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Investigating the Sensitivity of Vehicle Response to Inter-Vehicle Friction Values for Broadside Collisions Utilizing HVE (EDSMAC4 Algorithm)

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ABSTRACT

In this research, Engineering Dynamics Corporation's Human Vehicle Environment (*HVE*) software was utilized to model a series of broadside impacts where the inter-vehicle friction coefficient, relative vehicle mass ratio, and contact alignment were allowed to vary. The sensitivity of these parameters was examined by comparing the relative final rest positions, as predicted by EDSMAC4, when each parameter was individually varied. The research consisted of utilizing two identical vehicle models for all simulations where only the weight of the bullet vehicle weight was modified. All simulations are based on a stationary target vehicle, where a bullet vehicle traveling at 40-mph contacts the stationary vehicle at a 90-degree configuration. Results obtained from the target vehicle during simulation are presented for delta-V, change in heading, post-contact travel distance, CDC, and PDOF are presented and compared. The findings of this research are useful to aid *HVE* EDSMAC4 users in their understanding and application of inter-vehicle friction coefficients when simulating an array of broadside collisions.

BACKGROUND

The calculations which the EDSMAC4 algorithm utilizes, as described in the literature [1]*, will not be reviewed in great detail. It is necessary, however, to provide a brief overview to illustrate the model in general as a basis for further discussion related to the topic of interest.

1. Interaction between two vehicles occurs when the rectangular perimeter of one two-dimensional vehicle model overlaps with another vehicle or object model.

2. After interaction is detected, an array of vectors (radiating from the CG of each object) is directed toward the damage surface in the area of interaction. For each time-step in the simulation, forces between corresponding vectors from each object are calculated and checked for compliance with Newton's Third Law. There can be up to 360 vectors per time-step, each with a separation of angle which is typically 2-degrees.

3. The vectors are then used to determine the forces acting normal to the damage surface in the zone of interaction between the objects at each time-step.

4. When all calculations, including tire forces, have been computed for each time-step, the sum of external forces (X & Y) and moments (Z) is calculated and applied to the CG of each object (Fig. 1).

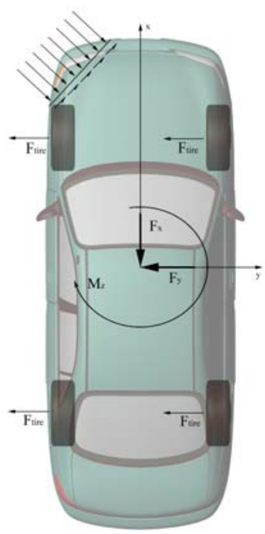

Figure 1. Collision Vectors & Shear Forces

The inter-vehicle friction factor, *AMU*, (a dimensionless input quantity, which typically ranges from 0.30 to 0.75), is used to determine the maximum tangential force acting at the damage surface in the zone of interaction at each time-step [1]. The algorithm which incorporates the inter-vehicle friction factor into the EDSMAC4 analysis and the effects of the *AMU* on output parameters has not been discussed at great length in the literature.

TERMINOLOGY

Delta-V - Sudden change in vehicle velocity resulting from contact with another vehicle or object (mph).

Principle Direction of Force (PDOF) - Represented in *HVE* as an angular measurement (deg), is the representation of the total collision force vector applied to the exterior of the vehicle model, and is oriented relative to a coordinate system [x,y,z] fixed to each vehicle.

Yaw Heading - Orientation of a vehicle relative to the global *HVE* coordinate system [X,Y,Z].

Distance Traveled – Absolute distance traveled by target vehicle CG after contact until simulation termination conditions are reached (ft).

VEHICLE SIMULATION DATA

In this research, two identical Volvo 740 4-door wagon passenger cars (Fig. 2) were chosen from the *HVE* vehicle database. The default vehicle specifications listed in the *HVE* vehicle data specifications were utilized throughout the analysis, except as modified to achieve the desired mass ratio between vehicles. The Volvos were found to have an overall width of 68.90 inches, and an overall length of 187.50 inches, which also corresponds to the rectangular perimeter of their two-dimensional model in *HVE*. The axles of the vehicles were listed to be 48.70 inches and 60.30 inches from the CG, front and rear, respectively. The bumpers of the vehicles were listed to be 84.25 inches and 103.25 inches from the CG, front and rear, respectively.

