A LOOK AT THE NHTSA MINIMALLY COMPLIANT UNDERRIDE GUARD AT IMPACT SPEEDS ABOVE 30 MPH

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ABSTRACT

The NHTSA has promulgated a new underride regulation (Ref 1) which became effective for heavy commercial trailers manufactured after January 26, 1998. Heavy trucks are excluded. Although this new rule is considered by many to be deficient in some respects (not as good as it could be), it certainly represents a safety improvement over the old FMCSR 393.86, which has been in effect since January 1953 and will continue to be so for heavy trucks. The new rule is also compatible with the European and Japanese rear underride standards.

A series of eight rear underride crash tests (Ref 2), used as a basis for this new rule, demonstrated the effectiveness of an underride guard that minimally complied with the new rule at impact speeds of 30 mile per hour (mph). But in some of the tests the underride magnitude was such that passenger compartment intrusion (PCI) occurred. It has generally been considered that for effective underride performance PCI should not be allowed. This raises the question: how would this minimally compliant guard (MCG) perform at impact speeds greater than 30 mph which occurs quite frequently in the real world?

This paper addresses this issue based on the previous eight NHTSA underride crash test results. The primary purpose is to illustrate the potential performance of the MCG at impact speeds above 30 mph, and also to demonstrate the effect of guard strength on underride magnitude.

BACKGROUND - NHTSA CRASH TESTS

Much research has been done on the underride problem involving crash testing and accident analysis. See Refs 2-10 which contain test results for a variety of underride guards and impact conditions. The NHTSA files contain a total of 87 rear underride crash test cases. But the new NHTSA rule was primarily based on the recent eight crash tests which were conducted at 30 mph. Concern for the 30+ mph impact speed is real because many underride accidents do occur above 30 mph (See Ref 11 & 12), and specifically because PCI did occur in some of the NHTSA tests which were centric, in-line impacts. Although tests with the MCG for offset and angle impacts have not been conducted, it is expected that greater PCI would occur for these conditions with potential for serious injury or death to the front seat occupants.

In order to evaluate the performance of the MCG at impact speeds above 30 mph it will be necessary to initially review the available 30 mph crash test conditions and results.

A) DESCRIPTION OF THE NHTSA TESTS

The eight NHTSA rear underride crash tests were conducted in the early 1990s with four different passenger cars. These were: 1991 Chevrolet Corsica, 1993 Ford Tempo, 1992 Honda Civic CX, and 1993 Saturn SL. All tests were conducted at 30 mph with the passenger cars centrically impacting the guard at zero angle. The guard height above the ground was 22 inches in all of the tests. The cars were also set at a nose down attitude representing a braking condition. Only the guard was involved with stopping the car (no trailer rear wheels or other barriers). Summary data are listed in Table 1, and additional details of the tests can be obtained from Ref 2. Seven of the eight tests used a guard which was designed to minimally comply with the requirements of the new rule in strength and geometry. This guard was mounted to a laboratory test fixture in five tests. Two of the tests were conducted with the MCG mounted to a Fruehauf van trailer. A rigid guard was used in one test. In all of the eight tests the occupant response measurements (HIC and chest G) were within the FMVSS No 208 allowables except for the rigid guard case. The driver chest G in this one case (rigid guard mounted to the laboratory fixture) exceeded the allowable but by only one count (61 G - See Table 1, TESTNO 921229). It should be noted, however, that in six of the tests (this one included), the driver belts were not used.

In the two trailer tests the guard was mounted directly to the trailer frame rails, which proved to be the weak link in the structural system. PCI magnitude of 10.5 inches occurred in the first of these tests. The addition of a reinforcing strap to each vertical strut at the frame attachment point substantially improved the trailer frame strength for the second test. The underride was greatly reduced in this test with no PCI.

TABLE 1. CRASH TEST RESULTS

YR	MAKE	MODEL	SPD	TESTNO	TWT	HICD	CGD	HICP	CGP	CMAX	CDYN	ANG	SG	PEAK F	NOTES
89	FORD	TEMPO	29.3	7715-04	3210	435	45	390	41	13.7	18.5				COMPLIANCE TEST
94	FORD	TEMPO	29.3	8145-06	3200	914	45	383	45	14.7	19.9				COMPLIANCE TEST
92	HONDA	CIVIC CX	29.6	7979-05	2470	382	44	169	35	16.3	22.1				COMPLIANCE TEST
93	SATURN	SL	29.8	8056-08	2754	317	35	311	35	19.0					COMPLIANCE TEST
91	CHEV	CORSICA	34.8	7893-05	3300	493	41	956	44	25.1	32.0			66300	NCAP TEST
93	FORD	TEMPO	35.0	MP0205	3099	655	51	772	43	19.2	28.1			83700	NCAP TEST
93	HONDA	CIVIC DX	35.3	8058-04	2769	744	54	902	43	21.7	26.0				NCAP TEST
92	SATURN	SL	35.0	920427	2922	705	51	1063	47	21.3	31.5			81800	NCAP TEST
91	CHEV	CORSICA	30	921207	3208	24	33	37	20		71.9	60	2.0	44900	LAB GUARD
91	CHEV	CORSICA	30	921229	3218	188	61	788	37		33.0	0		74000	LAB GUARD RIGID, CAR FRAME BUCKLED
91	CHEV	CORSICA	30	930420	3186	37	16	77	20		88.1	60	2.6	38600	TRAILER - FRAME FAILED
93	FORD	TEMPO	30	921203	3087	139	19	117	25		51.0	70		32700	LAB GUARD **
92	HONDA	CIVIC CX	30	921130	2462	127	24	119	31		51.6	30	5.6	51700	LAB GUARD
92	HONDA	CIVIC CX	30	930428	2654	129	28	118	36		41.2	20	7.6	50800	TRAILER - W STRAP
93 *	SATURN	SL	30	921106	2738	360	19	858	24		97.1	90	0.5	26000	LAB GUARD ** - BOLTS FAILED
93 *	SATURN	SL	30	921228	2748	100	27	117	27		62.6	45	2.7	37600	LAB GUARD **

SPD -- Impact speed - mph
TWT -- Vehicle test weight - pound
HICD -- Driver Head Injury Criteria
CGD -- Driver chest G
HICP -- Passenger Head Injury Criteria
CGP -- Passenger chest G
CMAX -- Post impact static crush - inch
CDYN -- Maximum crush or underride during impact - inch
ANG -- Guard bend angle - degree
SG -- Scrape-over G
PEAK F -- Peak force during impact - pound, based on equivalent filtered peak compartment G

- Driver Airbags were used in all of the above tests.
- In the underride tests, driver belts were used in only the two vehicles flagged with *.
- Right strut on the guard bent 1st in cases noted under the NOTES column with **.

It should also be noted that the low edge of the laboratory test fixture and trailer frames were set at 48 inches above the ground. This is a significant factor because this is the level of the rear structure that is most critical to PCI. But most of the current on-the-road trailers have the PCI critical frame level at approximately 42 inches above the ground. Some are as low as 38 inches, and drop-frame trailers are even lower. 42 inches is the height just above the outside rear view mirror of the typical passenger car. If the frame height had been set at the typical trailer level in the tests, the results would have been different with greater potential for PCI.

B) SALIENT FEATURES OF THE TEST RESULTS

Acceleration, velocity and displacement time histories (taken directly from Ref 2) are shown in Figures 1-8 for each of the eight NHTSA underride crash tests. Force vs displacement is also included. It should be noted that the force traces were derived by simply multiplying the acceleration trace by the vehicle test weight (GxW) which is a common procedure. The figures are presented in the order of those numbers used in Figure 11 for identification convenience only. The test numbers in this underride series are established based on the date on which the test was conducted. For example, TESTNO 921108 is derived from - 19<u>92</u> in the <u>11</u>th month on the <u>08</u>th day of that month.

