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16. Abstract

In response to petitions by the golf cart industry the National Highway Traffic Safety Administration reviewed its position on low speed vehicles and has taken steps to define a new class of low speed vehicle (LSV) which is exempt from the federal motor vehicle safety standards (FMVSS) that apply to motor vehicles. A new safety standard, FMVSS 100, has been proposed to regulate this new class of vehicle.

The Vehicle Research and Test Center conducted a survey and a series of tests to evaluate the safety and stability of LSVs. Two neighborhood electric vehicles, the Bombardier and the GEM, and one golf car, the Yamaha gasoline powered golf cart, were selected for this study. Testing included 1) measurement of the CG height of the vehicle to determine the Static Stability Factor (SSF) for both unloaded and two passenger configurations 2) measurement of lateral stability in a constant 50 foot radius turn, and 3) straight line braking on both a high coefficient surface and low coefficient surface.

LSV manufacturers raised concerns on the unsuitability of traditional windshield glazings on vehicles that would be used on golf courses as well as highways. Therefore, a short series of tests were conducted to evaluate and compare golf ball impacts on AS-1 and AS-6 glazing (specified in the proposed FMVSS 100). Results of these tests indicate that AS-4 or AS-5 glazing may be a better alternative than AS-6.

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TECHNICAL SUMMARY

In recent years there has been a growing trend for local governments and municipalities to allow golf carts restricted access to public highways. This has in turn created a market for the development of a class of vehicle popularly referred to as a Neighborhood Electric Vehicle, or NEV. In response to these developments and to petitions from the golf cart industry, NHTSA reviewed its position with respect to low speed vehicles and has taken steps to clearly define a new class of low speed vehicle (LSV) which is exempt from the federal motor vehicle safety standards (FMVSS) applicable to motor vehicles. A new safety standard, FMVSS 100, has been proposed to regulate this new class of vehicle.

An LSV has been defined as any motor vehicle, other than a motorcycle, whose speed attainable in one mile is more than 20 miles per hour but not more than 25 miles per hour. The Vehicle Research and Test Center (VRTC) conducted a study to survey the safety features currently present on potential LSVs and evaluate the safety and stability of such vehicles.

Three vehicles were selected for evaluation in this study. These were the Bombardier NV, the GEM NEV, and the Yamaha Golf cart. The Bombardier and GEM represented the new class of neighborhood electric vehicles while the Yamaha was a standard gasoline powered golf cart with a maximum “as delivered” speed of 15 mph.

Each of the three vehicles was subjected to a visual inspection noting general technical features of the vehicle and determining which elements of the proposed FMVSS 100 standard were currently present on the vehicle.

The center of gravity (CG) height of each vehicle was measured in an unloaded condition, and when ballasted to the equivalent of two 50th percentile male passengers. From this data a static stability factor (SSF) was calculated to estimate a general tendency for rollover. The vehicles were also tested in a 50 foot constant radius turn, at 20 mph, to evaluate lateral stability.

The vehicles were tested at 20 mph in straight line braking on a high friction coefficient surface (dry asphalt) to determine stopping distances. The results were evaluated using FMVSS 135. The vehicles were then tested in a similar manner on a low friction coefficient surface (wet Jennite) to evaluate any tendency for the vehicle to spin or pull out of line in a wheel lock up condition.

The Bombardier, with an unloaded/loaded SSF of 1.4/1.2, indicated good stability even when loaded. The GEM and Yamaha had good SSFs when unloaded (1.0 and 1.3 respectively) but when ballasted to the equivalent of two adult male passengers these values dropped to a level that indicated a degree of instability and a tendency to roll (0.86 and 0.88, respectivly).

The 50 foot constant radius turn at 20 mph verified the relative stability of the Bombardier and instability of the Yamaha Golf Cart (at this elevated speed), while the stability of the GEM at 20 mph could not be determined.

Braking tests showed the Bombardier and the GEM to have good to adequate stopping distances while the Yamaha Golf Cart had stopping distances consistently exceeding the 31 feet maximum specified for a 20 mph test in FMVSS 135. Both the Bombardier and the GEM showed excellent stability on the low friction braking surface while the Yamaha showed a slight tendency to pull out of line or spin.

In response to LSV manufacturers' concerns about the unsuitability of traditional motor vehicle windshield glazing, and the likelihood that many LSVs will be used on golf courses as well as highways, NHTSA sought to verify those concerns by testing the proposed glazing for LSVs for impact resistance against golf balls. A final series of tests was conducted to evaluate and compare golf ball impacts on AS-1 and AS-6 windshields. Tests were conducted at impact speeds up to 125 mph into an automotive laminated glass (AS-1), a motorcycle acrylic windscreen (AS-6), and a sheet of polycarbonate plastic. Results of these tests showed that the AS-1 glazing prevented penetration but resulted in a spray of fine glass particles into the passenger compartment while AS-6 glazing was shattered by the impact allowing penetration. The polycarbonate resisted penetration with little structural damage to the plastic. The results of these tests indicated that AS-4 or AS-5 glazings may be better alternatives than AS-6.

1.0 BACKGROUND

In recent years there has been an increasing trend in some states and municipalities to license golf carts for limited operation on public roads. Historically, the National Highway Traffic Safety Administration (NHTSA) has exempted motor vehicles with a top speed of 20 mph or less and of a "distinctive configuration" from complying with the federal motor vehicle safety standards. Golf carts, which have typically been considered a recreational vehicle limited to off road use and with a maximum speed of 15 mph, are exempt from these safety standards.

It appears that there is a developing market for low speed vehicles for use in retirement and "gated" type communities. Manufacturers have begun developing and marketing a vehicle often referred to as a neighborhood vehicle (NV) or neighborhood electric vehicle (NEV). These vehicles are typically portrayed as vehicles developed for both recreational use on the golf course and for local trips in the community.

In response to these recent developments and from petitions by the golf cart industry, NHTSA reviewed its position with regards to low speed vehicles (LSV) and in January 1997 issued a notice of proposed rulemaking (NPRM) to establish a new standard, Federal Motor Vehicle Safety Standard Number 100 (FMVSS 100).

2.0 INTRODUCTION

As part of the proposed FMVSS 100, a low-speed vehicle has been defined as any motor vehicle, other than a motorcycle, whose speed attainable in one mile is more than 20 miles per hour but not more than 25 miles per hour. As part of this program, the Vehicle Research and Test Center (VRTC) was tasked with obtaining two such LSVs and conducting a survey and evaluation on the safety and stability of the vehicles. While some of this evaluation, by necessity, is subjective in nature, an effort has been made to provide as detailed and comprehensive an evaluation as possible.

The neighborhood electric vehicle represents a new and emerging class of vehicle. As a result there are very few examples of this type of vehicle that are currently being marketed. At this point there are only two known manufactures of the NEV type of vehicles with speeds in the 20 mph to 25 mph speed range. These vehicles are the Bombardier NV manufactured by the Bombardier Motor Corporation and the GEM manufactured the Global Electric Motor Company.

VRTC's research has indicated, that although the standard golf cart is typically limited to speeds of less than 15 mph, the maximum speed capability is often the result of governors on the motors and/or the specific selection of gear ratios for the drive train. Aftermarket conversions, especially for electric carts, can significantly increase the top speeds of these vehicles. In order to assess the stability and safety of these vehicles and to provide a baseline for comparison with the two NEVs, it was decided to include a "standard" golf cart in this evaluation. A Yamaha golf cart was used.

3.0 OBJECTIVE

The results of the visual surveys, braking tests and dynamic handling tests will provide the basis for an evaluation of the potential stability of LSVs on public highways and the safety potential of these vehicles in a crash.

4.0 BOMBARDIER NV

4.1 Visual Inspection

4.1.1 Vehicle Description and Configuration

The first vehicle obtained for evaluation at VRTC was the Bombardier NV. Bombardier currently offers two models of the vehicle, the CLASS-E and the SPORT-E. Each vehicle is offered in a street version and in a golf version. Discussion with a local distributer indicated that the motor and drive train of both models are the same. The primary difference between the two models is the accessories offered.

Table 1 is a data table reproduced directly from a product brochure offered by Bombardier to its potential customers. The vehicle obtained for evaluation at VRTC was the SPORT-E model with the Golf option (this was the only model available to VRTC for lease). The primary differences from the vehicle obtained by VRTC and the Street version of the SPORT-E and CLASS-E mode are the addition of outside rearview mirrors and the use of street tires rather than golf tires. In addition, the CLASSE-E model offers: tinted windows, sun visor, license plate lamp, windshield wiper, and a speedometer/odometer.

	CLASS-E		SPORT-E	
	Street	Golf	Street	Golf
Front wheel hydraulic drum brakes	ι	ι	ι	ι
Rear wheel regeneration brakes	ι	ι	ι	ι
Four-wheel independent suspension	ι	ι	ι	ι
Maintenance-free recyclable batteries	ι	ι	ι	ι
Automotive lighting system	ι	ι	ι	ι
Brake lights, horn	ι	ι	ι	ι
Low speed golf mode	ι	ι	ι	ι
Sun visor; license plate lamp	ι	ι		
Lockable rear trunk	ι		ι	
Street tires	ι		ι	
Golf tires		ι		ι
Outside rearview mirror	2	1	1	
Tinted laminated glass windshield	ι	ι		
Delux speedometer/odometer	ι	ι		
Golf accessories* (cardholder steering wheel, golf bag holders, golf ball support)		ι		ι

* Some items such as golf clubs and bags are not included.
For a complete list of accessories and options please see spec sheet.

TABLE 1

Figure 1 is a frontal view of the Bombardier SPORT-E model evaluated at the VRTC. The cable visible in the photograph is an extension cord plugged into the battery recharging receptacle of the vehicle. Figure 2 is a side view of the vehicle with the rear bumper removed in preparation for mounting a fifth wheel unit for braking and handling testing.

Figure 1 - Bombardier SPORT E - Front View With Extension Cord in Charging Port.

Figure 2 - Bombardier - Side View - Rear Bumper Removed for Attaching Fifth Wheel

4.1.2 FMVSS 100 Regulations

Table 2 contains a listing of the specific motor vehicle safety items that FMVSS 100 could require on LSVs, and the Bombardier's and GEM's compliance with these requirements.

TABLE 2 FMVSS 100 Safety Requirements			
Requirements	Bombardier (LSV)	GEM (LSV)	Yamaha (Golf Cart)
Headlamps	YES	YES	NO
Front and Rear Turn Signals	YES	YES	NO
Tail Lamps	YES	YES	NO
Stop Lamps	YES	YES	NO
Red Reflex Reflectors	**NO**[(1)]	NO	NO
Interior Mirror	YES	YES	NO
Driver Side Exterior Mirror	**NO**[(2)]	NO	NO
Passenger Side Exterior Mirror	**NO**[(2)]	NO	NO
Parking Brake	YES	YES	NO
Windshield (AS-/1/AS-6)	YES	YES	NO
Vehicle Identification Number (VIN)	**NO**[(3)]	**NO**[(4)]	NO
Seat Belt Assembly (Type1/Type2)	YES	YES	NO
Warning Label	**NO**[(5)]	**NO**[(5)]	NO

1. There were no side reflectors on the vehicle evaluated. They do not appear to be standard for any of the Bombardier models.

2. The model evaluated had no exterior side mirrors. However, Table 1 indicates that all other versions (CLASS-E street and golf and SPORT-E street have one or more exterior side mirrors.

3. On the front left dashboard area where the VIN# of a typical motor vehicle is located was a metal tag (similar to those used for VIN #) with a stamped number on it. The tag was labeled as a serial number and did not appear to follow the standard convention of a VIN#. Whether the serial number observed on the vehicle can be defined as its VIN# or if a specific VIN# needs to be supplied needs to be determined.

4. The GEM was identified by a serial number. It is not clear if this is sufficient to be a VIN #

5. A warning label was centrally mounted to the interior roof of the vehicle (just beyond the upper edge of the windshield) While a number of disclaimers and warnings were listed, they were not specific to the requirements of FMVSS 100.

4.2 Technical Inspection

4.2.1 Technical Specifications Survey

Prior to obtaining the first LSV, a potential list of possible measurements and notable features was prepared for the evaluation. This list is included in the appendix of this report. In addition to this survey list, the following sections provide notes, comments, and photographs on the vehicle during the course of the survey. Table 3 is a short tabulation of the major vehicle dimensions and specifications as listed in published information by the manufacturer (for a more comprehensive listing see the survey list included in the appendix).

TABLE 3
Technical Specifications - Vehicle Dimensions

	BOMBARDIER (LAV)	GEM (LSV)	YAMAHA (Golf Cart)
Length	100 in	95 in	93 ¾ in
Width	55 in	43 in	46 in
Height	61 ¾ in	68 ¾ in	43 ½ in
Wheel Base	65 in	71 ½ in	65 ½ in
Curb Weight	1275 lb	928 lb	688 lbs
Height of Center Stop Lamp	58 ¾ in	49 ½ in	No Lamp

4.2.2 Seating and Safety Restraints

The seats of the Bombardier are shown in Figure 3. The height of the seat pan of the vehicle was 19.25 inches. The vehicle was outfitted with two bucket seats which were adjustable with a total range of about 5.0 inches fore/aft travel. There was no provision for adjusting the seat back angle. In the full rearward position, the height of the top of the seat cushion's front and rear edges measured 25 inches and 24 inches, respectively.

There were steel tubular side rails on each of the seats extending from the seat back to approximately half way along the bottom seat cushion. These rails were approximately 3.5 to 4.0 inches high and are typically found on standard golf carts where they are a required feature intended to restrain lateral movement of the occupants.

Figure 3 - (Bombardier) - Details of Bucket Seats. Note rails for lateral restraint (golf cart) as well as seat belts. Also note long stem on buckle (center) allowing for high placement of lap belt.

In addition to the lateral restraints, the vehicle was equipped with two 3-point retractable seat belts with inertial lock ups on the reel. The buckle was mounted on a fairly long stem. As a result, the lap portion of the belt system can inadvertently be positioned to ride high on the occupant's hips. In a passenger vehicle this condition often results in the belt riding over the iliac crest and creating a submarining condition in a frontal crash, with the potential for causing associated abdominal and spinal injuries.

The stem of the buckle, the D-ring attachment on the roof/B-pillar, and the floor mounted portion of the latch plate/reel assembly all used 3/8 inch bolts to anchor the safety belt assembly to the fiberglass/polymer body of the vehicle. Removal of these bolts showed that the bolts were threaded into steel plates (approximately 1/4 inch thick) sandwiched between the fiberglass/polymer layers of the main body.

4.2.3 Motor and Electronics

Technical literature for this vehicle lists the electric motor as a 4 kW (5.36 HP) DC shunt motor. It was a 72 volt system with a 300 AMP electronic module. Six 12 volt lead/acid maintenance free batteries supply voltage to the electric motor while a seventh, smaller 12 volt battery supplies power to the vehicle's electronics package (i.e., lights, horn, instrumentation, etc.). The batteries and electronic module were mounted onto a T-shaped tray (See Figures 4 and 5) which was raised and bolted into the underside of the vehicle. This tray was not gasketed or designed with any other apparent system to contain spilled battery fluid. However, the use of maintenance free batteries and the essentially monocock design of the main body of the vehicle would appear to limit the extent of battery fluid spilling onto the occupants in a tip or rollover situation.

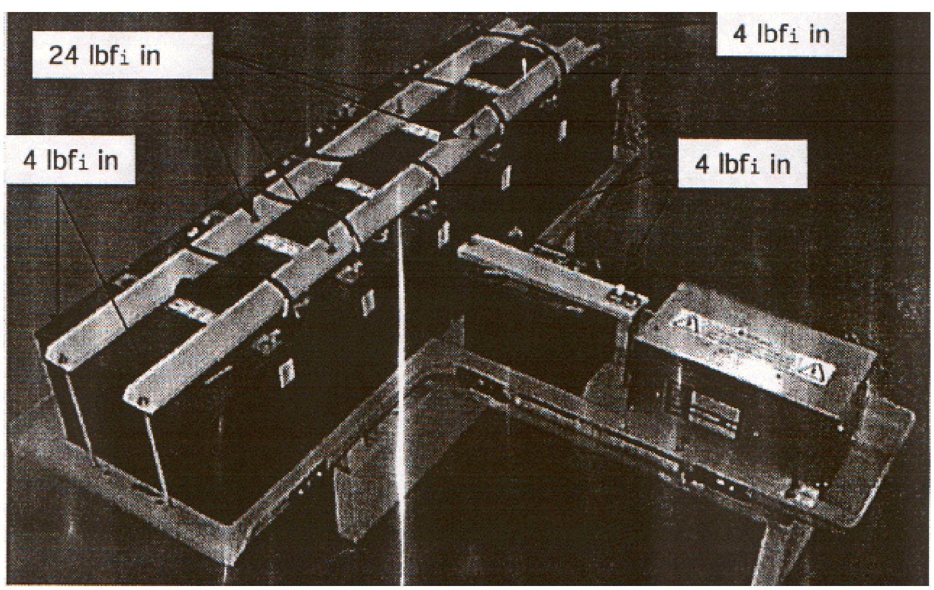

Figure 4 - Technical Manual Photograph of Battery Tray. Batteries and Electronic Controller

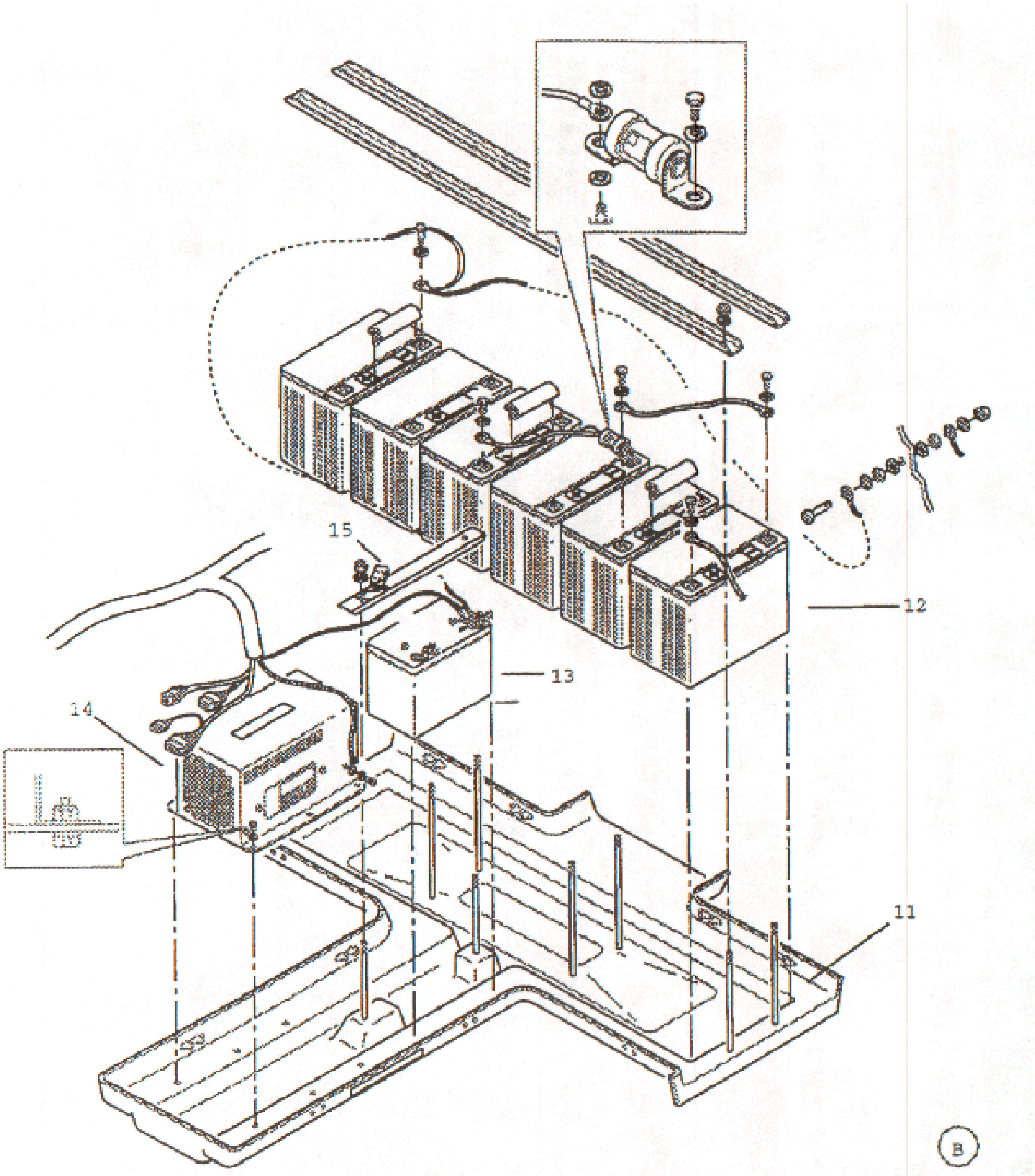

Figure 5 - Schematic of Battery Tray

4.2.4 Instrumentation and Control Features

The vehicle used a keyed system to operate the transmission selection. Figure 6 is a photograph of the ignition/transmission lock. The labeled positions were OFF (in the upright or 12:00 position) with R, N, D and G spaced clockwise around the lock. This information (transmission selection) was repeated on the instrument display panel as seen in Figure 7.

