

---

# **Evaluation of a Proposed ATV Design Modification**

**R. L. Piziali, G. F. Fowler, R. Merala, D. S. Grewal, and R. L. McCarthy**  
Failure Analysis Assocs., Inc.

The appearance of the ISSN code at the bottom of this page indicates SAE's consent that copies of the paper may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay a \$5.00 per article copy fee through the Copyright Clearance Center, Inc. Operations Center, 222 Rosewood Drive, Danvers, MA 01923 for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.



**GLOBAL MOBILITY DATABASE**

*All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database.*

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

**ISSN 0148-7191**

**Copyright 1994 Society of Automotive Engineers, Inc.**

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE transactions. For permission to publish this paper in full or in part, contact the SAE Publications Group.

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Activity Board, SAE.

**Printed in USA**

90-1203C/PG

# Evaluation of a Proposed ATV Design Modification

R. L. Piziali, G. F. Fowler, R. Merala, D. S. Grewal, and R. L. McCarthy  
Failure Analysis Assocs., Inc.

## ABSTRACT

Successful development of a product requires the consideration and balancing of many design parameters. Proposals to modify designs that have been fully implemented and put into production are often made by people who were not involved in the original design process. Such proposals, commonly focusing on a specific aspect of the product, must be evaluated in the context of the overall product and its intended use by consumers; a design change may improve performance in one area but compromise performance in another, or even introduce new problem areas.

As a case in point, several proposals have been made for operator protection systems with the claim that they would reduce the frequency and severity of injuries associated with All Terrain Vehicle (ATV) operation. For example, Johnson, Carpenter, Wright & Nelson (1991) considered selected accident modes and proposed a set of design changes involving a rollover protection system (ROPS) and significant vehicle modifications. In this paper, the design concept is evaluated in more detail.

A full-scale operating model of the proposed four-wheel vehicle prototype was built; systematic comparisons to ATVs were made considering mobility, utility, performance, and occupant protection. It was found that the proposed vehicle modifications in fact produce a new vehicle type with significantly reduced utility and performance compared to ATVs, without the likelihood of reducing the accident and injury risk associated with the use of the vehicle. Unlike existing ATVs, the Johnson *et al.* design does not appear to be a viable approach to balancing utility and safety. This outcome is consistent with other analyses and with the general conclusions reached by the Consumer Product Safety Commission (CPSC).

## INTRODUCTION

"Design" is a process in which "a need" is filled by the production of a tangible product. The form of the tangible product can be anything from a simple sketch to a fully developed commercial good. The design process is a series of steps or phases taken by the designer or design team in an effort to meet the targeted need. There is no single correct process for designing

and engineering a new consumer product. A typical process might include the steps shown in Figure 1. It is not unusual for the designer to go from any one step to any other shown in Figure 1 during the design process. For example, idea generation and development are typically ongoing throughout the process; prototype development often discloses unanticipated issues or challenges which spawn the need for further idea generation and development.

A typical design process might include these steps:

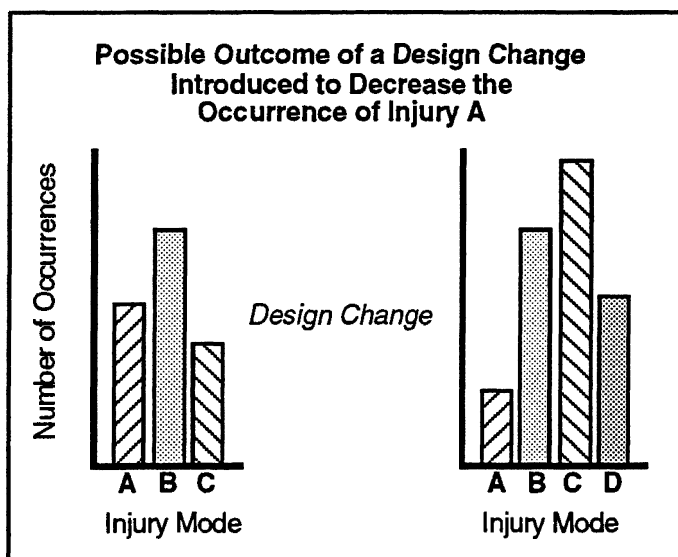
- Identify a Need
- Develop Functional Specifications
- Generate Ideas
- Develop Ideas
- Select Most-Promising Designs
- Develop Prototypes
- Develop Final Design

