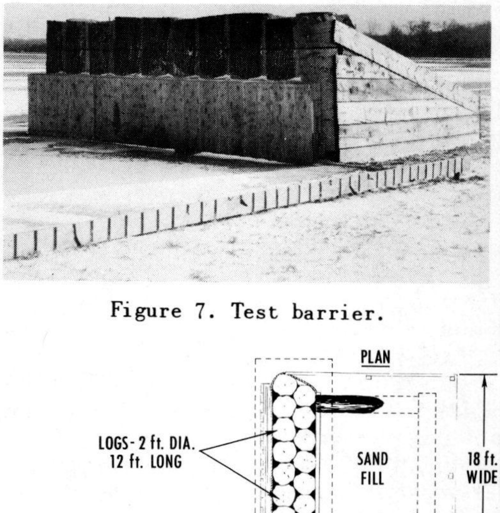

Figure 7. Test barrier.

TABLE 2

ANTHROPOMORPHIC TEST DUMMY PHYSICAL DATA

Dummy No.	Weight lb	Height ft-in.	Seating Ht in.
FERD No. 1	180	5-9½	36½
FERD No. 2	194	6-0	40
FERD No. 3	217	6-0	37½
FERD No. 4	194	6-0	38½

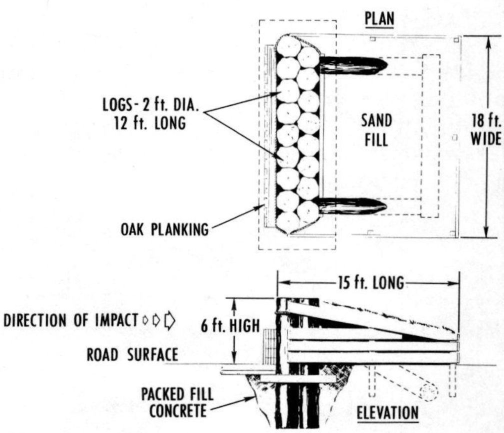

Figure 8. Test barrier construction.

dummies. Except for the transducers, all of the electronic equipment is contained in a mobile instrumentation van, (Figure 11), which connects to the crashing vehicle with multiple circuit cables. Since it is difficult to maintain a fixed distance between the instrumentation van and the test car, the cables which are wrapped together are supported from an elastic line of shock cord, (Figure 2). This arrangement permits a variation of 100 percent in the distance between the vehicles without dragging the cables on the ground or detaching the quick disconnects.

A portable power supply, complete with voltage regulator, is towed behind the van. This provides the power to operate the electronic equipment. However, each channel has its own predetermined bias supplied to the bridge by dry-cell batteries. All channels are balanced and calibrated separately in anticipation of the magnitude expected for each function.

Figure 9. Anthropomorphic test dummies.

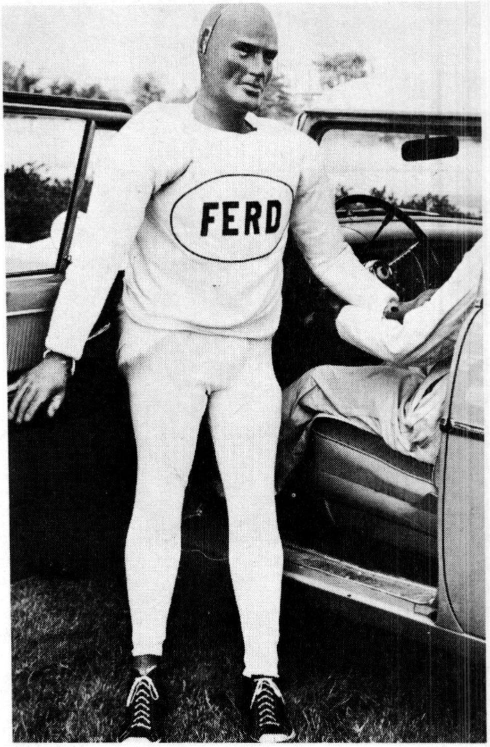

Figure 10. Anthropomorphic test dummies.