Some salient features of these data are as follows:

- o Initial car-to-guard contact is with the grill just above the bumper.
- o Peak compartment G occurs at or near the guard engagement of the engine block. This is compatible with observations from the crash test movies.
- o Minimum load usually occurs at a displacement (underride) of 35-50 inches.
- o Frontal stiffness of the vehicles is generally in the order of 2,000 pounds/inch. This is for that portion of the front structure (above the bumper) that engages the guard which extends from the grill to the engine block.
- o The presence of high frequencies in the acceleration response makes the determination of the absolute force using the product of GxW somewhat questionable. Since the acceleration trace is a filtered output, different levels of filtering will produce different force magnitudes per the GxW process. It is very likely that the actual force would be more closely associated with an acceleration trace in which the high frequencies are ignored.
- o Although the MCG was designed to withstand a loading of 45,000 pounds for the centric hit, the peak loads varied from 26,000 pounds (TESTNO 921108 in which the 3/4 inch attachment bolts failed) to 51,700 pounds.
- o Low peak loads are associated with the test cases in which the right vertical strut deformed first.
- o Strong similarities exist between traces from same vehicle tests particularly in the initial region of the pulse. This is the case regardless of the structure on which the guard was attached (laboratory fixture or trailer).
- o The loads that result at the end of the pulse (maximum underride) are generally in the order of 15,000 pounds. This occurs after the guard was well beyond its yield and fully displaced forward.
- o The energy associated with the force vs displacement trace closely matches the car's initial kinetic energy as it should.

COMMENTARY REGARDING THE NHTSA TEST RESULTS

Based on the measured occupant responses (driver and front seat passenger, see Table 1), and remaining distance (clearance) between the intruding laboratory fixture or trailer frame and the windshield of the underriding car, the test results generally indicated acceptable guard performance. This served as technical support for the new rule. But some questions remain regarding the overall efficacy of the 'minimally' compliant guard. These have to do with the following:

1) The rule allows that the guard itself can be certified by test as an equipment item using a laboratory fixture. The guard does not have to be mounted to the actual trailer frame. See Ref 1 for specifics.

<u>Comment</u>: This may not be an appropriate requirement because the trailer frame proved to be the weak link in one of the NHTSA tests (No 930420). The resulting peak load was considerably less than the 45,000 pounds required by the rule (the sum of both vertical struts) because of the frame structure. In this test the magnitude of underride was greater than it would have been with an appropriately structured frame (10.5 inches of intrusion) as evidenced by the results of a subsequent test (No 930428) where the strength of each frame member was significantly increased and underride was reduced by more than 1/2. In each case, however, the occupant responses were still well within the FMVSS 208 allowables. Prudent trailer manufacturers will most likely assure guard compliance by physically testing the guard as mounted to the trailer. However, manufacturers that produce a small number of trailers may have a problem with this approach because of costs involved.

The trailer frame also proved to be the weak link in a previous underride test program. See Ref 7.

2) The rule requires that the guard structure must absorb a minimum amount of energy within a specified displacement in the process of compliance test loading. See Ref 1 for specifics.

Comment: This energy requirement, although desireable, will very likely prevent a trailer manufacturer from installing a very strong (non-yielding) guard which can be beneficial in both offset impacts and at centric impact speeds above 30 mph. A very strong guard can be made to meet the energy requirement of Ref 1, but in an underride impact it will not absorb energy (which is the intent of the requirement) as long as its strength exceeds the impacting vehicle crush strength. A test (No 921229) demonstrated that a non-yielding guard (which would likely not comply with the new rule because of the energy requirement) resulted in acceptable occupant response levels with the exception of the driver chest G which was high by one count. In this case the driver was restrained with an air bag but no belts. It is likely that had the driver belts been used he would have experienced a lower chest G as evidenced by an NCAP test of the same vehicle (conducted at 35 mph into a full flat rigid barrier, 36% more kinetic energy) which produced occupant responses below the allowables. Compare TESTNO 7893-05 with 921229 (Table 1). In the NCAP test the full front structure of the vehicle engaged the barrier whereas only the structure above the bumper engaged the guard in the underride test. The stiffness of the upper front structure engaged in the underride test is considerably less than the total front structure stiffness. See Ref 13 for related data.

The NCAP test is a clear indication that a very strong guard would provide acceptable injury performance even though it would not meet the new rule's energy requirement. On the other hand, the energy requirement for the MCG assures that the guard will not fail catastrophically immediately after peak force is reached.

3) All of the tests were conducted at 30 mph with the vehicle contacting the guard centrically and in-line.

Comment: Rear underride accidents do occur at speeds well above 30 mph, and in offsets and angles to the guard as well. Page 21 of Ref 11 states that closing speed estimates for rear underride accidents exceed 30 mph approximately 67% of the time, and 40 mph 32% of the time. This represents a significant number of incidents. It is also well known that real world offset impacts into the rear of heavy vehicles are common. Refs 14 and 15 present data on this. The performance of the MCG has not yet been demonstrated by test at speeds above 30 mph.

4) If the guard performs acceptably at 30 mph centrically, how will it perform in offset impacts?

Comment: It is clear that offset impacts will result in greater underride magnitudes than in centric impacts, all else being the same. Underride is also expected to increase with increasing offset. But impacting vehicle rotation will also occur in offset impacts. This will, of course, depend upon the amount of offset and the interacting structural properties. It is very likely that the occupant responses will be less than with centric impacts, but this will be only if the occupant head and torso are not contacted by the intruding structure. Injury measures, however, will be greater for the occupant on the impacted side. It is possible that vehicle rotation can be either clockwise or counterclockwise depending upon the strengths of the interacting vehicle front structure and the guard. If the guard offset strength is less than the engaged portion of the car crush strength, then the guard will deform and may cause the car to rotate with its front deflecting somewhat away from the centerline. On the other hand, if the guard offset strength is greater than the car crush strength, then car rotation will be in the opposite direction where its rear end will displace away from the centerline. See offset impact data contained in Refs 5, 6 and 8 which indicate that a guard total strength of greater than 45,000 pounds is needed for adequate offset impact protection. It is expected that certain offset conditions could result in car rotation such that the passenger compartment may beneficially avoid intrusion entirely. The performance of the MCG has not yet been demonstrated by test for offset or angle impacts.

The minimum offset load requirement specified in Ref 1 is only 11,240 pounds. The MCG actually provided a load of nearly 14,000 pounds in one static test (Ref 2), but this will not provide sufficient underride protection for reasonable offset impacts at 30 mph.

5) The test frame height was set at 48 inches for both the laboratory fixture and trailer.

Comment: The trailer rear structure that is critical to PCI is the lower edge of the rear frame which for some trailer designs is as low as 36 inches. This is about the height of the hood at its intersection with the windshield which for most passenger cars is in the range of 35-39 inches. The rear lower edge on most trailers is about 42 inches. The NHTSA test results would certainly have been different with a lower frame height which would have caused greater PCI. But other effects will also be present such as guard higher bend angle and change in scrape-over force including potential penetration by the folded hood into the windshield.

WHY DOESN'T A 45,000 POUND GUARD EXPERIENCE 45,000 POUNDS?

The MCG was designed such that it would support a peak load of approximately 45,000 pounds with simultaneous strut loading. This was confirmed by static test in accordance with the procedure described in the new rule (Ref 1). See test results in Ref 2. Because of this, it would be expected that in the crash test cases where the MCG was deformed, the peak load should have been in the vicinity of 45,000 pounds. A review of Table 1 data shows that the peak loads generated in the crash tests varied significantly for the MCG from 32,700 pounds to 51,700 pounds. The bolt failure and rigid guard cases are not considered in this group. Possible explanations for the occurrance of this variation follows.

A) STRUCTURAL DISSYMMETRY

Some of the NHTSA tests show that with a centric impact the guard does not deform symmetrically as would have been expected. Study of the high speed test films indicated that the right vertical strut began to bend forward before the left one in some cases. This results in a total peak load that is somewhat less than the expected 45,000 pounds for both struts even though the struts individually met the rule's minimum static strength requirement. A comparison of the symmetric and unsymmetric strut bending is presented in Table 2. These data show that on average, the unsymmetric peak loads are approximately 2/3 of the symmetric.

