Passenger Ejection from Golf Cart Rear Seat

Kyle Schau
Florida Atlantic University
777 Glades Road
Boca Raton, FL 33431

kschau@fau.edu

Oren Masory
Florida Atlantic University
777 Glades Road
Boca Raton, FL 33431
Tel(561)297-3424
masoryo@fau.edu

ABSTRACT
The following report details the findings of a series of experiments and simulations performed on a commercially available, shuttle style golf cart during several maneuvers involving rapid accelerations of the vehicle. It is determined that the current set of passive restraints on these types of golf carts are not adequate in preventing ejection of a rear facing passenger during rapid accelerations in the forward and lateral directions. Experimental data and simulations show that the minimum height above the seat a hip restraint must be in order to secure a passenger during sharp turns is approximately 13 inches, compared to the current restraint height of 5 inches. Furthermore, it is determined that a restraint directly in front of the rear facing passenger is necessary to prevent ejection. In addressing these issues, golf cart manufacturers could greatly reduce the likelihood of injury due to ejection of a rear facing passenger from a golf cart.

Keywords
Golf cart, accident, ejection, low speed vehicle, rear facing passenger, hip restraint.

1. INTRODUCTION
The scope of this study is to analyze experimental data gathered during testing of a commercially available golf cart as it accelerates from rest along various trajectories. The term "golf cart" is used in this report to describe any 4-wheeled, electric or gas powered, vehicle that does not qualify as a Low Speed Vehicle[1] (LSV) [4]. The typical golf cart's top speed is between 12-15 mph, and is not fast enough to qualify as a LSV. These types of vehicles are not as well defined as LSV, and are unregulated in terms of safety standards. The vehicles of concern in this report are those with a seat facing the opposite direction of the golf cart's forward motion.

Tue to several environmental, social, and economic factors, the use of golf carts has become increasingly prevalent in recent years. These vehicles are no longer exclusively found on golf courses, but in residential areas, universities, business complexes and more [5]. With the increase in golf cart utilization by the general public, the injury rate due to golf cart accidents has also increased [6]. It was estimated that there were approximately 48,255 golf cart related injuries during the years 2002-2005 [6]. One of the leading causes of golf cart injuries is due to ejection from the vehicle [9,7]. It is estimated that 45% of golf cart injuries occur due to a person falling off a moving golf cart [7]. Moreover, Rear Facing Passengers (RFP) are particularly associated with golf cart ejection due to their orientation in the vehicle [9].

During forward acceleration of a golf cart from rest, a RFP is subjected to the same force as the driver and front passenger. This force will tend to push the front passenger into their seat backs, while it will pull the RFP off their seat backs. This presents a danger not faced by the driver or front passenger during forward acceleration. During a sharp turn, to the right for example, the apparent centrifugal force felt by the left side RFP will push the RFP out the left side of the vehicle. This creates another danger not faced by the driver or front passenger, in that the driver can hold onto the steering wheel, and the front passenger can see forward and anticipate subsequent maneuvers. A further concern for the RFP is the magnitude and direction of the net acceleration of the cart at any given time. If this value is great enough, the static friction force between the RFP and the seat will be overcome and the RFP will begin to slide. Depending on the direction of the acceleration at that given time, the RFP could slide in a direction in which no restraints are present, resulting in ejection from the vehicle. Given these risks associated with very typical maneuvers, it would follow that the RFP would be more protected in their respective seat. The current restraints however, do not provide any more support for the RFP than the front passenger.

Currently, neither the federal government nor the American National Standards Institute (ANSI) requires that seat belts be provided in their golf cart standard Z130.1[2] [1]. Due to this lack of regulation, it appears that the passive restraints currently used are aimed to facilitate ease of use rather than provide adequate safety. Even if seat belts were to be added as a safety measure to golf carts, it would be unreasonable to assume the user would regularly utilize this feature, due to the frequent entering and exiting of the vehicle during normal use. Therefore, passive restraints are needed to prevent ejection.