The normal photographic coverage for a test consists of two Fastax cameras which use black and white film and operate at 500 to 1,500 frames per second depending on the available light. Color film is taken at 128 and 24 frames per second, and one or more gunsight cameras, mounted on the moving car, take black and white exposures at 96 frames per second. In addition, still pictures are taken before, during and after impact. One or more doors are removed and holes are cut in the roof panel, (Figure 12), to provide adequate viewing and light conditions. Figure 12 also shows a typical mounting bracket for a gunsight camera. The locations of the Fastax cameras and a fixed reference scale are recorded to facilitate the analysis of the high-speed film. Targets, utilizing black on white, are placed on the body of the car and critical areas of the dummies so that displacement-time curves can be prepared.

Two typical transducers, an accelerometer mounted on a frame rail and a belt tensiometer, are shown in Figures 13 and 14 respectively. The exact time of various events is recorded on the oscillograph film record. For example, a bumper switch establishes the zero reference time. Additional time records also are obtained from aluminum foil contacts which cover critical impacting areas both of the car and dummy passengers.

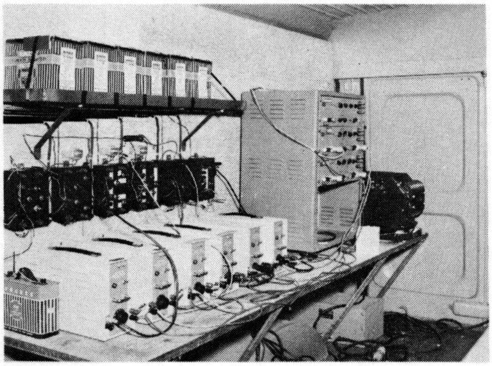

Figure 11. Mobile instrumentation van interior.

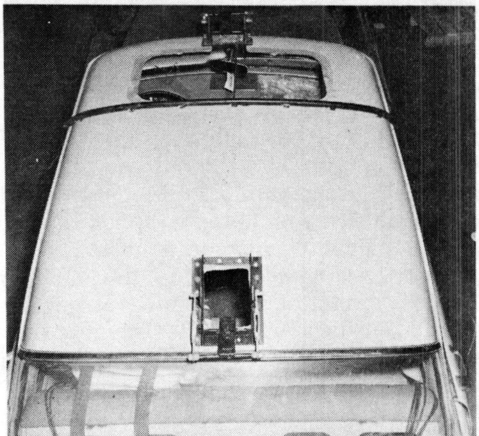

Figure 12. Roof area of test car.

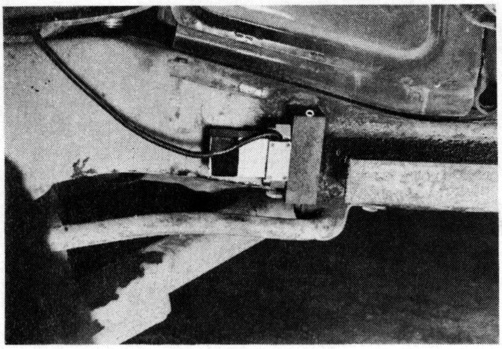

Figure 13. Accelerometer mounted on frame of test car.

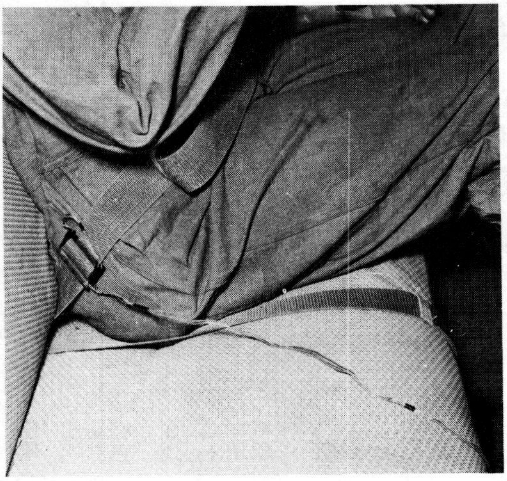

Figure 14. Belt tensiometer mounted on seat belt.