TABLE 2

SYMMETRIC LOADING				RIGHT STRUT BENT 1st			
VEHICLE	TESTNO	PK F	CLR	VEHICLE	TESTNO	PK F	CLR
Corsica	921207	44900	0.2	Saturn	921108	26000	-17.1
Civic CX	921130	51700	19.7	Tempo	921203	32700	12.4
Civic CX	930428	50800	23.8	Saturn	921228	37600	10.1
Average = 49133				Average = 32100			
Corsica	921229	74000	32.2				
Non-yield guard							
				Note: Negative CLR means PCI occurred			
Corsica	930420	38600	-10.5				
Trailer frame failed							

The unsymmetric deformation may be attributed to the alternator being located on the right side and several inches forward of the engine block which for these vehicles served as a hard point before guard contact with the engine block.

B) METHOD FOR DETERMINING THE PEAK LOAD

As stated above, centric impact of the vehicle with an MCG was expected to produce peak forces in the crash tests of approximately 45,000 pounds, because this was the peak load the MCG was designed to support. But in the crash tests the peak loads actually varied significantly between tests as shown in Table 2. It should be noted that these peak load values are different from (less than) those reported in the NHTSA test report (Ref 2) because the procedure used to determine the NHTSA results was simply to multiply the maximum value of the acceleration response (measured at the vehicle center of gravity) by the vehicle test weight (GxW). This procedure, which is commonly used, is not necessarily valid because the G output is obtained from a method of data processing involving specific electronic filtering. It is clear that different filtering would produce different peak G values (because of the high frequency amplitude) which in the GxW approach would in turn produce different values of peak load which is not possible. In fact, acceleration responses at different locations on the vehicle produce different peak G values which, in some cases, vary by as much as 25%.

It is quite logical that the high frequencies contained in the acceleration pulse (100-150 Hz, which would contribute to the peak G) are more likely to be associated with local resonance of the structure on which the accelerometer is attached and not associated with the total vehicle activity at the structural crushing interface.

To avoid this problem and to obtain a more appropriate value of peak force, the procedure used to determine the peak loads listed in Tables 1 and 2 was to use the slope of the velocity trace in Figures 1-8 to obtain an 'equivalent' filtered peak G to combine with vehicle weight. This is believed to be more acceptable for use in the GxW procedure although it deserves more study.

C) EFFECT OF STRAIN RATE

Strain rate is a phenomenon that results from a force that is dynamically applied to a structure. It causes the structure to increase resistance to a dynamically applied force over that which would exist for a force that is statically applied. Generally, the higher the rate of force application, the higher the effect of strain rate with some type of limitation. See Ref 18 for a study of strain rate effects in crushing structures. In the symmetric load application to the MCG (see Table 2), the peak load for the Corsica was nearly 45,000 pounds and for the Civic CX the peak force was above 45,000 pounds. Because of these data it appears that a strain rate effect may be present. But for test evaluation it would be best to disregard any potential effect of strain rate since a great variety of variables are present in the interaction of an underride guard with the crushing car front structure.