**Figure 1.** Engineering Design

Successful development of a product requires considering and balancing many design parameters. Throughout the design process many aspects of the design must be considered, including technical feasibility, functionality, performance, utility, reliability, maintainability, lifetime, safety, costs, ergonomics, aesthetics and environmental impact. The final form of a successfully introduced new product is a manifestation of the many trade-offs made in consideration of the many aspects of the design.

The design process does not necessarily end with the successful introduction of a product. Refinements often continue through the production lifetime of the product. Relatively minor changes implemented to reduce production cost or to improve some aspect of performance are most common. Often the basic design is modified to broaden its market appeal or areas of application. New need definitions form the basis for the design of additional models. An example of this is the passenger car which is produced in a wide variety of forms ranging from sports models to family sedans. Most often, successful and productive implementation of modifications to a basic design are made by those relatively close to the original design process.

Proposals to modify designs that have been fully implemented and put into production are often made by those outside and isolated from the original design process. These proposals may be made in the absence of all the experience and knowledge of the primary designer(s); the rationale for some or all of the trade-offs made during the initial design process may not be known. Though such proposals commonly focus on a specific aspect of the product, it is imperative that they be evaluated in the context of the overall product and its intended use by consumers. As illustrated in Figure 2, a design change may improve performance in one area but compromise performance in another, or even introduce new problem areas.



**Figure 2.** Possible Effects of a Design Change

As a case in point, several proposals have been made for design changes with the claim that they would reduce the frequency and severity of injuries associated with ATV operation. Injuries can be associated with accidents, which relate to handling, stability and crashworthiness. Current ATV design for crashworthiness is similar to that for motorcycles and other small, ride on vehicles. That is, the design of the vehicle should not restrict operator separation, the vehicle surfaces should be smooth when possible, handlebars should not be too stiff and the transition from the seat to the gas tank should be smooth (Ouellet, 1990 and Takeuchi, 1989). A different approach has been proposed by Johnson, Carpenter, Wright & Nelson (1991). They considered selected accident modes and proposed a set of design changes involving a rollover protective structure and operator restraint (ROPS), together with significant vehicle modifications. Their claim was that both stability and crashworthiness were improved. Going beyond their initial steps, this paper describes a more detailed analytical and empirical investigation of the potential benefits and drawbacks associated with the proposed changes.

#### THE ATV AND PROPOSED DESIGN CHANGES

The ATV is a light-weight, motorized vehicle designed for off-road use by a single operator/rider. ATVs are generally less than 50 inches in overall width, weigh less than 600 lb., and are

designed to travel on three or four low pressure (2.2 - 5 psi) tires. The single operator sits on a straddle type seat and uses handlebars for steering. The vehicles are light enough that the weight of the single operator can influence the vehicle's handling properties. The last three qualities (straddle seat, handlebars, and rider-activity) allow for movement of the operator, relative to the vehicle, which significantly enhances the off-road mobility and utility of the vehicle.

A testament to the ATVs popularity and functionality is the way in which ATVs are used today for both recreational and non-recreational activities. Recreational uses include transporting people, camping, fishing, off-road trail riding, challenging riding to refine skill, and racing. Some of the many non-recreational uses are transportation of man and material on the job, towing/hauling, livestock management and other farming or ranching duties. According to a 1989 ATV usage survey conducted by the CPSC, 58% of ATVs' use is non-recreational (CPSC, 1990).

Not surprisingly, as the popularity of ATVs increased in the early part of the last decade the number of accidents and injuries associated with their use also increased. Numerous changes have been suggested to the commercially produced ATV to supposedly improve their safety. These suggestions fall into two main categories: modifications intended to decrease the likelihood of an accident or particular accident mode, and modifications intended to offer greater protection during an accident. Among the accident mode related modifications are wider track width, longer wheel base, lower center of gravity, footguards, vehicle dynamics controlled engine kill switches, differential axles, and any combination of the above. The protection related suggestions consist primarily of implementation of Rollover Protection Systems (ROPS) consisting of a roll cage like structure and occupant restraint system.