However, it must be realized that there are many variations possible in test conditions which cannot be completely controlled when staging full-scale collisions.

All the data in this paper, with the exception of the permanent deformation measurements, either have been taken directly from, or are a result of, the electronic recordings. Analysis of the high-speed motion pictures is a lengthy procedure for which reason it lags other phases of measurement and interpretation. It is believed that the corresponding measurements of functions by electronic and photographic techniques would not necessarily yield equivalent numerical results. As an example, visualize an accelerometer mounted to the floor structure and a target fastened to the outside of an automobile. The deceleration obtained from the transducer could peak very differently from

Test Results

The results so far obtained have been most encouraging. Of course, they represent only a beginning and a great deal of their worth has been towards the formulation of techniques and appreciation of the problems in this important aspect of automotive engineering. Although the results presented here are considered rather general, they appear fundamental to the understanding of the problem.

It is realized that there are many specific questions which are not considered in this paper, but time has not permitted a more complete study of the subject. As the program continues, specific conditions will be treated in greater detail. The information herein submitted is presented in anticipation that other investigators probably will disagree with certain aspects of the study.

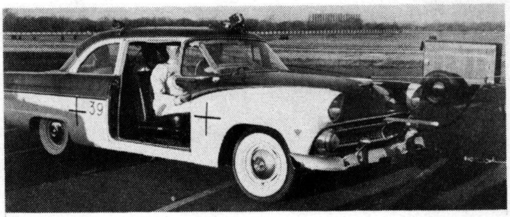

Figure 15. Crash 39 - Over-all view of test car.

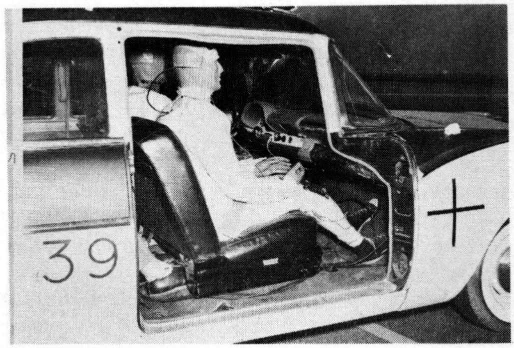

Figure 16. Crash 39 - Close-up view of test car.

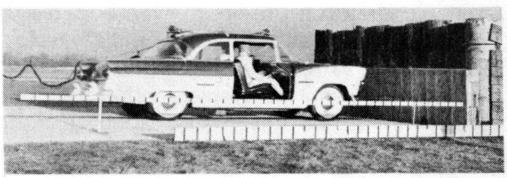

Figure 17. Crash 39 - Just before impact.

Figure 18. Crash 39 - Test dummy kinematics during impact.

that obtained by differentiating the displacement curve of the target as plotted from the high-speed movie film. The correlation of these two techniques would be an elaborate undertaking in itself.

In order to provide a more complete mental picture of automobile collision impact phenomena, a typical barrier test will be described in detail. The test car used was a 1955 Ford Tudor weighing 4,144 lb including four passenger dummies totaling 785 lb. The car was equipped with a 1956 instrument panel complete with pad, safety steering wheel, and padded sun visors. Both the driver and the right front passenger were restrained with lap belts. The left rear passenger was restrained with both a lap belt and an experimental shoulder harness which terminated at the lap belt. The right rear passenger was unrestrained. Mounted on the car were two gunsight cameras to record the movements of the dummies within the car during impact. In the barrier area, four cameras were stationed to film the impact. Two cameras were high-speed black and white and the other two were low-speed color. Attached to the front of the car was a velocity measuring device for accurate determination of the impact velocity. Strain gage type accelerometers were mounted on both right and left sides of the frame front and the floor pan of the passenger compartment to measure the decelerations. An accelerometer was placed in the stomach cavity of the driver and the head of the right front passenger to measure the decelerations at these points. The seat belts were equipped with strain gage transducers to measure the loads during impact. Sheets of thin aluminum foil were placed on the instrument panel, visor, and lower dash as well as the right front passenger's head and knees to record when contact occurred between these areas. Targets were taped on the car for future use in frame-by-frame analysis of the movie films. Figures 15 and 16 show the car after all preparations were completed.

