

MOOVOP



Use of 4WD Pickup Trucks as 2270P Vehicles for MASH Crash Testing

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1. Introduction

Introduction

Problematic :

- MOOVOP has recently focused on product development and crash testing;
- High volume of trucks are required for crash testing purposes;
- We had challenges in sourcing 4-door, 2WD trucks to use as 2270P vehicles for MASH;
- Similar trucks in 4WD configuration are readily available.



Introduction (Continued)

Question at hand:

Does using a 4WD truck instead of a 2WD truck as a 2270P vehicle have a significant effect on the outcome of a given crash test?



2. MASH Review

2270P Vehicle Definition per MASH

Per MASH 2016, Section 4.2.1 (p.84) :

“The 2270P test vehicle **should** be a half-ton, 2-wheel-drive, pickup truck with four full-size doors.”

2270P Vehicle Definition per MASH (continued)

Per MASH 2016, Section 4.2 (p. 82) :

“ Large sport utility vehicles (SUVs) make up the highest proportion of vehicles with a mass of 5,000 lb (2,270 kg) or greater. [.] **light of the lower cost for used pickup trucks compared to large SUVs**, a two-wheel-drive, four-door, half-ton pickup truck, weighing approximately 5,000 lb (2,270 kg), was selected to represent the large passenger vehicle class. These pickup trucks were found to **have masses and center of gravity heights similar to those of large SUVs.**”

2270P Vehicle Definition per MASH (continued)

Per MASH 2016, Section 4.2.1 (p. 84):

“ The 2270P vehicle **must** have a minimum c. g. height, in the ballasted configuration, of 28 in. (710 mm). This requirement will necessitate that the c. g. height for all 2270P test vehicles **be measured and reported**”

2270P Vehicle Choice per MASH

Per MASH 2016, Appendix H (pp. 250, 253) :

“Initially, a **3/4-ton, two-wheel drive, regular cab pickup truck**, such as the Chevrolet Silverado 2500, **was selected as the candidate test vehicle** This was the same vehicle recommended by NCHRP Report 350, and it **had the correct curb weight**. [...]. However, commonly available 3/4-ton pickup trucks were found to **have a center-of-gravity (c. g.) height significantly below that of the large SUV class** that the light truck is supposed to represent. [...]. In order to assure that the c. g. heights of the test vehicles are more closely matched with those of large SUVs, **a 1/2-ton, two-wheel drive, four-door pickup truck was chosen to replace the current test vehicle”**

2270P Vehicle Choice per MASH (Continued)

Per MASH 2016, Appendix H (p. 253) :

“Vehicles with curb weights near the the two selected target weight categories were then compared to identify their basic characteristics such as body style, wheelbase, track width, c. g. height, front overhang, rear overhang, weight distribution, overall height, overall length, and overall width. **Other characteristics, such as engine location, suspension type, and drive wheels were also identified.**”

2270P Vehicle Definition per MASH (continued)

Per MASH 2016, Section 4.2.1 (p.84) :

“The vehicle may include a heavy-duty suspension supplied by the manufacturer, provided the vehicle mass properties and c. g. heights fall in the proper range ”

2270P Vehicle Definition per MASH (continued)

Per MASH 2016, Section 4.2.1 (p.83, 85) :

“In addition to the body style and mass parameter that must be met, ranges for other vehicle properties, such as wheelbase, track width, and overall length, are presented to serve as a guide for test vehicle selection.

When practical, test vehicles should be selected to conform to all parameters shown in Tables 4-1 and 4-2.”