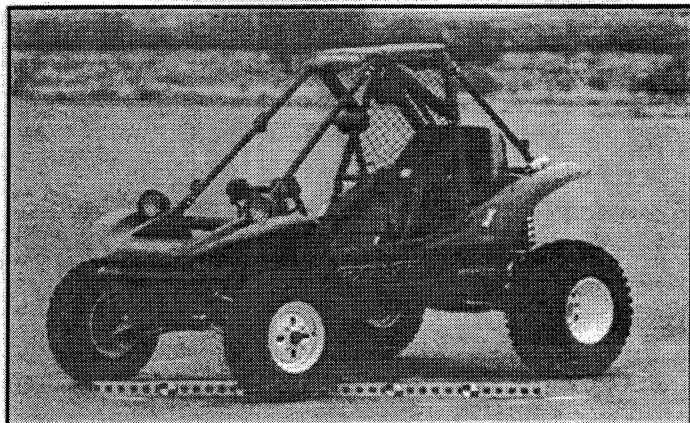
The purpose of a ROPS is to reduce the frequency and severity of operator injury due to accidental upset without significantly affecting the overall performance and utility of the vehicle. With regard to operator protection, a ROPS has the following functions:

- Arrest overturning motion during an accidental upset
- Provide an envelope in which the operator will not be crushed or struck
- Retain the operator within this envelope during an accidental upset.

An example of a commercially available, single operator, off-road vehicle with a ROPS is the Honda Pilot shown in Figure 3. In addition to the ROPS, the design includes an adjustable seat, a four point restraint system, a rectangular steering wheel with two hand brakes, wrist restraints, and a continuously variable transmission. The operator is essentially fixed in the vehicle and body motion does not effect handling and stability. The vehicle has reduced mobility and utility relative to the ATV and is primarily used for recreation riding in open terrain such as, sand dunes and desert.

ROPS for ATVs have been advocated in the literature and constructed by Dahle (1987) and Johnson *et al.* (1991). The Dahle ROPS prototype is a simple add-on roll cage and restraint for existing ATVs. Dahle's restraint systems allows for rider

motions relative to the vehicle. Analysis, testing and evaluation of the Dahle ROPS is presented in separate papers (Piziali *et al.*, 1992, Piziali *et al.*, 1993). This paper deals with the design modifications proposed by Johnson *et al.* which go beyond the retrofit ROPS concept of Dahle. The implementation of the Johnson design involves significant modifications to the conventional ATV and attempts to address both the frequency and severity of ATV related accidents.



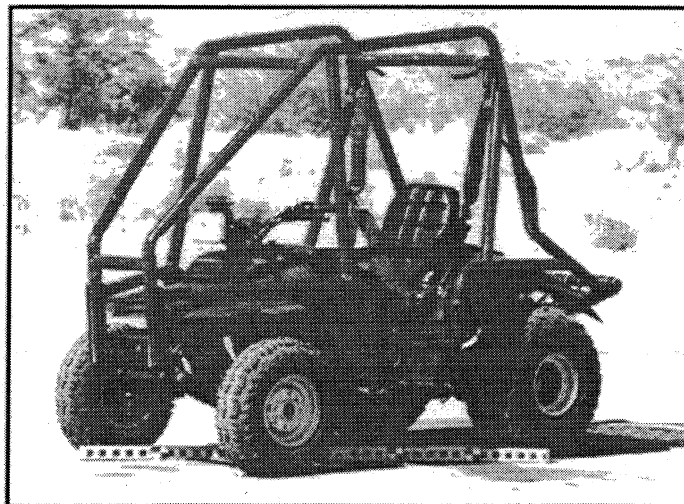
**Figure 3.** Honda Pilot

#### CRITERIA FOR EVALUATION OF ATV DESIGNS

A design change must be evaluated in the context of the entire design and expected use of the product to ensure that the change meets the intended objective and that it does not do more harm than good. Weir and Zellner (1986) suggest many considerations must be taken into account by ATV designers to establish the configuration of the vehicle. Some of these relate to the all-terrain nature of the vehicle while others relate to the requirements placed upon the vehicle from manual control and practical standpoints. Design areas, listed by Weir and Zellner, that warrant consideration when establishing the form and evaluating the utility of an all terrain vehicle include:

- performance characteristics (power, traction, speed, acceleration)
- handling qualities
- mobility characteristics
- drivability
- utility
- producibility
- reliability, durability, maintainability
- safety
- ergonomics
- cost

The areas listed above were used as a guide in evaluating the feasibility of the Johnson vehicle.



**Figure 4.** Johnson vehicle.

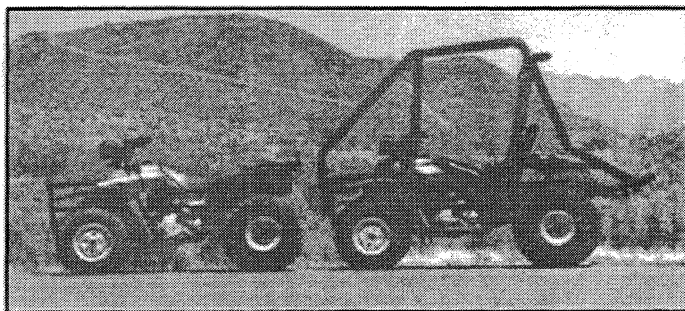
#### THE JOHNSON VEHICLE

Johnson *et al.* described ATV design modifications in “A Safer ATV” (1991). The modifications were offered under the premise of improving the safety of ATVs. The vehicle that they dubbed the “RCX250” (“roll cage experimental” with a 250 cc engine) was built by significantly modifying a 1985 Honda TRX250 and is shown in Figure 4. The major modifications required to fabricate Johnson’s vehicle from a 1985 Honda TRX250 are listed below:

- roll cage structure integrally attached to vehicle frame
- wheel base lengthened by 6 inches
- track width widened by 4 inches both front and rear
- weights added to each wheel
- seating position lowered by approximately 4.7 inches
- seat back added
- slack in restraint system for limited rider active inputs, up to 4 inches vertically and 6 inches laterally (shoulder restraints attached to bungee cords which are anchored to the vehicle frame)
- footpegs replaced by floorboards and foot guards



**Figure 5.** Front view of Johnson Vehicle and ATV from which it was built (Honda TRX250).



**Figure 6.** Side view of Johnson Vehicle and ATV from which it was built (Honda TRX250).

Detailed measurements of the original Johnson RCX vehicle were made and a replica was built.

Figures 5 and 6 show the Johnson vehicle and the ATV from which it was derived. The most visible difference between the ATV and the Johnson vehicle is the roll cage structure. The restraint system implemented by Johnson *et al.* is designed to limit rider activity. The shoulder belts are anchored to the frame of the vehicle via bungee-like cords.

A comparison of the dimensions, mass properties and other quantitative measures demonstrates some of the other significant differences between the ATV and the Johnson vehicle (Table 1).

As indicated in Table 1, the Johnson vehicle is 66% higher, 34% longer and 55% heavier than the ATV. Johnson *et al.* claim that these increases were required to make the ATV "safer." One measure used by them to evaluate safety is the stability coefficients: Kst, Kp and Kf (Table 2). These parameters represent the theoretical acceleration in g's required to tip the vehicle in the lateral, rearward and forward directions, respectively. The arc-tangent of the coefficients is the so called "critical angle". Theoretically, a vehicle inclined beyond this angle will tip. These measures are based purely on the geometry and weight distribution of a stationary vehicle on a horizontal plane. The CPSC attempted, without success, to find a relationship between one of these coefficients (Kst) and the risk of an ATV associated injury (CPSC, 1990).