The instrument display panel had a charge level display across the top with eight indicator lights to denote charge level. Across the bottom of the display (viewed from left to right) are

Left Turn Signal
R - Reverse Indicator
N - Neutral Indicator
D - Normal or Highway Speed Indicator
G - Low Speed or Golf Course Setting Indicator
Head Light Indicator
Battery Charging Indicator
Parking Brake Indicator
Overheat Indicator
Plug/Extension Cord in Charging Receptical Warning/Indicator
Right Turn Indicator

When the key was turned to the R (reverse) position, a loud piercing audible backup signal was activated. Turning the key to the N (neutral) position allowed the operator to activate the various electronics of the vehicle such as the charge level gauge, horn, lights, etc. without allowing the vehicle to move when the foot throttle was depressed. Selecting the D position allowed the vehicle to operate at its maximum design speed while selecting the G position limited the top speed of the vehicle to less than 15 mph.

The turn signals were activated by a stalk switch mounted on the left side of the steering column. Twisting the stalk clockwise and counter-clockwise activated the headlights. The headlights did not have a high beam feature. The headlights could be flashed by pulling on the stalk. The horn was activated by pushing the stalk (into the steering column).

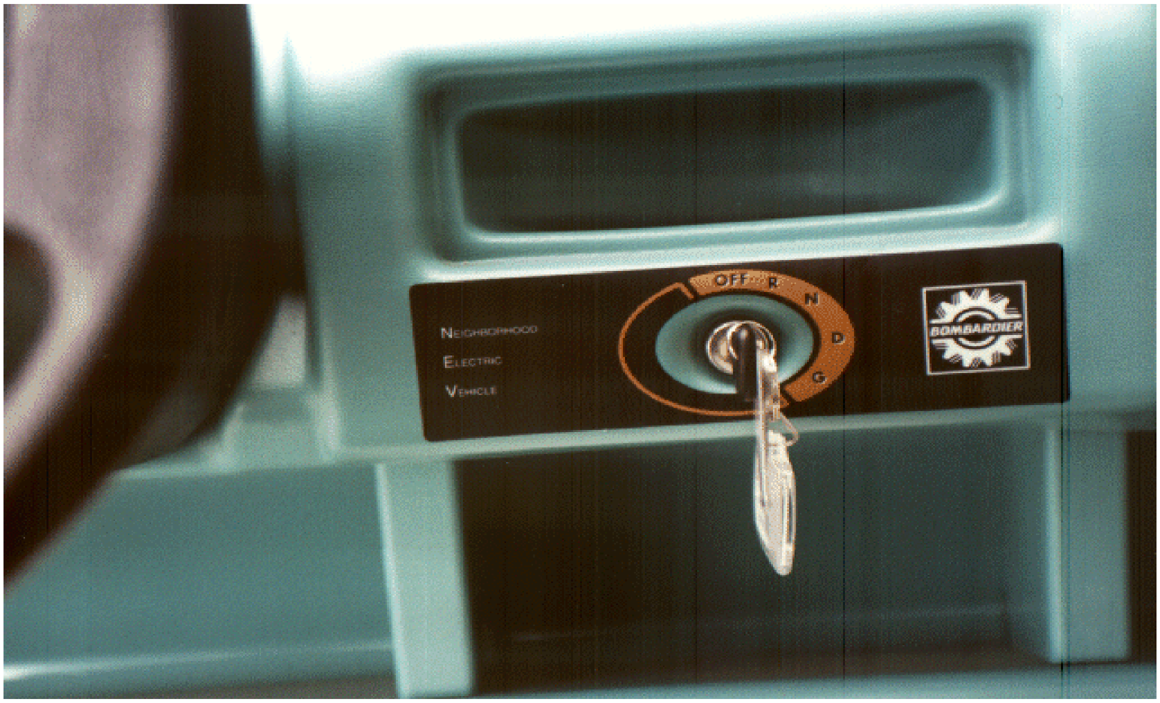

Figure 6 - Keyed Transmission Selector (Bombardier)

Figure 7 - Instrumentation Panel (Bombardier)

The steering system was a rack and pinion gear system with no power assistance. There did not seem to be any damping system in the control linkages to the front wheels. The steering wheel was 13 inches in diameter and had approximately 2.57 revolutions (925 degrees) from stop to stop.

Note: This measurement was made by turning the wheel to its hard stop then releasing the wheel to allow it to return to a rest position. The position of the wheel was noted and the wheel was rotated in the opposite direction until the hard stop was encountered. The wheel was released and allowed to return to a rest position and the total amount of rotation was measured.

4.2.5 Suspension System

The vehicle was equipped with a four wheel single A-arm independent suspension system. Each wheel had a coil spring with a shock absorber running up the center of the spring (Figure 8). There was an adjustment system located at the base of each coil spring (Figure 9). The adjustment system was a stepped rachet that compresses the coil spring by up to three increments, thereby increasing the force of the spring element of the suspension system.

The upper ends of the suspension system were mounted to plates that bolted to the body of the vehicle. The bolts may have threaded into steel plates sandwiched within the polymer body of the vehicle in a manner similar to the anchorage points used for the safety restraint systems. This could not be verified by visual inspection though.

4.2.6 Brake System

The Bombardier had hydraulic drum brakes for the front wheels. There was no power assistance for the system. The diameter of the drum was measured to be 6.25 inches. There was no adjustment mechanism to take up slack in the brake system as the pads begin to wear. Figure 10 is a photograph showing the drum, pads, and control lines to the system.

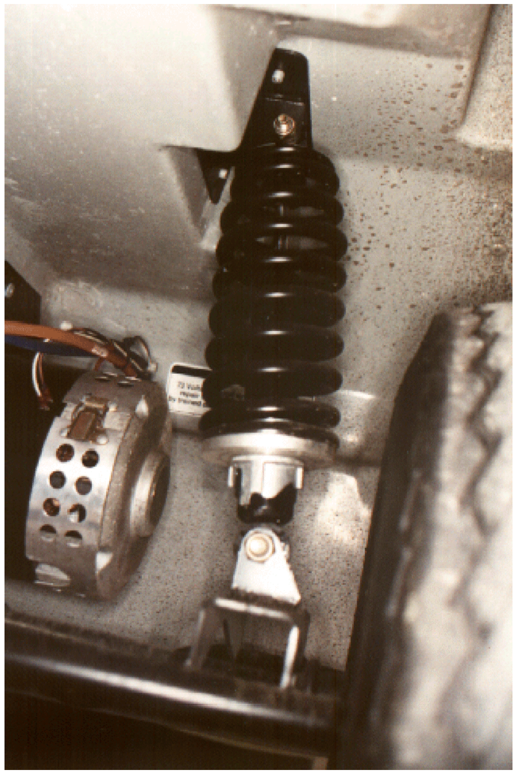

Figure 8 - Right Rear Suspension

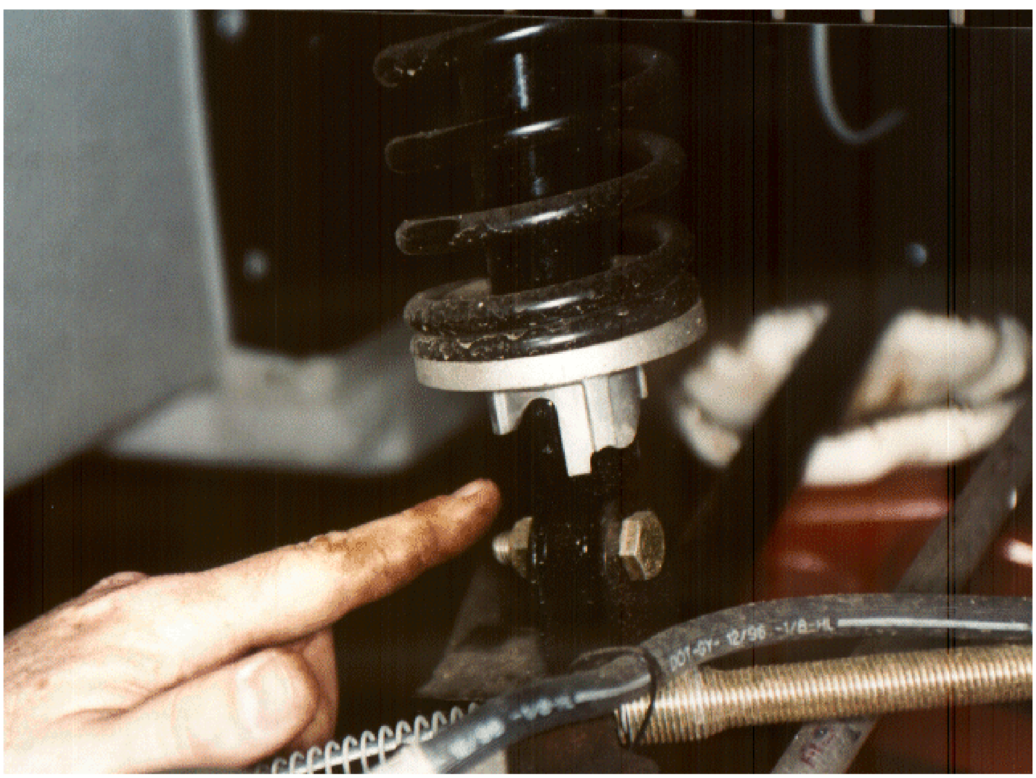

Figure 9 - Spring Tension Adjustment for Shock

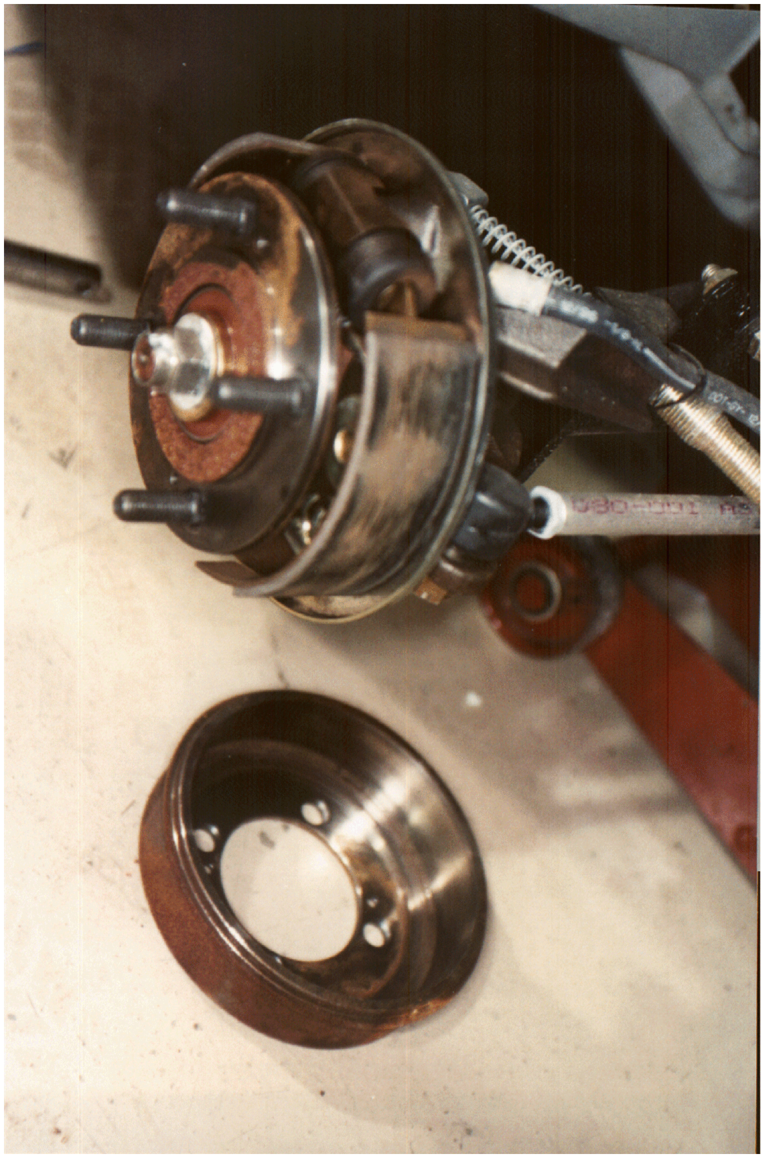

Figure 10 - Details of Drum, Brake Pads, and Wheel Cylinder

There was no brake system on the rear wheels. Literature on the Bombardier lists regenerative braking on the rear wheels as a technical feature. This would imply that when power is not being supplied to the electric motor, the rotation of the drive wheels will turn the motor. With supplemental electronics, the motor should perform as a generator to supply electricity to recharge the on-board batteries of the vehicle. The results of some of the braking tests raise questions on this issue (See section 4.3.2 for more details).

As a point of general interest, regenerative braking was noted in only one other golf cart/car during the initial research phase on the golf cart industry. The vehicle was a customized upper end design, listing this feature as a unique and proprietary design.

As can be seen in Figure 10 the parking brake is a mechanical/cable system. The parking brake was a center mounted, hand activated lever mounted between the two seats. The lever had a ratchet set mechanism with a thumb activated release button located on the end of the handle. The system is similar to that of many passenger vehicles with a hand activated parking brake located in the same position. As noted previously, the instrument panel had a warning light to indicate when the parking brake is activated.

4.2.7 Wheels

Stamped on the inner hub of the front right wheel was TITAN USA 10 6ATDOT296. The hub was a four stud mounting design. Based on visual inspection, the front axle used sealed wheel bearings rather than the tapered roller bearing generally seen in front axle design for American passenger vehicles.

The tires on this vehicle were a quality high speed trailer tire with a road tread (See Figure 11). Markings on the tire side wall indicated that it was a 10 inch diameter tire (20.5 x 8 - 10^{o} 76M 00871).


Figure 11 - Front Right “Turf” Style Tire

Additional markings on the tires were:

DURO
DOT X2BU
Trailer 4 P.R. High Speed
Tread Area 3 Plys
Side Walls 2 Ply/Nylon
Load Range B - Max. Load 905 lbs @ 35 psi cold.

The street versions of these vehicles use a 12 inch diameter street tire. A quick field inspection of a street version showed the tire used was a P145/80 R12 74S Uni Royal Tiger Paws. While no measurements were made of this “street tire,” it was clearly a narrower tire than the “turf” tires on the inspection vehicle.

4.3 Vehicle Dynamics/Handling Measurements

4.3.1 Height of Center of Gravity and Static Stability Factor

The Bombardier was transported to S.E.A. Inc. to be tested on their Vehicle Inertia Measurement Facility (VIMF). The datum of interest is the center of gravity (C.G.) height. The vehicle was first tested in an unloaded configuration then ballasted with 328 lbs and re-tested. Sandbag ballast was used to simulate two adult occupants. S.E.A.'s experience indicates that, for the VIMF tests, sandbags are acceptable surrogates for ballast dummies. The results generated by S.E.A. for these tests are included in the appendix.

The C.G. height of a passenger vehicle is used to determine a vehicle's propensity for tipping (or rollover) by calculating a Static Stability Factor (SSF). This factor is calculated using the following equation:

$$SSF = \frac{T}{2H}$$

where T is the track width (measured from the center of the tires) and H is the measured C.G. height of the vehicle. The range of SSF values for many passenger vehicles (sedans) is about 1.2 to 1.4. For sport utilities, this value more typically ranges between 0.9 and 1.1.

The C.G. height of the un-ballasted vehicle was 17.11 inches while the height of the ballasted vehicle was increased to 19.86 inches. The calculated SSF value for the unloaded condition for the Bombardier was 1.37. This value compares favorably with a standard passenger vehicle's SSF. Since this vehicle was very light weight, ballasting the vehicle with the equivalent of two adult occupants raised the C.G. height to a greater degree than is typically encountered with a full sized motor vehicle. The SSF for the ballasted test was 1.17. While the addition of two adult occupants lowered the stability factor significantly, the results were still reasonably good, as can be seen from the SSF range for typical sport utility vehicles.

4.3.2 Brake Testing

The rear bumper of the Bombardier was temporarily removed and the vehicle was instrumented with a standard fifth-wheel. A series of simple straight line braking tests were conducted at the Transportation Research Center Inc. (TRC) Vehicle Dynamics Area (VDA). The braking tests were conducted on both the standard high friction coefficient (hi-co) braking surface and on the low friction coefficient (lo-co, wetted Jennite) surface. Table 4 is a compilation of the test matrix and results.

TABLE 4
Straight Line Brake Tests - Bombardier

TEST #	Configuration	Speed (mph)	Stop Distance (ft)	Corrected Stop Distance (ft)
1	In Drive - Dry Asphalt	19.9	22.1	22.3
2	In Drive - Dry Asphalt	20.2	19.4	19.0
3	In Drive - Dry Asphalt	20.4	21.3	20.5
4	In Drive - Dry Asphalt	20.3	22.2	21.6
5	In Neutral - Dry Asphalt	20.0	20.2	20.2
6	Wet Jennite - Lockup	20.8	Stable Straight Braking	
7	Wet Jennite - Lockup	21.0	Stable Straight Braking	
8	Wet Jennite - Best Effort	20.5	Stable Straight Braking	
9	Wet Jennite - Best Effort	21.3	Stable Straight Braking	
10	Wet Jennite - Best Effort	20.4	Stable Straight Braking	

The 20 mph braking on the hi-co brake surface gave an average corrected stopping distance of 20.8 feet and a maximum stopping distance of 22.0 feet over 4 tests. The FMVSS 135 standard for passenger car brake systems specifies a cold effectiveness stopping distance of about 31 feet for a 20 mph test. While applied brake pedal forces were not measured for these tests, significant pedal force was applied. There was little noticeable nose dive of the vehicle and little tendency to lock up even under hard braking conditions. For one test, the transmission selection was switched to neutral as the brakes were applied. This was done to see if the regenerative effects on the rear axle could be bypassed. The results of this test showed the same stopping distances as observed with the normal straight line braking tests. Therefore, either the effort to bypass the regenerative braking system was unsuccessful, or the regenerative brakes do not noticeably contribute to the overall braking performance of the vehicle.

The brake lockup tests and best effort braking tests on the Jennite surface showed relatively little differences in stopping distances. For both the lockup tests and the best effort tests, the left rear tire continued to roll forward while the right rear tire rotated slowly in reverse. In all of the tests on the low friction surface, the vehicle exhibited excellent braking stability. The vehicle stopped in a straight line with little to no demonstrated tendency to spin or pull out of line.