Vehicle Name :	Volvo 740 4-Dr Wagon - Targ
Vehicle Type :	Passenger Car
Make :	Volvo
Model :	740
Year :	1983-1998
Body Style :	4-Door Wagon
Source Database :	EDC.db
Number of Axles :	Two
Driver Location :	Left
Engine Location :	Front
Drive Axle(s) :	Axle No. 2

Figure 2. General Vehicle Information

Throughout the research, the target and bullet vehicles were oriented at a relative angle of 90-degrees (Fig. 3), with the front of the bullet vehicle facing toward the left (driver) side of the target vehicle. The bullet vehicle was set with an initial speed of 40-mph, the target vehicle was set with its rear axle locked, a drag factor on the front axle of 0.01 of available friction, and an initial speed of 0-mph. To prevent secondary contact between the two vehicles, the brakes of the bullet vehicle were locked approximately 0.1 seconds after initial contact with the left side of the target vehicle (Fig. 4). No other driver inputs were initiated at any time during the simulations.

Figure 3. Vehicle Alignment (90-deg.) CG Overlap – 0 feet

Table : Available Friction

Available Friction vs. time

time (sec)	Axle 1 Right (%/100)	Axle 1 Left (%/100)	Axle 2 Right (%/100)	Axle 2 Left (%/100)
0.0000	0.00	0.00	0.00	0.00
0.3500	0.00	0.00	0.00	0.00
0.3600	1.00	1.00	1.00	1.00

Figure 4. Bullet Braking Table

SIMULATION OVERVIEW

The following is a brief description of the test procedure utilized during this research. For all simulations, the X and Y coordinates of the target vehicle CG were positioned at (0,0), while the Z-coordinate of the CG remained constant at the default *HVE* specification. The X-coordinate of the bullet vehicle CG was placed 24.20 feet from the CG of the target vehicle, the Y-coordinate of the bullet vehicle CG was allowed to vary, and the Z-coordinate of the CG remained constant at the default *HVE* specification. In order to avoid secondary contact between the target and bullet vehicles, the Y-coordinate of the bullet vehicle CG was placed at values of (-8.89, -7.89, 0, 9.44, 10.44) feet during this research. The above Y-coordinates correspond with the following 5 vehicle alignments:

1) Front face of bullet vehicle overlaps 1 foot of the left-front of target vehicle.

2) Front face of bullet vehicle overlaps 2 feet of the left-front of target vehicle.

3) Target CG inline with bullet CG.

4) Front face of bullet vehicle overlaps 2 feet of the left- rear of target vehicle.

5) Front face of bullet vehicle overlaps 1 foot of the left- rear of target vehicle.

In order to investigate the effects of mass ratio between the vehicles, the weight of the bullet vehicle was increased to achieve mass ratios of 1.5:1 and 2.0:1. The value of the *AMU* was evaluated during this research in the range from 0.0 through 1.0, in increments of 0.1 for each of the 5 relative CG locations and 3 separate mass ratios. The simulation control options of output time interval and linear velocity termination conditions were changed from their default values (0.1 seconds/ 2 mph) to (0.01 seconds/ 2.84 mph) in order to achieve increased resolution and reduce post-contact vehicle motion (Fig. 5).