Looking at Tables 1 and 2, it is important to note that in spite of their attempts to build a "safer" vehicle, there is no significant change in the parameters Johnson *et al.* use to evaluate safety. And, as we will discuss later, the increase of size and weight of the ATV has adverse effects on the mobility and utility of this type of vehicle.

#### NEW ACCIDENT AND INJURY MODES ASSOCIATED WITH THE JOHNSON VEHICLE

Accident modes can be described as different ways of getting into an accident or distinct types of accidents. And injury modes can be thought of as ways of getting injured during an accident. Johnson, in attempting to reduce certain accident and injury modes has created new ones. These modes arise both from the fundamental characteristics of ROPS and from the specific problems with this implementation of a ROPS.

Static and dynamic testing demonstrated that three primary new injury modes exist with this vehicle. We refer to these as the mousetrap, the fly-swatter and submarining.

**Table 1.** Comparison of the physical properties of the Johnson vehicle and the basis ATV

	85 Honda TRX250	Johnson Vehicle	
<b>DIMENSIONS</b>			
Wheelbase	48.8	54.5	in
Track Width (Front)	31.9	36.3	in
Track Width (Rear)	31.5	36.3	in
Track Width (Average)	31.7	36.3	in
Vehicle Length	74.4	99.8	in
Vehicle Width	43.2	47.1	in
Vehicle Height	41.5	68.8	in
Overhang (Front)	13.5	16.0	in
Overhang (Rear)	12.4	29.3	in
<b>MASS PROPERTIES</b>			
Total Weight	493.5	764.5	lb
Weight (Front)	239.0	380.5	lb
Weight (Rear)	254.5	384.0	lb
Center of Gravity			
CGx (From Rear Axle)	23.7	27.1	in
CGy (Left of Center)	0.4	0.7	in
CGz (Above Ground)	16.8	19.2	in
CG with 50th %tile male			
CGx (From Rear Axle)	21.8	25.9	in
CGy (Left of Center)	0.3	-0.1	in
CGz (Above Ground)	23.3	22.7	in
Moment of Inertia			
Ixx	151	650	in-lb-s <sup>2</sup>
Iyy	498	1000	in-lb-s <sup>2</sup>
Izz	629	1300	in-lb-s <sup>2</sup>

**Table 2.** Comparison of selected performance parameters

	85 Honda TRX250	Johnson Vehicle	
<b>STATIC TIPPING</b>			
Vehicle Only			
Kp (rearward pitch)	1.41	1.41	
Kf (forward pitch)	1.49	1.43	
Kst (lateral roll)	0.94	0.95	
with 50th percentile male			
Kp (leaning forward)	1.13	1.19	
Kf (leaning rearward)	1.25	1.26*	
Kst (rider leaning uphill)	0.84	0.84	
<b>TURNING</b>			
Wall-to-Wall Turning Circle	19.9	25.8	feet
*Since it is not possible to lean back in the Johnson Vehicle, this number is for a normally seated rider			

The mousetrap is the result a body part being trapped under the ROPS structure or pinched between the structure and another object. Figure 7 illustrates one of the common ways that the mousetrap can occur. The operator can be either thrown partially out of the structure during the accident or can become trapped during a failed escape attempt. Since the Johnson Vehicle has compliant elements in the belt attachment system, and Johnson (1991) recommends that slack be maintained for some operator movement, mousetrap injuries are possible with the restraint system in use.

This injury mode is obviously more likely if the operator is not using the restraint. In the occupational environment, studies have shown that restraint usage rates in ROPS equipped vehicles can be expected to be low (Woodward, 1980; IASS, 1985; Bowman, 1988). Furthermore, operation of the Johnson vehicle in the off-road environment revealed that the restraint system, as proposed, adversely affected both operator comfort and control (discussed in later in the paper). Because of this, it is believed that usage rates of the Johnson restraint will not be very high.

The fly-swatter effect, as illustrated in Figure 8, occurs mostly during a roll type accident but can occur in any accident where the angular motion of the vehicle is abruptly stopped and the loosely restrained occupant forcefully strikes the ground (or the vehicle or another object) due to his/her continuing angular momentum. Static testing demonstrated that this effect was consistent with the design and adjustment of the Johnson restraint system. This effect has also been demonstrated in crash testing of the ATV ROPS proposed by Dahle (Piziali *et al.*, 1992).