The kinematics of the crash are shown in Figure 18. This is a selected series of

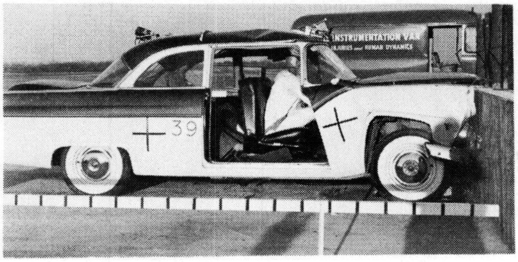

Figure 19. Crash 39 - Right side view after impact.

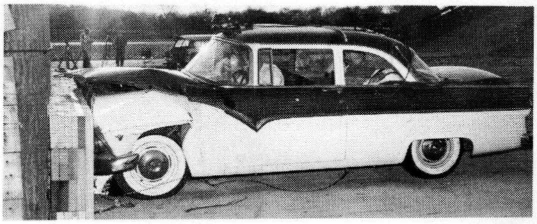

Figure 20. Crash 39 - Left side view after impact.

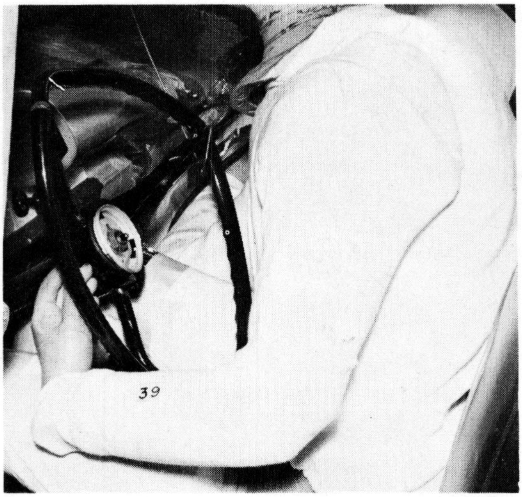

Figure 21. Crash 39 - Steering wheel deformation after impact.

Figure 22. Crash 39 - Final dummy position side view.

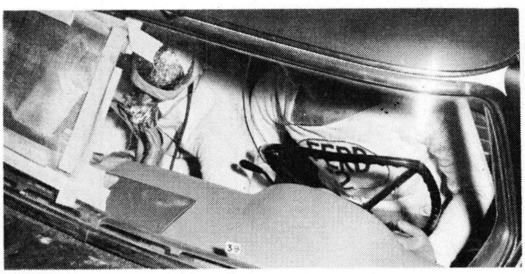

Figure 23. Crash 39 - Final dummy position front view.

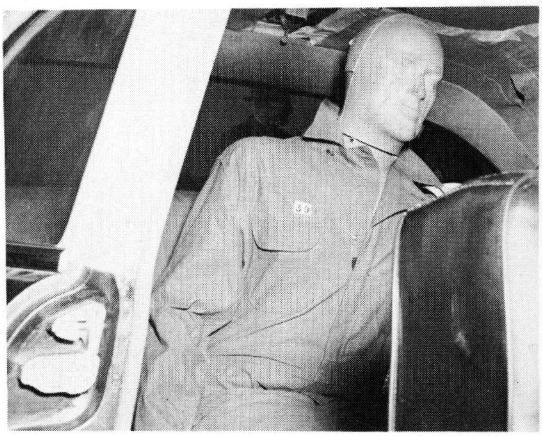

Figure 24. Crash 39 - Final position of rear dummy.

enlargements taken from the Fastax film. This camera operated at 500 frames per second. The time in seconds from "O" reference (contact) is given for each frame shown.