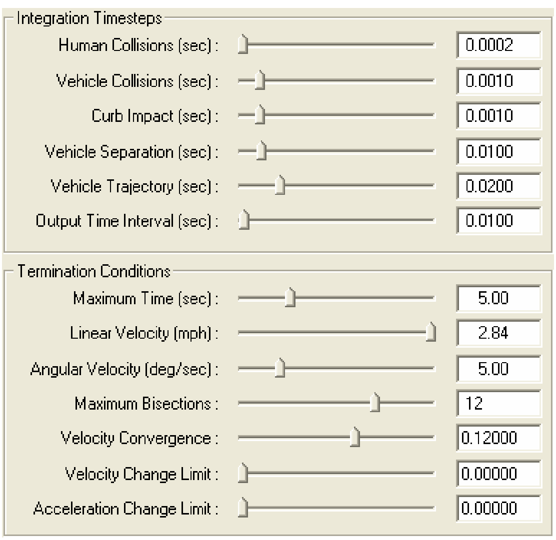

Figure 5. EDSMAC4 Simulation Controls

The following information was recorded for the target vehicle after each simulation performed in this research: 1) post-contact X and Y coordinate values, 2) yaw heading, 3) delta-V, 4) PDOF, and 5) CDC. From these values, the total post-contact travel distance of the target vehicle CG and the total change in yaw heading were also calculated. Simulations which appeared to be abnormal or erratic were checked for error messages prior to recording of the above outputs. All graphical data which is pertinent to the findings of this research can be found in *Appendix A.*

DISCUSSION

The following subsections (1-5) discuss the data collected throughout this research:

Vehicle Alignment 1): Analysis of the data collected during this research configuration revealed the most consistent and distinct trends of the multiple configurations utilized for this research. The delta-V, distance traveled, and change in yaw heading output parameters all displayed a parabolic trend as the AMU value was varied. Similar to the results observed other alignments, the increase in mass ratio resulted in an increase in delta-V, change in yaw heading, and distance traveled. The mass ratio was also noted to have minimal effect relative to the change in yaw heading at low AMU values. (Fig.6)

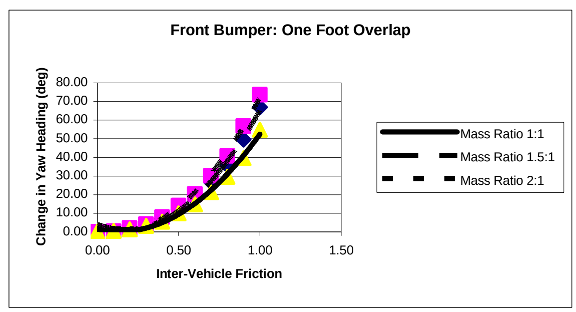

Figure 6. Alignment #1, Change in Yaw Heading Output

Vehicle Alignment 2): Analysis of the data collected during the second vehicle alignment configuration revealed several interesting trends which were not observed in vehicle alignment 1. The distance traveled, and change in yaw heading output parameters displayed similar results trend as the AMU value was varied, but differed greatly from the results observed in vehicle alignment 1. The mass ratio was also noted to have large effect relative to the change in yaw heading at all AMU values. (Fig.7) Also, the PDOF and delta-V were noted to be remarkably inconsistent in the analyses with mass ratios of 1:1 and 1.5:1 for all AMU values.

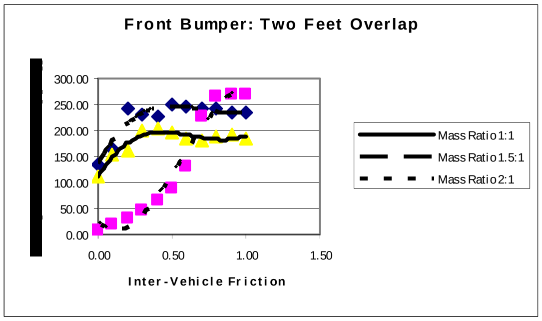

Figure 7. Alignment #2, Change in Yaw Heading Output

Vehicle Alignment 3): The delta-V and distance traveled of the target vehicle remained relatively constant as the AMU was increased, and as is expected, an increase in mass ratio increased both the delta V and distance traveled post contact. Strangely, as the mass ratio increased, the change in yaw heading output results became increasingly unstable. The PDOF output remained constant for all mass ratios, but became somewhat unstable when the AMU was increased to values 0.6 and greater (Fig. 8).