ANSI Standard Safety Requirements for Golf Cars only requires accessible hand holds and restraints to prevent the body from

[1] Low Speed Vehicles are defined as any four wheeled vehicle whose top speed is between 20-25 mph as ruled by the Department of Transportation in 1998. LSV are held to much higher standards than vehicles that would be referred to as "golf cars"

[2] This standard is optional and is complied with on a discretionary basis by golf car manufacturers

sliding out of the vehicle during a maneuver such as turning [1]. The typical shuttle style golf cart provides hip restraints to the side of a RFP (typically 4-6 inches above the level of the seat) along with a center railing (typically 6 inches wide) that is installed directly in the center of the two rear facing passengers. The location of the hip restraint is such that during sharp turns, the restraint can become a pivot point. If the forces pushing the RFP out the side of the vehicle are great enough, the RFP can tip over the hip restraint, resulting in ejection from the vehicle. As shown in Figure 1, there is virtually nothing in front of the passenger to prevent them from falling out of the cart during forward acceleration of the vehicle. The closest support (the center railing) is not in front of either RFP, and is out of reach while they are seated, making them unavailable for support. It has already been shown that the hip restraints typically found on golf carts are not tall enough to secure the front passenger during sharp turns at speed [8]. This study will show that this risk applies for the rear facing passengers and that the center railing is insufficient in preventing ejection during forward acceleration.

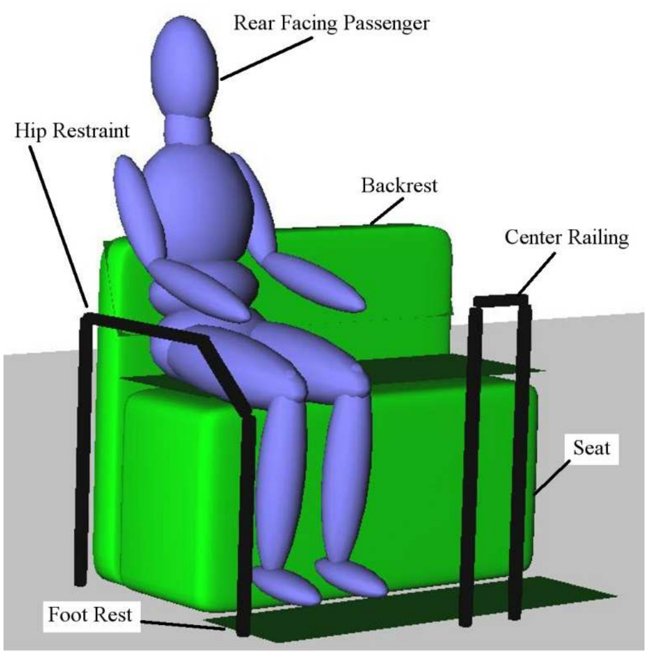

Figure 1: View of modeled rear seat of the tested golf cart. Dimensions were measured directly from test vehicle.

2. METHOD

A three axis accelerometer[3] sampling at 100Hz was used to gather acceleration data from the rear facing, driver's side seat of a shuttle style golf cart. Two types of maneuvers were measured:

1.) Maximum acceleration from rest along various circular trajectories

2.) Maximum acceleration from rest along a straight line

Data was recorded with 90, 180, 270, 360, and 540 degree turns of the steering wheel[4] in the clockwise direction. Figure 2 and Table 1 detail the maneuvers performed and measured. The acceleration data signals were filtered using a moving average with a window of 0.5 seconds and displayed in terms of 'g' force. Knowing the forward and lateral accelerations of the cart along with the trajectories of the maneuver (radius), the angular acceleration about the vehicle's center was also calculated for simulation purposes.

These data were utilized as both input for simulations, and to determine if sliding was likely to occur. One of the main forces securing the RFP is the friction between the RFP and the seat. Sliding between the RFP and the seat was deemed to have occurred if the root-sum of squares of the forward and lateral components of the acceleration were larger than the static friction coefficient between the seat and passenger. If at any time during the motion this value was exceeded, the instantaneous values of each acceleration component were used to determine the direction a RFP would slide.