TABLE 4-1. Recommended Properties of 1100C, 1500A, and 2270P Test Vehicles

Property	1100C (Small Car)	1500A (Intermediate Car)	2270P (Pickup Truck)
MASS, lb (kg)			
Test Inertial Dummy	2420 ± 55 (1100 ± 25)	3300 ± 75 (1500 ± 35)	5000 ± 110 (2270 ± 50)
Max. Ballast	165 (75)	Optional ^a	Optional ^a
Gross Static	175 (80)	440 (200)	440 (200)
	2585 ± 55 (1175 ± 25)	3300 ± 75 (1500 ± 35) ^a	5000 ± 110 (2270 ± 50) ^a
DIMENSIONS, in. (mm)			
Wheelbase	98 ± 5 (2500 ± 125)	N/A	148 ± 12 (3760 ± 300)
Front Overhang	35 ± 4 (900 ± 100)	N/A	39 ± 3 (1000 ± 75)
Overall Length	169 ± 8 (4300 ± 200)	N/A	237 ± 13 (6020 ± 325)
Overall Width	65 ± 3 (1650 ± 75)	N/A	78 ± 2 (1950 ± 50)
Hood Height	24 ± 4 (600 ± 100)	N/A	43 ± 4 (1100 ± 75)
Track Width ^b	56 ± 2 (1425 ± 50)	N/A	67 ± 1.5 (1700 ± 38)
CENTER OF MASS LOCATION, c in. (mm)			
Aft of Front Axle	39 ± 4 (990 ± 100)	N/A	63 ± 4 (1575 ± 100)
Above Ground (minimum) ^d	N/A	N/A	28.0 (710)
LOCATION OF ENGINE	Front	Front	Front
LOCATION OF DRIVE AXLE	Front	Front or Rear	Rear
TYPE OF TRANSMISSION	Manual or Automatic	Manual or Automatic	Manual or Automatic

a If a dummy (surrogate occupant) is used, the gross static vehicle mass should be increased by the mass of the dummy.

b Average of front and rear axles.

c For "test inertial" mass.

d 2270P vehicle must meet minimum c. g. height requirement.

MASH 2016 Vehicle Choice Philosophy

Per MASH 2016, Section 4.2 (p.82) :

“It should be noted that the passenger vehicle fleet is changing constantly as a function of consumer preferences and other unforeseen circumstances, such as fuel availability and pricing. **The selected test vehicles should be reviewed periodically to make sure that they remain representative of the current vehicle fleet.** Appendix H outlines a recommended procedure for re-evaluating and selecting test vehicles when changes in the vehicle fleet are deemed significant enough to revise the test vehicles.”

MASH 2016 Vehicle Choice Philosophy (Continued)

Per MASH 2016, Appendix H (p. 249) :

“As automobile manufacturers revise vehicle designs more frequently, it is possible that vehicle sizes and/**major characteristics may change significantly over a very short time**. In that event, it is recommended that the procedures described below be utilized to select new test vehicles on an interim basis, **without a complete updating of the impact performance evaluation guidelines. Some limited full-scale testing of any new test vehicles may be needed** to accurately identify the relevance of changes in test vehicle sizes.”

Conclusions for MASH 2016

In summary :

- The 2WD recommendation from MASH seems to be rooted more in cost saving measures for crash testing rather than a fundamental requirement.
- The most important feature for 2270P vehicles is to have the proper mass and c. g. height to represent large SUVs.
- It is recommended to do some limited full-scale crash testing in order to characterize any new test vehicle before using them on an interim basis.



3. Vehicle Fleet over Time

2WD vs 4WD in MASH (2002 Statistics)

Per MASH 2016, Appendix H, Table H.1 (p.252) :

In 2002, looking at stats for “Light Trucks and SUV Sales Volume in the USA , we can see that :

- 6.42% of total market were 4WD light truck and SUV;
- 3.16% of total market were 2WD light truck and SUV;
- 1.34% of total market were mixed/ not specified.

Assuming the worst case scenario where all mixed vehicles were 2WD, at least 62% of all light trucks and SUVs in 2002 were 4WD.