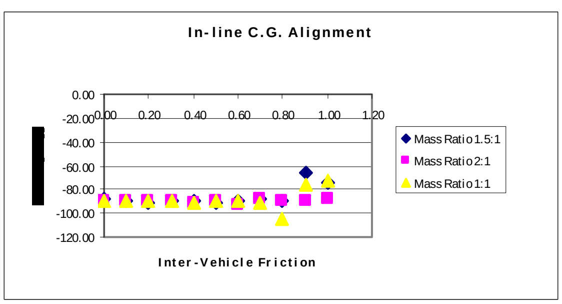

Figure 8. Alignment #3, PDOF Output

Vehicle Alignment 4): Analysis of the data collected during the vehicle alignment number 4 configuration again revealed consistent trends between change in yaw heading and distance traveled outputs, which are more dependent on mass ratio than AMU value in this case. The PDOF and delta-V were noted to be very inconsistent in the analyses for all mass ratios with AMU values greater than approximately 0.3 (Fig.9)

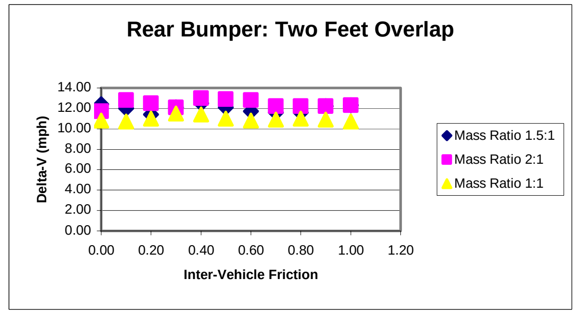

Figure 9. Alignment #4, Delta-V Output

Vehicle Alignment 5): The data collected during this research configuration, similar to vehicle alignment number 1, revealed consistent and distinct trends. The distance traveled and change in yaw heading output parameters displayed parabolic trends for AMU values less than 0.7, and was quite linear in the range of typical AMU values from 0.3 to 0.75 (Fig. 10). Also, in contrast to vehicle alignment number 1, mass ratio was not observed to have a significant effect on the outputs for vehicle alignment number 5. The delta-V values for all mass ratios were observed to be relatively consistent for AMU values less than 0.4, but began to differ slightly for larger AMU values. It is likely that the locked rear wheels of the target vehicle had a significant effect on post-contact vehicle motion at large AMU values.

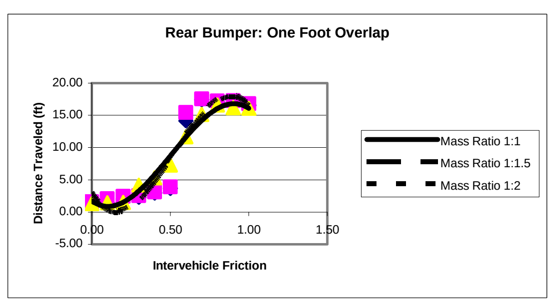

Figure 10. Alignment #5, Distance Traveled Output

CONCLUSIONS

1. The value of the AMU has very little effect on the post-contact vehicle motion of the target vehicle when the CG of a target vehicle is aligned with the velocity vector of a bullet vehicle during a broadside collision at 90-degrees.

2. The effects of the AMU value on *HVE* EDSMAC4 output increase as the relative offset between the CG of each vehicle increases during a broadside-type collision at a 90-degree alignment.
3. In vehicle configurations with substantial offset, the PDOF and delta-V outputs are very sensitive to the specified AMU value, and can change drastically with relatively small changes in inter-vehicle friction.

4. The AMU value can have a significant effect on *HVE* outputs in offset broadside-type collision simulations.

RECOMMENDATIONS

1. A comprehensive study detailing the effects of the *AMU* on post-contact vehicle motions with contact alignments other than 90-degrees.

2. Further investigation should be performed regarding the anomalies which surfaced during this research regarding erratic variance in delta-V and PDOF as the *AMU* value utilized varied linearly.

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REFERENCES

1. Day, T.D., "An Overview of the EDSMAC4 Collision Simulation Model," SAE Paper No.1999-01-0102, presented at the SAE International Congress and Exposition, Detroit, MI, March, 1999.

2. Day, T.D., "An overview of the HVE Vehicle Model," SAE Paper No. 950308, presented at the SAE International Congress and Exposition, Detroit, MI, February, 1995.

3. Day, T.D., Hargens, Randall L, "An Overview of the Way EDSMAC Computed Delta-V," SAE Paper No. 880069, Society of Automotive Engineers, Warrendale, PA, 1988.

4. *HVE User's Manual*, Version 4, 5th Ed., Engineering Dynamics Corporation, Beaverton, OR, April, 2002.