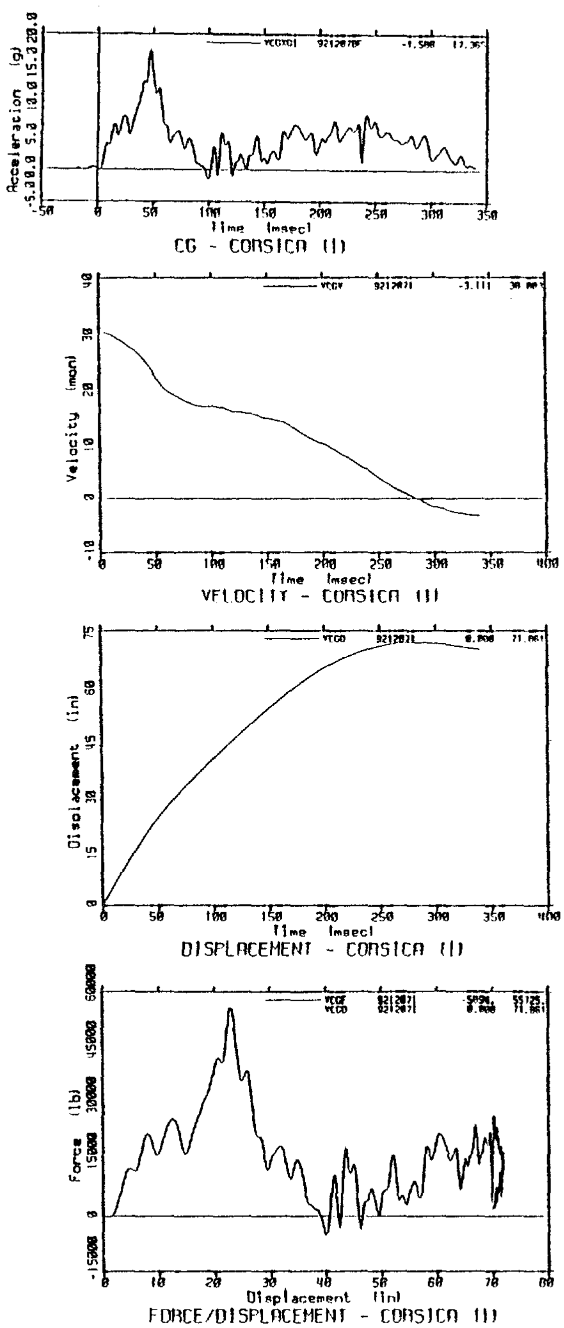


FIGURE 1: CRASH TEST RESPONSE
- CORSICA
- LAB FIXTURE

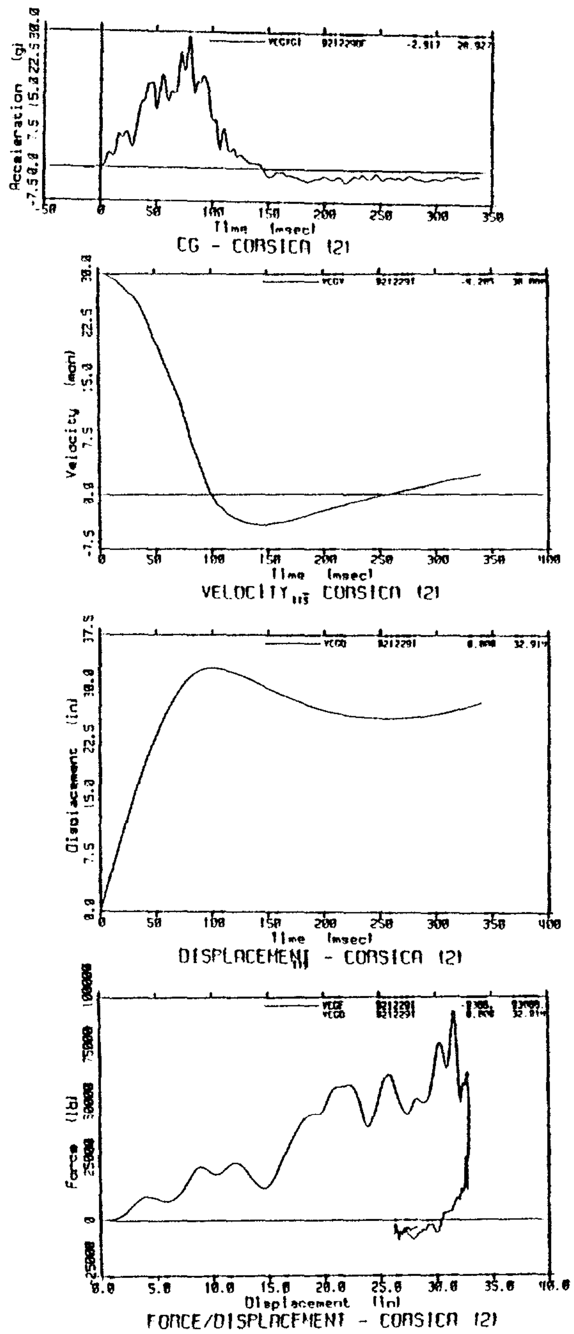


FIGURE 2: CRASH TEST RESPONSE
- CORSICA
- LAB FIXTURE - RIGID GUARD

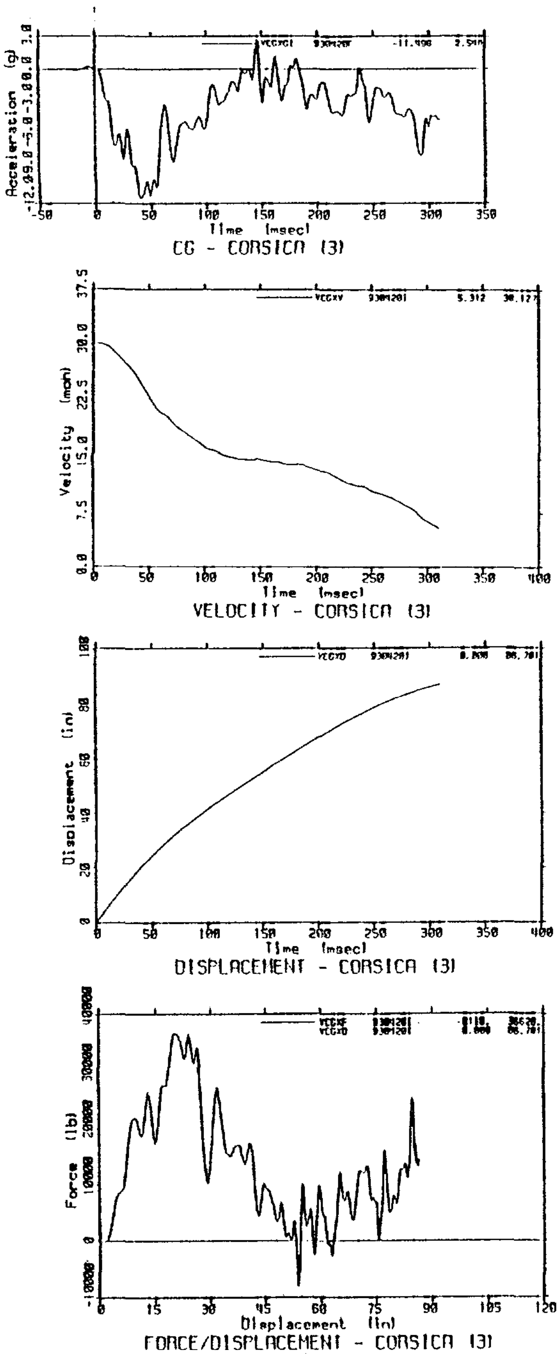


FIGURE 3: CRASH TEST RESPONSE
- CORSICA
- TRAILER, FRAME FAILED

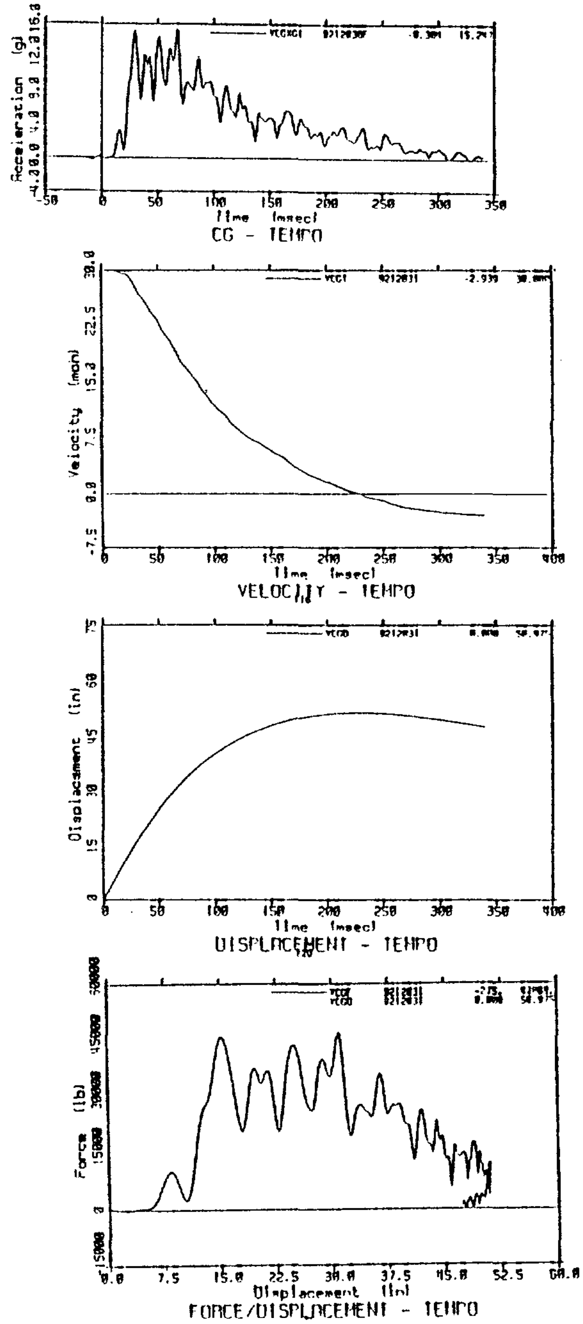


FIGURE 4: CRASH TEST RESPONSE
- TEMPO
- LAB FIXTURE

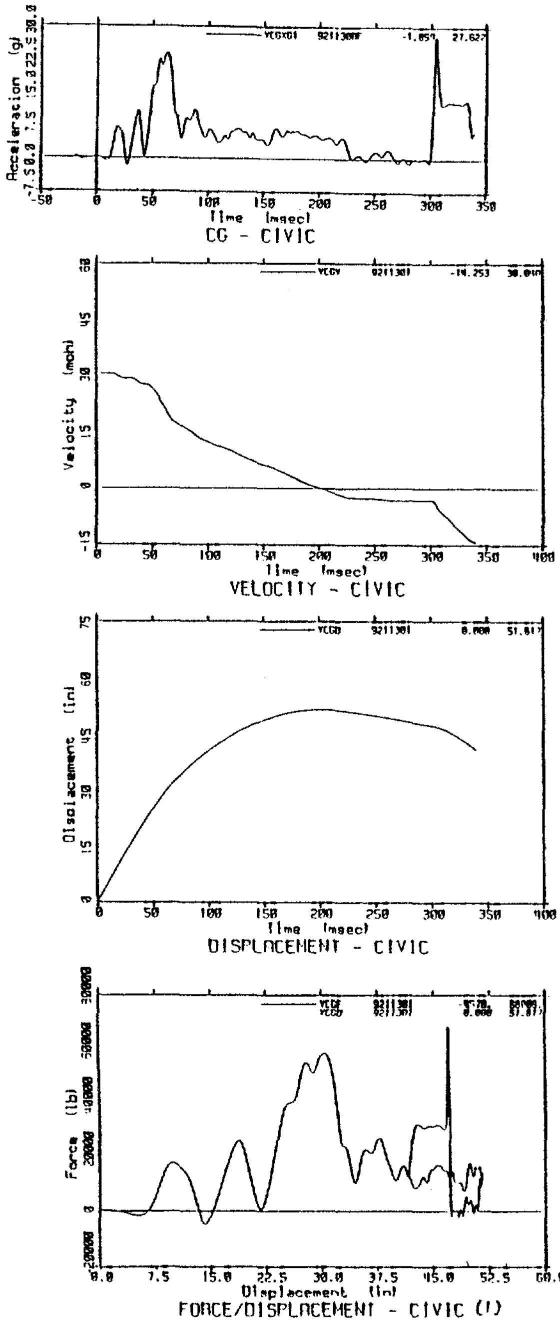


FIGURE 5: CRASH TEST RESPONSE
- CIVIC CX
- LAB FIXTURE

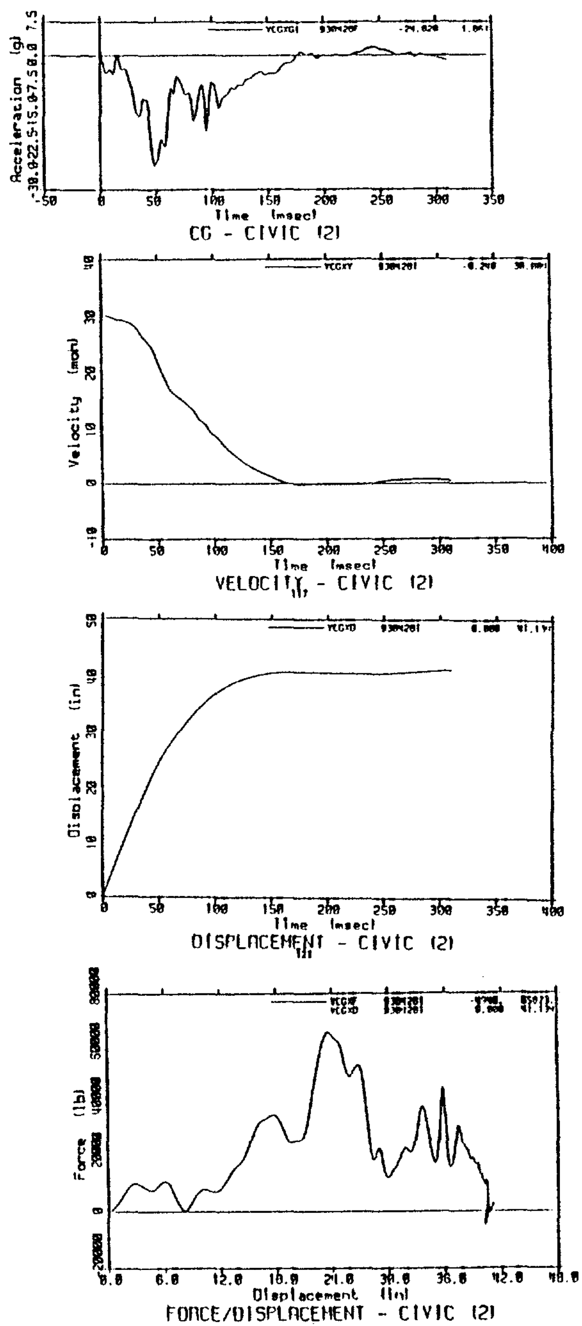


FIGURE 6: CRASH TEST RESPONSE
- CIVIC CX
- TRAILER w STRAP

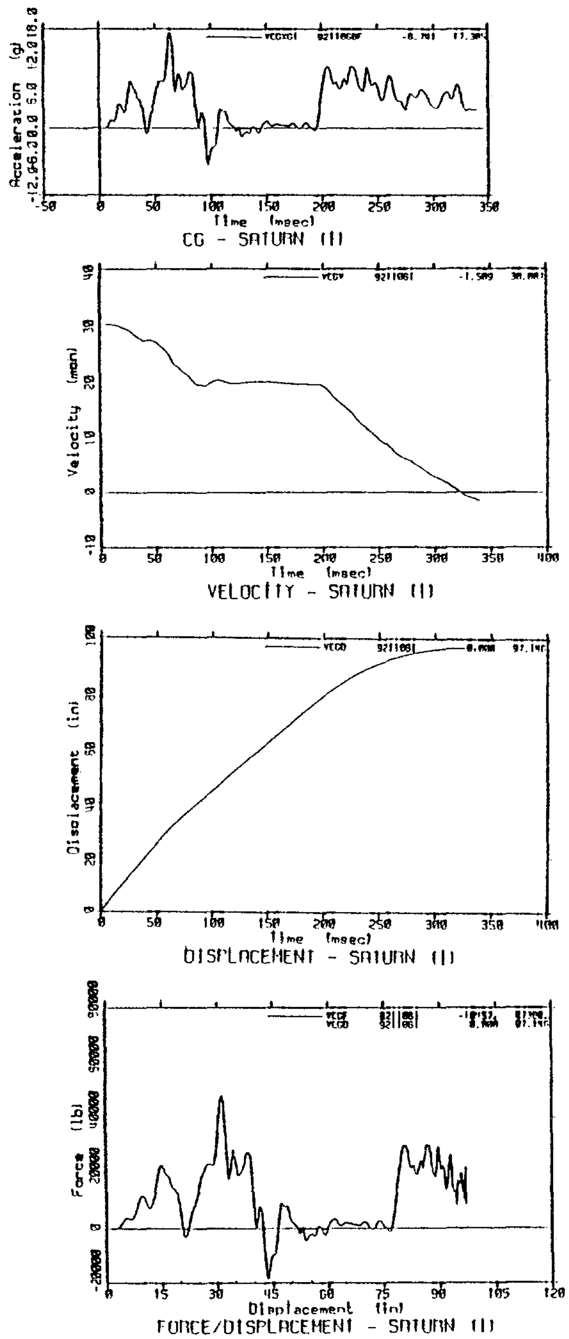


FIGURE 7: CRASH TEST RESPONSE
- SATURN SL
- LAB FIXTURE BOLT FAILURE

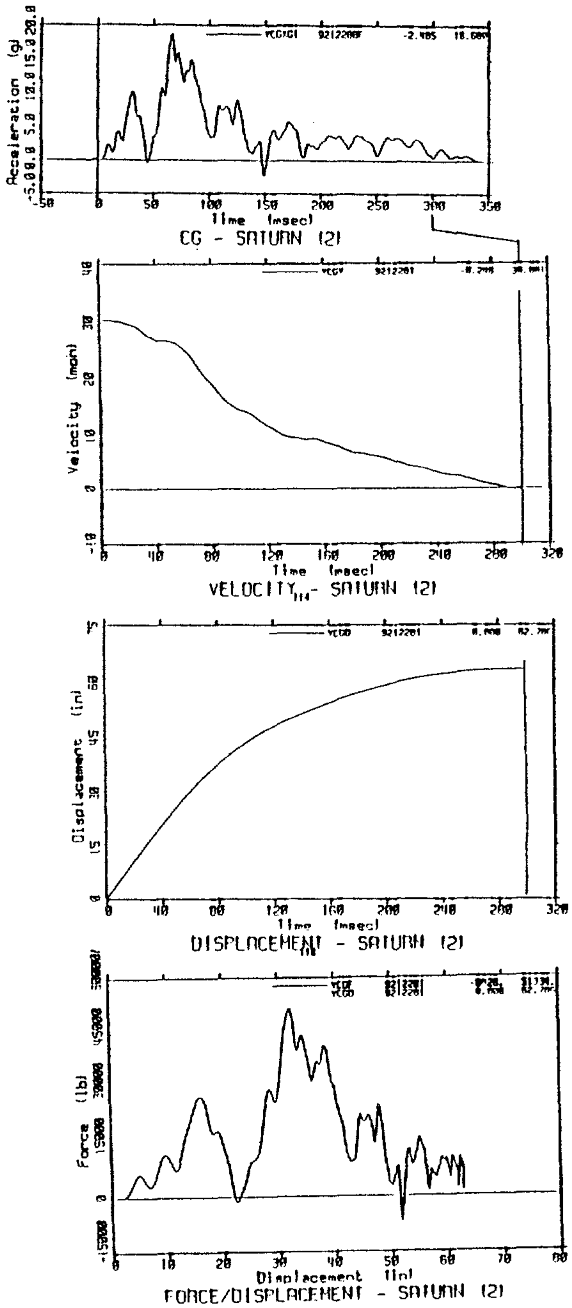


FIGURE 8: CRASH TEST RESPONSE
- SATURN SL
- LAB FIXTURE

GENERAL PERFORMANCE OF THE DEFORMING UNDERRIDE GUARD (MCG)

Figures 1-8 show the performance of each of the NHTSA underride crash tests. Taken directly from Ref 2 they show the acceleration, velocity, and displacement traces for each of the vehicles tested. The force vs displacement trace is also included.

A review of these crash pulses reveal that there are several distinct regions of energy dissipation. These are:

Region 1: Initial crush phase - involves the car upper front structure crush only, which extends generally to the engine block. The guard remains undeformed in this crush region.

Region 2: This region involves guard deformation only. The horizontal member of the guard is being displaced forward and upward until it is at the height of the top of the engine block at which point it begins to override and scrape over the engine and engine compartment.

