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Evaluation of the ARAS HD ICATS System in Relation to the RICSAC Staged Crash Events.

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ABSTRACT

ARAS HD is a software application designed to allow users to draw crash scene diagrams from electronic measurements or hand measurements, and to create three-dimensional animations and scene models. It also contains a 2.5D (2D with terrain following) simulation tool called ICATS (Interactive Collision and Trajectory Simulation). ICATS is based on the original published SMAC (Simulation Model of Automobile Collisions) algorithms produced for NHTSA (National Highway Traffic Safety Administration) in the 1970s. The results generated by this tool are often taken to both criminal and civil trials at which the accuracy of the tool will be questioned. This means that the user of the system must be able to describe how the tool works in terms of foundational mathematical algorithms. Users must also give information on the accuracy of the tool in relation to staged crashes. The validation procedure must be described and documented for review by non-scientific parties. This paper describes the way the ICATS system in ARAS HD works and the method and results of the validation study.

INTRODUCTION

In the 1970s, NHTSA commissioned Calspan to create a computer program to model two-vehicle collisions. This led to the creation of the SMAC program. SMAC is a planar, 2D only simulation system that models the vehicles as rectangular boxes with three degrees of freedom (x, y, and yaw). ICATS implements the same system, but in 2.5D. All simulation calculations are done using the three degrees of freedom model, but with terrain following added in for the generated simulation paths. That is, the elevation, pitch, and roll along the simulation trajectories are adjusted to follow the terrain while keeping the x, y, and yaw results from the simulation calculations. Simulation is a multivariable system in which different combinations of parameters can be adjusted to achieve the same result.

VALIDATION STUDY

Validation of the ICATS system was done by comparing the rest positions, orientations, post-impact trajectories and Delta V from the impact determined by the ICATS run with the data provided by the RICSAC (Research Input for Computer Simulation of Automobile Collisions) tests. These twelve tests were commissioned by NHTSA in the late 1970s to provide a standardized series of tests and data to validate accident reconstruction techniques, such as SMAC and CRASH. The authors of this paper have relied upon the diagrams and data provided by the RICSAC reports, particularly from volumes II and III (Shoemaker, 1978). The diagrams from the reports were scanned and imported into ARAS HD as images and then scaled using the scale indicated on the diagram. No more than ten minutes was spent on each test, modifying input data to get as close a match as possible to the test data while also attempting to stay true to the data provided by the RICSAC tests.

In the case of Delta V comparison, as mentioned in several other studies done on the RICSAC tests, the data for Delta V's cannot be used directly as it was taken from sensors that were placed at a distance from the center of gravity of the vehicles. Instead, the Delta V's used for comparison here come from the Engineering Dynamics Corp. (EDC) study of the RICSAC tests (Day & Hargens, 1990). Several tests had data that indicated rear wheel damage causing some rear wheel steerage. Since this cannot be simulated with the current system, these tests will have a higher degree of error in post-impact results. Some of the diagrams did not match the specified inputs; for example, one test had the vehicles listed as having a 10 degree angle of impact, but the diagram was drawn with about a 25 degree angle. Other diagrams showed an inconsistency in the size of the vehicles drawn, with some vehicles being off by as much as three feet. So, as with any test, the results are only as good as the data provided. One of the inputs that is a major influence in the tire-road model is the braking (or roll-resistance) values of each tire. While the RICSAC tests provided a road way friction coefficient (0.87), they provided no data on the roll-resistance of the vehicles, other than to say that they were 100% braked or not. No values for partial braking/damaged tires were provided. In all cases, except for the 100% locked, the actual value for braking/roll-resistance combined with roadway friction had to be estimated. This resulted in values from 0.04 to 0.06 for "free-rolling" for most of the tests. The data from several of the tests indicated that there had to be either partial braking on some/all tires or other forces in effect simply due to the fact that the length of post-impact trajectories did not support either a 100% braking scenario or the low end "free-roll" scenario. Several tests also had an obvious "snag" situation. That is, where the two vehicles stuck together for some amount of time after the initial impact, and in some cases remained in contact at their rest positions; the current iteration of ICATS cannot account for these differences.