5. *HVE Physics Manual (EDSMAC4)*, Version 5, 5th Ed., Engineering Dynamics Corporation, Beaverton, OR, November, 2001

Appendix A

1:1 Mass Ratio

C.G. inline

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	21.99	21.97	21.95	21.66	21.60	21.51	21.46	21.26	21.18	21.12	21.01
y	-0.10	-0.06	-0.05	-0.03	-0.03	-0.05	-0.04	-0.09	-0.01	-0.09	-0.05
yaw heading	273.25	272.92	272.60	272.51	272.49	272.53	272.44	273.60	272.07	273.32	272.53
delta v	21.80	21.90	21.90	21.70	21.80	21.70	21.70	21.70	21.80	21.70	21.50
CDC	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3
PDOF	-90.20	-89.70	-89.70	-88.80	-90.90	-89.70	-89.60	-91.60	-104.10	-76.40	-73.00
dtotal	21.99	21.97	21.95	21.66	21.60	21.51	21.46	21.26	21.18	21.12	21.01
delta yaw head	3.25	2.92	2.60	2.51	2.49	2.53	2.44	3.60	2.07	3.32	2.53

1 foot overlap front bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.06	0.08	0.14	0.27	0.46	0.77	1.15	1.70	2.36	3.06	3.89
y	1.17	1.02	0.92	0.84	0.77	0.77	0.80	0.90	1.14	1.52	2.23
yaw heading	270.12	270.60	271.35	273.27	275.54	280.01	284.85	291.40	299.61	309.58	324.91
delta v	2.90	2.60	2.60	2.90	3.10	3.50	4.00	4.40	5.40	5.80	6.7
CDC	12FDEW2	12FDEW3	12FDEW4	12FDEW5	12FDEW6	11FDEW2	11FYEW2	11FDEW2	10FDEW2	11FYEW2	10FYEW2
PDOF	-4.50	-6.00	-9.70	1.90	-7.00	-37.50	-20.00	-35.80	-54.30	-42.10	-61.2
dtotal	1.17	1.02	0.93	0.88	0.90	1.09	1.40	1.92	2.62	3.42	4.48
delta yaw headin	0.12	0.60	1.35	3.27	5.54	10.01	14.85	21.40	29.61	39.58	54.91

1 foot overlap rear bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.26	0.41	0.66	2.81	4.13	6.38	10.33	13.33	14.34	14.20	14.12
y	-1.27	-1.37	-1.37	-3.09	-3.32	-3.54	-5.41	-7.23	-8.35	-7.79	-7.74
yaw heading	266.11	261.70	258.92	216.80	200.28	184.28	161.91	149.20	138.38	142.04	142.25
delta v	2.80	3.00	3.40	5.80	6.40	7.40	8.70	9.40	10.10	10.00	10.10
CDC	06BYEW1	06BYEW1	06BYEW1	07BYEW2	06BYEW2	07BYEW2	08BYEW2	08BYEW2	08BYEW2	08BYEW2	08BYEW2
PDOF	-166.50	-173.60	-179.30	-140.40	-166.80	-144.60	-121.10	-115.40	-110.00	-109.90	-112.70
dtotal	1.30	1.43	1.52	4.18	5.30	7.30	11.66	15.16	16.59	16.20	16.10
		2 contacts?									
delta yaw head	3.89	8.30	11.08	53.20	69.72	85.72	108.09	120.80	131.62	127.96	127.75

2 foot overlap rear bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	13.65	14.05	14.80	15.88	15.65	15.20	14.99	15.04	15.10	15.04	14.99
y	-10.90	-9.81	-9.14	-7.28	-7.03	-7.58	-8.02	-8.08	-8.06	-8.02	-7.90
yaw heading	130.94	134.74	124.85	97.20	101.96	115.40	124.27	121.75	120.15	122.99	128.22
delta v	10.80	10.70	11.00	11.50	11.40	11.00	10.80	10.90	11.00	10.90	10.70
CDC	08BYEW3	08BYEW3	08BYEW3	08BYEW3	06BYEW3	06BYEW3	09BYEW3	09BYEW3	09BYEW3	08BYEW3	06BYEW3
PDOF	-126.90	-119.60	-112.90	-106.00	178.50	175.90	-92.50	-92.70	-102.10	-105.10	171.30
dtotal	17.47	17.14	17.39	17.47	17.16	16.99	17.00	17.07	17.12	17.04	16.94
delta head	139.06	135.26	145.15	172.80	168.04	154.60	145.73	148.25	149.85	147.01	141.78