Sliding is not the only cause of ejection from the rear seat of a golf cart; therefore the Articulated Total Body (ATB) modeling software was used to visualize the above mentioned maneuvers and determine if ejection may occur even if friction is not overcome [2]. ATB is a software program developed by the Air Force that uses an iterative process to simulate the dynamic interactions of free bodies (such as a human body) with input geometries, boundaries, and surfaces subjected to a prescribed motion. A human body with dimensions of a 50th percentile adult male [3] was placed in the rear seat of a cart modeled after the geometry of the cart used in the accelerometer experiments. Acceleration data gathered in the golf cart tests were input as the modeled cart's accelerations and a simulation was performed. The simulated RFP is a free body with no reactive forces of its own; for all intents and purposes, the simulated body is viewed as a crash test dummy [5]. Due to the rapid nature of the tests, and lack of reaction time, the RFP can be viewed as a fairly reactionless subject[6] when a sudden, unexpected acceleration takes place.

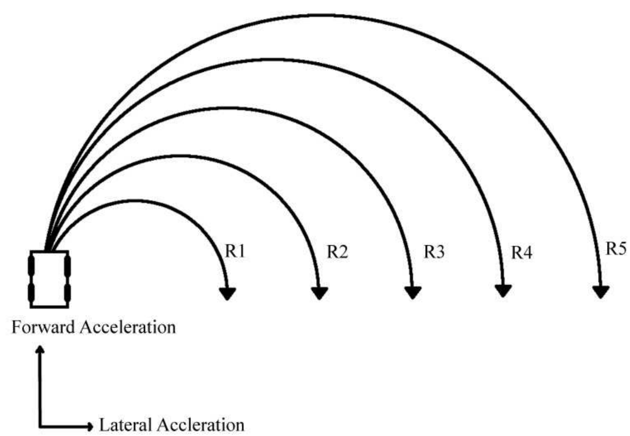

Figure 2: Visualization of maneuvers performed and measured.

[3] Sensr GP1 V2.2 Wireless Accelerometer

[4] From a straight forward position

[5] Some joints were locked to prevent collapse of the body during accelerations from rest

[6] As would be expected when the RFP cannot see what the driver is doing and has no anticipation of subsequent maneuvers

Table 1: Details of maneuvers R1-R5

Figure 2 Label	Steering Wheel Turn	Turning Radius (m)
R1	540°	1.73
R2	360°	3.46
R3	270°	5.08
R4	180°	7.87
R5	90°	8.36

A feature of the ATB software is the prescription of physical properties of the geometries and boundaries that make up the vehicle's model. Deflection forces, restitution coefficients, and friction factors are prescribed to each section of the environment. Most importantly, a friction factor of 0.5 is used to characterize the seat cushion and back rest, as determined from experiments with vinyl and cloth. Only the back seat will be modeled, along with its restraints (Figure 1), as the rest of the golf cart is beyond the scope of study. With the golf cart modeled, each maneuver performed in the golf cart tests were simulated with the ATB software and the occurrence of ejection determined.

3. RESULTS

3.1 Measured Maneuvers

The golf cart's lateral and forward accelerations were measured, from rest, through maximum acceleration with five turning radii. Figure 3 shows a typical time history of the acceleration data gathered for each of the maneuvers. Specifically, Figure 3 is the gathered, filtered data from maneuver R2. The general shape of each recorded maneuver was similar. Table 2 shows the maximum lateral and forward accelerations of each maneuver, along the occurrence of sliding. The direction of the forces acting on the RFP the moment friction could be overcome is measured counter clock wise from the lateral direction of the RFP (see Figure 4).

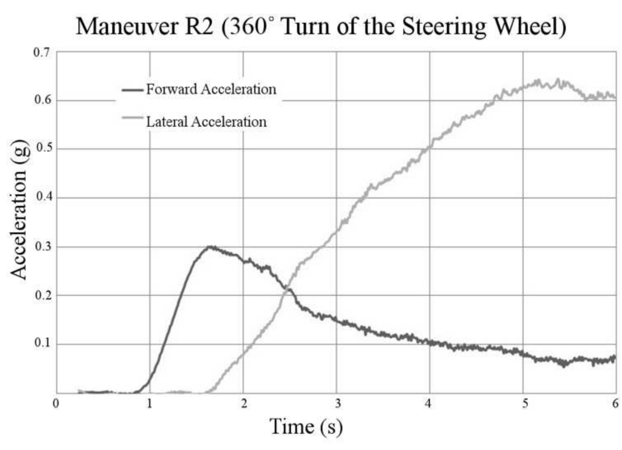

Figure 3: Time history of acceleration data recorded during maneuver R4 from Figure 2.