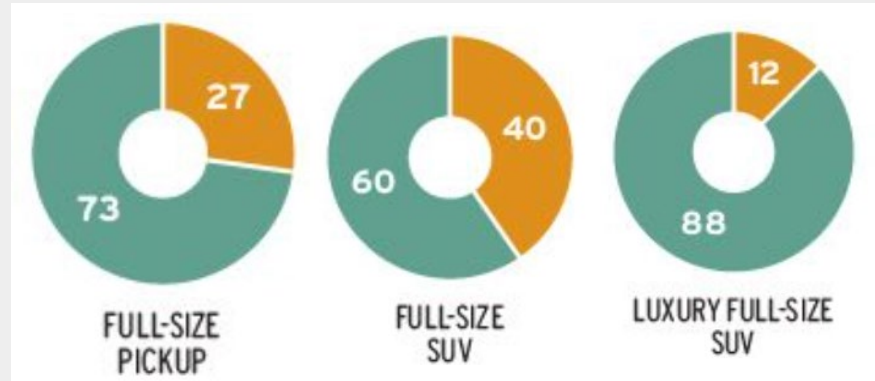
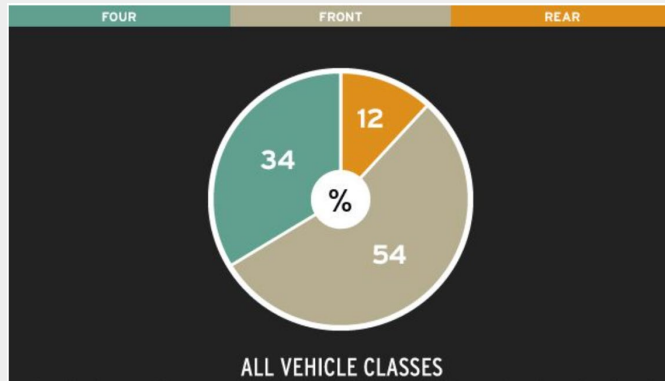
TABLE H-2. Light Truck and SUV Weights and Sales Volumes

Make/Model	Curb Weight, lb (kg)	2002 Sales, No. of Units	Market Share, %	Cumulative Market Share, %
Ford Excursion (4WD)	7,087 (3,215)	21,883	0.13	100.00
Ford Excursion (2WD)	6,650 (3,019)	9,877	0.06	99.87
Dodge Ram 3500 Quad Cab (4WD)	6,638 (3,014)	11,683	0.07	99.81
Hummer H2 Wagon	6,400 (2,906)	7,422	0.04	99.74
Chevrolet Avalanche 2500 (4WD) ^a	6,353 (2,884)	4,702	0.03	99.70
Ford F-250 Crew Cab (4WD) ^b	6,271 (2,847)	43,049	0.26	99.67
Chevrolet Silverado 3500 Ext. Cab ^{c,d}	6,231 (2,829)	25,527	0.15	99.41
Dodge Ram 3500 Quad Cab (2WD) ^e	6,216 (2,822)	12,251	0.07	99.26
Ford F-250 SuperCab (4WD) ^f	6,005 (2,729)	155,120	0.92	99.19
Chevrolet Silverado 2500 Crew Cab (4WD) ^a	5,992 (2,675)	37,866	0.23	98.27
Chevrolet Silverado 3500 Reg. Cab (4WD) ^a	5,870 (2,665)	6,397	0.05	98.04
Ford F-250 Crew Cab (2WD) ^b	5,841 (2,652)	18,449	0.11	97.99
Ford F-250 Reg. Cab (4WD) ^b	5,837 (2,650)	42,326	0.25	97.88
Lincoln Navigator (4WD)	5,774 (2,621)	14,178	0.08	97.63
Dodge Ram 2500 QuadCab (4WD)	5,768 (2,619)	38,860	0.23	97.55
Chevrolet Silverado 1500 Crew Cab (4WD) ^a	5,763 (2,616)	45,529	0.27	97.32
Chevrolet Suburban 2500 (4WD) ^a	5,760 (2,615)	7,175	0.04	97.05
Chevrolet Avalanche 1500 (4WD) ^a	5,652 (2,566)	95,429	0.57	97.01
Ford F-250 SuperCab (2WD) ^b	5,601 (2,543)	66,480	0.40	96.44
Cadillac Escalade (4WD) ^d	5,554 (2,522)	48,001	0.29	96.04
Dodge Ram 2500 Regular Cab (4WD)	5,501 (2,497)	12,609	0.07	95.75
Dodge Ram 2500 Quad Cab (2WD)	5,464 (2,481)	12,272	0.07	95.68
Chevrolet Silverado 1500 Crew Cab (2WD) ^a	5,461 (2,479)	48,357	0.29	95.61
Lincoln Navigator (2WD)	5,424 (2,462)	15,607	0.09	95.32
Chevrolet Silverado 2500 Reg. Cab (4WD) ^a	5,424 (2,462)	159,943	0.95	95.23
Chevrolet Silverado 2500 Ext. Cab (2WD) ^a	5,393 (2,448)	35,688	0.21	94.28
Toyota Land Cruiser ^a	5,390 (2,447)	15,172	0.09	94.07
Ford F-250 Regular Cab (2WD)	5,356 (2,432)	16,280	0.09	93.98
Ford Expedition (4WD)	5,297 (2,405)	55,714	0.33	93.89
Toyota Sequoia (4WD)	5,270 (2,393)	33,883	0.20	93.56
Chevrolet Suburban 1500 (4WD) ^a	5,219 (2,369)	127,427	0.75	93.36
Dodge Ram 1500 Quad Cab (4WD)	5,184 (2,354)	87,263	0.52	92.61
Ford E-150 Econoline Wagon (2WD)	5,101 (2,316)	22,147	0.13	92.09
Toyota Sequoia (2WD)	5,070 (2,302)	36,414	0.21	91.96
Chevrolet Tahoe (4WD) ^a	5,050 (2,293)	159,914	0.95	91.75
Dodge Ram 1500 Quad Cab (2WD)	5,035 (2,286)	136,488	0.81	90.80
Ford F-150 Crew Cab (4WD)	5,008 (2,273)	36,552	0.22	89.99
Chevrolet Silverado 2500 Reg. Cab (2WD) ^a	4,995 (2,268)	16,060	0.09	89.77
Ford Expedition (2WD)	4,909 (2,229)	101,266	0.60	89.68