2 foot overlap front bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	11.01	15.30	15.74	17.20	17.44	17.01	16.55	16.52	16.71	16.89	16.61
y	5.18	6.65	5.69	5.45	5.03	5.19	5.13	5.00	4.98	4.88	4.70
yaw heading	381.80	424.60	432.83	468.98	474.83	466.72	453.63	450.87	456.60	460.39	456.11
delta v	10.60	11.70	11.80	12.50	0.10	13.00	0.10	12.90	0.00	0.20	0.20
CDC	10FYEW3	10FYEW3	10FYEW3	09FYEW3	12FYEW3	09FYEW3	12FYEW3	09FYEW3	01FYEW3	12FYEW3	01FYEW3
PDOF	-57.20	-65.20	-73.00	-80.20	12.40	-85.60	3.40	-83.50	17.80	1.20	24.00
dtotal	12.17	16.68	16.74	18.04	18.15	17.78	17.33	17.26	17.44	17.58	17.26
delta yaw headin	111.80	154.60	162.83	198.98	204.83	196.72	183.63	180.87	186.60	190.39	186.11

1.5:1 Mass Ratio

C.G. inline

friction factor	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	32.37	32.35	32.22	31.80	31.67	31.62	31.74	31.52	31.31	31.35	31.31
y	-0.46	-0.42	-0.24	-0.07	-0.14	-0.29	-0.16	0.02	-0.21	-0.15	-0.42
yaw heading	275.88	276.91	276.50	273.30	272.72	276.64	274.04	271.34	274.54	273.61	276.65
delta v	26.40	26.30	26.30	26.30	26.20	26.20	26.30	26.30	26.30	26.20	26.40
CDC	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	10LDEW3	10LDEW3
PDOF	-88.50	-90.10	-90.50	-90.10	-90.30	-90.60	-88.90	-87.50	-89.70	-66.50	-75.00
dtotal	32.37	32.35	32.22	31.80	31.67	31.62	31.74	31.52	31.31	31.35	31.31
delta yaw	5.88	6.91	6.50	3.30	2.72	6.64	4.04	1.34	4.54	3.61	6.65

1 foot overlap front bumper

friction factor	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.07	0.09	0.13	0.32	0.55	0.97	1.42	2.10	2.81	3.66	4.64
y	1.50	1.57	1.26	1.03	0.90	0.96	0.99	1.17	1.48	2.14	2.80
yaw heading	269.01	270.29	271.82	273.66	277.00	282.11	287.69	296.73	305.85	319.54	337.01
delta v	3.20	3.50	3.50	3.50	3.90	4.30	4.40	5.10	5.80	6.70	7.70
CDC	12FDEW2	12FDEW2	12FDEW2	12FDEW2	11FDEW2	11FDEW2	11FDEW2	10FDEW2	10FDEW2	10FYEW2	10FYEW2
PDOF	0.70	-4.30	-0.60	-11.20	-31.20	-36.20	-41.60	-49.50	-51.40	-55.70	-58.00
dtotal	1.50	1.57	1.27	1.08	1.05	1.36	1.73	2.40	3.18	4.24	5.42
	3 CONTAC	2 contacts	2 contacts	2 contacts	2 contacts						
delta yaw head		0.29	1.82	3.66	7.00	12.11	17.69	26.73	35.85	49.54	67.01