Region 3: In this region the guard does not deform any further but it begins the process of scraping over the engine compartment and continues to do so until all of the car's kinetic energy is finally consumed (dissipated). This region may extend to the point of initial PCI.

Region 4: This region exists only if PCI occurs.

Figure 9 shows the force vs displacement traces reproduced directly from Ref 2 for three different tests of the Corsica vehicle, namely laboratory fixture test, trailer test, and rigid (non-yielding) guard test. Note that the force build-up during the initial portion of the traces are very similar and nearly identical. Note also that they are essentially linear when the oscillatory content is ignored. The vehicle stiffness in this region is approximately 2,000 pounds per inch. This is Region 1 which extends from zero displacement to approximately 22 inches for this vehicle. The next portion of the traces (Region 2) is due mainly to the guard deformation after peak force is reached. The force then decreases with increasing displacement. This is because the guard is being displaced forward and upward losing strength and direct contact with the car structure in the process. For this vehicle, Region 2 covers a displacement range of approximately 22-37 inches. The force for the rigid guard test, however, continues to increase as expected. Region 3 extends from the end of Region 2 to maximum displacement (underride) in which the guard scrapes over the engine and engine compartment or to the start of PCI.

To illustrate these regions more clearly a simplified picture is presented in Figure 10 which represents the response of the Corsica into the MCG mounted to the laboratory fixture. The energy associated with this chart matches that of the test. The peak force in this case is approximately 45,000 pounds and the force at maximum displacement is approximately 15,000 pounds. The energies associated with each of these regions are independently signficant as shown below:

- o Region 1: 43% - Car front upper structure
- o Region 2: 29% - Guard deformation
- o Region 3: 28% - Guard scrape-over engine compartment
  Total: 100%

Note that the greatest individual batch of energy is consumed during the crush of the car front upper structure.

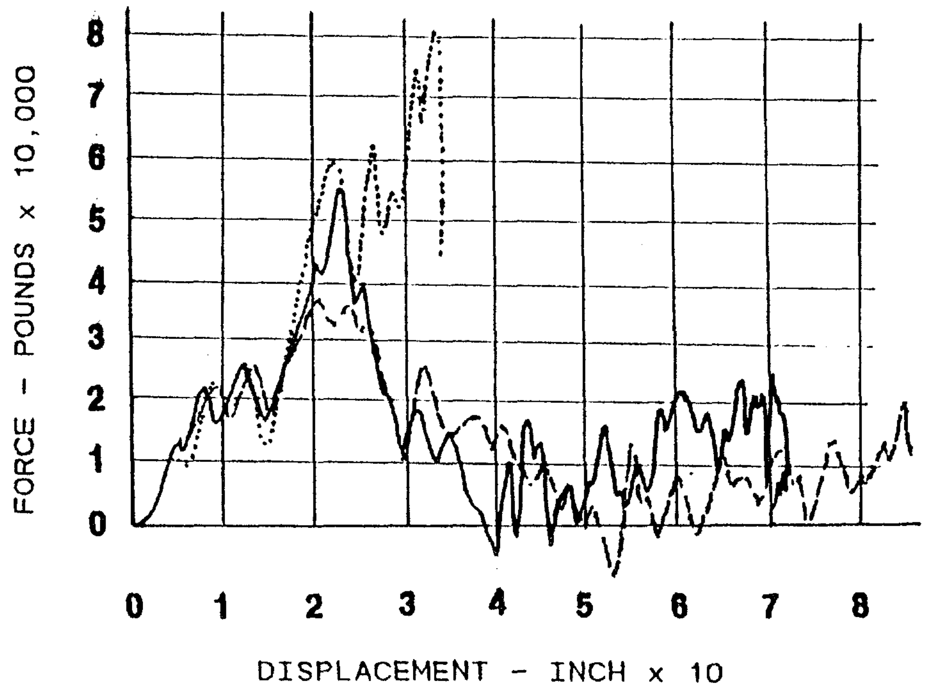
IMPACT SPEEDS ABOVE 30 MPH

A clear understanding of the underride crash test results is needed in order to project or estimate the guard performance at impact speeds above 30 mph. Tests at higher impact speeds would, of course, be more appropriate for this purpose. Critical to the determination of underride performance of the vehicles used in the NHTSA tests for impact speeds above 30 mph is the force level that occurs during the end of the crash pulse, which is the point of maximum underride. The remaining distance between the trailer or laboratory fixture frame and windshield is referred to as clearance. A negative clearance value indicates PCI.

The test results for those cases involving a deforming guard show that the force level at the tail end of the crash pulse is approximately 15,000 pounds. The exact value would certainly be somewhat different for each vehicle, and it would also be affected by the height of the intruding frame. This value, however, is supported as being reasonable by other underride test results where the upper compartment was severely penetrated by the intruding heavy vehicle body. See Ref 6 for the Ford Fiesta underride test in which the guard failed in a 40 mph impact, and Ref 17 where a series of underride crash tests were conducted with passenger cars into the side of a van trailer.

To estimate the MCG performance at impact speeds above 30 mph it was assumed that the 15,000 pound force would continue to extend as a constant value with increasing displacement until the additional energy for speeds above 30 mph would be consumed (35% for 35 mph, and 78% for 40 mph).

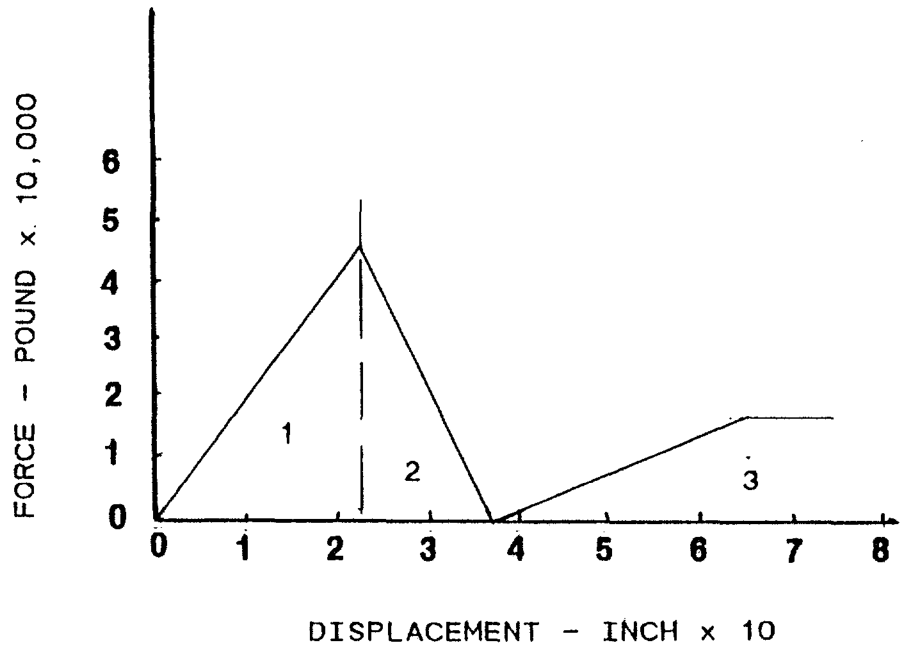
The clearance which resulted from the eight NHTSA underride tests is presented as a function of peak force in the upper chart in Figure 11. Note from this chart that a specific trend exists where clearance logically becomes more beneficial (less total underride) with increasing peak



TEST DESCRIPTION	TEST NO
——— LAB FIXTURE *	921207
- - - - TRAILER - FRAME FAILED *	930420
······ LAB FIXTURE - RIGID GUARD	921229