The error analysis done on each test follows the same approach employed by EDC (Day & Hargens, 1990).

Path length used for each test was approximated using a spline curve drawn on top of the scaled diagram, rather than the straight-line approach used in other studies for path length.

Delta Rest Position

(R.X rest x component, R.Y is rest y component)

$$\Delta R = |(R.X_{pred} - R.X_{acc}, R.Y_{pred} - R.Y_{acc})|$$

Delta Path Length

$$\Delta L = Path_{pred} - Path_{acc}$$

Path Error

$$\frac{\Delta R}{\Delta L}$$

Yaw Error

$$\frac{|\Delta Yaw_{pred} - \Delta Yaw_{acc}|}{360}$$

Delta V Error

$$\frac{|\Delta V_{pred}| - |\Delta V_{meas}|}{|\Delta V_{meas}|}$$

See Appendix 1 for full tables of results.

See Appendix 2 comparing just Delta V's.

LIMITATIONS OF SIMULATION

The simulation is simplified to a two-dimensional, homogenous plane with only three degrees of freedom. The current ICATS vehicle model is limited to steering inputs on the front tires only. The simulation assumes that during impact the collision forces are much greater than the tire-road forces and, therefore, tire-road forces are neglected during the collision impulse. In the case of large mass differences between vehicles this would not necessarily hold true. The simulation also assumes both "vehicles" are of the two-axle, four-tire variety. While this is so, a single vehicle and vehicle-barrier impact can still be set up, keeping in mind that the primary configuration was intended to be two-vehicle collisions.

SENSITIVITY TO DATA

Simulation is highly sensitive to the data provided by the user. While small changes in incoming position/angle will only cause small changes in the separation speeds and Delta V's, they can still cause huge variations in the post-impact trajectories, rest positions and orientations of the vehicles. One of the pitfalls of using simulation is that there are so many variables for which the user may have to estimate the values. Changing different combinations of these values can still end up with the same apparent result. This makes simulation a tool that is, potentially, very easy to misuse.

SUMMARY AND CONCLUSION

Important observations for users have come from this study. As with any model, the results can never be better than the input. As mentioned in other studies done on the RICSAC tests, the test data itself is subject to some rather large errors in some cases. This is due to limitations in resources and technology at the time these tests were done. Even the Impact Speeds given for these tests are an approximation. Other data, such as Delta V's, have to be calculated based on different sensor data, and again is subject to its own errors.

The post-impact trajectory and resulting rest positions/orientation are very sensitive to input data. This author found that even small changes in location and orientation at time of impact could cause a large change in the resulting post-impact response. Other changes, such as Load Deflection, seemed to have less effect on the overall results.

Looking at the Delta V comparisons, the range of error is -43% to + 14%, indicating that the simulation is predominantly underestimating the Delta V's. The worst case, Test 9, is out by -43% on Vehicle 2, but the actual difference is only -3.8 mph for the Delta V. The absolute differences range from -5.4 mph to +3.1 mph.

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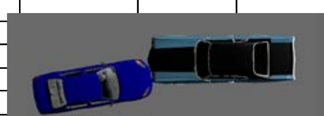
APPENDIX 1