Figure 5 shows the forward acceleration and lateral acceleration from rest of the golf cart in a straight line. Integration of the forward acceleration of the signal yields a top speed of approximately 14 mph (below the LSV threshold). This number was supported by timed trials of the same maneuver.

3.2 Simulated Maneuvers

The maneuvers involving full acceleration with the wheels turned (R1-R5) were simulated using the ATB software to determine if ejection was likely. Table 3 details the results of the ATB simulations. As a display of the simulation's validity, the time from initial acceleration to ejection (defined as the moment the RFP's person leaves the seat) was recorded. As shown, the only turn that did not cause ejection of the simulated RFP over the hip restraint was maneuver R5, a 90° turn of the steering wheel. Maneuvers R4-R1, all of which have greater lateral accelerations than maneuver R1, showed ejection of the dummy in decreasing amounts of time. Figure 7 shows a time lapse sequence of maneuver R2, which resulted in an ejection of the RFP.

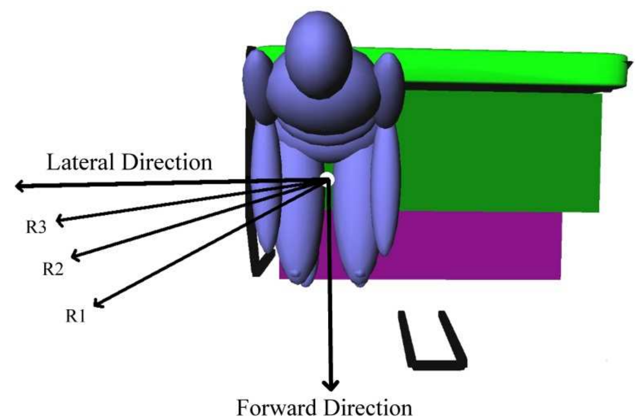

Figure 4: Top view of RFP detailing the direction of slip, when slip first occurs. Trend shows that sharper turns move the direction of slip towards the space between restraints.

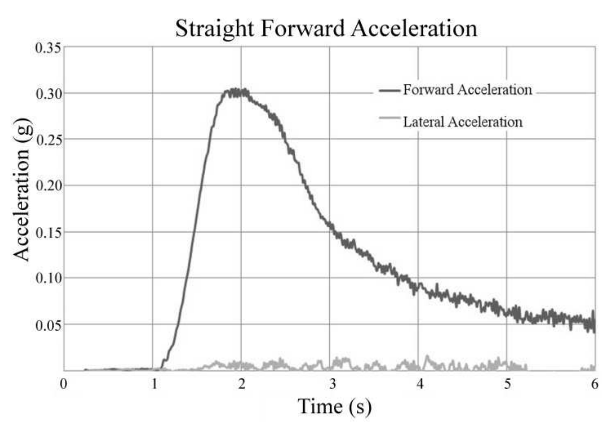

Figure 5: Time history of acceleration data measured for straight forward acceleration.

A simulation of maximum acceleration in a straight line was run to determine if a reactionless RFP would be ejected out the back of the golf cart. Due to the lack of passive restraints directly in front of the passenger, the simulated RFP was ejected almost immediately as shown in Figure 6. This is a fairly trivial solution, in that the simulated human is a reactionless object. Even moderate acceleration would result in ejection from the vehicle. Restraining the hip joint's motion, allowing the simulated dummy to remain upright, the simulated RFP was not ejected from the vehicle.

Table 2: Peak forward and lateral acceleration of each maneuver, as well as the direction of force in which friction is first overcome (see Figure 4)

Rasius	Steering Wheel Rotation	Maximum Lateral Acceleration (G)	Maximum Forward Acceleration (G)	Direction of Slip (Degrees)
R1	540°	0.691	0.318	23.8
R2	360°	0.644	0.315	13.2
R3	270°	0.542	0.292	6.4
R4	180°	0.447	0.315	DID NOT OCCUR
R5	90°	0.268	0.293	DID NOT OCCUR

With the dangerous maneuvers known (R1-R4 in Figure 5) new restraint geometry was implemented during the simulation of the same trials stated above. The height of the side restraint was increased incrementally until the RFP was no longer ejected during any of the trials. The first height to prevent ejection was a height of 13 inches above the seat. Figure 8 shows the comparison of the original and altered hip restraints.