4.3.3 Lateral and Turning Stability

To examine lateral stability, the vehicle was driven at a constant speed through a known, constant radius, turn. The normal component of acceleration, a, of an object moving in a constant radius arc, r, is expressed as

$$a = r\omega^2$$

where ω, is the angular velocity. Since velocity can be expressed as ($v = r\omega$) or

$$\omega = \frac{v}{r}$$

the normal acceleration component, or lateral acceleration, of a vehicle moving at a constant velocity through a known radius can be expressed as:

$$a = \frac{v^2}{r}$$

The vehicle was driven at 20 mph through a series of decreasing radius turns. Although the literature indicates that the vehicle has a curb to curb turning diameter of 21 feet, at a turning radius of 50 feet the driver discontinued the test. Using the relationships presented here, the lateral acceleration for a 50 foot turn at 20 mph is 17.2 ft/sec^2 or 0.53 g. Although the vehicle was still exhibiting stable handling characteristics and was tracking well, it was not considered prudent to push a leased vehicle any closer to a possible tipping point and subsequent rollover. Preparing both the driver and the vehicle for this level of testing was beyond the intended scope of this evaluation program.

In both braking and turning maneuvers, a 0.5 g load is generally perceived by most vehicle occupants as a very severe loading condition (on the verge of loss of control). Most drivers generally will not approach this level of loading voluntarily. The level of loading achieved for this test was considered sufficient to demonstrate the turning stability of the vehicle.

4.3.4 Vehicle Speed

Two top vehicle speed measurements were conducted on this vehicle. The first test was conducted on the VDA which has an asphalt surface with a known and constant North/South drainage slope of 1% grade. The top speed for the North/South run was 24.2 mph with top speed being attained at about 200 feet. The top speed for the South/North run was 23.9 mph with top speed again being attained within 200 feet. The driver weight for these tests was approximately 270 lbs. Since there are straight line distance limitations on the VDA, the length of these runs were under 200 yards.

A second series of speed measurements were conducted on a second asphalt surface that had a straightaway greater than one mile. The surface was relatively level but of undetermined slope. The top speeds for these tests were 24.3 mph and 23.9 mph, respectively. The weight of the driver for these tests was approximately 150 lbs. Top speeds were attained at 180 feet and 200 feet, respectively.

The results of these tests suggest that the motor of this vehicle had sufficient power to accelerate the vehicle quickly, but that the top speed was governed to stay below 25 mph. The vehicle exceeded speeds of 20 mph within 200 feet. Literature on the vehicle claims accelerations of zero to 20 mph in less than 6 seconds.

4.4 General Observations and Notes

The Bombardier evaluated at the VRTC had an integral windshield and roof structure. While this structure was definitely more substantial than the simple covers seen on a typical golf cart, the effectiveness of this roof as a support structure in a rollover is not known. The battery compartment was completely separated from the occupants by the body of the vehicle. As long as the body of the vehicle remains intact, the occupants appear to be well protected from any spillage or leakage from the batteries.

The bumpers of the vehicle had a very light and flexible cosmetic cover. Beneath the cover was a block of closed cell foam (similar to Styrofoam) backed with a long polymer/fiberglass flat spring structure (see Figures 12 and 13). The rear bumper attached directly to the differential. The rack and pinion gearing was located directly behind the front bumper attachment (See Figure 14).

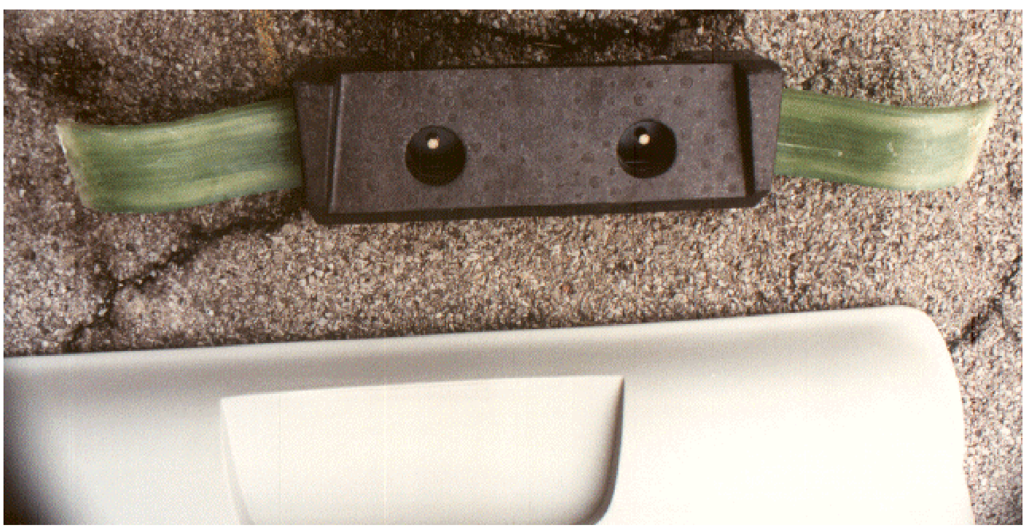

Figure 12 - Rear Bumper and Bumper Cover

Figure 13 - Details of Bumper

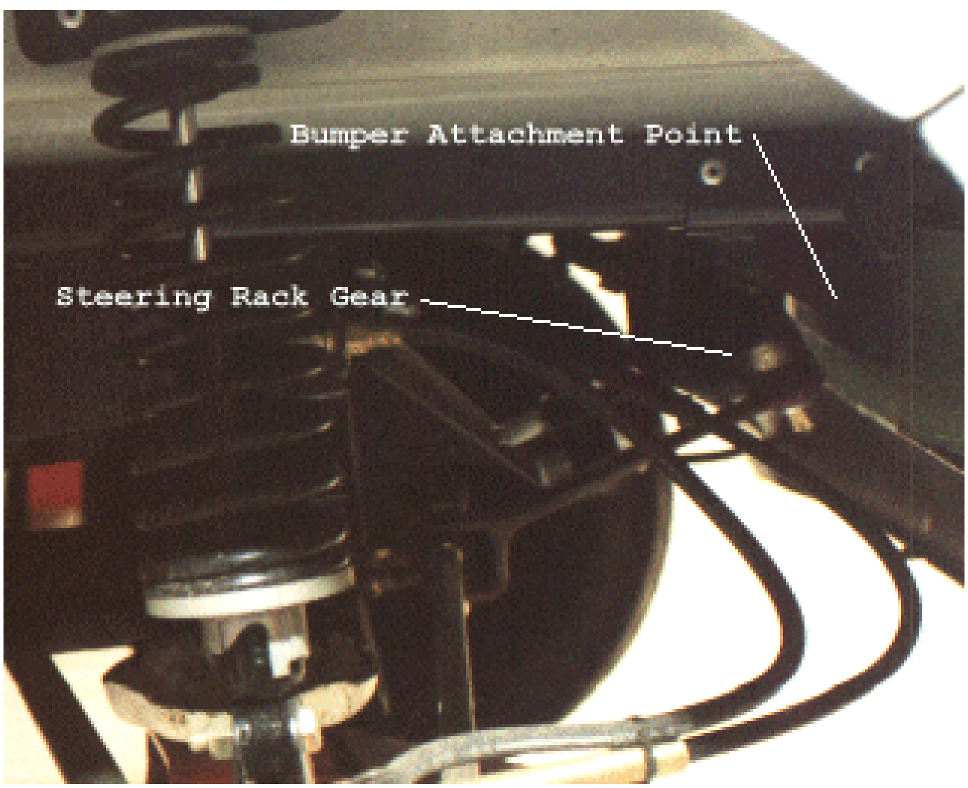

Figure 14 - Details of Steering Components and Bumper Attachments

On a subjective basis, driving experiences with the Bombardier tended to agree with the results suggested by the braking and handling tests. The vehicle was lively and had responsive handling characteristics with a feeling of stable response even under mildly aggressive maneuvering and braking conditions. The light weight and relatively stiff nature of the suspension along with the open body design gave the occupant a definite overall impression of a golf cart rather than passenger vehicle.

5.0 GEM NEV

5.1 Visual Inspection

5.1.1 Vehicle Description and Configuration

The second vehicle tested was a GEM. The TRANS2 was purchased by the Global Electric Motor Company and the vehicle that was originally marketed as the TRANS2 is currently being manufactured and marketed as the GEM. The new company was contacted and a model of the GEM was obtained for evaluation at the VRTC.

The GEM is currently being modified and reconfigured by the new company to upgrade the performance of the vehicle. The original version of the GEM is a 48 volt system while the upgraded version will have a 72 volt system with associated upgrades in the electronics and motor. Apparently, one result of these upgrades is the increase in maximum speed. The upgraded version of the vehicle is currently being re-engineered to limit the top end speed to below 25 mph. Since this vehicle is still in its development phase, a unit of this type was not available for testing at the VRTC. The unit that was obtained was the older 48 volt system. The heritage of this vehicle was apparent by the presence of TRANS2 inspection stickers on several of the body panels of the vehicle.

Figure 15 is a frontal view of the GEM, Figure 16 is a rear view and Figure 17 a side view.

Figure 15 - Front View of GEM

Figure 16 - Rear View of GEM

Figure 17 - Side View of GEM

5.1.2 FMVSS 100 Regulations

Table 2 of Section 4.1.2 is reproduced here for comparison of the Bombardier and the GEM. As can be seen in the table the two vehicles are almost identical in terms of their compliance to the proposed FMVSS requirements. Both vehicles would be in full compliance with the addition of side reflectors, a side mirror, and the addition of the appropriate warning labels and VIN number identifications.

5.2 Technical Inspection

5.2.1 Technical Specifications Survey

As stated in Section 4.2.1 (Bombardier) the appendix of this report contains the completed survey question list for the evaluation of this vehicle. The following information is an addition to this survey list and provides a more complete set of notes, comments and photographs of the vehicle which were made during the course of the survey. Table 3 (from section 4.2.1) is reproduced here for comparison between the GEM and the Bombardier. The measurements recorded here were either obtained from published literature (such as the owner's manual) or recorded as direct measurements taken either at VRTC or S.E.A. (for the VIMF testing).

5.2.2 Seating and Safety Restraints

The seat of the GEM was a padded bench type seat similar to the bench seat of a typical golf cart. Figure 18 is a photograph of the seating arrangements which shows the molded bench seat. The seat was molded in such a manner as to suggest/limit the occupancy to two. The bench was attached to the seat pan with a series of small Velcro tabs (approximately 1 inch in diameter) located around the rim of the pan and the bottom of the bench. The seat pan and bench had a definite angle that dropped from front to back. The forward height of the pan was approximately 24 ¼ inches from the ground while the rear of the seat dropped approximately 2 inches (22 ¼ inches from the ground). The padding on the bench was approximately 4 inches thick making the seat height measurements approximately 28 ¼ inches high for the front of the seat and 26 ¼ inches high for the back.

TABLE 2 FMVSS 100 SAFETY REQUIREMENTS			
Requirements	Bombardier (LSV)	GEM (LSV)	Yamaha (Golf Cart)
Headlamps	YES	YES	NO
Front and Rear Turn Signals	YES	YES	NO
Tail Lamps	YES	YES	NO
Stop Lamps	YES	YES	NO
Red Reflex Reflectors	**NO**(1)	NO	NO
Interior Mirror	YES	YES	NO
Driver Side Exterior Mirror	**NO**(2)	NO	NO
Passenger Side Exterior Mirror	**NO**(2)	NO	NO
Parking Brake	YES	YES	NO
Windshield (AS-/1/AS-6)	YES	YES	NO
Vehicle Identification Number (VIN)	**NO**(3)	**NO**(4)	NO
Seat Belt Assembly (Type1/Type2)	YES	YES	NO
Warning Label	**NO**(5)	**NO**(5)	NO

1. There were no side reflectors on the vehicle evaluated. They do not appear to be standard for any of the Bombardier models.

2. The model evaluated had no exterior side mirrors. However, Table 1 indicates that all other versions (CLASS-E street and golf and SPORT-E street have one or more exterior side mirrors.

3. On the front left dashboard area where the VIN# of a typical motor vehicle is located was a metal tag (similar to those used for VIN #) with a stamped number on it. The tag was labeled as a serial number and did not appear to follow the standard convention of a VIN#. Whether the serial number observed on the vehicle can be defined as its VIN# or if a specific VIN# needs to be supplied needs to be determined.

4. The GEM was identified by a serial number. It is not clear if this is sufficient to be a VIN #

5. A warning label was centrally mounted to the interior roof of the vehicle (just beyond the upper edge of the windshield) While a number of disclaimers and warnings were listed, they were not specific to the requirements of FMVSS 100.

TABLE 3 Technical Specifications - Vehicle Dimensions			
	BOMBARDIER (LAV)	GEM (LSV)	YAMAHA (Golf Cart)
Length	100 in	95 in	93 ¾ in
Width	55 in	43 in	46 in
Height	61 ¾ in	68 ¾ in	43 ½ in
Wheel Base	65 in	71 ½ in	65 ½ in
Curb Weight	1275 lb	928 lb	688 lbs
Height of Center Stop Lamp	58 ¾ in	49 ½ in	No Lamp

Figure 18 - GEM Bench Seating

The seatback for the bench seat was a padded, plywood backed, panel attached to the rear frame of the compartment with light sheet metal screws. The seat back can be seen in Figures 15 and 16 and shows the headrest type outlines of the top of the seatback. The height of the seatback, as measured to the top of the head restraints, was 53 ½ inches.

There was a steel tubular side rail on the passenger side of the seat. This lateral restraint started at the seat back with a height of 5 ¾ inches (above the cushion) and extended forward about 11 inches while dropping to less than 2 inches above the seat cushion. There was no matching lateral restraint located on the driver's side of the seat.

In addition to the lateral restrains, the vehicle was equipped with two 3-point retractable seat belt systems. The upper attachment point of the restraint system was bolted to the structural framework behind the seatback which formed part of the cross-bracing of the vehicle. Figure 19 is a photograph showing the mounting of the upper end of the restraint system. The belt threaded through a D-ring bolted to the frame of the vehicle at the height of the seat back. This D-ring had no height adjustment capabilities. The buckle of the restraint system, shown in Figure 20, was mounted on a short

Figure 19 - Seat Belt Anchor for Reel and D-Ring Mount

Figure 20 - Seat Belt Anchor for Buckles

stalk that bolted directly to the framework behind the seatback. The anchor points for both the upper and lower portions of the seat restraint appeared to be located at structurally secure points on the frame of the vehicle.

5.2.3 Motor and Electronics

The GEM used a 48 volt electric motor to drive the front wheels of the vehicle. Two 12 volt lead/acid maintenance free batteries were mounted in the floor pan area beneath the seat with 2 additional batteries mounted above the electric motor in a compartment forward of the passenger compartment. Figure 21 is a photograph showing the position of the two forward batteries. The second battery was located directly behind the one visible in the picture (essentially beneath the dash of the passenger compartment). Figure 22 shows the two batteries located beneath the bench seat of the vehicle. As can be seen in these photographs, the removable bench seat was all that separated the passenger compartment batteries from the occupants. The two batteries that were located in the forward position were isolated from the occupants by the fiberglass shell of the body of the vehicle. All of the batteries appeared to be mounted to their trays with a heavy ½ inch plastic tie strap. There was no gasket or containment shell in the battery compartment beneath the seat.

Figure 21 - Two Batteries in Forward Compartment

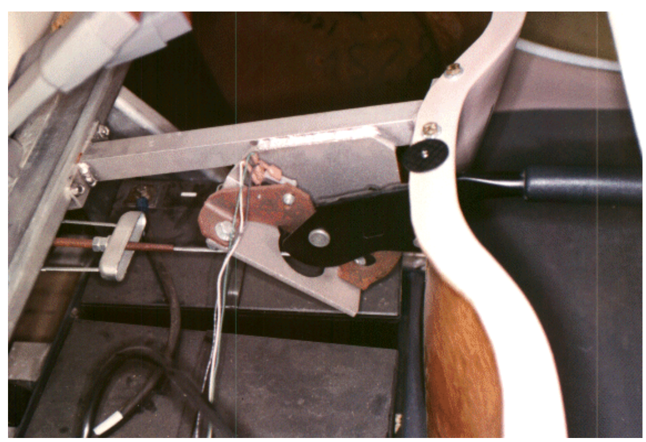

Figure 22 - Two Batteries in Passenger Compartment

5.2.4 Instrumentation and Control Features

The vehicle used a keyed system to operate the transmission selection. Figure 23 is a photograph showing the details of the ignition/transmission selection. There were three keyed positions labeled OFF, FORWARD, and REVERSE. When the key was turned to the REVERSE position, there was an audible warning beep . When the key was turned to start, there was an audible warning beep if the charging cable was plugged into the charging outlet or if the hand operated parking brake was engaged. Figure 24 is a photograph of the left side control features. The stalk was the turn signal lever and the red button located in front of the stalk activated the horn.

Figure 23 - Vehicle Controls - Right Side

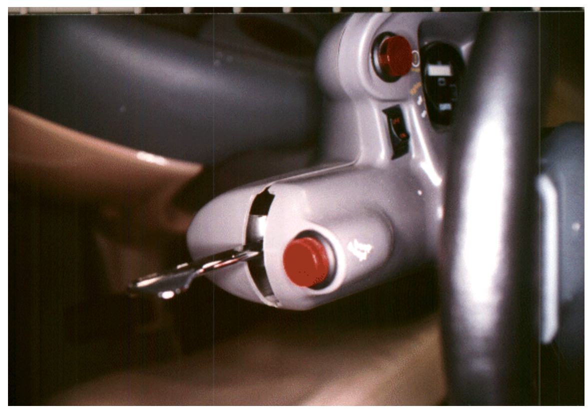

Figure 24 - Vehicle Controls - Left Side

Figure 25 shows the central control panel as seen by the driver. The windshield wiper switch is located at the far right of the picture. The next switch is a non-operative plug. The switch mounted on the right center portion of the panel is the “Road/Turf” switch to select the high (road speed) and low (golf or turf speed) option. The light switch is the left central switch. The gauge located in the center of the control panel had a charge indicator across the top and an odometer across the bottom. The red lens located on the right side of the panel is a seat belt warning light which came on momentarily when the ignition switch was turned to either the FORWARD or REVERSE position. The red lens located to the left of the control panel is labeled Brakes. Since this light did not come on with any position of the parking brake it is assumed that the light was a warning light for the primary brake system. An audible warning buzzer was activated if the ignition switch was turned to the OFF position without engaging the hand brake.

Figure 25 - Control Panel - Center View Through the Steering Wheel

5.2.5 Suspension System

The GEM was a front wheel drive vehicle. The forward suspension system must accommodate both the drive system and the steering system. As a result the front suspension system appeared to be relatively complex. Figure 26 is a photograph taken beneath the vehicle showing the A-Arms, electric motor and forward framework of the vehicle.

Figure 27 shows the details of the front axle and suspension system. The suspension was a shock within a coil spring system similar to that seen on the Bombardier. The lower anchor point for the shock is visible in this figure. The electric motor and part of the transmission are also visible along with the CV drive shaft/axle and the steering linkage. The axle mounting was a split king pin arrangement common in drive axles.