1 foot overlap rear bumper

friction factor	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.22	0.41	0.72	1.12	1.72	2.75	12.12	14.50	14.61	14.67	14.40
y	-1.44	-1.41	-1.88	-2.03	-2.39	-2.40	-7.35	-9.61	-8.72	-8.40	-8.18
yaw heading	265.08	261.74	255.97	249.28	237.14	221.67	150.69	125.78	121.57	111.57	118.03
delta v	3.30	3.10	3.50	4.00	4.90	5.60	9.20	10.60	0.00	11.30	10.90
CDC	06BYEW1	06BYEW1	06BYEW1	07BYEW1	07BYEW1	07BYEW1	08BYEW2	08BYEW2	06BYEW2	08BYEW2	08BYEW2
PDOF	-175.70	-170.50	-174.20	-147.10	-135.90	-135.60	-120.70	-117.00	168.90	-110.00	-112.40
dtotal	1.46	1.47	2.01	2.32	2.94	3.65	14.17	17.40	17.01	16.90	16.56
delta yaw head	4.92	8.26	14.03	20.72	32.86	48.33	119.31	144.22	148.43	158.43	151.97

2 foot overlap rear bumper

friction factor	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	14.75	15.75	15.01	16.72	17.93	17.21	16.32	16.08	16.09	16.43	16.56
y	-11.38	-9.30	-9.55	-7.69	-7.27	-6.91	-6.88	-6.98	-6.99	-6.89	-6.91
yaw heading	89.94	88.14	108.04	78.13	54.32	66.87	83.89	90.16	89.92	83.51	80.60
delta v	12.40	12.00	11.40	12.10	12.50	12.10	11.70	11.60	11.60	12.20	12.30
CDC	08BYEW3	08BYEW3	08BYEW3	08BYEW3	06BYEW3	06BYEW3	05BYEW3	05BYEW3	07BYEW3	09BYEW3	08BYEW3
PDOF	-126.00	-119.10	-112.10	-106.60	178.40	173.10	157.00	159.30	-161.00	-94.60	-112.20
dtotal	18.63	18.29	17.79	18.40	19.35	18.55	17.71	17.53	17.54	17.82	17.94
delta yaw head	180.06	181.86	161.96	191.87	215.68	203.13	186.11	179.84	180.08	186.49	189.40

2 foot overlap front bumper

friction factor	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	14.18	15.93	19.50	19.12	18.75	20.71	20.35	20.30	20.12	19.46	19.60
y	7.09	7.63	7.04	6.04	6.08	5.37	5.71	5.68	5.55	5.38	5.52
yaw heading	405.69	434.02	510.39	501.99	496.02	518.23	515.38	513.87	511.03	503.43	504.07
delta v	11.70	12.00	13.80	13.50	13.50	0.30	0.00	14.80	0.00	0.30	0.10
CDC	11FYEW3	10FYEW3	10FYEW3	10FYEW3	09FYEW3	12FYEW3	12YEW3	09FYEW3	01FYEW3	12FYEW3	01FYEW3
PDOF	-39.30	-60.90	-68.10	-72.20	-77.20	9.00	13.50	-93.10	30.80	7.50	25.60
dtotal	15.85	17.66	20.73	20.05	19.71	21.39	21.14	21.08	20.87	20.19	20.36
delta Yaw	135.69	164.02	240.39	231.99	226.02	248.23	245.38	243.87	241.03	233.43	234.07

2:1 Mass Ratio

1 foot overlap front bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.09	0.07	0.11	0.35	0.64	1.08	1.59	2.36	3.14	4.05	5.40
y	1.87	1.62	1.52	1.27	1.11	1.12	1.16	1.38	1.80	2.63	3.13
yaw heading	270.03	270.35	271.98	274.12	277.94	284.07	290.23	300.18	310.74	326.78	343.56
delta v	3.60	3.40	3.50	3.90	4.20	4.70	5.20	5.50	6.20	7.40	8.20
CDC	12FDEW2	12FDEW2	12FDEW2	12FDEW2	12FDEW2	11FDEW2	11FDEW2	11FDEW2	11FDEW2	10FYEW2	10FYEW2
PDOF	-0.60	-4.70	-9.60	4.50	-14.80	-36.20	-38.90	-31.30	-41.50	-55.00	-60.50
dtotal	1.87	1.62	1.52	1.32	1.28	1.56	1.97	2.73	3.62	4.83	6.24
delta yaw head	0.03	0.35	1.98	4.12	7.94	14.07	20.23	30.18	40.74	56.78	73.56