Ricsac Test	Vehicle No	Vehicles	Impact Speed	Crash Orientation	DeltaV Measured	DeltaV pred	Rest Measured		Rest Pred		Path Length Measured	Path Length Pred	Delta Yaw Measured	Delta Yaw Pred	Delta Rest Position		|Delta Rest|	Delta Path Length	Delta Yaw
1	1	Chevy Chevelle	19.8		12.2	13.9	-1.94	-2.54	1.29	8.52	11.72	21.35	14	19	3.23	11.06	11.522	9.63	5
	2	Ford Pinto	19.8		15.6	10.2	4.73	4.79	9.12	8.63	11.53	17.81	27	49	4.39	3.84	5.832	6.28	22
					V1 Delta V Error	0.13934							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.34615							0.9831	0.5059					
													V1 Yaw Error	V2 Yaw Error					
													0.0139	0.0611					
2	1	Chevy Chevelle	31.5		19.6	20.08	4	2.65	-3.8	1.5	28.3	18	86	47	-7.8	-1.15	7.884	10.3	39
	2	Ford Pinto	31.5		n/a	27.26	13.5	12.8	25	15.25	30.7	41.1	45	89	11.5	2.45	11.758	10.4	44
					V1 Delta V Error	0.02449							V1 Path Error	V2 Path Error					
					V2 Delta V Error	n/a							0.2786	0.3830					
													V1 Yaw Error	V2 Yaw Error					
													0.1083	0.1222					
3	1	Ford Torino	21.2		9.5	9.6	-16.1	20	-3.4	21.8	114	99.7	0	0	12.7	1.8	12.827	14.3	0
	2	Ford Pinto	0		15.8	15.2	-86	9.6	-87	11.3	170	171.7	18	23	-1	1.7	1.972	1.7	5
					V1 Delta V Error	0.01053							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.03797							0.1125	0.0116					
													V1 Yaw Error	V2 Yaw Error					
													0.0000	0.0139					
4	1	Ford Torino	38.7		18.7	15.9	-83.4	23.5	-86.1	-18.4	97.6	56.4	140	48	-2.7	-41.9	41.987	41.2	92
	2	Ford Pinto	0		22.2	22.9	-105	27.4	-79	-8.3	85.8	33.2	80	73	26	-35.7	44.164	52.6	7
					V1 Delta V Error	-0.14973							V1 Path Error	V2 Path Error					
					V2 Delta V Error	0.03153							0.4302	0.5147					
													V1 Yaw Error	V2 Yaw Error					
													0.2556	0.0194					

Ricsac Test	Vehicle No	Vehicles	Impact Speed	Crash Orientation	DeltaV Measured	DeltaV pred	Rest Measured		Rest Pred		Path Length Measured	Path Length Pred	Delta Yaw Measured	Delta Yaw Pred	Delta Rest Position		|Delta Rest|	Delta Path Length	Delta Yaw
5	1	Ford Torino	39.7		16.3	16	-327.6	0.5	-362.1	-0.2	250	284.6	1	-15.5	-34.5	37.822	250.2	283.6	0
	2	Honda Civic	0		25.1	28.2	-137	34.1	-139.4	18.8	61.6	51.6	296	5.9	-2.4	6.369	42.8	244.4	16.5
					V1 Delta V Error	-0.01840							V1 Path Error	V2 Path Error					
					V2 Delta V Error	0.12351							1.0008	0.6948					
													V1 Yaw Error	V2 Yaw Error					
													0.0458	0.8058					
6	1	Chevy Malibu	21.5		9.2	7.2	-43.5	4.7	-115.9	4.5	63.1	133.5	17	6	-72.4	-0.2	72.400	70.4	11
	2	VW Rabbit	21.5		11.9	10.7	-2	13.9	14.7	30.7	22.1	33.9	122	181	16.7	16.8	23.688	11.8	59
					V1 Delta V Error	-0.21739							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.10084							1.1474	1.0719					
													V1 Yaw Error	V2 Yaw Error					
													0.0306	0.1639					
7	1	Chevy Malibu	29.1		12	10	-81	-6.3	-187.7	5.1	91.1	190	16	10	-107	11.4	107.307	98.9	6
	2	VW Rabbit	29.1		16.5	15.4	-19.25	22.8	2.5	21.2	44.1	44.8	144	214	21.75	-1.6	21.809	0.7	70
					V1 Delta V Error	-0.16667							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.06667							1.1779	0.4945					
													V1 Yaw Error	V2 Yaw Error					
													0.0167	0.1944					
8	1	Chevy Chevelle	20.7		15.3	15	-33.6	-21.4	-53.6	-5.6	14.8	39	43	21	-20	15.8	25.488	24.2	22
	2	Chevy Chevelle	20.7		10.7	12.2	-36.8	-10.4	-28.7	-11	22.7	28.2	50	78	8.1	-0.6	8.122	5.5	28
					V1 Delta V Error	-0.01961							V1 Path Error	V2 Path Error					
					V2 Delta V Error	0.14019							1.7222	0.3578					
													V1 Yaw Error	V2 Yaw Error					
													0.0611	0.0778					