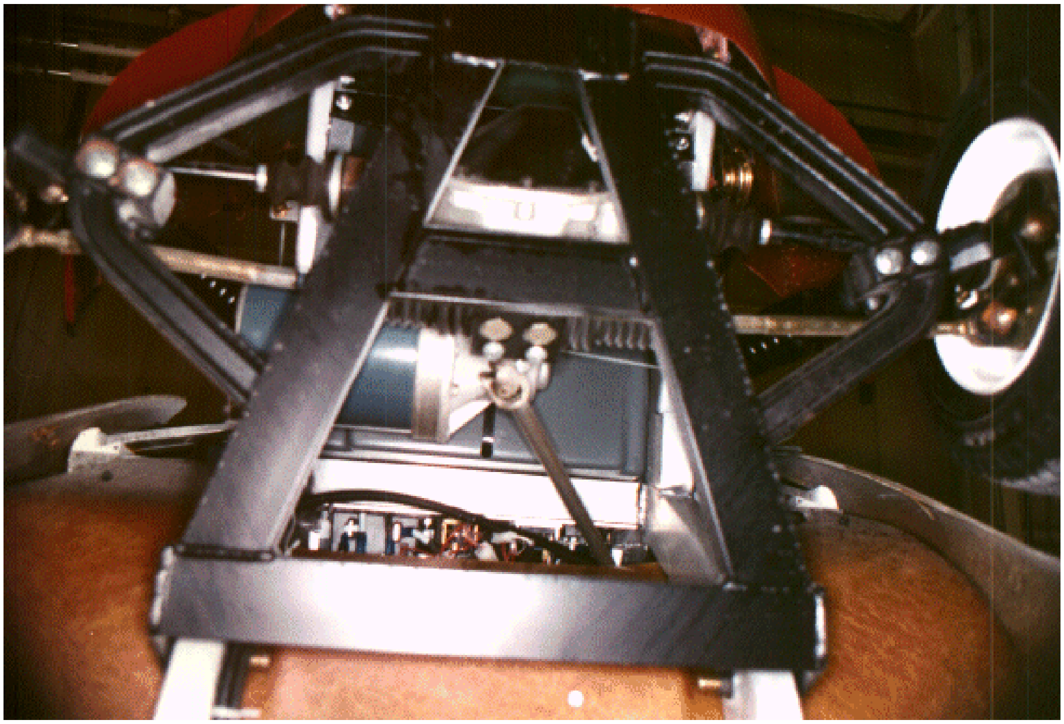

Figure 26 - Front Suspension as Seen From Beneath the Vehicle

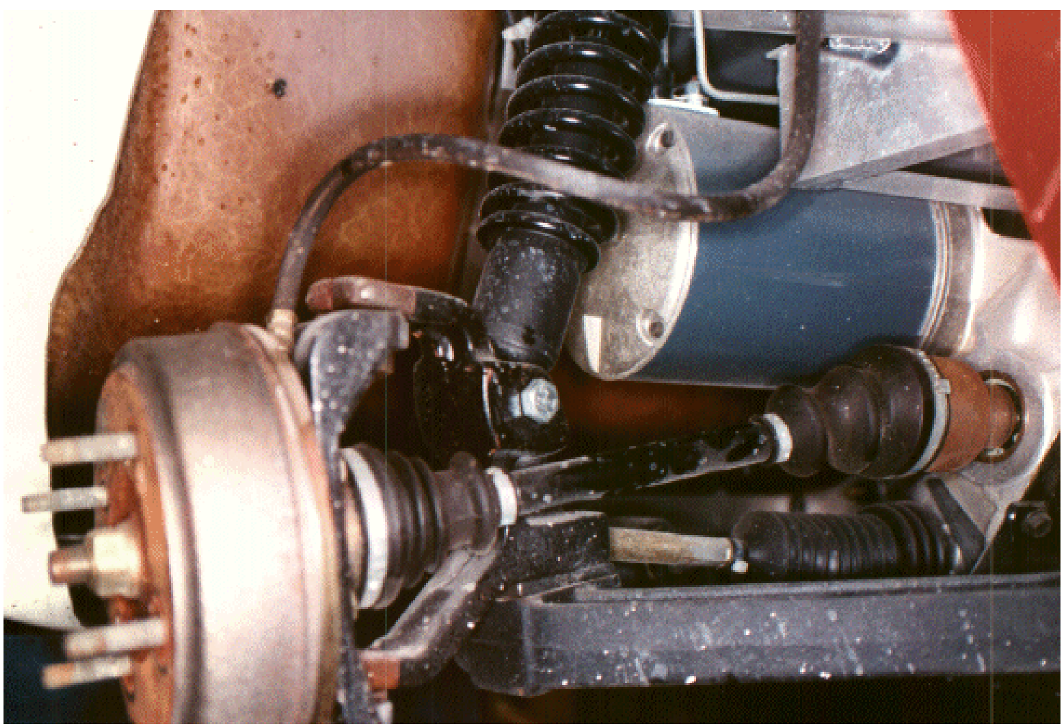

Figure 27 - Details of Front Suspension, Drive Train, and Steering Linkage

Figure 28 is a photograph of the rear suspension system taken from beneath the vehicle. The system used a solid rear axle that did not utilize a true independent suspension. It was mounted to the framework of the vehicle at three points. The shock system was anchored to the axle and to the framework at a fairly shallow angle. While the resulting system should be capable of normal motion in the vertical direction, there appeared to be relatively little torsional movement capabilities. This torsional “stiffness” would tend to couple the motion of the body of the vehicle to that of the rear axle. Thus, the vehicle would exhibit little or no body roll in a sharp (high g) turn. A possible consequence of this could be the lack of an “intuitive” feed back that a driver receives when cornering sharply, therefore increasing the possibility of rolling the vehicle in a high g turn.

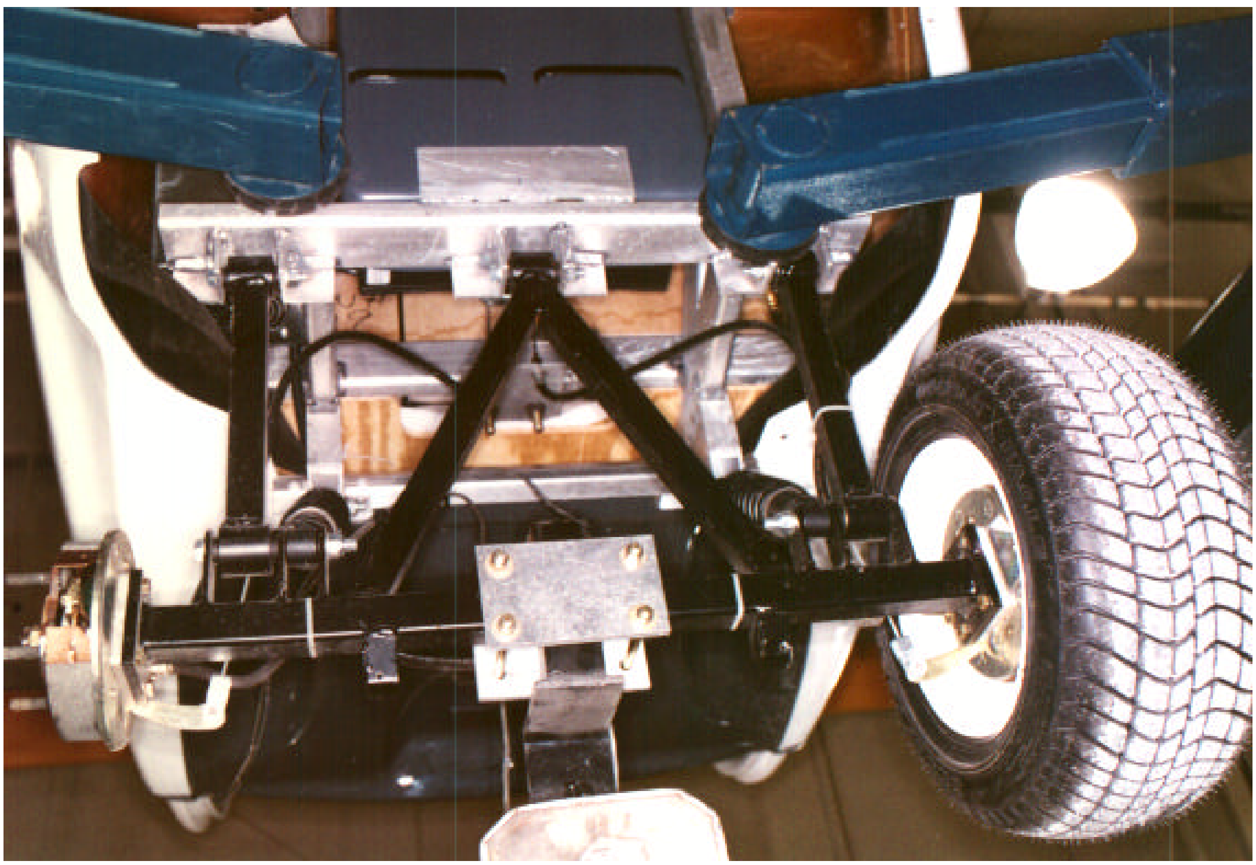

Figure 28 - Rear Suspension System - As Seen From Beneath the Vehicle

5.2.6 Brake System

The GEM had hydraulic drum brakes for all four wheels. There was no power assistance for the system. The diameter of the drum was measured to be 6.34 inches. There was no apparent adjustment mechanism to take up slack in the brake system. Figure 29 is a photograph of the right rear wheel showing the wheel cylinder and pads for the system.

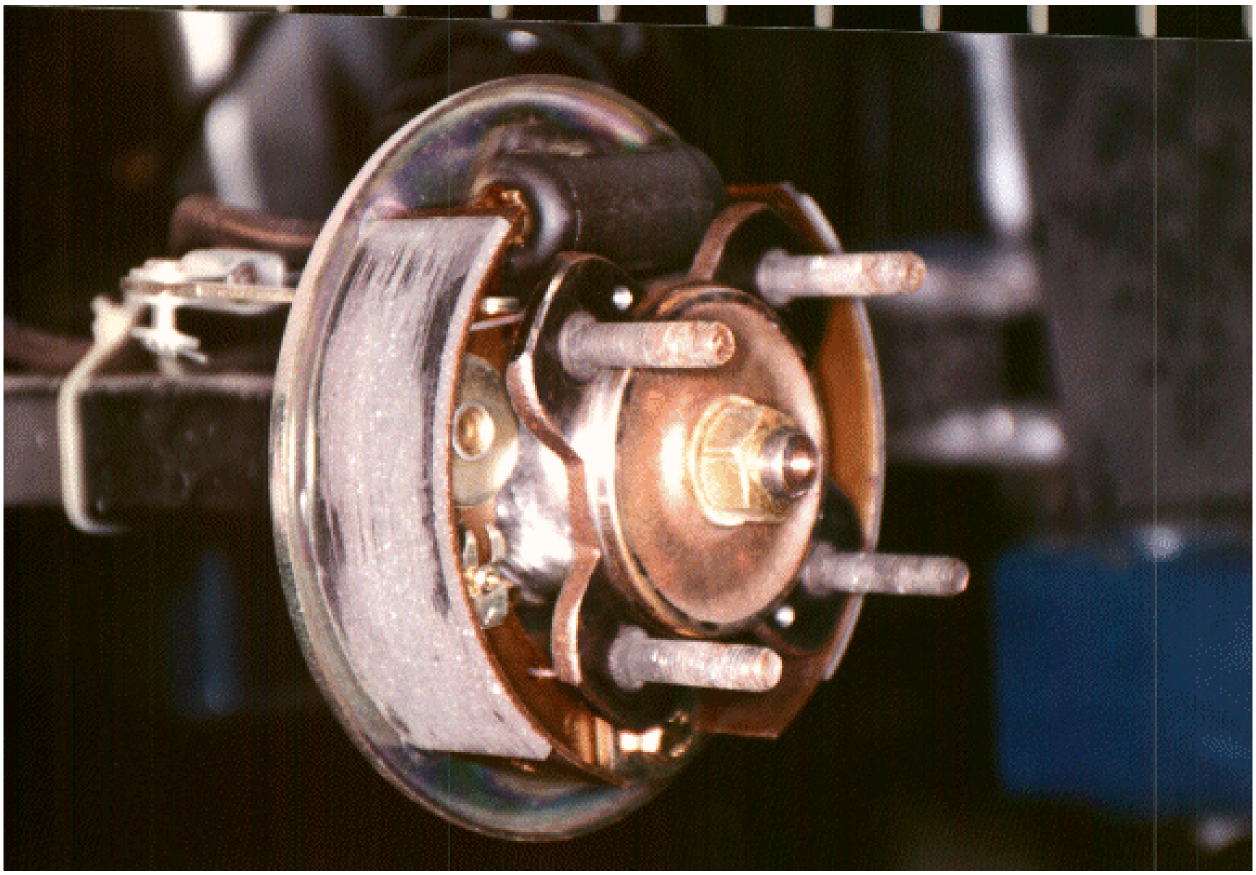

Figure 29 - Left Rear Brake Cylinder and Brake Pads

The brake system used a combination of stainless steel tubing and flexible hose to route the lines to the individual tires. The parking brake was a mechanical/cable system which engaged the rear wheels. The parking brake was engaged by a hand lever located in the face of the seat pan between the driver and passenger seating positions (See Figure 18).

Figure 30 is a view of the left rear wheel showing the flexible brake line and the cable linkage of the parking brake. This photograph shows a potential hazard with this braking system. As shown in this photograph, the flexible line for the hydraulic brake system bridged over the cable for the parking brake system. In the photograph, the hose is not in contact with the cable, but as can be seen, the line is secured with tie wraps. Any inadvertent movement of the line could bring it into contact with the cable of the parking brake. If this occurs, the use of the parking brake will result in the cable sawing into the flexible cable, eventually causing a failure of the hydraulic system. Since the hydraulic system appeared to be a single unit, this would result in total failure of the hydraulic system

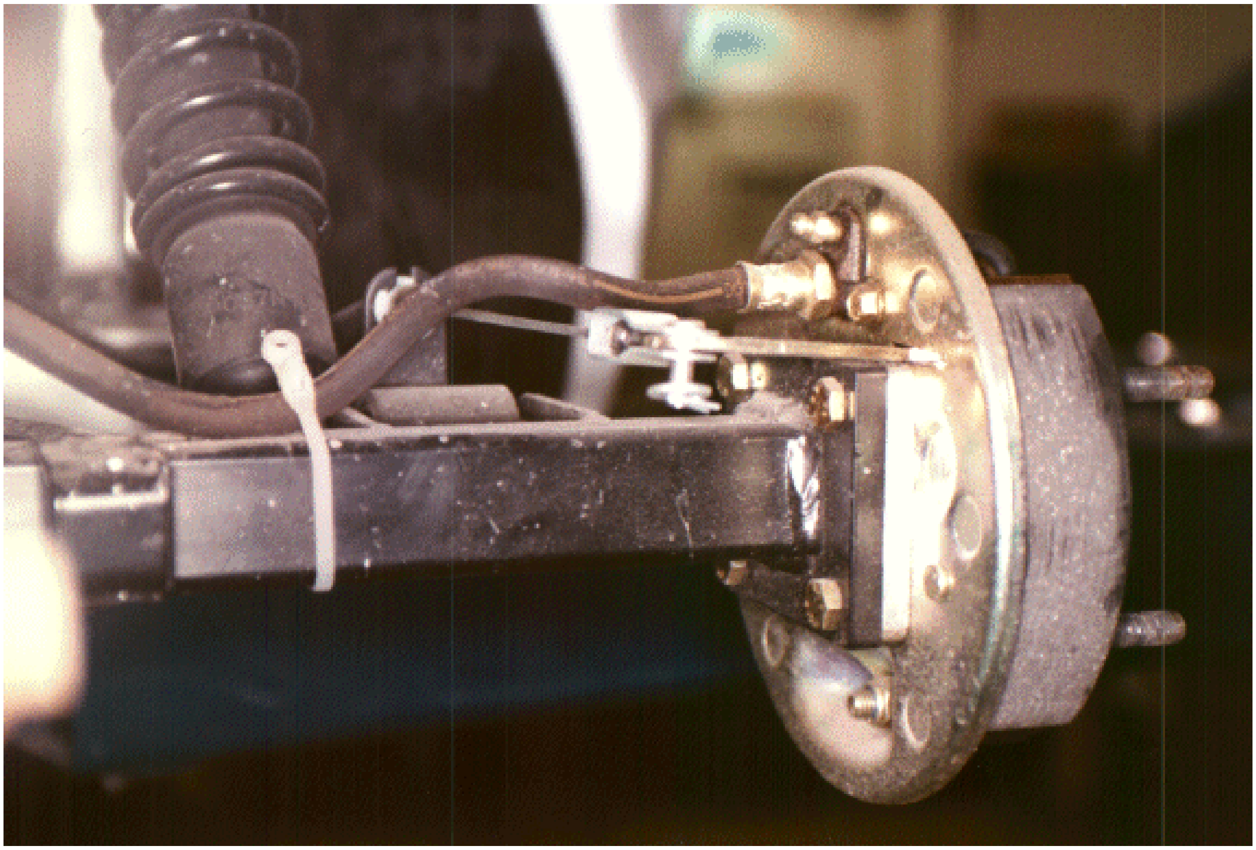

Figure 30 - Left Rear Axle - Hydraulic Brake Line and Parking Brake Cable

5.2.7 Wheels

The wheel hub was a four stud mounting design. Based on visual inspections, it used sealed wheel bearings. No attempt was made to open or remove the bearing. The vehicle was equipped with Good Year Double Eagle tires.

Additional markings on the tires were:

Tubeless

205/50-10

2 PLY - Nylon Cord

273625-GRJ-32M

MAX Load 665 lbs. @ 30 psi Cold

Figure 31 is a photograph of the left rear tire showing the tread pattern.

Figure 31 - Goodyear Double Eagle Tire and Brake Drum Used on GEM.

5.3 Vehicle Dynamics/Handling Measurements

5.3.1 Height of Center of Gravity and Static Stability Factor

The VIMF tests conducted by S.E.A. Inc. on the GEM indicated an un-ballasted C.G. height of 19.06 inches. Using the equations presented in Section 4.3.1, the calculated SSF value for the unloaded test condition for the GEM was 1.03. The SSF for a sport utility vehicle typically ranges between 0.9 and 1.1. In the unloaded configuration the GEM appears the have the same roll stability as typical sport utility vehicles.

When the vehicle was loaded with 328 pounds of ballast to simulate two 50th percentile males, the C.G. height was increased to 22.76 inches. For a vehicle with a track width of 39.30 inches, the calculated Stability Safety Factor becomes 0.86. Because of its light weight, the addition of the ballast weight increased the C.G. height 3.7 inches. Because of the narrow track width, this reduced the SSF to a very low level, as compared to passenger vehicles.

5.3.2 Brake Testing

The rear bumper of the GEM was removed and the vehicle was instrumented with a standard fifth-wheel. The vehicle was subjected to the same series of straight line braking tests that were conducted with the Bombardier.

However, there were difficulties in reaching the desired test speed for these tests. As can be seen in Table 5, the maximum obtainable speed for this series of tests was below 18 mph. During the period the vehicle was available for testing it was unseasonably cold. The conditions at the time of testing were dry with a temperature of 18 degrees F. It was speculated that the low ambient temperature had a detrimental effect on the batteries and therefore affected the speed and endurance capabilities of the vehicle.

While the cold did have an apparent effect on the endurance (charge capacity of the batteries), subsequent maximum speed tests indicate that 17 mph to 18 mph may be the maximum speed that this individual vehicle can reach in its current configuration. For comparison purposes, the stopping distances were corrected to 20 mph. This somewhat large extrapolation may result in larger errors in the corrected stopping distance values than for the other vehicles tested.

TABLE 5 Straight Line Brake Tests - GEM					
TEST #	Configuration	Comments	Speed (mph)	Stop Distance (ft)	Corrected Stop Distance 20 (ft)
1	Dry Asphalt	Lockup	17.5	17.0	22.2
2	Dry Asphalt	Lockup	17.2	16.8	22.7
3	Dry Asphalt	Lockup	17.4	17.4	23.0
4	Dry Asphalt	Best Effort	17.7	25.9	33.1
5	Dry Asphalt	Best Effort	17.7	21.8	27.8
6	Dry Asphalt	Best Effort	17.5	22.9	29.9
7	Jennite	Lockup	15.4	Stable Straight Line	
8	Jennite	Lockup	14.7	Stable Straight Line	
9	Jennite	Lockup	14.7	Stable Straight Line	

The high-coefficient lockup and best effort braking tests resulted in little to no observable nose dive and the brake line was straight and stable. The stopping distances show results that are similar to those of the Bombardier. Subjectively, the vehicle responded well and was felt to be in good control during the braking maneuvers.

The Jennite tests were conducted as lockup tests with no best effort braking tests conducted. The top speed of the vehicle appeared to be dropping (presumably due to the low ambient temperatures) and the tests on the low friction surface were conducted at approximately 15 mph. The vehicle showed no tendency to verve or pull out of line during these maneuvers. Again, the general subjective observations of these braking maneuvers were positive with the vehicle feeling to be in good control at all times.