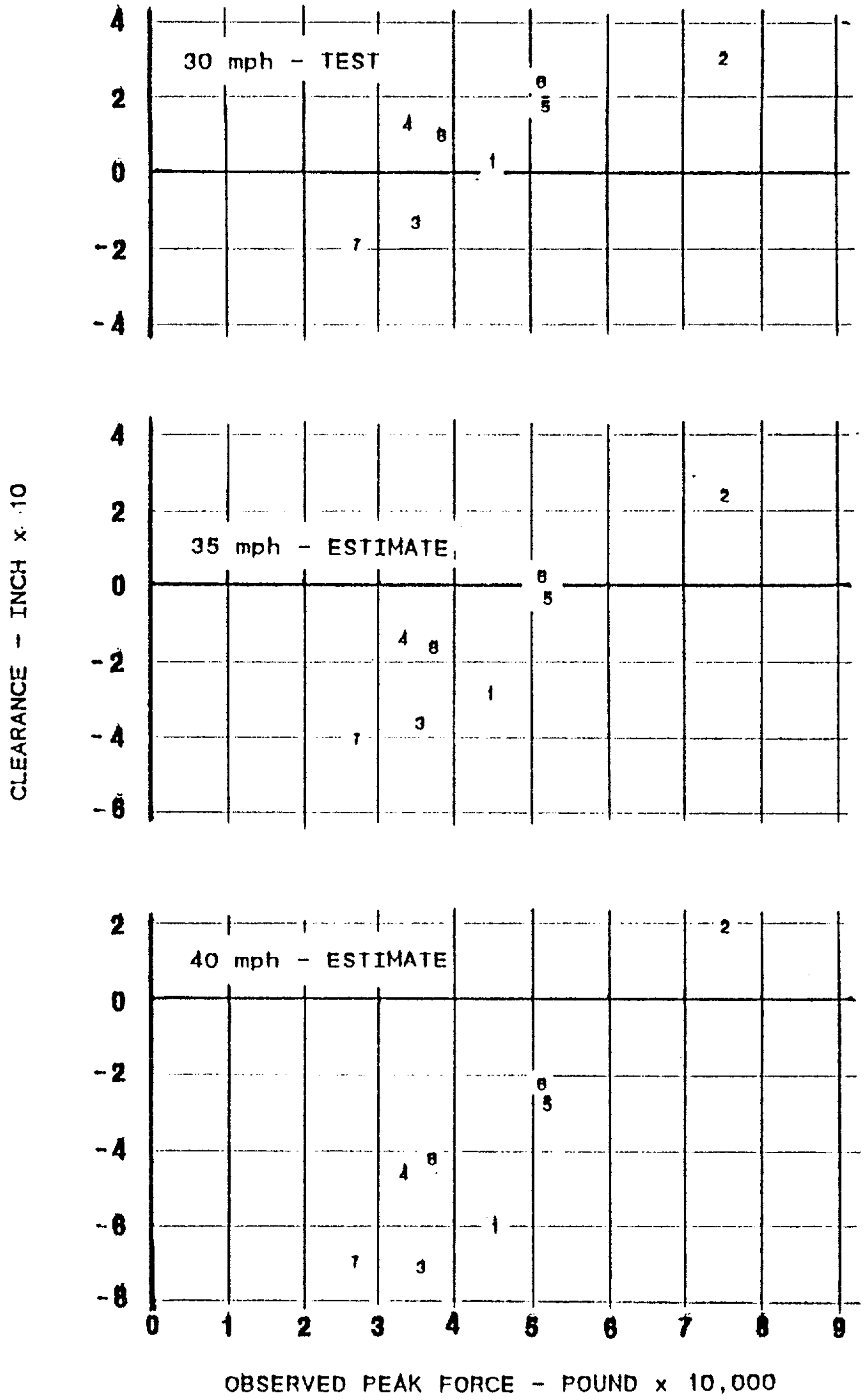
* MINIMUM COMPLIANT GUARD

FIGURE 9: UNDERRIDE CRASH TEST RESPONSE - CORSICA
FORCE v DISPLACEMENT



REGIONS OF ENERGY DISSIPATION
1 - Grill-to-Engine
2 - Guard Deformation
3 - Engine Compartment Scrape-Over

FIGURE 10: GENERALIZED UNDERRIDE FORCE v DISPLACEMENT
o BASED ON CORSICA LAB FIXTURE TEST
o TEST NO 921207 - SEE FIGURE 9



1 -	921207	CORSICA	LAB
2 -	921229	CORSICA	LAB - RIGID GUARD
3 -	930420	CORSICA	TRAILER - FRAME FAILED
4 -	921203	TEMPO	LAB
5 -	921130	CIVIC CX	LAB
6 -	930428	CIVIC CX	TRAILER - w STRAP
7 -	921106	SATURN SL	LAB - BOLT FAILURE
8 -	921228	SATURN SL	LAB

FIGURE 11: VEHICLE CLEARANCE AS A FUNCTION OF GUARD OBSERVED PEAK FORCE

force. The primary trends would be specific to the individual vehicles, such as points 1, 2, and 3 which are for the Corsica. It is expected, however, that a different set of data would exist for groups of larger or smaller size vehicles.

The estimated clearance values based on the procedure described above are shown in Figure 11 for the 35 mph and 40 mph impact speeds. Note that the clearance decreases significantly with the increase in impact speed. Note also that although the clearance for the rigid guard case decreases with increasing impact speed, PCI does not occur, even at 40 mph. These data charts are presented to essentially quantify the guard minimum peak force capacity that would be required to prevent PCI for this group of vehicles in a centric type impact.

Figure 12 is presented to illustrate the average minimum force that would be required to prevent PCI as a function of impact velocity for the NHTSA test series. Note that on average, a 45,000 pound force would be adequate to an impact speed of 33 mph. But based on the unsymmetrical MCG loadings as listed in Table 2 (presumably because of the car's unsymmetrical front crushing structure) the sum of the independent strut load capacity must be greater than 45,000 pounds in order for the guard to generate an impact resistance equivalent to 45,000 pounds. Also, it must be recalled that these test data were obtained with a 48 inch frame height, and since the critical height of most current trailers is considerably lower, the associated impact speed at which PCI will occur will decrease somewhat as shown by the dashed curve in this figure. Note also that the minimum required load varies as a function of the square of the impact velocity.

The data in Figures 11 and 12 indicate that a guard load capacity of greater than 45,000 pounds is needed in the 30-40 mph impact speed range based on PCI concerns. Noteworthy is the fact that occupant injury measures were, in general, quite low for the NHTSA 30 mph tests with the MCG. Although injury measures would certainly increase with increasing impact speeds for a given guard load capacity, more studies are needed to determine the impact speed at which they will exceed injury allowables in combination with the guard strength needed to prevent PCI. This should be done for a variety of vehicle sizes and types. But it is very likely that large magnitudes of PCI that will occur for the MCG at impact speeds above 30 mph will cause serious injury or death to the front seat occupants.

Vehicle size is expected to have an effect on clearance depending upon vehicle weight, hood length and height, and windshield slope. For a given impact speed, the higher kinetic energy of higher weight vehicles will be consumed through larger overall crush distance (underride). Less overall distance will be associated with lower weight vehicles. The peak force will be limited by the guard load capacity regardless of the vehicle size unless the guard is very rigid. Tests with different sized vehicles are needed to evaluate the MCG overall effectiveness for vehicle size and weight. Pickups, vans and sport utility vehicles which have been increasing in popularity since the NHTSA tests were conducted should also be examined for underride protection against the MCG.

SHOULD PCI BE A CRITERION FOR UNDERRIDE SAFETY?

When rear underride was initially treated as a safety problem (in the 1950s), the windshields of the early car models were moderately sloped and occupants were not restrained. The combination of these two factors indicated that any level of PCI from underride would likely cause very serious injury or death to the front seat occupants. It was clear, therefore, that the safety objective of an underride guard was primarily to prevent PCI. But current car highly sloped windshield designs in combination with the use of airbag and belt restraints have shown through the recent NHTSA underride crash tests that some level of PCI will not neccessarily be injurious. All injury levels with the MCG in these tests were relatively low.