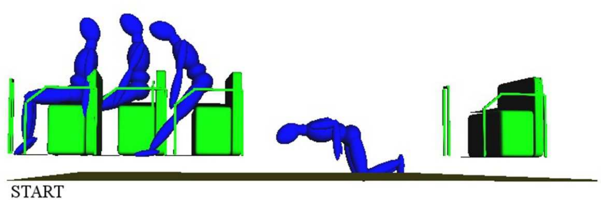

Figure 6: Simulation of the RFP reaction during maximal acceleration in a straight line.

4. Discussion

The results of these experiments and simulations show that a commercially available golf cart is capable of accelerations large enough to eject a RFP as well as cause the RFP to slide out of the vehicle. The most problematic maneuvers were those first presented, full acceleration from rest with the wheels turned. This is not an infrequent maneuver, if a driver were to provide maximum power from rest, without knowing the position of the wheels a rapid turn would be induced, and the passenger possibly ejected. Table 3 shows that every simulated ejection took place in less than 1.5 seconds, a short time for the driver to react by either braking or making a correction with the steering wheel. From the acceleration data in Table 2, it can be seen that a golf cart is capable of producing accelerations high enough to overcome friction between the RFP and the seat. As shown in Figure 4, the direction in which a person will begin to slide during circular motion is towards the hip restraints; however, as the turning radius decreases, or the golf cart's forward acceleration increases, slipping is induced in a direction such that neither the hip restraint nor the center railing can prevent them from being ejected (see Figure 4). This indicates that the space between the center railing and the hip restraint should be occupied by a passive restraint

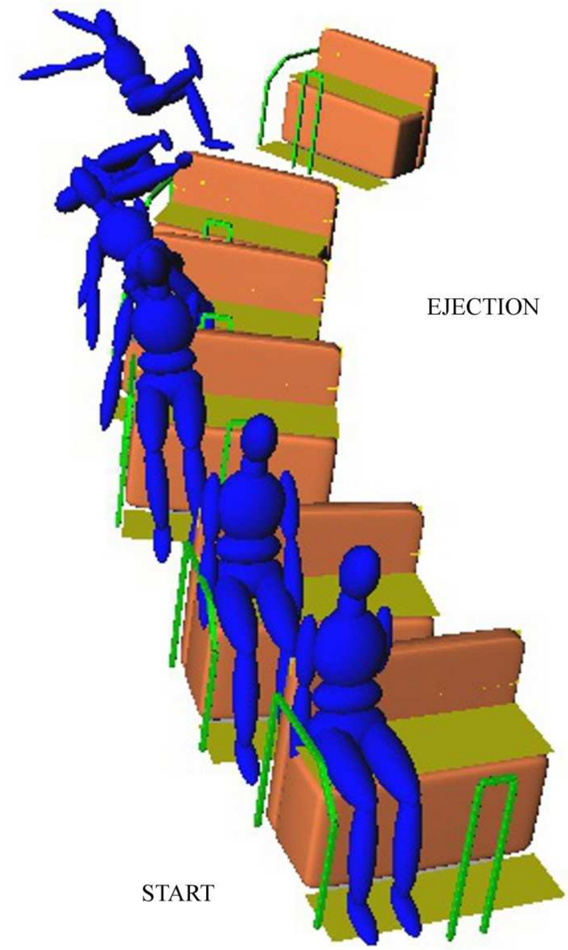

Figure 7: Simulation of maneuver R4 resulting in ejection of the rear facing passenger.