5.3.3 Lateral Turning Stability

The GEM was driven at its maximum attainable speed through a constant fifty foot radius turn. The maximum speed, as recorded by the fifth-wheel for this maneuver was 15.2 mph. Using the relationships shown in Section 4.3.3, the lateral acceleration for the 50 foot turn at 15.2 mph was 9.9 ft/sec^2 or 0.31 g. At this speed the vehicle exhibited stable handling characteristics. There was very little roll or sway to the body/chassis of the vehicle and no tendency for the vehicle to tip or the wheels to lose traction with the road surface.

Since there was some concern about the low ambient temperature conditions during this test (18 degrees F), the test was repeated at a later date with a higher ambient temperature (approx 40 degree F). The batteries were freshly charged and no other tests (braking tests) were conducted prior to the 50 foot lateral stability test. The maximum speed obtained in this test was 15.7 mph (lateral acceleration = 10.6 ft/sec^2 or 0.33 g) with results that were essentially the same as for the first test.

The results of the VIMF tests conducted by the S.E.A. Inc. suggest that the GEM may have some propensity towards rollover. The fully loaded configuration for the GEM produced a SSF value of 0.86 (compared to SSF = 0.88 for the Yamaha and SSF = 1.17 for the Bombardier). The lateral stability test did not appear to confirm this conclusion. This may have been due to the limit of the maximum speed of 15.7 mph obtainable during these tests which was below the desired 20 mph speed. This maximum obtainable speed may have been insufficient to test the vehicle to a point of instability.

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It is also possible that the relative sophistication of the suspension and the potential torsional stiffness of the rear axle design, acted to either improve the stability of the vehicle or mask its instability at the speeds at which it was possible to test it.

5.3.4 Vehicle Speed

Two top vehicle speed measurements were conducted on the GEM. The first test was conducted on asphalt surface of the VDA with a constant north to south drainage slope of 1% grade. The top speed for the north to south run was 17.8 mph. The top speed for the south to north run was 14.9 mph.

The driver weight for these tests was approximately 270 lbs. Since there are straight line distance limitations on the VDA where these tests were conducted, the length of these runs were under 200 yard (typically under 100 yards). There were indications that the top attainable speed of this vehicle was not reached in these tests. The short straight line distance and the low ambient temperatures were both considered to be conditions that might limit the top measured speed for these tests.

A second series of speed measurements were conducted on a second asphalt surface that had a straightaway distance greater than one mile. This surface has a relatively level but undetermined slope. The top speeds for these tests were 18.3 mph and 18.5 mph, respectively. Top speeds were attained at 800 feet and 950 feet respectively. The weight of the driver for these tests was approximately 150 lbs.

The results of these tests suggest that the power to weight relationship of this vehicle was much less than that of the Bombardier. The driver commented that during these tests the vehicle accelerated very quickly to about 15 mph then preceded to accelerate slowly to its maximum recorded speed (18.3/18.5 mph). After reaching a maximum speed on the return leg of the test, the vehicle began to show a steady decline in speed. By the end of the return leg of the test (i.e.,after less than two miles of travel) the speed of the vehicle dropped to about 15-15.5 mph. The results of these tests indicate that the batteries may be contributing to the low maximum speeds seen in this vehicle.

5.4 General Observations and Notes

The GEM evaluated at the VRTC had a unique structure built around two ellipsoid aluminum hoops. These two hoops, which define the passenger compartment were crossed braced along the lower edges of the vehicle. Figure 32 is a photograph of the underside of the vehicle showing some of the cross struts along the bottom of the hoop structure. The upper edges of the hoops provided the attachment structure for the windshield and roof structure. The hoops also appeared to form a sort of roll cage for the vehicle. Since the hoops were not strongly crossed braced along the roof, their stability in the side loading that may occur in a rollover event (i.e., collapsing in a parallelogram mode) is not known.

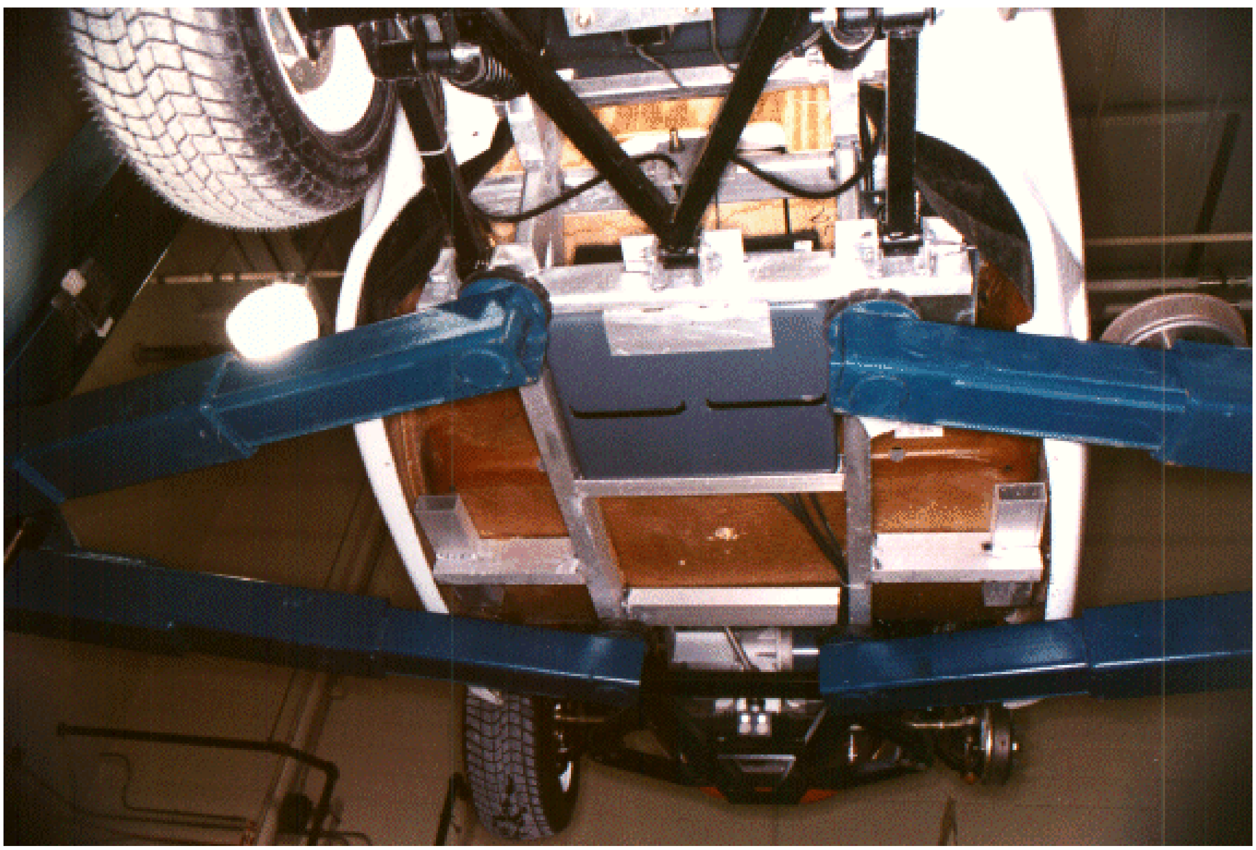

Figure 32 - GEM - Framework Showing Aluminum Hoops and Cross Bracing

The tires, motor, and suspension of the GEM did not appear to have much, or provide much, protection in a low speed crash. The level of underride may be significant due to the low profile of these structures. On the other hand, the passenger compartment was well defined by the twin aluminum hoops, which may provide reasonable passenger compartment integrity in the event of a crash.

The use of front wheel drive along with the associated motor and transmission, as well as the placement of two of the batteries forward of the passenger compartment, acted to bias weight towards the front of the vehicle. This resulted in a front weighted bias for the vehicle even when it was ballasted to simulate two 50^{th} percentile adult males. What the effects of this design are on the overall stability of the vehicle is only speculation at this point, but it is quite possible that the GEM is more stable than the VIMF results would appear to indicate. Unfortunately, it was not possible to verify this speculation with the vehicle in its current configuration.

An additional factor for consideration is the upgrades being planned for this vehicle. The addition of two more batteries, and the possible modifications to the motor, transmission, and electronics, may significantly affect the C.G. height and the handling performance of this vehicle.

The general comments made by the test driver during test tests are subjective but informative. The overall impression is that the GEM's handling and braking characteristics are as stable or more stable than that of the Bombardier and noticeably better than that of the Yamaha golf cart.

6.0 YAMAHA GOLF CART

6.1 Visual Inspection

6.1.1 Vehicle Description and Configuration

The Bombardier and the GEM are both examples of the new potential class of vehicles currently being defined as NEVs or neighborhood electric vehicles. The development of these vehicles arose from the use of standard golf carts on public roads. While "golf carts" are limited to top speeds of 15 MPH, this is typically a pre-set or governed speed and does not represent the true top speed potential of the vehicle.

While a standard golf cart is not required to meet the proposed FMVSS 100 regulations, it appears to be relatively easy to modify the vehicles to increase their top speeds. At this point they may become subject to FMVSS 100. This appears to be a current potential option for individuals who wish to purchase a NEV type vehicle. Discussions during the background research phase of this project gave some indications that the major golf cart manufacturers do not approve of their products being operated at higher top speeds (20 mph or higher). The concern is that these vehicles were not designed to operate at these speeds and may be (or are) inherently unstable at these speeds.

In order to address this issue and to provide a base line of data to reference the performance of the two NEVs, a Yamaha G-16A golf cart was subjected to the same inspections and tests that were performed on the two NEVs evaluated in this study. It should be noted that this vehicle is a typical "golf cart" and no attempt was made to modify it for road use or to pass the FMVSS 100 regulations. The model available for lease, did not come equipped with a windshield or a top. For the purposes of this evaluation the lack of these features was not considered essential to provide a baseline comparison for the two NEV type vehicles. As a general observation, the addition of a lightweight "surrey" type top and a polycarbonate windshield would have the effect of raising the weight and CG of the vehicle. The handling and braking results reported in this evaluation will therefore tend to represent the vehicle in its best possible configuration.

The Yamaha cart obtained for this evaluation was a gasoline powered model. Figure 33 is a front end view while Figure 34 is a side view of the test vehicle. The gasoline powered versions of this vehicle are equipped with a 9.5 hp (7.1 kw) motor. Discussions with the dealer (that leased the vehicle to VRTC) indicated that both the electric and gasoline powered versions were equipped with motors of similar performance, and that the electric motor was rated at either 9.6 hp or 10 hp. The "dry weights" (i.e., without fuel or batteries) of the gasoline version of the vehicle is stated as 653 lbs., as compared to 560 lbs. for the electric version (weight as tested for the C.G. height was 688 lbs.).

Figure 33 - Front View of Yamaha Golf Cart

Figure 34 - Side View of Yamaha Golf Cart

The speed of the gasoline powered version was governed, to some extent, by a throttle linkage adjustment. The top speed of this vehicle could be increased somewhat simply by adjusting a nut on the throttle linkage. In practice this adjusted top speed was approximately 19 mph to 20 mph. An electric powered cart's top speed is potentially much higher but would require the replacement or modification of the axle to a high gearing ratio. This exceeded the scope of this evaluation.

6.1.2 FMVSS 100 Regulations

As stated in the previous section, the Yamaha golf cart was not configured for operation on the public highways. As a result, it did not meet any of the proposed FMVSS 100 safety requirements (See Table 2).

6.2 Technical Survey

6.2.1 Specifications Survey

Table 3 (from Section 4.2.1) includes the tabulation of the major vehicle dimensions and specifications of the Yamaha golf cart. Data was obtained from both published sources and from measurements made at VRTC and S.E.A. Inc. The more comprehensive listing, based on the evaluation list, is included in the appendix with the data from the two NEVs.

TABLE 3
Technical Specifications - Vehicle Dimensions

	BOMBARDIER (LAV)	GEM (LSV)	YAMAHA (Golf Cart)
Length	100 in	95 in	93 ¾ in
Width	55 in	43 in	46 in
Height	61 ¾ in	68 ¾ in	43 ½ in
Wheel Base	65 in	71 ½ in	65 ½ in
Curb Weight	1275 lb	928 lb	688 lbs
Height of Center Stop Lamp	58 ¾ in	49 ½ in	No Lamp

6.2.2 Seating and Safety Restraints

A frontal view of the seating arrangement of the Yamaha can be seen in Figure 34. The height of the seat pan of the vehicle was 23.75 inches. The vehicle was outfitted with a single bench seat which had no provisions for adjustment. The seat pad itself was approximately 5.5 to 6.0 inches thick, therefore the height to the top of the seat was about 29.5 inches. There were separate back rests for the driver and the passenger, which can be seen in Figure 33.

The steel tubular side rails on either end of the seats can be seen in Figure 34. These rails were the lateral restraint features that are the industry standard on golf carts. The rails extended from the seat back forward, with the driver side rail measuring 4.5 inches above the seat cushion and extended forward 7.0 inches from the seat back. The passenger side rail was 6.5 inches above the seat cushion and extended 15.0 inches forward of the seat back (approximately the full width of the bench seat).

There were no seat belts or additional safety restraint systems on this vehicle. Discussions with various manufacturers and vendors produced an essentially unanimous viewpoint on the subject of safety restrains on a golf cart. They are viewed as a potentially dangerous accessory and a definite legal/litigation liability for the low speeds and uneven terrain that is a golf cart's typical operating environment. The perception is that it is generally preferable to step from or be thrown from a golf cart that is starting to roll over than to be strapped to the vehicle. The sculpted or hilly terrain of many golf courses, along with the very tight turning radius of most golf carts, results in a fairly high propensity for tipping, which can occur at very low speeds.

The addition of a belted safety restraint system to this vehicle should be possible, but would probably require some modification to the vehicle. The body of this vehicle was a thin composite/fiberglass shell. The major components of the vehicle (motor, fuel tank, drive train, etc.) were attached to a substantial tubular frame that formed the underside of the vehicle. The bench portion of the seat, seen in Figure 35, was flexible and lightly built with very little structural integrity.

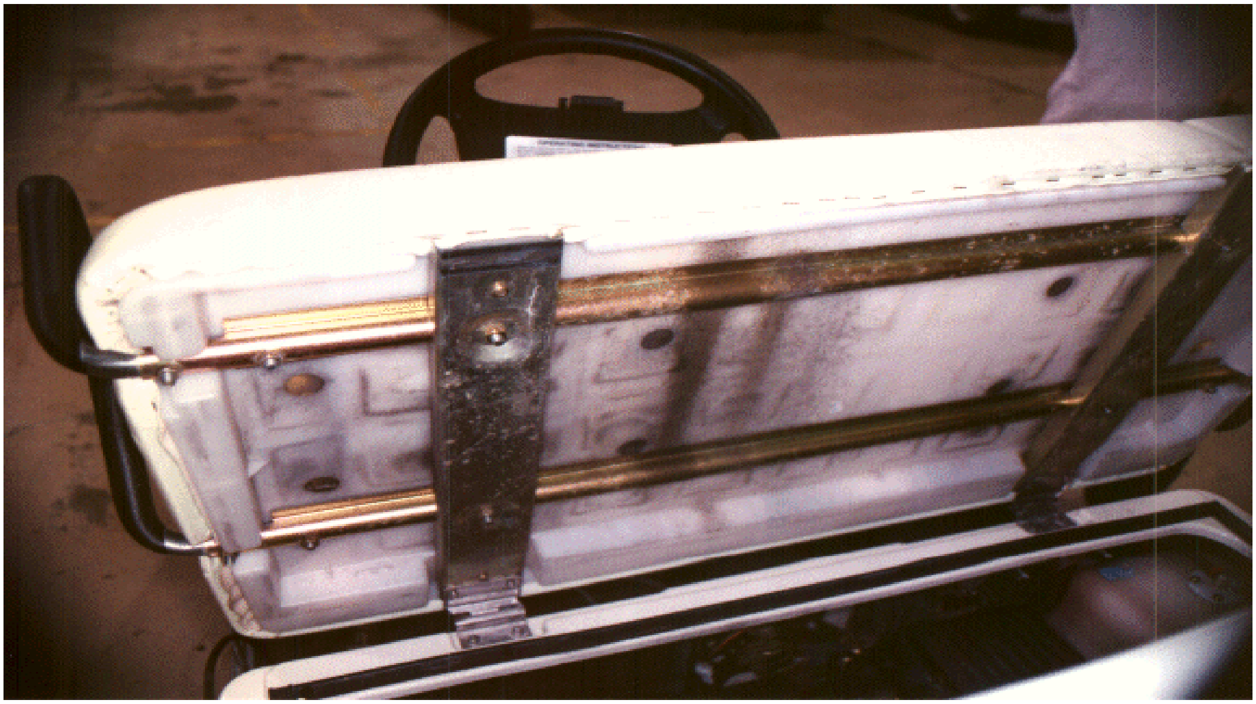

Figure 35 - Details of Bench Seat

There did not appear to be any satisfactory attachment points on the upper body of the vehicle. The substructure that comprised the seat appeared to be too insubstantial to provide a good anchorage point for a safety restraint system (See Figures 35 and 36) . It appeared that any restraint system would have to extend downward to the floorboard/base of the vehicle to be securely attached to a strong structural component of the vehicle.

6.2.3 Motor and Fuel System

The motor for this vehicle was a single cylinder, gasoline, OHV (overhead valve), 4-cycle (4-stroke), forced air cooled engine. The engine was rated at 9.5 HP @ 4000 rpm with a displacement of 301 cm^3 (3.07 inch bore / 2.48 inch stroke) and a TCI magneto ignition system. The fuel tank had a capacity rating of 6.5 gallons. The transmission was a V-belt automatic centrifugal engagement system.

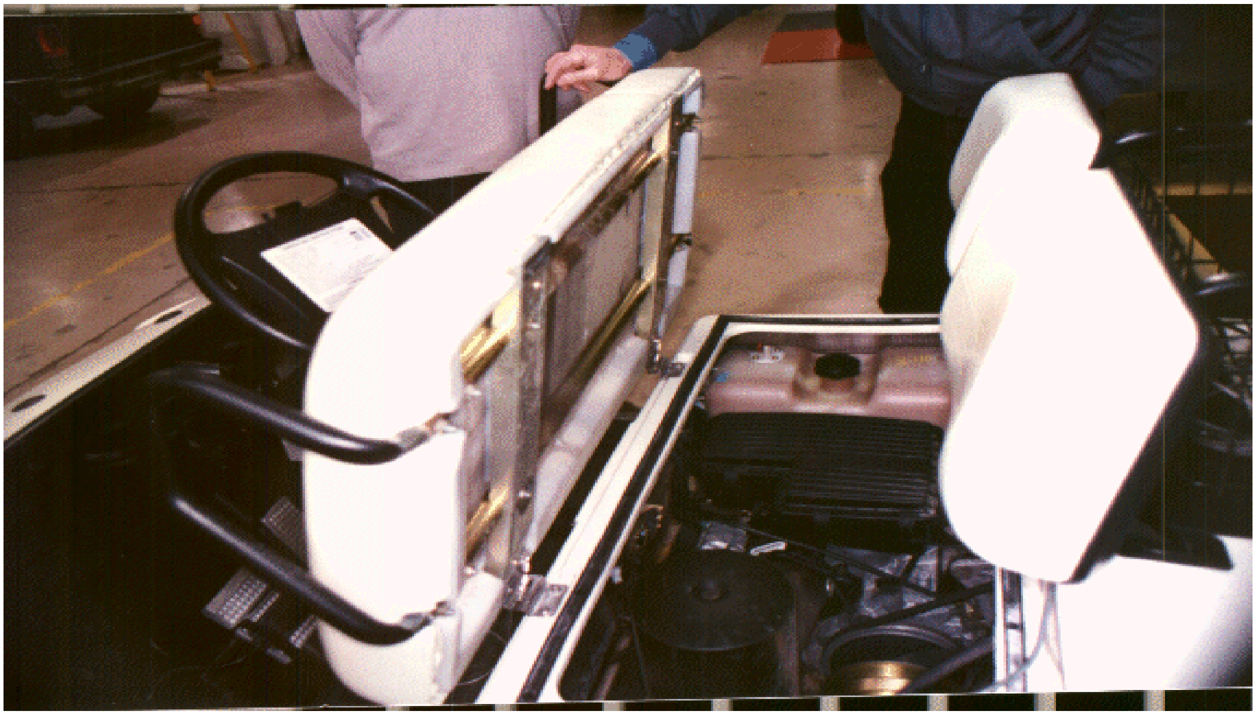

Figure 36 - Bench Seat and Engine Compartment

The battery, and motor for the system was located beneath the bench seat in the engine compartment of the vehicle. As can be seen in Figure 36, the front edge of the seat cushion was hinged to the body of the vehicle and the rear of the bench lifted up to access the engine compartment. Figure 37 is a photograph of the right side of the engine compartment showing the fuel tank, and the cover for the air filter (seen in the center). Figure 38 is a photograph of the left side of the engine compartment showing the sealed, maintenance free battery (on the left), the clutch, exhaust manifold and muffler (center) and the top of the engine and air filter cover (on the right).