Submarining (Figure 9) is an injury that is caused by the lap belt riding over the ischial tuberosities and loading the abdomen. The Johnson Vehicle has a high attachment point for the lap belt. During a sufficiently forceful accident that causes the body to move in a forward direction, the restraint would impact the abdomen.

In order to change the Johnson ROPS system to reduce the possibility of these new injury modes one can take two approaches. The first is to remove the ROPS and restraints and allow separation as in the case of the ATV. The second is to provide a stiff restraint system designed to be worn with a minimum of slack, as in the case of the Honda Pilot.

Our testing also demonstrated that the Johnson vehicle increases the possibility of new accident modes or risky situations. The Johnson ROPS structure provides a convenient means of

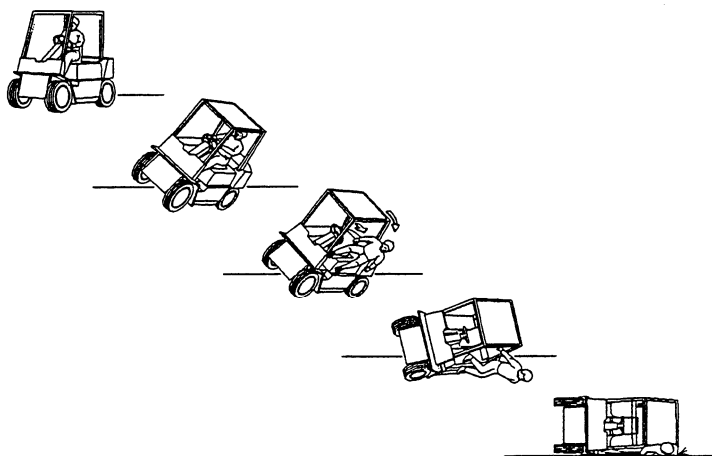


Figure 7. Mousetrap

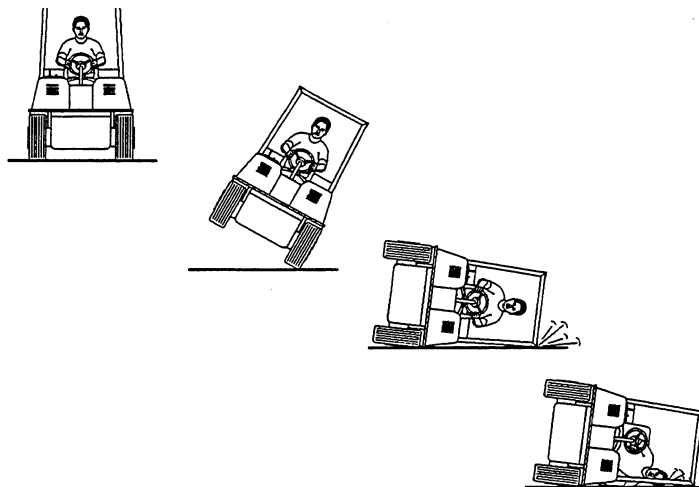


Figure 8. Fly-swatter Effect

carrying cargo and passengers which can have a negative effect on handling and stability. The greatly increased height of the vehicle allows it to strike or hang-up on overhead obstructions. The increased weight and inertia combined with a more rounded shape for the vehicle can cause it to roll uncontrolled down a hill during a rollover type accident. Being loosely attached to the vehicle during such a roll may allow the operator to sustain multiple impacts with the ROPS and the ground. This was demonstrated during a dynamic test of the rearward pitch response of the Johnson vehicle on a 30° hill with a restrained 50th percentile adult male Hybrid II anthropomorphic dummy sitting in the operators seat. Both the ATV and the Pilot offer less risk of such events.