a Includes both 2WD and 4WD models
 b Includes both 1-ton and 1.1-ton models
 c Includes both 2WD and 4WD models
 d Includes extended cab and crew cab models
 e Includes equivalent models in multiple brands
 f Includes both 2WD-quad cab and 4WD-regular cab models

2WD VS 4WD in More Recent Years

Per Car and Driver (Feb. 20, 2014), based on sales data from IHS Automotive :

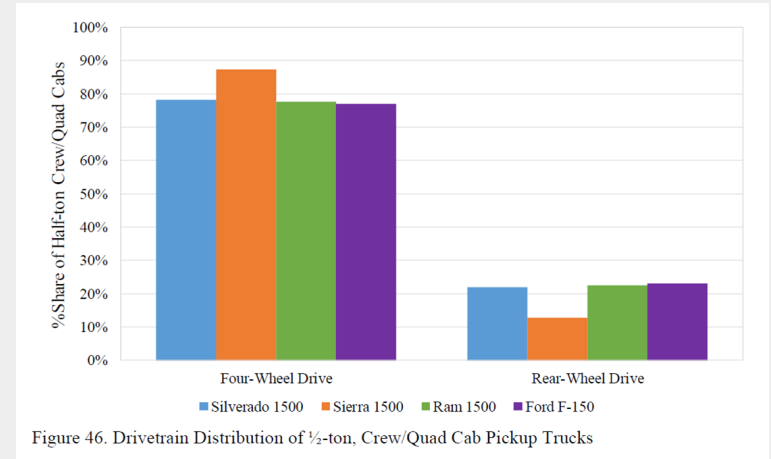


<https://www.caranddriver.com/news/a15366192/differential-distribution-where-rwd-awd-and-fwd-vehicles-are-sold-in-the-u-s-infographic/>

2WD VS 4WD in More Recent Years (Continued)

Per Ronspies (2020):

- 4WD pickup trucks outnumber 2WD pickup trucks on the road by a magnitude of about 4:1.
- The report concludes that 4WD pickup trucks should be used for MASH crash testing.
- The report also notes that the interaction between the front wheel of a 4WD pickup truck and a barrier has never been tested nor documented.