As can be seen in the photographs, there did not seem to be any seals or significant barriers to prevent fuel or caustic fluids from leaking from the engine compartment into the vehicle occupant area in the event of a rollover. This did not appear to present a significant problem in the vehicle's current configuration, but this may not be true if the maximum speed of the vehicle were increased and/or if the vehicle were fitted with a safety restraint system that retained/restrained occupants in a rollover.

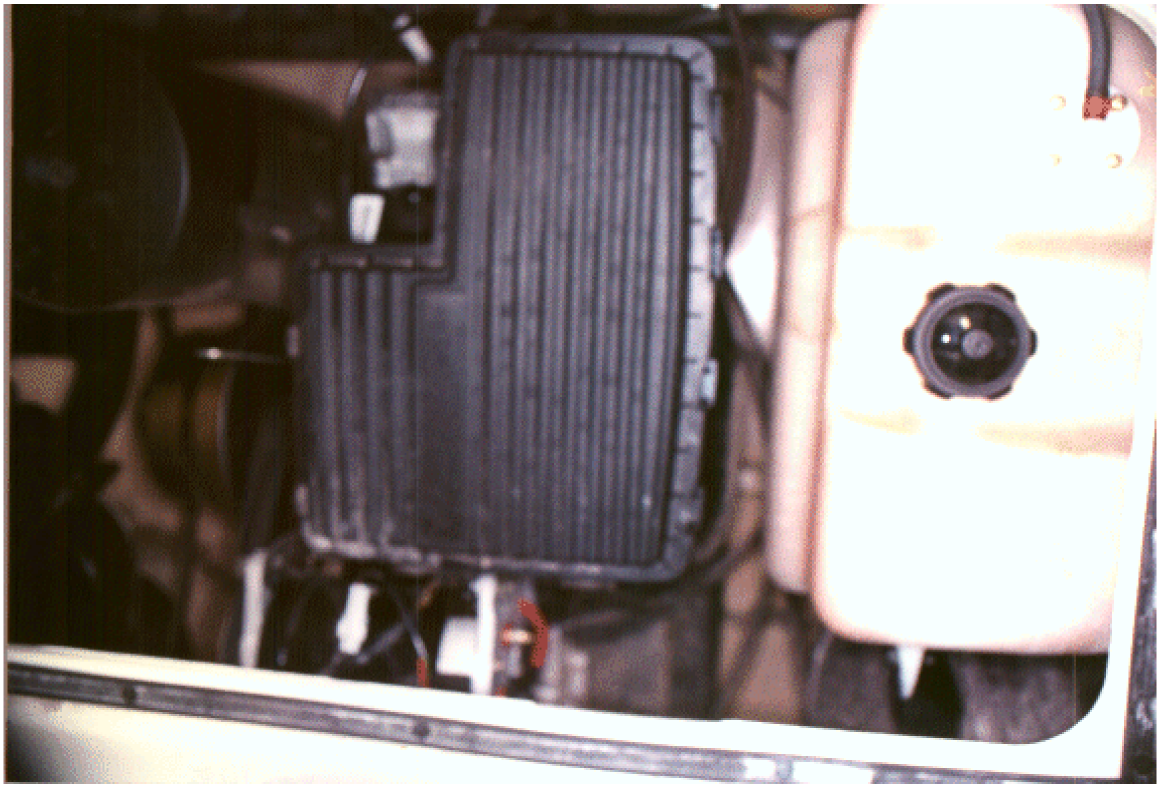

Figure 37 - Right Side of Engine Compartment

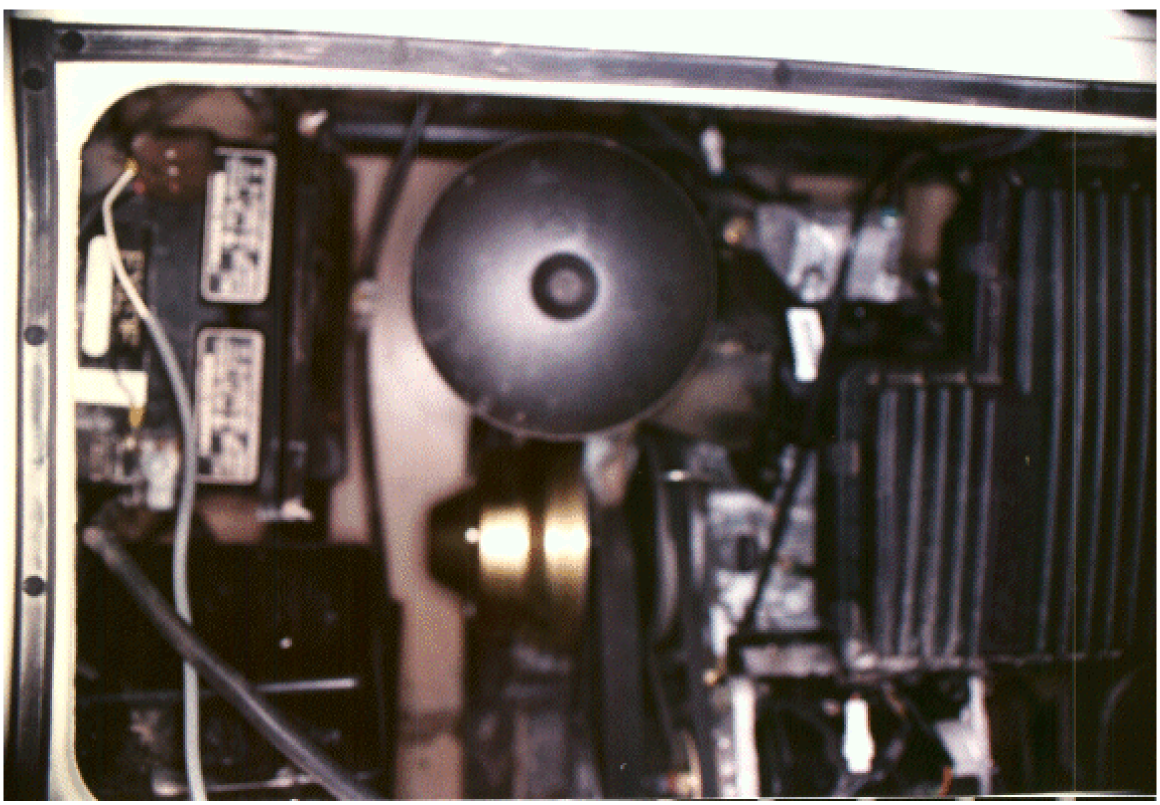

Figure 38 - Engine Compartment (Left Side)

6.2.4 Instrumentation and Control Features

The vehicle used a keyed system mounted on the dashboard to allow the starter for the motor to be engaged. Figure 39 is a photograph of the ignition lock switch with the ON and OFF positions and operating instructions illustrated. The only other instrumentation was a low oil pressure warning light located to the left of the switch. The starter was engaged by turning the ignition switch to the ON position and stepping on (depressing) the foot operated throttle control. This started the engine and, when a sufficient engine rpm was reached, engaged the clutch. When the throttle control was released, the motor automatically shut off and the clutch decoupled from the drive train.

Figure 39 - Keyed Ignition Control Panel With Oil Pressure Warning Light

The transmission selection lever, shown in Figure 40, was located against the front edge of the seat bench between the two occupants. There were two transmission positions marked FORWARD and REVERSE. Turning the lever to the REVERSE position activated a loud piercing audible beeping signal. The only other control feature was a cold start chock pull knob located next to the transmission selection lever.

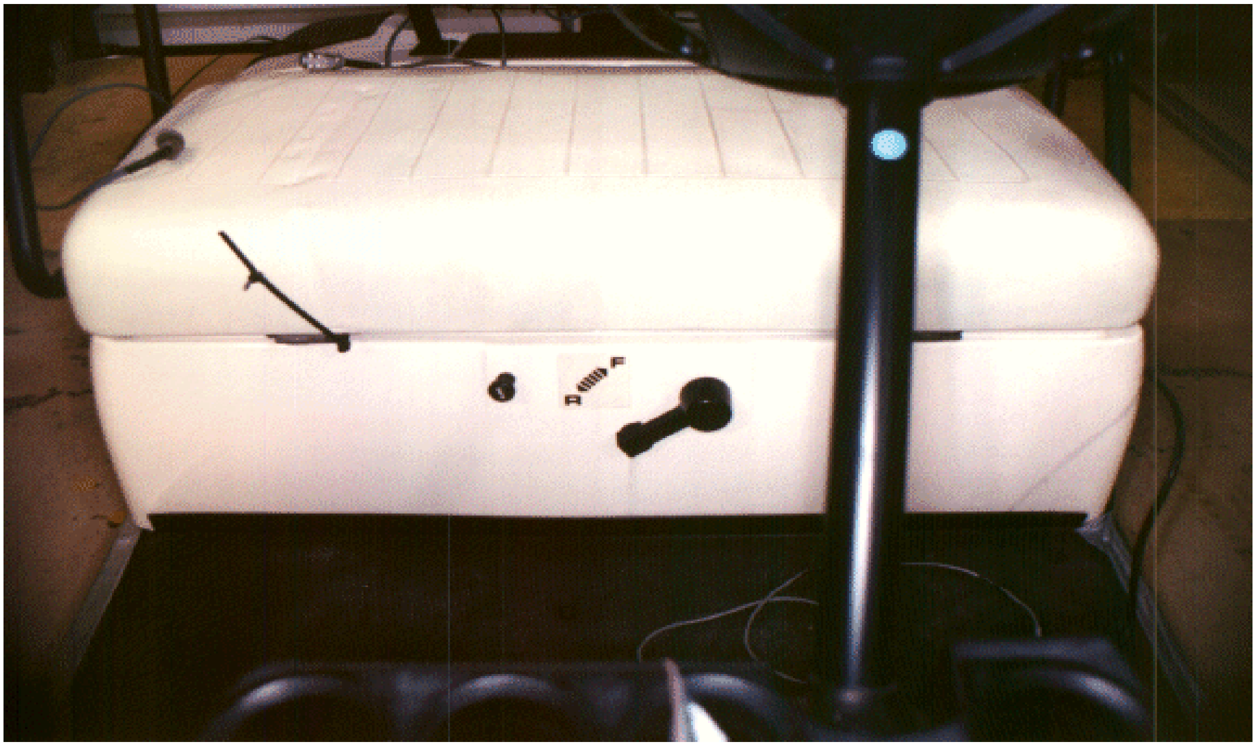

Figure 40 - Front of Bench Seat Showing Transmission Selection Lever and Choke

The steering system was a worm and pin system. The steering box (containing the gearing system) is shown in Figure 41, and like the other vehicles examined in this survey, there was no power assistance. There was no apparent damping system in the control linkages to the front wheels. The steering wheel was 14 inches in diameter and had a listed steering angle of 1.5 revolutions counterclockwise (left hand) and 1.5 turn clockwise (right hand). The measured angle was 3.1 revolutions (540 clockwise - 580 counter clockwise. from the center position) from stop to stop.

> **Note**: As with the other two vehicles, this measurement was made by turning the wheel to its hard stop then releasing the wheel to allow it to return to a rest position.

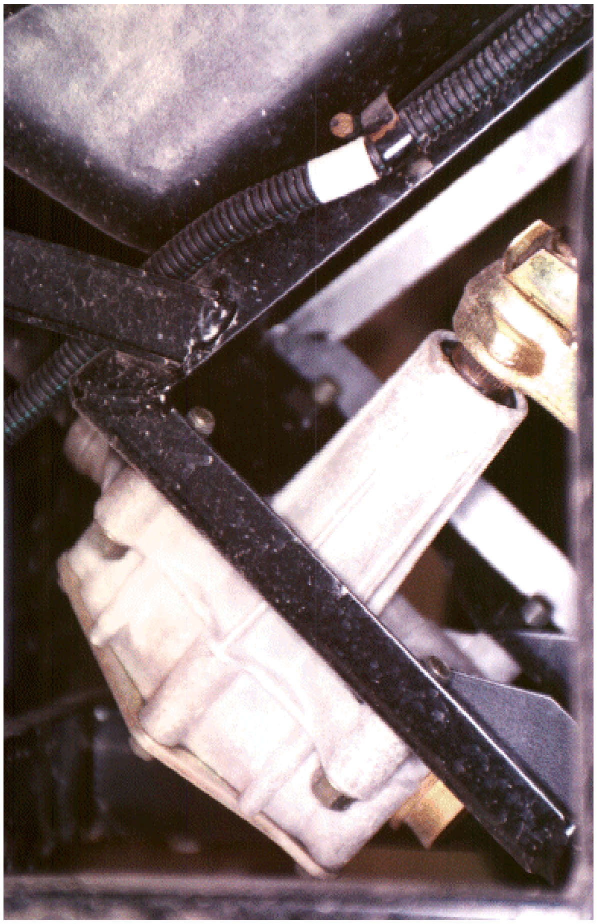

Figure 41 - Yamaha Steering Box

6.2.5 Suspension System

The chassis of this vehicle was a strong tubular framework with a series of lighter frame bars welded to the tubular framework. The front wheels of the Yamaha were equipped with single A-arm suspension elements with a shock within a coil spring design similar to those seen with the other two vehicles examined. There appeared to be no adjustment for the spring tension of this system. Figure 42 is a photograph of the steering and front suspension elements as seen from beneath the vehicle. The forward pivot point of the A-arms and the front bumper attached at essentially the same point on the tubular frame of the vehicle. Figure 43 is a side view of the same structure showing the plastic bumper on the right and the wheel hub and spring/shock system on the left.

Figure 44 shows the upper end of the shock absorber unit along with its anchor point. The flat bar stock seen in the photograph provided a framework to attach the upper anchor of the suspension system and was welded to the main tubular framework.

The rear wheels of the Yamaha were attached to a single solid axle. Each rear wheel was equipped with a shock within a coil suspension unit like the front wheels of the vehicle. The vehicle was also equipped with a Panhard or transfer bar. A bar of this type is typically to used reduce sway (side to side or lateral shifting motion) and to control the roll center (generally the height of the roll axis) of the vehicle. Figure 46 is a photograph of this structure.

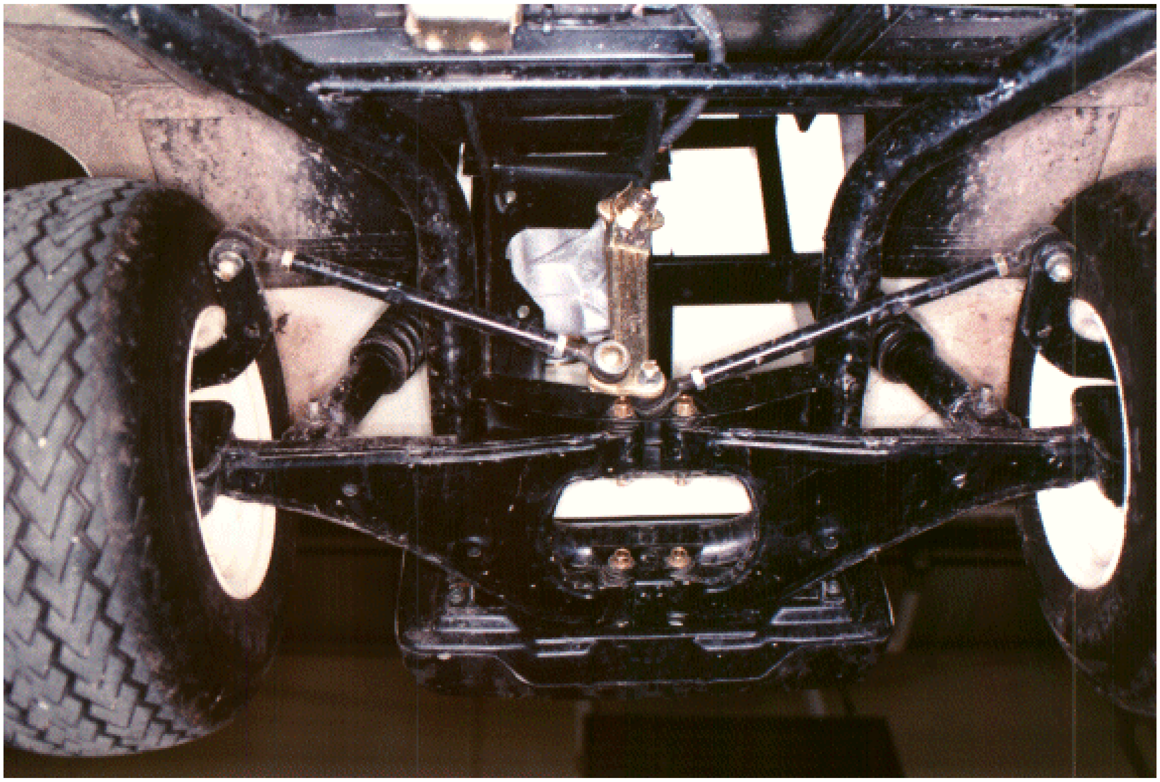

Figure 42 - Front Suspension and Steering Linkage (Seen From Below the Vehicle)

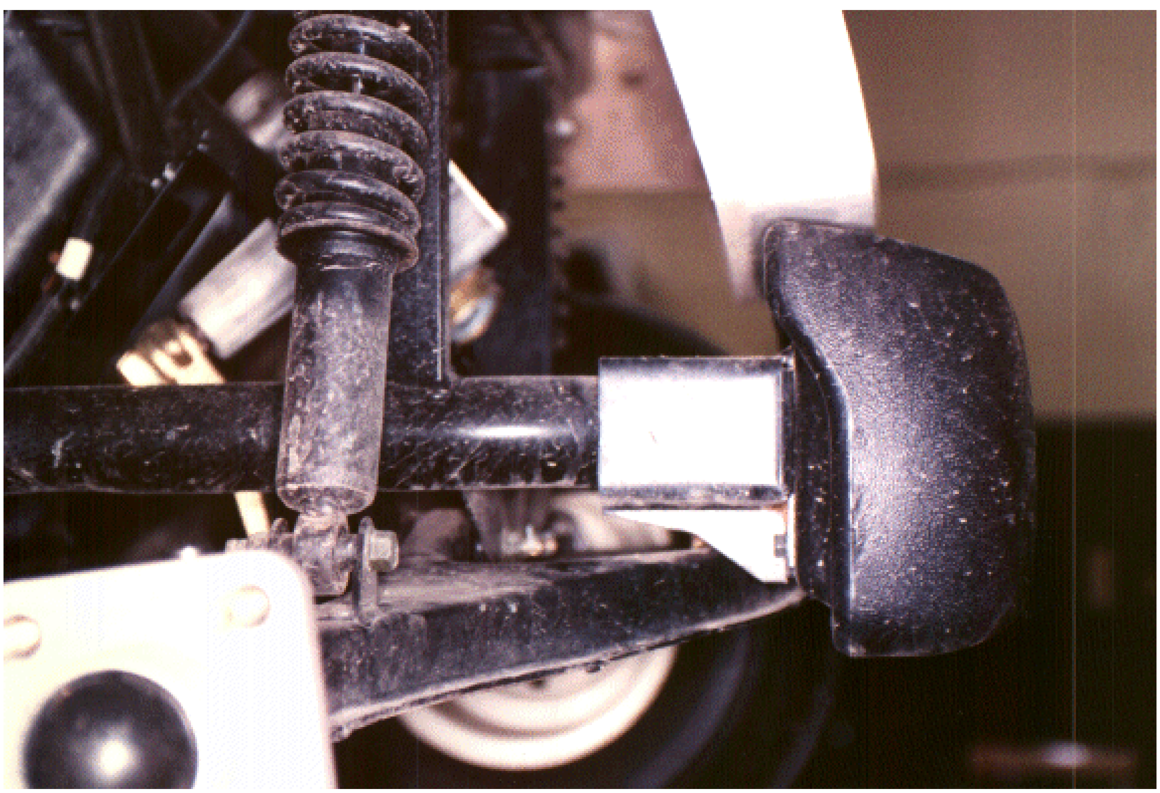

Figure 43 - Front Suspension and Steering Linkage (Side View - Showing Front Bumper)