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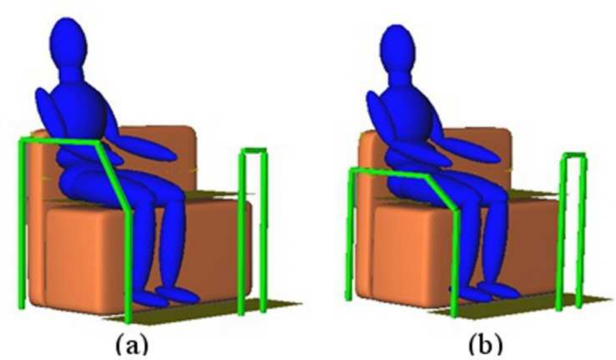

Figure 8: Comparison of height of hip restraint (a) required to prevent ejection, and (b) the current hip restraint found on shuttle style golf carts.

The accelerations in the forward direction, without a turn, reveal that the maximum acceleration of a golf cart in the forward direction is 0.3 g. These results also show that acceleration in a straight line is not accompanied by a G force great enough to overcome friction, and that lateral acceleration is necessary to induce sliding. Although ejection did not occur when the hip joint of the RFP was locked, that does not rule out the possibility of ejection due to acceleration in a straight line. A human with lesser strength and reaction time, such as an elderly person, would fit the reactionless simulated RFP better than the rigid RFP. The reactionless simulated RFP was ejected from the vehicle almost immediately.

The ATB simulation results show a more urgent problem that current golf carts face: the tipping of the RFP over the side rail. As seen in Table 3, all but the most gentile maneuver measured (R1 in Figure 2) showed accelerations capable of tipping the RFP over the hip restraint (modeled with a measured height of 5 inches). This indicates that the heights of the current hip restraints are not adequate in preventing ejection of the RFP. The minimum height of hip restraints required to secure the RFP during maneuver R4 was found to be 13 inches above the seat. This drastic difference between the current, and necessary, height of the hip restraint show the need for modification if injury due to ejection is to be mitigated. This dimension is consistent with a previous study performed by [8]. This previous study indicated a restraint height of 12 inches is necessary to prevent ejection of a front passenger during sharp turns at full speed. Place Tables/Figures/Images in text as close to the reference as possible (see Figure 1). It may extend across both columns to a maximum width of 17.78 cm (7”).

Table 3: Results of ATB simulation along with time until ejection.

Radius	Results	Time to Ejection (sec)
R1	Ejected	0.950
R2	Ejected	1.200
R3	Ejected	1.450
R4	Ejected	1.500
R5	Not Ejected	N/A

5. Conclusions

Based on the evidence provided, it is clear that the shortcomings of current golf carts are twofold: 1.) the hip restraints are not high enough to prevent a RFP from falling out of the vehicle while making sharp turns, and 2.) the complete lack of support for a RFP directly in front of their person leaves them vulnerable to slide out of the back of the vehicle or tipping forward out of the back with nothing to secure them. Gathered data shows that the lateral acceleration, in combination with the forward acceleration of the tested maneuvers is sufficiently high enough to overcome friction between the seat and the RFP, and cause sliding. Furthermore, the direction of this sliding indicates that there is a danger of a passenger sliding in a direction such that neither the hip restraint, nor the center railing is capable of providing any resistance to the ejection of the RFP. Simulations conclude that the lateral forces of a turning golf cart provide enough force to cause a RFP to tip over the hip restraint in all but the mildest turn tested. In order to prevent ejection during simulated accelerations, the required hip restraint height was 13 inches above the seat. The suggestion of this article is to raise the height of the hip restraint, and to relocate the center railing from between the two RFPs, to in front of each passenger.

Golf cart manufacturers could utilize this information to redesign their future models of shuttle style golf carts. Aftermarket products could be developed fairly easily in order to accommodate the needs of consumers with existing golf carts in efforts to improve safety and reduce the likelihood of incident to do rear facing passenger ejection.

Areas for further study could be the analysis the vehicles that occupy the speed gap between typical golf carts (12-15 mph) and LSV (20-25 mph) to determine whether sliding could be induced in a straight forward acceleration with these more power vehicles. Another item of further interest would be to test these scenarios and vehicles with proper crash test dummies as validation of the simulations.

6. ACKNOWLEDGMENTS

The author would like to thank Kristopher Seluga, whose previous research on similar topics proved invaluable in the completion of the presented works. Also, we like to thank Florida Atlantic University – Undergraduate research program for their support.

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