<https://digitalcommons.unl.edu/mechengdiss/158/>

Conclusions from Literature Review

In summary :

- Looking at the current vehicle fleet, it would make sense to use 4WD trucks for MASH crash testing due to their high prevalence on the roads.
- The interaction between the front wheel of a 4WD truck and a barrier seems to be the biggest undocumented unknown that could affect the results of a given crash test.
- If 4WD vehicles are to be used for crash testing, it is imperative to do some limited full-scale crash testing to document this interaction in order to satisfy MASH and Ronspies recommendations.



4. Comparative Crash Test (2WD VS 4WD)

Main Difference between 2WD and 4WD

Added CV axles in front wheel assemblies



2WD



4WD

* Pictures are taken from a Ford F-150 XL 2017 (2WD) and a Ford F-150 XLT 2016 (4WD)

CV Axle

Main Mechanical Characteristics :

- Weight : Around 11 kg each;
- High degree of flexibility in rotation;
- Free plunge for inboard cup;
- Connected to the middle of the front wheel assemblies.



[https://www.fordpartsgiant.com/parts/ford-shaft-front-axle_gl3z-3a427-a.html?vin=&make=Ford&model=F-150&year=2016&submodel=&extra1=&extra2=&filter=\(36694;4188\)&location=pd.](https://www.fordpartsgiant.com/parts/ford-shaft-front-axle_gl3z-3a427-a.html?vin=&make=Ford&model=F-150&year=2016&submodel=&extra1=&extra2=&filter=(36694;4188)&location=pd;)
[https://www.fordpartsgiant.com/parts/ford-shaft-front-axle_gl3z-3a428-a.html?vin=&make=Ford&model=F-150&year=2016&submodel=&extra1=&extra2=&filter=\(36694;4188\)&location=pd.](https://www.fordpartsgiant.com/parts/ford-shaft-front-axle_gl3z-3a428-a.html?vin=&make=Ford&model=F-150&year=2016&submodel=&extra1=&extra2=&filter=(36694;4188)&location=pd.)

Working Hypotheses

- Since the CV axles are connected to the middle of the wheel and can pivot, they should not significantly affect any turning motion applied to the wheel during an impact.
- Since the CV axles are very flexible and can plunge on the inboard side, they should not significantly affect the rigidity of the wheel on a side impact.
- Since the CV axles are relatively lightweight, their presence in the wheel assembly should not significantly affect the wheel assembly reaction during an impact with a barrier.

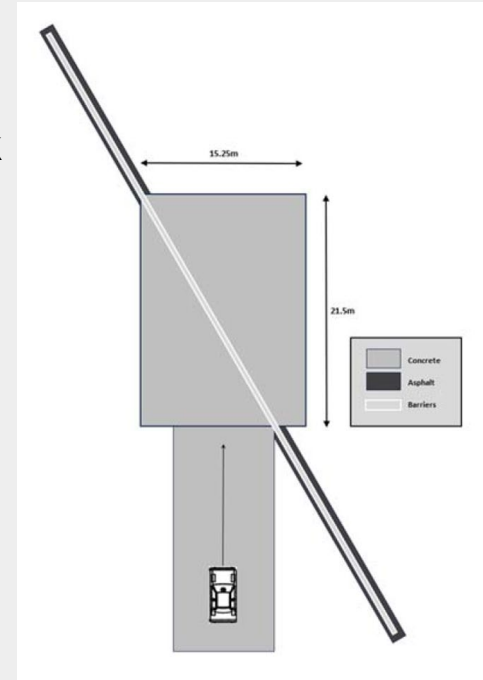
Therefore, given two similar vehicle (same brand and model) adjusted to similar mass and c. g. height and the same test article, **a 2WD and a 4WD vehicle should produce similar results in a crash testing scenario.**

Testing Approach

Do the same crash test with a 2WD and 4WD pickup truck and compare the results.

Test Parameters :

- Test : MASH 3-11 (2270P, 100 km/h, 25 degrees, CIP 1,3 m before central connection);
- Test Article : Portable Concrete Barrier (HP-Lock Prototype), 16 x 4 m sections, for a total installation length of 64 m.