It is of interest to note that the time for maximum deformation of the car is 0.06 seconds from contact. However, at this time the occupants have just started to move forward. At 0.10 seconds after contact the front seat occupants have attained maximum forward movement and the rear unrestrained occupant is still moving forward. The rear dummy's head hit and dented the roof panel at 0.14 seconds and reached the farthest forward position at 0.20 seconds after impact. The total time for the rear dummy to go forward and return was 0.74 seconds.

Figures 19 through 24 show over-all damage to the car and final dummy positions. The deformation of the energy-absorbing steering wheel can be seen in Figures 21 and

26. It should be noted that the dummy's chest did not contact the hub of the steering column. Figure 27 shows the area and resulting dent where the right front dummy's head impacted the instrument panel pad after jackknifing on the seat belt. This illustrates the necessity for proper design of the panel and pad combination to obtain adequate yielding and load distribution to moderate or prevent soft tissue injury. It will be observed that the seat belt prevented windshield impact. FERD No. 1, with a

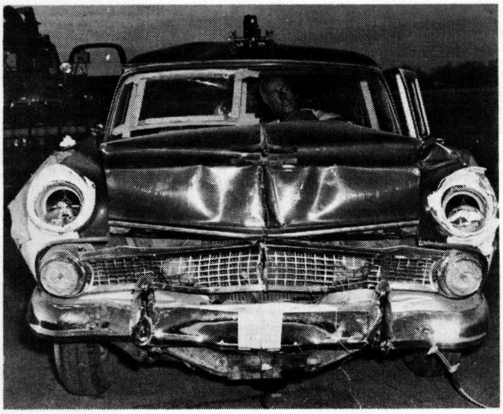

Figure 25. Crash 39 - Over-all damage to front of car.

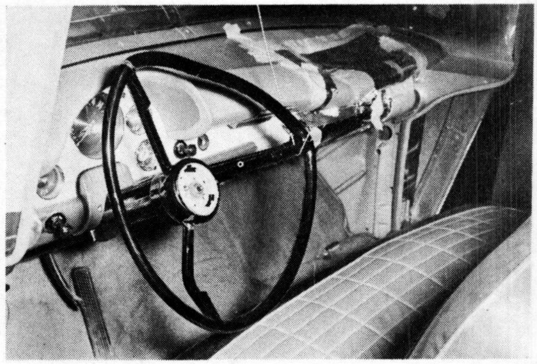

Figure 26. Crash 39 - Steering wheel and instrument panel deformation.

TABLE 3

TABULATION OF DATA FROM OSCILLOGRAPH FILM RECORD - TEST NO. 39

No.	Measurements	Peak Value of Measurement	Time to Peak Value From Start of Impact (Seconds)	Duration of Measurement (Total Time from Start of Rise to End) (Seconds)
DECELERATIONS				
1	Floor Pan Passenger Compartment - Right Side	30.4g	.065	.085
2	Floor Pan Passenger Compartment - Left Side	29.6g	.069	.087
3	Front of Frame, Right Side	88.0g	.022	.057
4	Front of Frame, Left Side	80.5g	.022	.070
5	Driver Chest (Impacting Safety Steering Wheel)	75g	.087	Value After Peak Unobtainable
6	Right Front Passenger Head (Impacting Padded Instrument Panel)	65g	.115	.037
BELT LOADS				
7	Driver Lap Belt	2540 lb.	.087	.070
8	Front Right Passenger Lap Belt	2440 lb.	.088	.110
9	Rear Left Passenger Lap Belt	2900 lb.	.050	Unobtainable
10	Rear Left Passenger Shoulder Harness Belt	2220 lb.	.055	.080
CONTACT POINTS				
11	Windshield and Head (Right Passenger)	NO CONTACT		
12	Upper Dash (Right Passenger)	DID NOT FUNCTION		
13	Lower Dash (Right Passenger)		.063 after impact	
VELOCITY MEASURING DEVICE				
14	14.25 Inches in .03329 Seconds	24.4 MPH		

seated height of $36\frac{1}{2}$ inches, occupied this seat.

The oscillograph film record of this crash is shown in Figure 28, and a tabulation of the results appears in Table 3.