Ricsac Test	Vehicle No	Vehicles	Impact Speed	Crash Orientation	DeltaV Measured	DeltaV pred	Rest Measured		Rest Pred		Path Length Measured	Path Length Pred	Delta Yaw Measured	Delta Yaw Pred	Delta Rest Position		|Delta Rest|	Delta Path Length	Delta Yaw
9	1	Honda Civic	21.2		21.4	16.7	13.8	-9.9	14.8	-7.7	42.8	38.4	104	100	1	2.2	2.417	4.4	4
	2	Ford Torino	21.2		8.9	5.1	29	-16.3	19.5	9.4	62.1	47	60	14	-9.5	25.7	27.400	15.1	46
					V1 Delta V Error	-0.21963							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.42697							0.0565	0.4412					
													V1 Yaw Error	V2 Yaw Error					
													0.0111	0.1278					
10	1	Honda Civic	33.3		35.1	30.9	-46.5	-30.8	-46	-50.6	45	25.3	90	146	0.5	-19.8	19.806	19.7	56
	2	Ford Torino	33.3		14.1	13.5	0	0	0	0	0	0	0	0	0	0	0.000	0	0
					V1 Delta V Error	-0.11966							V1 Path Error	V2 Path Error					
					V2 Delta V Error	-0.04255							0.4401	n/a					
													V1 Yaw Error	V2 Yaw Error					
													0.1556	n/a					
						can't do actual comparison for vehicle 2 due to post-impact collision with a foreign object plus moving onto a gravel/grass area that was not recorded													
11	1	Chevy Vega	20.4		24	26.5	-78	-34.3	-73.9	-33.3	10.6	9.2	2	18	4.1	1	4.220	1.4	16
	2	Ford Torino	20.4		15.7	17.8	-61.8	-27.8	-57.3	-27.2	7.8	3.2	0	0	4.5	0.6	4.540	4.6	0
					V1 Delta V Error	0.10417							V1 Path Error	V2 Path Error					
					V2 Delta V Error	0.13376							0.3981	0.5820					
													V1 Yaw Error	V2 Yaw Error					
													0.0444	0.0000					
12	1	Chevy Vega	31.5		40.1	39.5	-81.5	-32	-83.3	-34.4	8	15.5	53	24	-1.8	-2.4	3.000	7.5	29
	2	Ford Torino	31.5		26.4	27.3	-66.9	-22.8	-66.9	-22.8	7.5	6.36	13	13	0	0	0.000	1.14	0
					V1 Delta V Error	-0.01496							V1 Path Error	V2 Path Error					
					V2 Delta V Error	0.03409							0.3750	0.0000					
													V1 Yaw Error	V2 Yaw Error					
													0.0806	0.0000					

APPENDIX 2

Comparison of Delta V's

RICSAC Delta V Comparison

RICSAC Test #	Vehicle 1 Measured	Vehicle 2 Measured	Vehicle 1 Predicted	Vehicle 2 Predicted	Vehicle 1 Error %	Vehicle 2 Error %	Vehicle 1 Error Abs	Vehicle 2 Error Abs
1	12.2	15.6	13.9	10.2	14%	-35%	1.7	-5.4
2	19.6	n/a	20.1	27.3	3%	n/a	0.5	n/a
3	9.5	15.8	9.6	15.2	1%	-4%	0.1	-0.6
4	18.7	22.2	15.9	22.9	-15%	3%	-2.8	0.7
5	16.3	25.1	16	28.2	-2%	12%	-0.3	3.1
6	9.2	11.9	7.2	10.7	-22%	10%	-2	-1.2
7	12	16.5	10	15.4	-17%	-7%	-2	-1.1
8	15.3	10.7	15	12.2	-2%	14%	-0.3	1.5
9	21.4	8.9	16.7	5.1	-22%	-43%	-4.7	-3.8
10	35.1	14.1	30.9	13.5	-12%	-4%	-4.2	-0.6
11	24	15.7	26.5	17.8	10%	13%	2.5	2.1
12	40.1	26.4	39.5	27.3	-2%	3%	-0.6	0.9