MASH 311 on HP-Lock Prototypes



Model : Dodge Ram 2016 (2WD)

VIN : 1C6RR6GG3GS127950

Test Facility : PMG Technologies

Test Number : 23-7144 - TC64-285

Test Article : HP-Lock Prototype - MASH 3-11

Test Date : March 6th, 2023

MASH 311 on HP-Lock Prototypes



Model : Dodge Ram 2017 (4WD)

VIN : 1C6RR7GG6HS710830

Test Facility : PMG Technologies

Test Number : 24-7035 - TC64-086

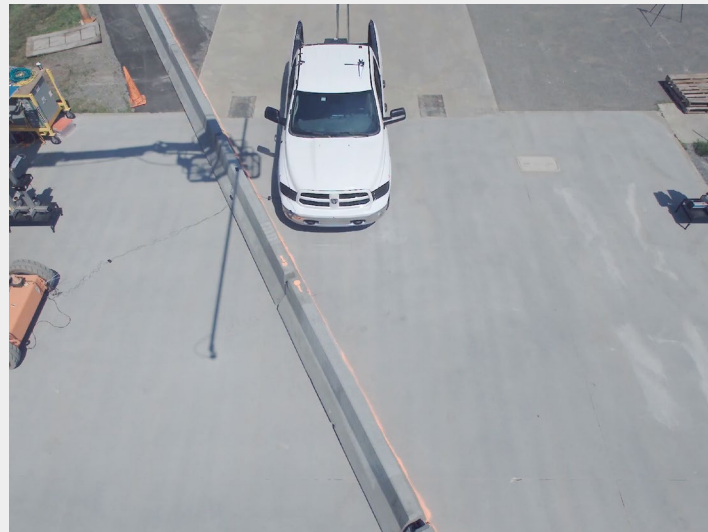
Product : HP-Lock Prototype - MASH 3-11

Test Date : July 6th, 2023

Crash Test Comparison



2X4



4X4

Crash Test Comparison (Continued)



2X4



4X4

Post Test Comparison



2X4



4X4

Post Test Comparison (Continued)



2X4



4X4

Post Test Comparison (Continued)