The deceleration that has the first and most significant effect on the passenger is that of the passenger compartment. It is this deceleration which causes the passenger to move relative to the interior of the car. Everyone has heard the expression "It isn't the speed that kills, it's the sudden stop." This of course is true. However, usually the greater the velocity the more violent and consequently the more hazardous the stop.

The curves in Figure 29 are the results of plotting the electronically-measured decelerations which occurred in the pas-

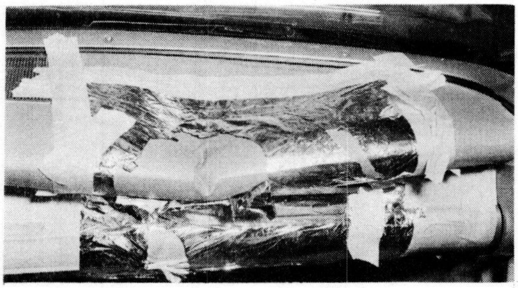

Figure 27. Crash 39 - Close-up view of padded instrument panel deformation.

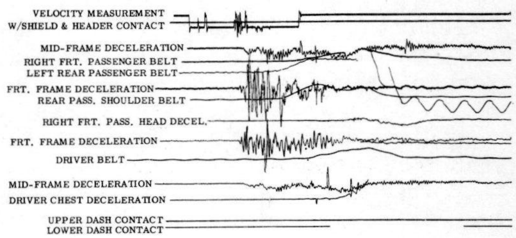

Figure 28. Crash 39 - Oscillograph film record.

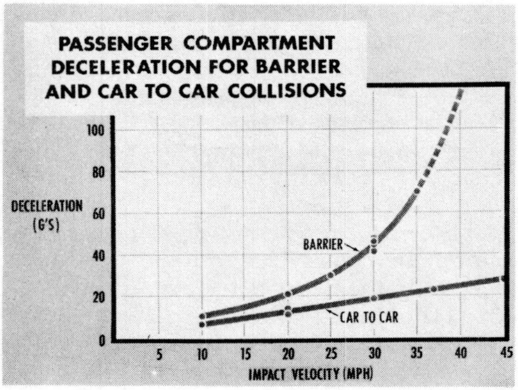

Figure 29.

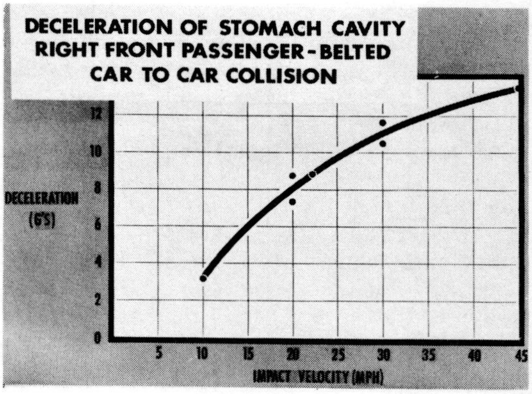

Figure 30.

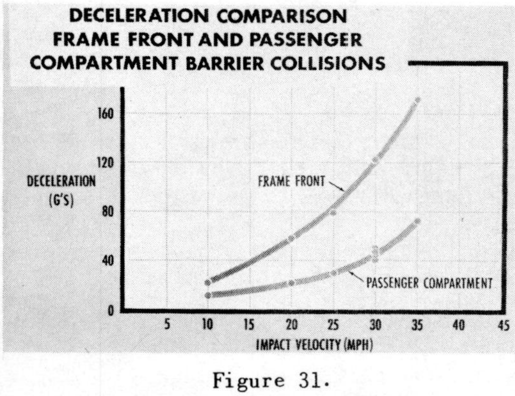

Figure 31.

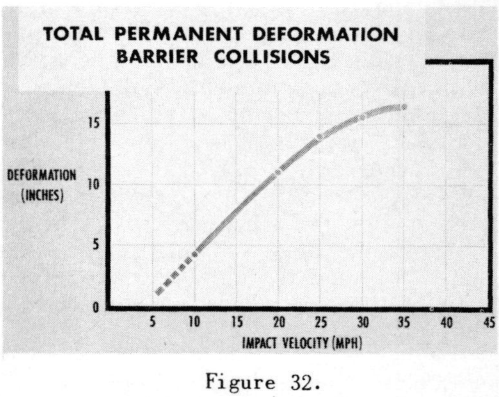

Figure 32.