The height of the intruding frame in combination with the slope of the windshield and its distance forward of the steering wheel are also significant parameters affecting underride distance to PCI or zero clearance as exemplified in Figure 13 below:

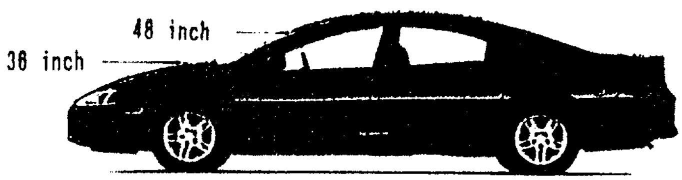


FIGURE 13: EFFECT OF FRAME HEIGHT ON POINT OF PCI

Consideration should also be given to PCI being associated with hood penetration as well. In all impact cases involving an underride guard, accident or test, the hood folds and is displaced rearward. In many cases the hood will penetrate the windshield before the trailer frame does. This is more likely to occur with lower trailer frames which will decrease clearance for a given underride magnitude, and

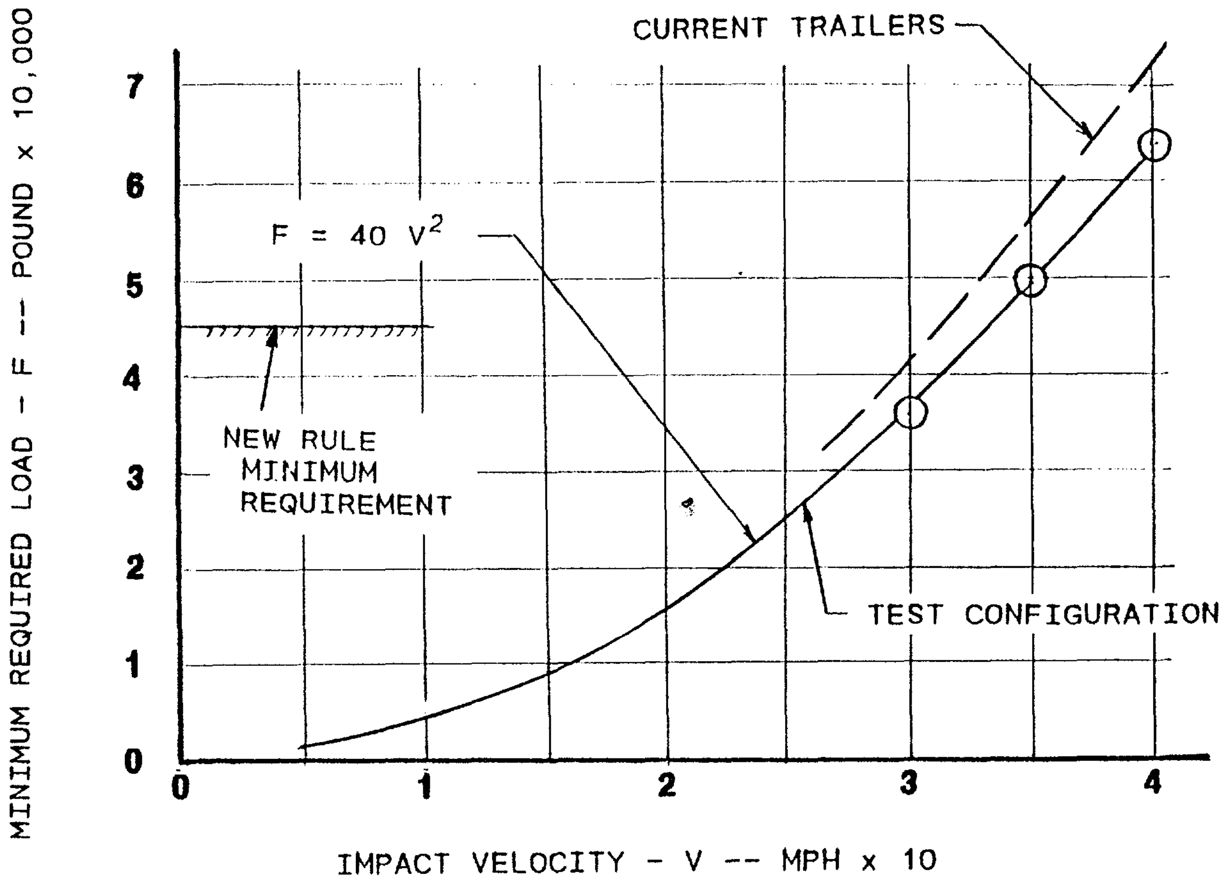


FIGURE 12: MINIMUM REQUIRED LOAD CAPACITY FOR THE UNDERRIDE GUARD TO PREVENT PASSENGER COMPARTMENT INTRUSION - CENTRIC IMPACT

further, hood penetration will increase the potential for occupant injury or death.

In every frontal impact the occupants will move forward with respect to the compartment as far as the restraints will allow. In the NHTSA underride crash tests the farthest forward that the passenger head progressed (belted with no airbag) was to the dash. The head of the unbelted but airbag restrained driver progressed far enough forward to contact the windshield in three cases. To prevent serious injury or death, it is clear that occupant head and torso should not be allowed to be contacted by any intruding object. Fatalities can occur even with low HIC values from contact with sharp surfaces such as intruding folded hoods and the various trailer components (tail light boxes, door locking rods, latches, frame edges).

Consequently, it is recommended for underride test evaluation that a safe distance for allowable underride be established as the distance to, say, 12 inches forward of the steering wheel hub whether PCI occurs or not. This should include structures such as the folded hood as well.

In the real world PCI can be avoided by locating the rear wheels of the trailer as far to the rear as possible.

CONCLUSIONS

The following conclusions are based primarily on the eight NHTSA underride crash tests reported in Ref 2. These tests were conducted with the cars aligned centrically at impact speeds of 30 mph, and the frame height at 48 inches.

o All injury measures from the tests conducted with the MCG were well within the allowables.

o PCI occurred in some of the tests and the driver head contacted the deformed upper structure. But injury measures were still well within allowables. Had the frame height been set at the lower typical trailer heights the PCI at a 30 mph impact speed would have been much greater. The injury measures would likely have been different, but it is suspected that they would not have exceeded allowables.

o Many rear underride accidents occur in the real world above 30 mph. Examination of the NHTSA test results indicates that the MCG would not provide sufficient protection for the front occupants at impact speeds above 30 mph (30-40 mph). At these speeds PCI will be quite severe with the potential for serious injury or death.

o Protection can be provided at impact speeds above 30 mph, but a guard strength higher than the minimum required value of 45,000 pounds (combined strength of both vertical struts) as specified in the new rule (Ref 1) will be needed. The studies herein show that on average, for the cars tested, the following minimun loads will be required to prevent PCI:

- At 30 mph -- 41,000 pounds
- At 35 mph -- 56,000 pounds
- At 40 mph -- 72,000 pounds

o A rear underride guard designed to meet the minimum static load requirements specified in the new underride regulation (Ref 1) will not provide adequate protection in offset impacts.

o A rigid guard would provide adequate protection in a centric impact for the properly restrained occupants at impact speeds of 35 mph and possibly at 40 mph. This is based on comparisons of NCAP and underride test results for the same vehicle. The rigid guard is expected to provide some improved protection in offset impacts over that with the MCG. Even though a rigid guard would provide protection at impact speeds above 30 mph, it would not comply with the intent of the energy requirement specified in Ref 1.

o Some of the NHTSA underride tests showed that the right strut of the MCG began to deform before the left one. This indicates that centric impacts into the guard do not neccessarily result in symmetric loading at the guard/car interface for certain vehicles. This unsymmetric condition caused the guard to produce a peak load that was significantly less than it was designed to provide. Consequently, for a guard to produce a 45,000 pound resistive force it would have to be designed for a load capability higher than 45,000 pounds. Some cars will not be protected as well as others.

o For crash test evaluation of the performance of an underride guard it is recommended that allowable underride be established to be not less than 12 inches to a laterally oriented vertical plane which passes through the center of the steering wheel whether PCI occurs or not.

o See also the sections of this paper which address the salient features and commentary of the NHTSA test results.

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NOMENCLATURE

CLR -- Clearance, distance between the intruding frame and windshield. The value is negative if intrusion past the windshield occurs.
FMCSR -- Federal Motor Carrier Safety Regulation.
FMVSS -- Federal Motor Vehicle Safety Standard.
MCG -- Minimally Compliant Guard.
NCAP -- New Car Assessment Program.
NHTSA -- National Highway Traffic Safety Administration.
PCI -- Passenger Compartment Intrusion.