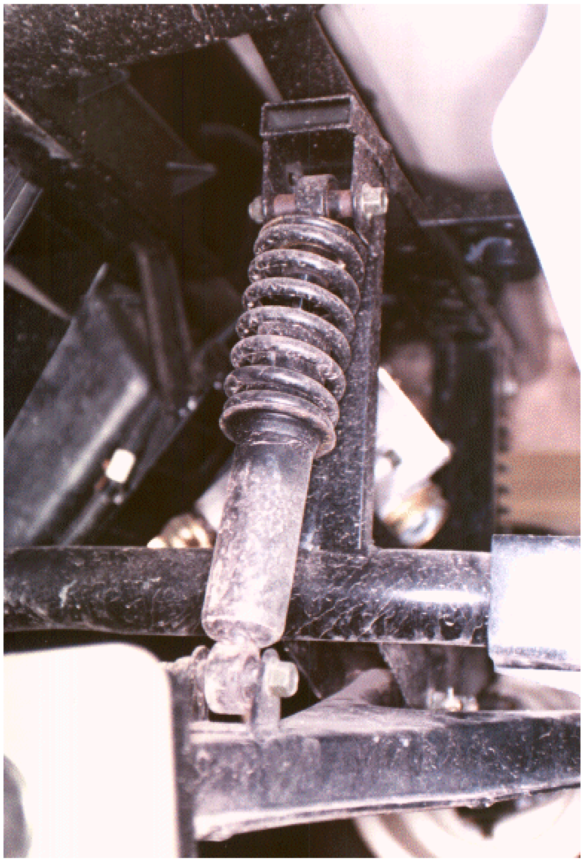

Figure 44 - Front Suspension Anchor Points

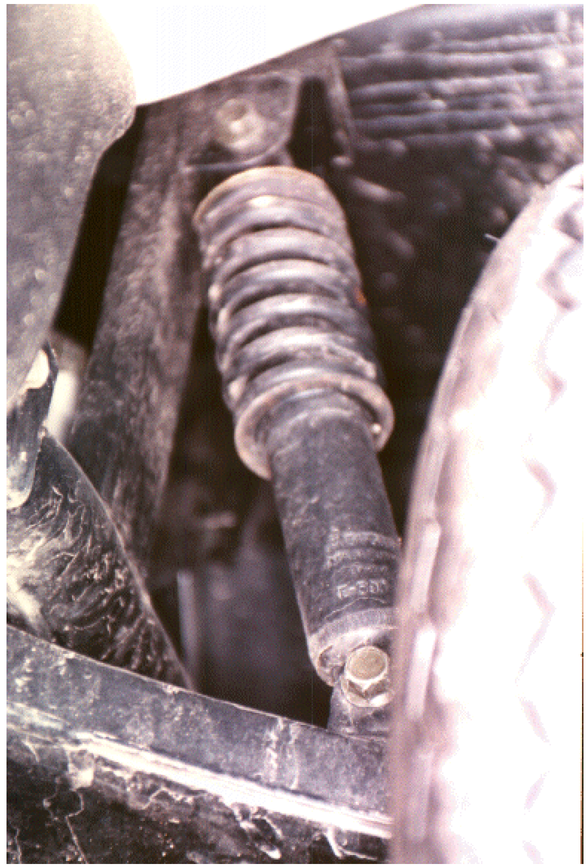

Figure 45 - Rear Suspension Anchor Points

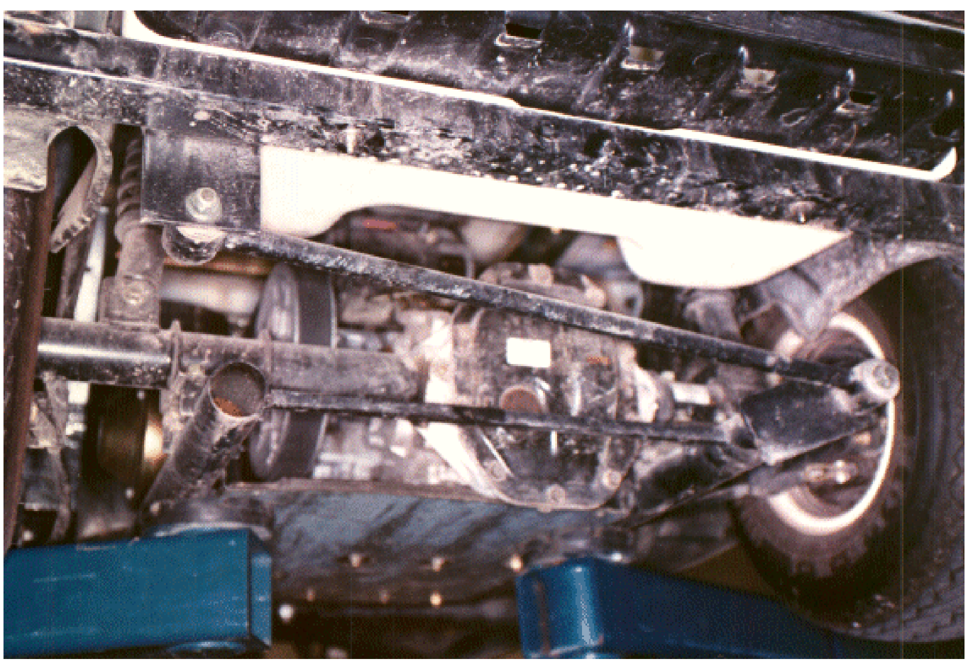

Figure 46 - Rear Suspension - Showing the Transfer Bar

The front wheels were mounted to the axles with a king pin arrangement (as compared to a ball joint type of design). Figure 47 is a photograph of the king pin on the front right wheel assembly.

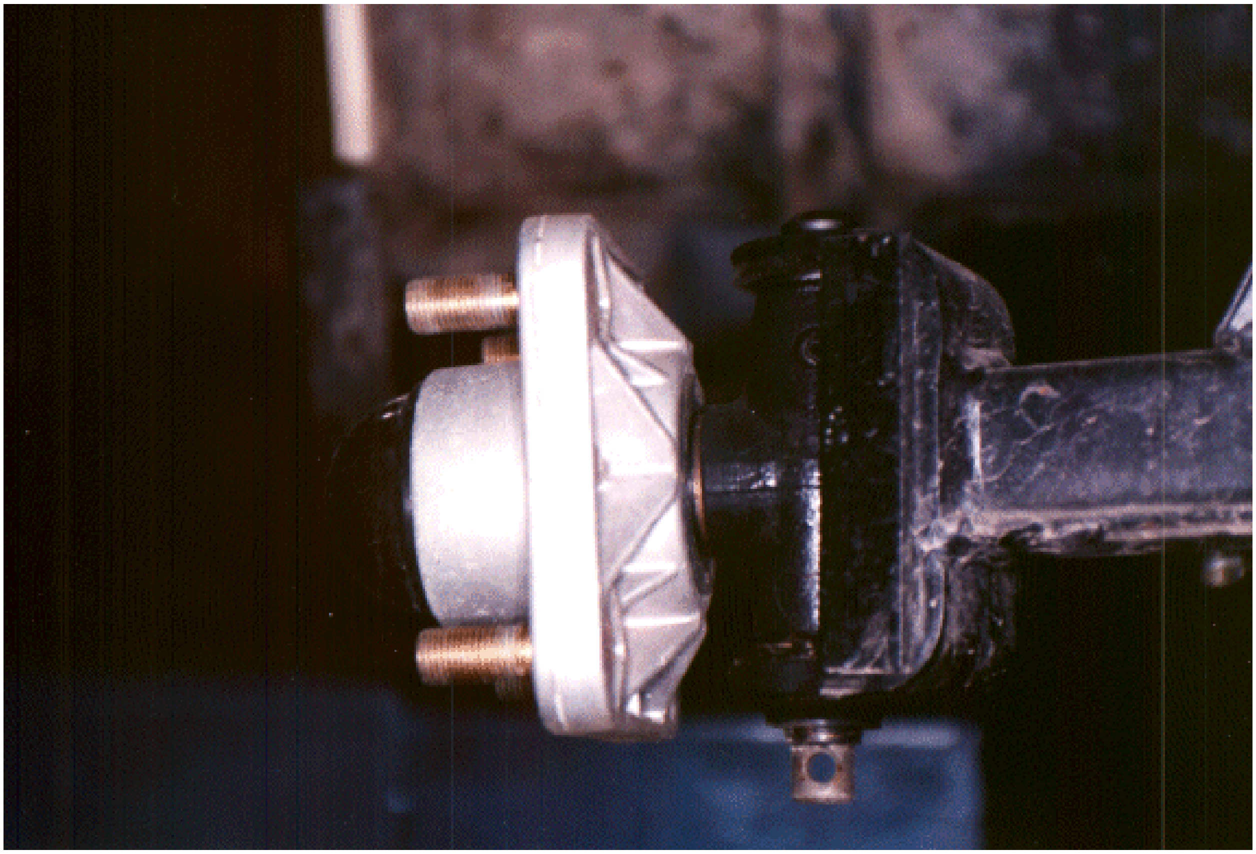

Figure 47 - Wheel Hub With King Pin

6.2.6 Brake System

The Yamaha used a mechanical cable system to operate a set of drum brakes mounted on each of the rear wheels. There was no power assistance for the system. The diameter of the drum was measured to be 6.34 inches. There was no visible adjustment mechanism to take up slack due to wear, however, the literature (owner's manual) stated that the system had self adjusters. The brakes were listed as dual internal expanding leading/trailing shoes (self-adjusting).

The parking brake was a foot actuated brake with an automatic release. Figure 48 is a photograph of the foot controls. The brake pedal, seen on the left, is instrumented with a foot switch for the dynamic tests. The pedal was comprised of two plates. The lower plate actuated the brake system while the upper (narrow plate) set the parking brake. This parking brake could be released by depressing the throttle control. Figure 49 is a photograph of the operating instructions for the braking system as well as a warning that the vehicle is not intended for use on public streets.

6.2.7 Wheels

The front and rear hubs (see Figure 47) were to be sealed units. No attempt was made to disassemble these hub units.

The tires on this vehicle were to be a standard type of low pressure “turf tire”. Tire size information on the tire (and listed in owner’s manual) indicated an 18 x 8.5 - 8 PR tire. Additional information listed on the tires inspected was:

KENDA
HOLE-N-ONE
Nylon Tubeless - 4 Ply Rating
Maximum Inflation 16 psi
K-389-06

The recommended tire pressure, as listed in the driver’s manual, for the gasoline model was 16 psi (versus 20 psi for the electric model). Figure 50 is a photograph of the tire and tread design.

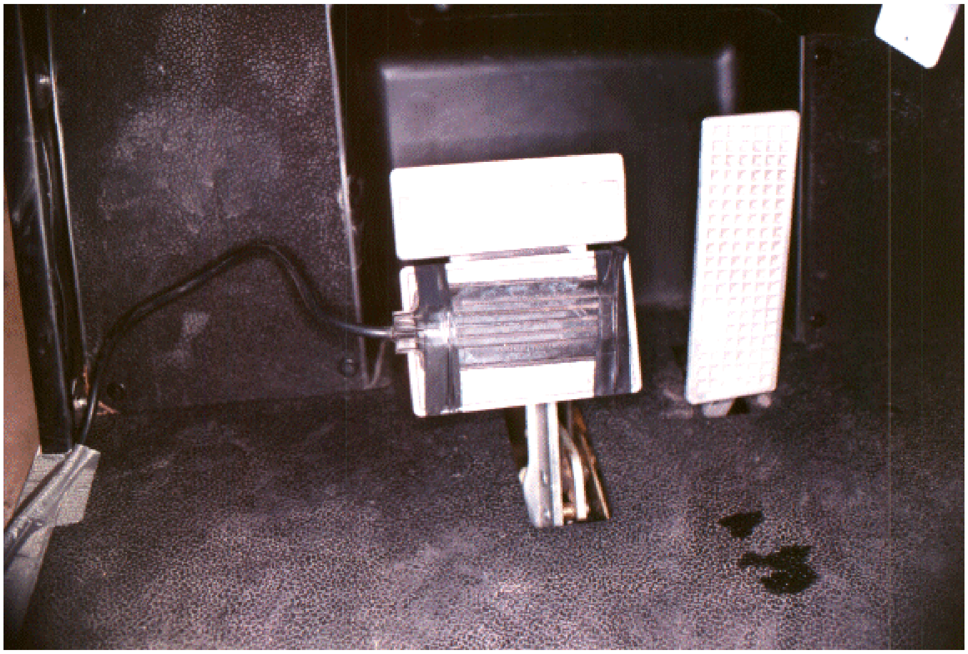

Figure 48 - Foot Controls - Parking Brake Pedal, Brake Pedal, and Accelerator Pedal

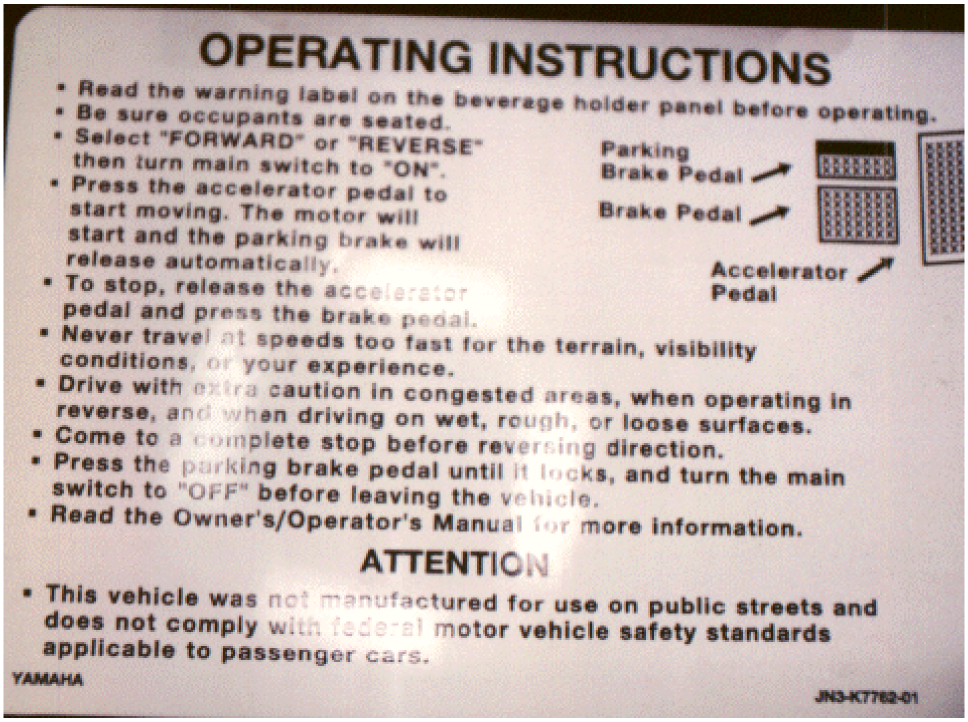

Figure 49 - Operating Instructions for Foot Controls

Figure 50 - Turf Tire With Tread Design and Brake Drum

6.3 Vehicle Dynamics/Handling Measurements

6.3.1 Height of Center of Gravity and Static Stability Factor

The C.G. height of the un-ballasted vehicle was 13.99 inches. Using the formulas presented in section 4.3.1, the calculated SSF value for the unloaded condition for the Yamaha was 1.30. This value compares favorably with passenger vehicles indicating that the "unloaded" vehicle had a low propensity to roll. (Passenger cars typically have SSF =1.2 - 1.4 and sport utility vehicles have SSF = 0.9 to 1.1.)

For the ballasted test, the cart was loaded using sandbag ballasts to increase the weight by 328, the equivalent of two 50th percentile human male adults. The C.G. height for the ballasted test was increased to 20.79 inches. The calculated SSF value for the loaded condition was 0.88. This compares unfavorably with a full sized motor vehicle possibly indicating a higher potential for rollover when the vehicle is loaded at or near its intended capacity.

This golf cart was a very light weight vehicle. The addition of 328 pounds increased the weight by nearly 50%. The addition of a given amount of weight to the vehicle affected the C.G. height to a proportionately greater degree than for the NEVs. The C.G. height was increased by 6.8 inches. As a result the SSF dropped from 1.30 to 0.88. These results suggest that this vehicle is not particularly stable in terms of its propensity to tip or roll when it is carrying a load. This observation tends to be confirmed by the results of the lateral stability test presented in Section 6.3.3.

6.3.2 Brake Testing

The rear bumper of the golf cart was removed and the vehicle was instrumented with a standard fifth-wheel. The Yamaha was subjected to the same series of straight line braking tests conducted with the NEVs, but the tests were run at two different speeds.

For the first series of tests the vehicle was operated in the condition as it was received from the dealer. The motor for the cart was governed and had a top speed of 15 mph. Upon completion of all of the braking and handling tests, the governor was adjusted to increase the maximum speed. While there appeared to be a second governor on the transmission that could be adjusted at the factory, a simple throttle adjustment was also possible. Using this adjustment, it was possible to increase the speed of the vehicle to just under 20 mph (19.8 mph recorded max.). The series of braking and handling tests were repeated with this new maximum speed. The 20 mph speed adjustment allows a better comparison of both the braking and handling performance of this vehicle with that of the Bombardier and GEM. The results of these tests are presented in Table 6.

TABLE 6
Straight Line Brake Tests - Yamaha

TEST #	Configuration	Comments	Speed (mph)	Stop Distance (ft)	Corrected Stop Distance 15/20 (ft)
1	Dry Asphalt	Lockup	13.8	15.8	18.7/33.2
2	Dry Asphalt	Lockup	12.5	11.9	17.4/30.5
3	Dry Asphalt	Lockup	13.6	15.9	19.3/34.4
4	Dry Asphalt	Lockup	15.0	17.7	17.7/31.5
5	Dry Asphalt	Best Effort	14.5	19.4	20.8/36.9
6	Dry Asphalt	Best Effort	14.7	20.7	21.6/38.3
7	Dry Asphalt	Best Effort	14.9	21.3	21.6/38.4
8	Dry Asphalt	Lockup	19.5	33.1	34.8
9	Dry Asphalt	Lockup	19.5	37.9	39.9
10	Dry Asphalt	Lockup	19.4	33.9	36.0
11	Dry Asphalt	Best Effort	18.8	28.4	32.1
12	Dry Asphalt	Best Effort	19.4	28.6	30.4
13	Dry Asphalt	Best Effort	19.4	29.6	31.5
14	Dry Asphalt	Best Effort	19.3	29.8	32.0
15	Jennite	Best Effort	14.8	Out of Line (Left)	
16	Jennite	Best Effort	14.5	Out of Line (Right)	
17	Jennite	Lockup	14.7	Out of Line (Left)	
18	Jennite	Lockup	14.7	Out of Line (Left)	
19	Jennite	Best Effort	19.1	Out of Line (Left)	
20	Jennite	Best Effort	19.4	Out of Line (Left)	
21	Jennite	Best Effort	19.3	Out of Line (Left)	

There was some slight observable nose dive but there was no observed tendency for the vehicle to plow or swerve out of line for the hi-co brake tests. The 15 mph braking tests on the hi-co brake surface gave an average corrected stopping distance of 18.3 feet in a “panic” or brake lockup condition. A best effort (without lockup) gave and average corrected stopping distance of 21.3 feet. The 20 mph braking tests on the same surface gave and an average corrected stopping distance of 36.9 feet for lockup and 31.5 feet for best effort braking.

