MODEL FOR OCCUPANTS EJECTED FROM VEHICLES WITH ROLL AND YAW

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INTRODUCTION

In the fields of accident reconstruction and injury biomechanics, it is often of interest to know details of an occupant's ejection from a vehicle during a rollover. Determining the trajectory of an occupant, both in the air and on the ground, assists in the understanding of injury mechanisms.

The ejection event consists of three general phases: (1) occupant in the vehicle, (2) occupant in the air, and (3) occupant on the ground. During phase (1), the occupant is moving in a vehicle that is rolling over. The vehicle has translational and angular velocity, and may be yawing. In phase (2), the occupant has been ejected from the vehicle. The occupant is thrown from the vehicle with a trajectory that is dependent on the dynamics of both the vehicle and the occupant at time of ejection. Gravity causes the occupant to fall, and the occupant impacts the ground. In phase (3), the occupant may bounce and slide, the degree of which depends on the impact dynamics, to the point-of-rest (POR).

METHODS

We model the vehicle as a cylinder moving in the ground plane. There are two translational degrees of freedom: longitudinal—in the direction of the vehicle's heading at roll inception, and lateral—perpendicular to the vehicle's initial heading. There are two rotational degrees of freedom: roll and yaw. The dynamics of the vehicle are governed by a drag factor, which allows the translational time history to be determined. The roll and yaw rates are obtained from the time values at discrete roll and yaw positions. We interpolate functions of all vehicle degrees of freedom to describe the vehicle's motion during the rollover event.

We model the occupant as a point mass ejected from the vehicle at any time except for when the occupant's ejection portal is blocked by the ground. For each admissible ejection time, we construct an occupant trajectory based on the dynamics of the vehicle moving in the inertial frame, and the occupant moving within the vehicle. Each trajectory gives rise to a landing point, where the occupant impacts the ground. The occupant may then have continued motion, consisting of bouncing and sliding on the ground, from impact to rest. Each trajectory produces candidate occupant PORs. Candidate PORs that match the actual occupant's POR are considered possible occupant ejection solutions.

RESULTS AND DISCUSSION

We calculate the occupant landing position and occupant rest position for each admissible ejection time, as a function of roll position, as shown in Figures 1 and 2. We superimpose the actual occupant POR, indicated with the red dashed line, in both the longitudinal and lateral directions. Possible ejection solutions exist where candidate PORs intercept actual PORs.

In this case study, we have a four roll event and a leading-side occupant ejection. We find seven ejection candidates from the longitudinal solutions. We rule out two of these candidates since their lateral solutions do not satisfy the actual occupants POR, leaving five possible occupant ejection solutions.

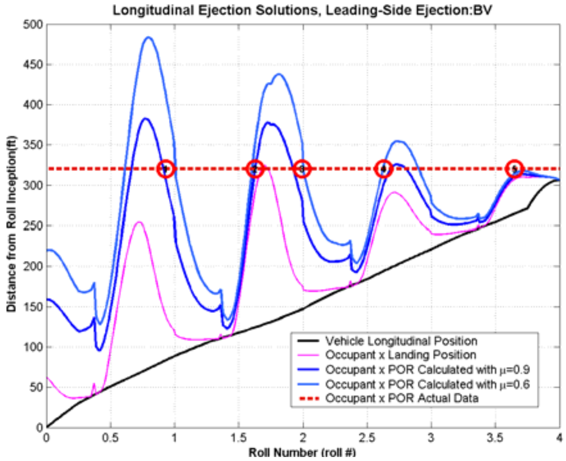

Figure 1: Longitudinal direction solutions.

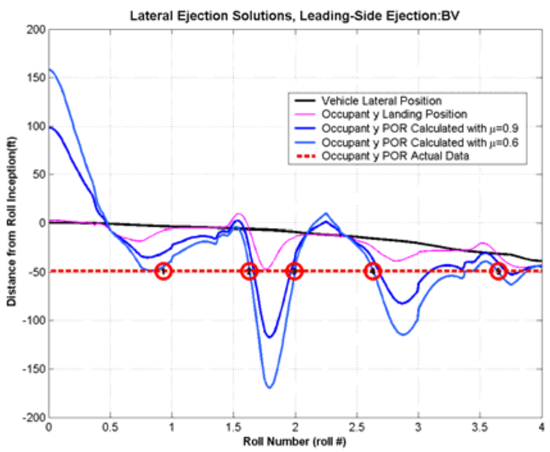

Figure 2: Lateral direction solutions.

Table 1 shows numeric values for vehicle and occupant positions and speeds for each of the ejection solutions. The occupant launch speed, launch angle, and maximum height indicate if the occupant is thrown up in the air, through a high arc; or, if the occupant is thrown horizontally or downward from the vehicle. The occupant's vertical landing speed is used to quantify the severity of occupant's impact with the ground. The slide distance is used to determine if the occupant slid for a significant distance after ground impact, or if the occupant came to rest at or near the point of impact. The occupant's injuries can be correlated with the vertical impact speed and slide distance help to identify likely ejection points from the possible ejection solutions.

Table 1: Vehicle and occupant positions and speeds for each ejection solution.