2X4



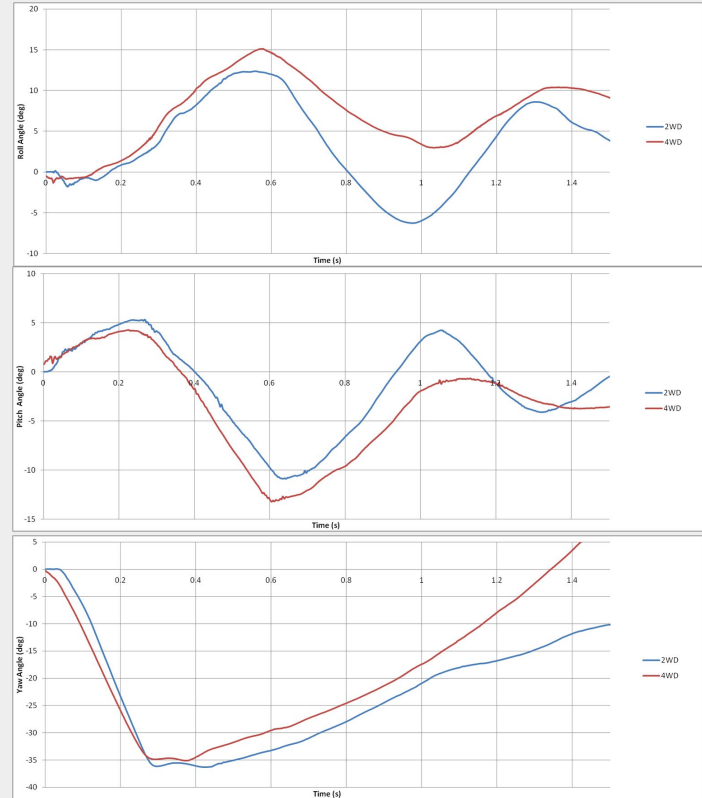
4X4

Crash Test Data Comparison

Test Vehicle	2WD	4WD	Difference
Vehicle Mass (kg)	2261.4	2275.4	+14.0 (+0.6%)
Vehicle Speed (km/h)	100.92	101.36	+0.44 (+0.4%)
Impact Angle (degrees)	25.0	25.0	-
Impact Energy (kJ)	158.7	161.1	+2.4 (+1.5%)
Test Article Deflection (m)	1.55	1.60	+0.05 (+3%)
Longitudinal Occupant Impact Velocity (m/s)	4.8	5.7	+0.9 (+19%)
Lateral Occupant Impact Velocity (m/s)	5.4	6.1	+0.7 (+13%)
Longitudinal Occupant Ridedown Acceleration (G)	4.8	3.9	-0.9 (-19%)
Lateral Occupant Ridedown Acceleration (G)	9.9	8.5	-1.4 (-14%)
Maximum Roll Angle (degrees)	12.4	15.1	+2.7 (+22%)
Maximum Pitch Angle (degrees)	10.9	13.2	+2.3 (+21%)

Vehicular Response

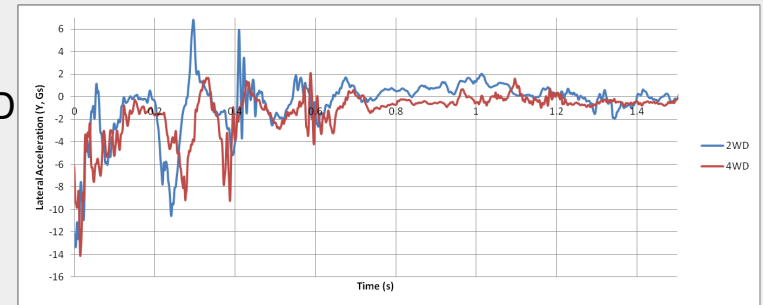
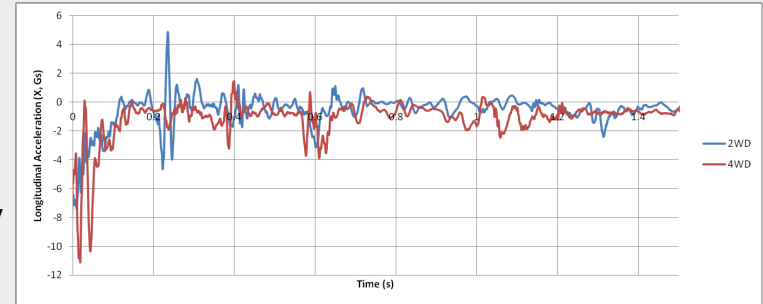
- In general, vehicle behavior is very similar in both cases while the vehicle is in the barrier.
- The 4WD vehicle seems to hit the barrier slightly harder than the 2WD vehicle, causing higher overall roll and pitch values.
- The biggest behavior variation starts to occur at around 0.6 s when the front wheel catches back to the ground outside of the barrier.
- At around 1 s, yaw starts to diverge significantly when the right rear wheel touches the ground.



* 4WD test data was offsetted backwards by 0.046s to compensate for different tape switch positions between both tests.

Vehicular Accelerations

- In general, acceleration are very similar in both cases while the vehicle is in the barrier.
- The 4WD vehicle seems to hit the barrier slightly harder than the 2WD vehicle, causing higher average accelerations during the first contact.
- The accelerations on the second contact are higher for the 2WD vehicle compared to the 4WD vehicle, most likely due to the broken rear right wheel on the 4WD vehicle.



* 4WD test data was offsetted backwards by 0.046s to compensate for different tape switch positions between both tests.

Summary and Recommendations

- There were no significant differences when comparing the crash test results of similar 2WD and 4WD 2270P vehicles when testing on PCB longitudinal barriers according to MASH 311.
- Some variation were observed between both tests, but they were not significant and can be explained by many factors (variations in impact conditions, different rims, etc.)
- This study does not reflect all impact cases with all types of longitudinal barriers.
- More experiments should be conducted in order to determine if similar conclusions can be drawn for other longitudinal barrier types such as permanent concrete walls, guardrails, and cable barriers.