The FMVSS 135 standard for passenger car brake systems specifies a cold effectiveness stopping distance of about 31 feet for a 20 mph test. The results of the Yamaha test indicate that the brake performance for this vehicle would be unsatisfactory or, at best, very marginal if the vehicle were to be considered for highway use.

The test driver for these braking tests noted that the brake system had a definite tendency to lock up the wheels in hard braking maneuver. As a result, it was difficult to execute a best effort brake maneuver without at least some wheel lockup. This apparent lack of sensitivity or control became apparent only under the more extreme braking conditions. Under normal braking conditions the brakes performed smoothly with no apparent tendency to grab or be aggressive. It is speculated that this behavior was probably due to the mechanical (cable linkage) nature of the brake system.

The brake lockup tests and best effort braking maneuvers on the Jennite surface resulted in some degree of spin in all of the tests conducted. This degree of instability was small and did not present any control problems for the driver at the speeds the vehicle was capable of obtaining. For these tests, lockup of the rear wheels was maintained while the driver used moderate steering efforts to maintain vehicle control (i.e., to steer out of the spin). Figures 51 and 52 are frames obtained from the video documentation of the Jennite surface brake tests. The first frame is at the beginning of the braking sequence while the second frame shows the vehicle at a stop at the end of the brake test. As can be seen in these images, the degree of spin was very small. Again, the comments of the driver for these tests indicated that while some out of line movement did occur, the vehicle always felt stable and controllable.

Figure 51 - Jennite Brake Test - Initiation of Brake Test

Figure 52 - Jennite Brake Test - Final Rest Position (Showing the Degree of “Spin”)

6.3.3 Lateral and Turning Stability

The vehicle was driven at its maximum (as received) speed thought a constant fifty foot radius turn. The maximum speed recorded for this test was 14.7 mph. Using the relationships shown in section 4.3.3, the lateral acceleration for a 50 foot turn at 14.7 mph was 9.3 ft/sec^2 or 0.29 g. At this speed the vehicle exhibited stable handling characteristics.

A second test was conducted with the throttle governor set to allow a higher maximum speed. The maximum speed recorded for this second test was 19.8 mph. The lateral acceleration for a vehicle moving in a 50 foot radius turn at this speed was 16.9 ft/sec^2 or 0.52 g.

The driver showed a tendency to lean his weight into the turn for both the right turn (clock wise) and left turn (counter clock wise) maneuvers. When the drive sat upright and continued the testing at this higher speed the vehicle exhibited noticeable roll in the turns. During the right turn maneuver, the inboard front wheel was observed to come off of the ground by approximately 1 to 2 inches. The test driver noted that the rear wheel periodically came off of the ground as well, but each time ground contact was lost, the vehicle slowed until contact was re-established.

The results of the VIM tests suggest that the Yamaha golf cart may have a propensity toward rollover. The results of the lateral stability tests appear to confirm this conclusion. However, it should be noted that this vehicle exhibited no tendency towards excessive lean or rollover at its intended operating speed of less than 15 mph. Instability was observed only when the governor was defeated and the maximum speed of the vehicle was increased to nearly 20 mph.

One significant conclusion that might be drawn from this test is the potential problems that might exist for standard golf carts which have undergone aftermarket modifications to increase their top end speed. It appears that with a relatively simple change in the gear ratio of the rear differential, the top end speed of an electric golf cart could be boosted to over 35 mph. While this clearly is unacceptable, even a more modest speed increase to 20 or 25 mph may present potential safety problems for this class of vehicle.

6.3.4 Vehicle Speed

Top vehicle speed measurements were not conducted on the Yamaha golf cart. The owner's manual supplied with the vehicle, listed a top speed of 12 mph for the gasoline powered model. The vehicle's top speed as received from the dealer and tested at the VRTC during the braking tests was between 14 mph and 15 mph. Even with adjustments to the throttle governor, the top speed achieved in the handling and braking tests was slightly less than 20 mph. Further verification of the top speed of this vehicle was not performed.

6.4 General Observations and Notes

The Yamaha golf cart evaluated at the VRTC did not have a windshield or a roof structure. For a golf cart, these are typically very light and insubstantial structures. While their presence would have some effect on the measured C.G. height, this effect should be small. Such a roof would offer the occupant very little protection in the event of a rollover incident.

The engine, battery and fuel tank were located directly beneath the seat of the vehicle's occupants. In a battery powered model of the same type of golf cart, the batteries would be located in the same general area. As shown earlier in the report, the construction of the engine compartment was open in design. There was little to protect the occupants of this vehicle from any potential spill of fuel or battery acid in the engine compartment.

The front bumper of this vehicle was a substantial block of formed plastic, approximately six inches thick, attached directly to the heavy tubular framework of the cart. As can be seen in Figure 33, the bumper did not extend across the entire front of the vehicle to protect the tires or fenders.

The rear bumper was much lighter in construction, but did extend across the entire width of the vehicle. It was attached to the framework that supports the rear drive components of the cart.

On a subjective basis, the Yamaha's performance was largely what is expected of a golf cart. The vehicle was lively and maneuverable at low speeds but did not have the highly aggressive low speed accelerations noted in both of the NEVs. At 15 mph, the top rated speed, the vehicle exhibited stable performance characteristics. On a smooth level surface, such at a roadway or open test surface, the governor (transmission) could be felt as it limited the top speed of the vehicle. This condition, as well as the relative stability of the vehicle (at this speed), tended to create a subjective impression that the vehicle was being held back and was excessively slow. This observation was in contrast to the perceived performance of both of the NEVs.

7.0 GOLF BALL / WINDSHIELD IMPACTS

One point frequently raised by the cart manufacturers on the proposed FMVSS 100 was the requirement of AS 1 type glazing for the windshields. This proposal may be expanded to include AS 6 type glazing (a flexible plastic allowed in motor cycle and ATV recreational vehicles). A number of the golf cart and golf car manufactures are proposing the use of a polycarbonate, such as Lexan®, as the glazing material of choice.

Polycarbonates are currently used by many cart manufacturers and after-market companies which customize golf carts. This material is a hard clear plastic material which is very resistive to penetration. This potential glazing has both advantages and disadvantages over the traditional glass glazing. Polycarbonates do not have the tendency to shatter under sufficient impact like most glasses. At the same time, they do not have the excellent abrasion resistance of glass. It is this poor resistance to abrasion which typically makes polycarbonate unsuitable for some automotive glazing applications.

7.1 Test Setup and Equipment

A short series of tests were conducted at VRTC to evaluate the impact characteristics of AS-1 glazing with the projectile type impact of a golf ball. A compressed-air cannon was fabricated to accelerate a golf ball under controlled conditions. The velocity (both speed and direction) was regulated and measured to a sufficient degree of accuracy for the purposes required for this evaluation. The cannon was designed with sufficient compliance to allow adjustment so the velocity vector of the ball was normal to the plane of the glazing at the point of impact. The propellant for this unit was welding grade compressed nitrogen gas.

Each test was recorded using two separate imaging units. A high speed video camera was used on the impact side of the glazing to record the speed of the ball before impact. The video unit, which records at 500 frames per second, was used with an inch tape background to allow the speed of the ball to be determined for speeds up to about 200 mph. The second imaging unit was a high speed digital camera used to record the impact event from the occupant side of the glazing. This imaging unit has a recording rate of 1000 frames per second with notably higher resolution and image clarity than is generally achievable with the high speed video unit.

7.2 Impact Velocities

Based on data presented in reference 1, a driver club head speed of 132 mph (a speed achievable by a touring pro) results in a ball speed off of the club face of about 177 mph. This datum provides an upper speed boundary limit. An average male golfer typically generates a head-speed nearer 100 mph with a resulting lower ball speed. This speed will drop even further as the limiting effects of air drag come into play. No source could be located that cited either the terminal speed of golf ball in flight or the range of potential speeds a struck golf ball would have at the end of its flight.

The tests speeds were increased incrementally until the first definite evidence of glass spalling from the inner surface was noted (test #4 @ 59 mph). The impact speed was then increased to 120 - 125 mph. This speed was selected as the maximum probable impact speed that might be typically encountered on a golf course. The results of these tests are present in Table 7.

TABLE 7
Golf Ball Impact Results

TEST #	Speed (MPH)	Comments
1	18	No visible damage to the glazing
2	40	No visible damage to the glazing at point of impact but there was a ring of cracks circling the point of impact approximately four inches in diameter
3	47	No visible damage at point of impact but there was a complete ring of cracks circling the point of impact approximately four inches in diameter
4	59	Cracked glass at point of impact. Several small pieces of glass spalled from inner side of glass - apparently dropping to the dashboard (i.e., indicating low speed of ejection material). Multiple concentric rings about the center of impact.
6	125	Glass completely shattered in a 3 inch diameter circle. Much of the glass pulverized. Inner side also completely shattered/pulverized with a large amount of spalled glass fragments spalled into passenger compartment. A general network or webbing of cracks covering approximately **a** to ½ of the windshield.

7.3 Test Results

Figures 53, 54, and 55 are a series of images captured from the high speed digital camera recording of the 125 mph test. Figure 53 is an image of the golf ball in flight just before impact into the windshield of a 1985 Toyota Corolla. Figure 54 is 10 milliseconds later, showing the shower

Figure 53 - Golf Ball Just Prior to Impact Into Windshield (**Time = 0 ms)**

Figure 54 - Golf Ball at Post Impact With Glass Spray **(Time = 10 ms)**


Figure 55- Post Impact - Expanding Spray and Particle Size Distribution **(Time = 20 ms)**

of ejected glass particles spraying from the back surface of the windshield into the passenger compartment. Figure 55 is an additional 10 milliseconds into the impact showing the expanding spray of glass particles which ranged in size from 2-3 mm down to a pulverized dust like size. The gold ball did not penetrate the glazing.

A second series of impact tests were conducted in which a golf ball was directed into a sheet of polycarbonate plastic. This plastic, manufactured by Sheffield Plastics under the brand name HYZOD was 0.210 inches thick. Tests were started at approximately 40 mph and increased to a measured speed of approximately 225 mph. While a slight indentation (less than 1/8 inch) of the plastic at the point of impact was observed, failure (i.e., penetration, cracking/shattering, or clouding) of the plastic did not occur in any of the tests.

Finally, a motorcycle windshield was purchased for testing. The windshield was marked with the registered trade name LUCITE and had the following information listed on the plastic:

M-3
AS-6
DOT 80

This windshield, which was an acrylic plastic, had a measured thickness of 0.1808 inches. The impact test was run at approximately 120-125 mph. The results of these tests are documented in Figures 56 and 57.

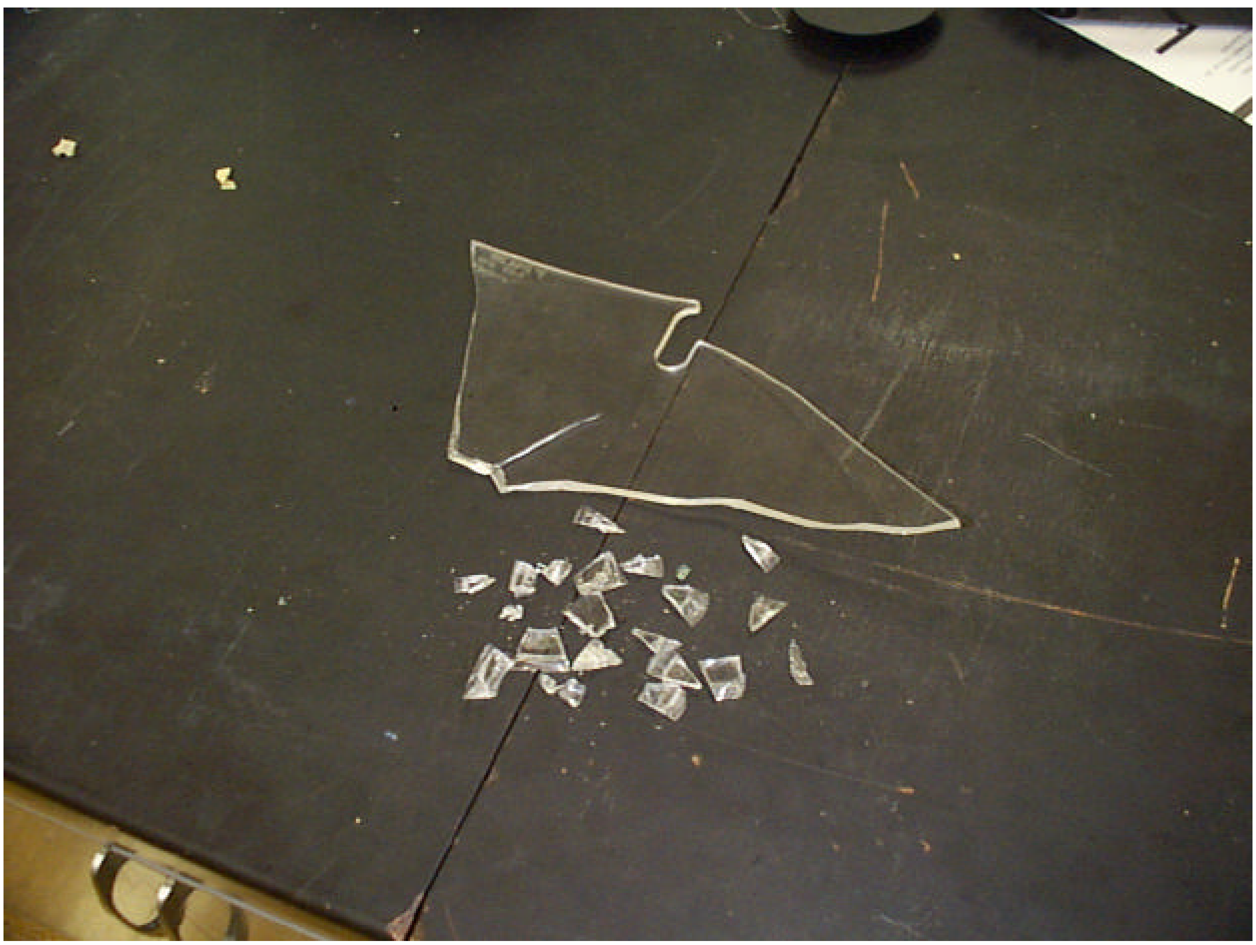

Figure 56- Fragments From Motorcycle Windshield Test


Figure 57 - Motorcycle Windshield Post-Test Showing Point of Impact and Fracture of Windshield.

The windshield split into four major segments and shattered into a number of fairly large fragments at the point of impact, allowing the golf ball to penetrate. Figure 56 is a photograph of the fragments collected. The smaller fragments ranged in size from about ½ inch down to **c** inch or less in width. Figure 57 shows a post test photograph of the windshield with the gas cannon still in position. The edges of the windshield and windshield fragments were irregular (jagged) and formed relatively sharp cutting edges, although not as sharp as typically seen with glass.

The results of these tests show that AS-1 type glazing is capable of effectively stopping a golf ball from penetration at the fastest speed an average male golfer is likely to hit the ball off of a tee. However, as shown in the previous series of images, there is a second factor that should be considered. When a projectile, such as a golf ball, strikes a glass windshield, the local concentration of forces spalls glass fragments off of the reverse side of the automotive glazing into the passenger compartment of the vehicle.

While this situation does not present a life threatening situation, there is a definite possibility of showering the occupant with glass fragments and the resulting threat to the eyes. There is also a general maintenance cost of periodically replacing such glazing. The vehicles represented in this study may be expected to spend a significant portion of their operational lives in a golf course environment, where the possibility of such an impact is much higher than for the general population of automotive vehicles.

The test conducted on the motorcycle windshield illustrates the brittle nature and poor penetration resistance of an acrylic plastic. The projectile impact of the golf ball produced a number of long sharp edges (the four edges of the main windshield segments) and a number of smaller fragments which present some of the potential problems mentioned with the spalled glass of the AS-1 tests.

The polycarbonate plastic had superior impact characteristics in these tests. The material resisted penetration, even when tested at higher impact speeds, and showed no tendency to spall fragments off of its inner surface in the manner seen with the AS-1 glazing.

Since polycarbonate plastics meet and/or exceeds all the requirement of an AS-6 glazing, its use by NEV or golf cart manufacturers would be allowed, if not actually required, under the current proposal. However, if AS-6 requirements are permitted in the proposal, then the use of acrylic plastics would also be permitted. Its poor impact characteristics make it potentially unsuitable for golf course use while its poor resistance to abrasion has typically made it unsuitable for automotive glazing use.

Possible alternatives to the AS-6 glazing specifications may be the AS-4 specifications which match all of the AS-6 requirements, but have an additional abrasion test requirement that effectively eliminates acrylic plastics. The AS-5 specifications are similar to AS-4 requirements with the abrasion requirements, but add a dart drop impact test requirement. Either of these glazing specifications may be more suitable if the goal is to allow manufactures an alternative to AS-1 requirements, but still insure a glazing suitable for forward facing applications on public highways.

8.0 SUMMARY

8.1 Requirements of NPRM

One of the goals of this examination was to determine if potential LSVs would meet the requirements of the proposed regulation. It was noted in Table 2 of the report that two vehicles which were manufactured for golf and highway use meet nearly all of the proposed requirements. Those criteria that were not met in this examination would be relatively easy to upgrade (reflectors, warning labels, VIN). It was noted that a vehicle which was manufactured for golf course use would require substantial modification to meet the requirements of the proposed regulation.

8.2 General Assessment of LSV Safety

The proposed regulation would not require the level of safety for LSVs that is required for other passenger vehicles. In addition to those aspects of the proposed regulation, judgements were made regarding the general level of safety of the vehicles examined.

Belts - The only crashworthiness requirement of the proposed regulation was that LSVs have Type 1/Type 2 seat belts. Both of the vehicles manufactured for highway use had acceptable seat belt systems. The belt hardware was anchored to a solid structure. It was not determined whether the belts would actually restrain an adult occupant in a severe collision (this would require destructive testing of the vehicles) but the belts are probably fine for minor, and perhaps moderate crashes. The golf cart inspected did not contain belts, nor would it have the structure to attach lap/shoulder belt hardware without substantial modification.

Stability - The proposed regulation does not address vehicle stability or brake performance. The level of stability was assessed by measuring the static stability factors (SSF) of these vehicles and comparing the values with those of the passenger car and light truck fleet. It was noted that SSFs (T/2H) for passenger cars typically range from 1.2 - 1.4, and light trucks 0.9 - 1.1. The two LSV type vehicles had SSF's of 1.0 and 1.4 empty which lowered to .86 and 1.2 with occupants. The golf cart had similar SSF's empty and loaded of 1.3 and .88. Stability could be an issue with golf carts due to the turning radius.

Brakes - The proposed regulation does not address stopping distance. The three vehicles were subjected to straight line stopping distance tests at 20 mph (or for two vehicles, scaled up to 20 mph). Both of the LSVs manufactured for golf and road use met the requirements of FMVSS 135, while the golf cart tested did not.

Electrolyte Spillage - The proposed regulation does not address containment of electrolyte for battery powered vehicles. A general assessment was made based on the design features of the two LSVs. The golf cart examined was gasoline powered. Of the two LSVs, one appeared to have the batteries shielded from the occupant so long as the fiberglass shell was intact. The other did not have the batteries shielded from the occupant area. In a crash or rollover event, battery electrolyte spillage could be a serious problem.

Glazing - The proposed regulation requires AS-1 or AS-6 type glazing. It was noted in the glazing testing, that golf ball impacts into AS-1 glazings caused spraying of glass particles. It was also noted that an acrylic plastic windshield meeting AS-6 was shattered by the golf ball impact. Polycarbonate materials, which also meet AS-6, were not shattered. As long as the regulation allows polycarbonate materials, as seems to be the case, manufacturers can provide windshields appropriate for road and golf uses. Specifying AS-4 or AS-5 type glazings would pressure manufactures toward polycarbonate materials.

9.0 REFERENCES

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3. Bombardier Motor Corporation of America Inc. Sales Brochure.

APPENDIX