Other injury modes that have been identified and must be considered in evaluating the Johnson ROPS include high lumbar spine loads experienced when landing from a jump, impact of the head and face on the handlebars or ROPS structure in frontal collisions, and crushing of the trachea as the neck becomes tangled in the loose bungy cords. The spinal loads can be reduced by allowing full posting as on a ATV or using a tight restraint to hold the occupant in the seat of a well suspended vehicle as with the Pilot. The remaining modes can be solved by eliminating the ROPS or designing it as used on the Pilot.

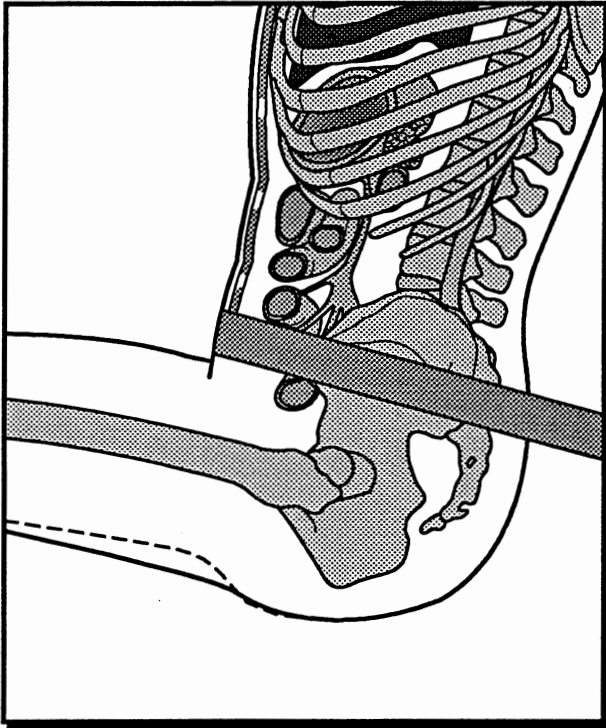
Another concern is the possibility that a ROPS could increase the occurrence of certain accident modes by modifying operator behavior in an adverse way. An operator may engage in more aggressive riding or intentional vehicle abuse while relying on the ROPS for protection.

## OPERATIONAL FACTORS

The modifications proposed by Johnson significantly change the operation, mobility and utility of the vehicle when compared to the original ATV.

To begin, the new lowered seat position while maintaining the original ATV's steering geometry and foot location puts the operator in a semi-reclined position which revealed, upon testing the vehicle, an unsatisfactory reduction in the operator's ability to control the vehicle. The location of the seat along with the restricted operator motions due to the restraint system, necessitates a push/pull arm motion to steer the vehicle. This creates a condition where an average person has difficulty reaching one





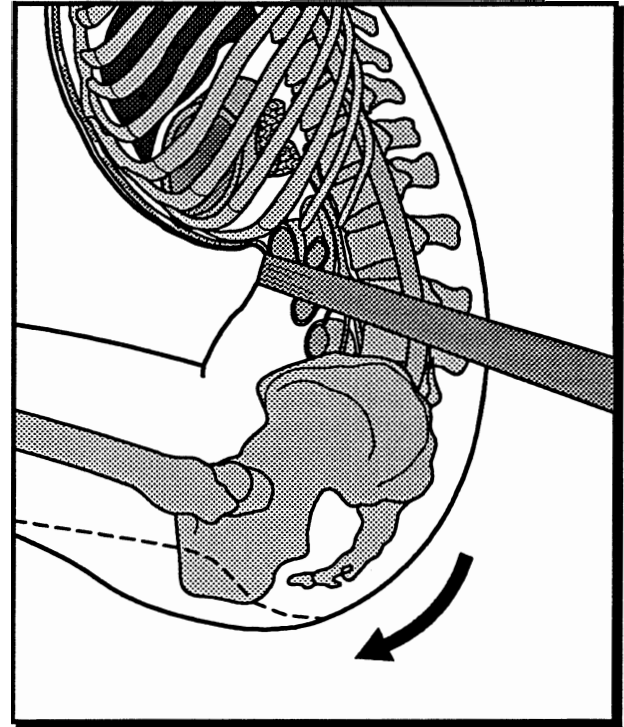
**Figure 9.** Submarining

of the handlebars when executing a tight turn. This has the disadvantage that the size of the operator influences the ability to impart handlebar steer angles. The posture and position of the operator also renders the operation of foot controls (the gear shift and foot brake) more difficult than for the original vehicle. This is a direct result of the leg angles created by the lower seating position. These shortcomings could be overcome by restoring the sit-on nature of the ATV where a handlebar steering mechanism is appropriate and the body is correctly oriented to operate foot controls or by implementing a steering wheel, eliminating foot controls and installing an adjustable seat as is done in the Pilot.