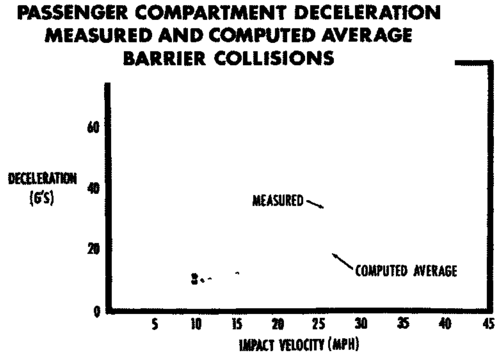

Figure 33.

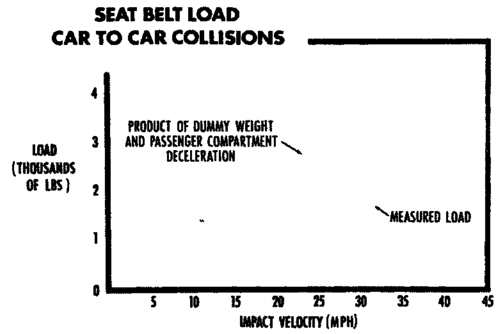

Figure 34.

senger compartment during a series of barrier and car-to-car tests at various velocities. The curve for the barrier condition beyond 35 mph is dotted since it is an extrapolation. All barrier impacts were with the line of motion of the test vehicle perpendicular to the face of the barrier. The car-to-car impacts, reported in Figure 29, were run with the line of motion of the test vehicle 10 degrees off the perpendicular to the centerline of the parked vehicle. The centerline of the moving car impacted the right front wheel of the parked car. The cars used in this series of tests were 1955 Tudor and Fordor Fords with four occupants; a driver, a right front passenger, and a left and right rear passenger.

It is sometimes very convenient to separate an accident into two collisions; the first, when the vehicle strikes another object, and the second, when the occupants strike the vehicle in which they are riding. It may be logical to visualize a situation where, if the passenger was adequately restrained, it might be possible to eliminate the second collision which is the real injury-producing condition. With reference to Figure 29, at 45 mph a deceleration of 28 g's was measured in the passenger compartment, but this resulted in a measured deceleration of only 13. 8 g's, Figure 30, in the stomach cavity of the dummy. It will be noted, in Figure 29, that an equivalent passenger compartment deceleration would be attained at a velocity of approximately 24 mph during a barrier crash. Since no braking is effected prior to impact, the velocities mentioned in discussing any of the figures are the velocities at the time of impact.

In Figure 31, the passenger compartment deceleration curve for barrier crashes, previously shown in Figure 28, is compared to the frame front deceleration. For the full range of velocities tested, the deceleration level in the passenger compartment always has been less than half that observed at the front of the frame. This fact indicates that the front structure of the present vehicle is a substantially effective energy absorber for decreasing the severity of the so-called second collision.

The total permanent deformation, or over-all shortening of the vehicle, which results from barrier impacts is shown in Figure 32, for velocities up to 35 mph. The fact that the total deformation increases at a decreasing rate logically agrees with the data in Figure 29 which shows the peak passenger compartment deceleration increases at an increasing rate. By using the deformation and performing a simple computation, it is possible to plot the average deceleration which corresponds to any velocity. It is evident, from an examination of Figure 33, that this computed average deceleration is less than the measured deceleration for the same velocity.

Measured seat belt loads as a function of impact velocity are shown in Figure 34 for front corner car-to-car collisions. In addition, the product of the dummy weight and the peak passenger compartment deceleration is shown. It will be noted that this computed load is approximately double the measured load.

The subject of Automobile Collision Impact Phenomena covers a tremendous scope. This paper, and all other available information on the subject, constitute only an introduction to this important phase of automotive design.