Ejection Solutions Results, Leading Side Occupant:BV

Solution (#)	$\Theta^{vehicle}_{launch}$ (roll #)	$\Theta^{vehicle}_{launch}$ (deg)	$s^{vehicle}_{launch}$ (ft)	$(v.s)^{vehicle}_{launch}$ (mph)	$\beta^{ejectee}_{launch}$ (deg)	$\|v\|^{ejectee}_{launch}$ (mph)	$(v.z)^{ejectee}_{land}$ (mph)	$z^{ejectee}_{max}$ (ft)	$\Delta s^{ejectee}_{air}$ (ft)	$\Delta s^{ejectee}_{slide}$ (ft)
1	0.93	334.8	83.5	58.2	-3.48	76.4	-15.2	7	53.9	223
2	1.63	586	124	52.7	29	53.5	-28.3	26.8	170	53.8
3	1.99	717	147	49.3	-9.94	64.8	-17.5	6.09	27.1	145
4	2.63	947	195	41.4	21.5	40.8	-18.8	11.9	85.8	40.4
5	3.65	1314	268	25.1	23.5	26.8	-16.1	8.66	44	14

SUMMARY/CONCLUSIONS

We created a model of occupant ejection that incorporates vehicle roll and yaw. Candidate solutions, calculated from the model, and actual occupant PORs, obtained from physical evidence, give rise to possible solutions. Possible solutions, correlated with occupant injury, indicate likely points of occupant ejection. Knowing when and how an occupant is ejected is useful for explaining an occupant's injury mechanism.

REFERENCES

Parenteau, C., *et al.* (2001). *SAE 2001-01-0176.*

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ACKNOWLEDGEMENTS

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We model the vehicle as a cylinder moving on the ground plane. There are two translational degrees of freedom: longitudinal - in the direction of the vehicle's heading at roll inception, and lateral - perpendicular to the vehicle's initial heading. There are two rotational degrees of freedom: roll and yaw. The dynamics of the vehicle are governed by a drag factor, which allows the translational time history to be calculated.

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We calculate the occupant landing position and occupant rest position for each admissible ejection time, as a function of roll position, as shown in Figure 1. We superimpose the occupant's actual POR, indicated with the red dashed line, in both the longitudinal and lateral directions. Possible ejection solutions exist where candidate PORs intercept actual PORs.

In this case study, we have a four roll event and a leading-side occupant ejection. We find eight ejection candidates from the longitudinal solutions. We rule out six of these candidates since their lateral solutions do not satisfy the occupant's actual POR, leaving two possible occupant ejection solutions.

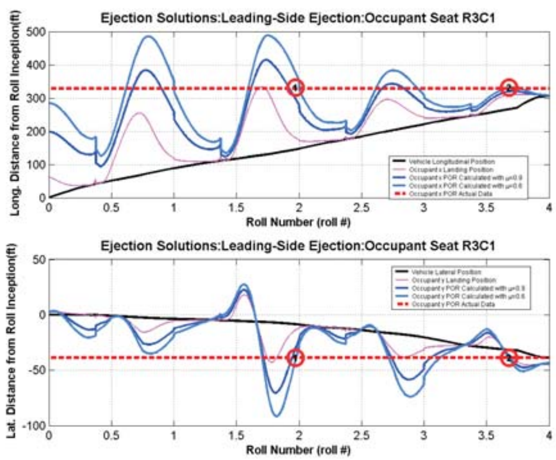

Figure 1: Longitudinal and lateral ejection solutions.

Table 1: Vehicle and occupant data for each ejection solution.

solution (#)	veh. roll angle (roll #)	veh. roll angle (deg)	veh. dist. (feet)	veh. speed (mph)	launch angle (deg)	ejectee speed (mph)	ejectee land (mph)	max. ej. ht. (feet)	air dist. (feet)	slide dist. (feet)	total dist. (feet)
1	1.97	710	146	49.5	-8.2	66.7	-16.8	6.42	32.3	158	190
2	3.68	1325	270	24.5	21.8	27.5	-16.4	8.97	45.3	15.3	60.6

Table 1 shows numeric values for vehicle and occupant positions and speeds for each of the ejection solutions. The occupant launch speed, launch angle, and maximum height indicate if the occupant is thrown up in the air, through a high arc; or, if the occupant is thrown horizontally or downward from the vehicle. The occupant's vertical landing speed is used to quantify the severity of occupant's impact with the ground. The slide distance is used to determine if the occupant slid for a significant distance after ground impact. Figure 2 shows the vehicle's position, occupant's ejection point, landing, and rest point for the two possible solutions.

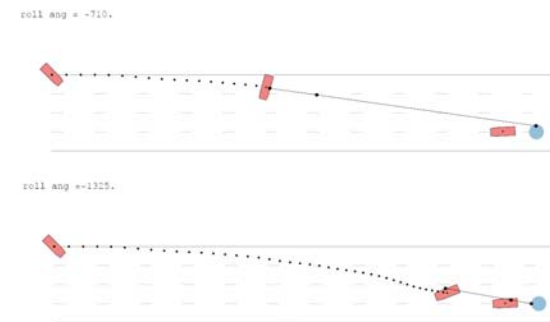

Figure 2: Top view of vehicle at roll inception, ejection solution, and final position. Occupant's ejection point, landing point, and rest point are indicated by the linear path from vehicle to actual POR.

The occupant's injuries can be correlated with the vertical impact speed and slide distance to help identify likely ejection points from the possible ejection solutions.

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We created a model of occupant ejection that incorporates vehicle roll and yaw. Candidate solutions, calculated from the model, and actual occupant PORs, obtained from physical evidence, give rise to possible solutions. Possible solutions, correlated with occupant injury, indicate likely points of occupant ejection. Knowing when and how an occupant is ejected is useful for explaining an occupant's injury mechanism.

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