2 foot overlap front bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.88	1.66	2.47	3.59	4.67	7.52	14.20	19.10	23.00	23.63	23.87
y	2.39	2.29	2.21	2.66	3.54	3.89	5.35	7.12	7.24	7.60	8.13
yaw heading	279.48	288.52	299.38	316.58	336.81	358.83	400.99	495.70	533.48	537.67	539.36
delta v	6.10	6.40	7.10	7.70	8.80	10.00	11.80	13.90	15.60	16.40	0.10
CDC	12FDEW3	12FDEW3	12FDEW3	11FYEW3	10FYEW3	11FYEW3	10FYEW3	10FYEW3	09FYEW3	09FYEW3	12FYEW3
PDOF	-1.40	3.80	-11.50	-24.50	-46.70	-44.70	-59.00	-65.70	-75.60	-76.60	0.40
dtotal	2.55	2.83	3.31	4.47	5.86	8.47	15.17	20.38	24.11	24.82	25.22
delta yaw head	9.48	18.52	29.38	46.58	66.81	88.83	130.99	225.70	263.48	267.67	269.36

CG to CG

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	43.6	45.14	44.38	43.31	42.48	41.95	40.49	40.25	39.93	39.57	39.84
y	-1.57	-0.51	-0.79	0.24	-0.51	-0.29	-0.41	-0.94	-0.08	0.22	-0.31
yaw heading	286.27	276.79	278.31	268.64	276.74	275.05	276.21	281.22	272.86	268.24	275.33
delta v	30.4	31	30.9	30.5	30.2	30.2	29.6	29.5	29.5	29.4	29.6
CDC	09LDEW4	09LDEW4	09LDEW3	09LDEW4	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3	09LDEW3
PDOF	-89.9	-89.7	-90	-89	-91.9	-89.2	-93	-87.3	-89.1	-90.3	-88.6
dtotal	43.63	45.14	44.39	43.31	42.48	41.95	40.49	40.26	39.93	39.57	39.84
delta yaw	16.27	6.79	8.31	1.36	6.74	5.05	6.21	11.22	2.86	1.76	5.33

1 foot rear bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	0.32	0.43	0.83	1.21	1.81	2.97	12.88	14.89	15.04	15.38	15.05
y	-1.58	-2.04	-2.3	-2.2	-2.52	-2.51	-8.52	-9.31	-8.36	-7.81	-7.41
yaw heading	264.52	260.19	253.24	246.13	233.95	217.27	144.6	109.22	103.22	87.85	95.06
delta v	3.4	3.3	4	4.2	4.8	5.9	9.8	11.2	11.2	11.6	11.4
CDC	06BYEW1	06BYEW1	06BYEW1	06BYEW1	06BYEW1	07BYEW1	08BYEW2	08BYEW2	08BYEW2	08BYEW2	08BYEW2
PDOF	-166.4	179.9	-167.9	-165.4	-167	-135.2	-121.9	-117.1	-107.6	-106.4	-108.4
dtotal	1.61	2.08	2.45	2.51	3.10	3.89	15.44	17.56	17.21	17.25	16.78
delta yaw	5.48	9.81	16.76	23.87	36.05	52.73	125.4	160.78	166.78	182.15	174.94

2 foot overlap rear bumper

	friction factor										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
x	13.67	17.21	17.13	16.39	18.54	18.5	18.05	17.42	17.46	17.42	17.59
y	-12.12	-9.9	-8.59	-8.45	-8.17	-7.65	-7.47	-7.1	-7.01	-6.91	-6.77
yaw heading	117.19	56.14	66.02	80.88	38.37	37.75	47.43	63.28	61.06	62.73	60.1
delta v	11.7	12.8	12.5	12.1	13	12.9	12.8	12.2	12.2	12.2	12.3
CDC	08BYEW3	08BYEW3	08BYEW3	08BYEW3	09BYEW3	06BYEW3	06BYEW3	05BYEW3	06BYEW3	09BYEW3	06BYEW3
PDOF	-125.2	-119.4	-112.1	-105.7	-103	178.1	176.4	155.1	178.9	-88.7	172.2
dtotal	18.27	19.85	19.16	18.44	20.26	20.02	19.53	18.81	18.81	18.74	18.85
delta yaw	152.81	213.86	203.98	189.12	231.63	232.25	222.57	206.72	208.94	207.27	209.9