When operating the Johnson vehicle over rough terrains such as rocky stream beds, significant flaws with the compliant restraint concept were discovered. Under these conditions the operator's upper torso would move (often violently and unpredictably) relative to the motions of the vehicle and up against the limits of the restraints due to their looseness. This resulted in degraded ride quality and impacted the controllability of the vehicle over rough terrain to the point where an operator might purposefully unbuckle the restraint to achieve acceptable comfort and control.

Although the Pilot also did not achieve the same level of ride quality as the ATV on this class of terrain due to the inability of the operator to absorb shock by posting, the Pilot's restraint system did however, enhance the operator's ability to control the vehicle. This is because the operator is strapped firmly to the seat of the Pilot with the steering wheel oriented directly ahead of the operator at all times, irrespective of the vehicle's motions.

The concept of mobility is fundamental to the design of an off-road vehicle. Mobility is concerned with the performance of the vehicle in relation to soft terrain, obstacle negotiation, obstacle avoidance, ride quality over rough terrain and water



crossing (Wong, 1978). The Johnson vehicle was compared to the original ATV in all these areas of mobility over a wide variety of terrains such as, desert, sand dunes, stream crossings and forest trails. Table 3 compares observations regarding some of

**Table 3.** Comparison of the TRX250 and Johnson vehicle based on mobility criteria.

	85 Honda TRX 250	Johnson Vehicle
Soft terrain negotiation	Low tire pressure, low weight, small size, rider active (rock or push vehicle when stuck)	Higher tire pressure, greater weight – increased likelihood of getting stuck; larger size, no rider activity – inability to extricate vehicle
Obstacle negotiation	Low tire pressure, low weight, small size, good visibility, good ground clearance, rider active	Larger wheelbase results in more hang-ups; rider constraint affects visibility and ability to negotiate over obstacles
Obstacle avoidance	Rider activity, good maneuverability aides identification and avoidance	Larger turning radius; reduced visibility; less maneuverable; size hinders avoidance
Ride quality	Operator free to move independently of vehicle	Operator tied to motions of vehicle; unable to damp out motion with legs
Water crossing	Good visibility, light weight, maneuverable	Reduced visibility; increased weight; greater likelihood of getting stuck



the mobility characteristics of the ATV and the Johnson vehicle based on this testing. In general, the overall mobility of the Johnson vehicle was degraded with respect to the original ATV. The mobility of the Pilot was also restricted when compared to the ATV. The longer wheelbase affects the maneuverability of the vehicle. The lack of operator activity limits transferring weight from one axle to another in conditions where the wheels lose traction.

The influence of the proposed design changes on the vehicle's utility was also investigated. As discussed above, the ATV has a wide range of both recreational and occupational uses. For example, the Honda TRX250 has both front and rear racks providing for a limited cargo capacity for transporting hunting, fishing and camping gear as well as tools. In the proposed Johnson design, the available locations for carrying cargo are restricted to being outside or upon the ROPS structure itself. Having cargo attached outside the vehicle's wheelbase or high on the ROPS structure was found to be detrimental to the vehicle's handling and stability. The ease of ingress and egress is dramatically affected by the ROPS structure. Both the structure itself and the restraint system renders ingress and egress a much slower and laborious process in the Johnson vehicle. The difficulty associated with use of the prototype four-point restraint system reduces the likelihood of the operator using the restraint. This would be especially true in the occupational environment where the operator often gets on and off the machine as part of his/her job (*i.e.*, checking fencing, opening and closing farm gates).

Another aspect associated with utility is the ease of transportation. The Johnson vehicle is longer, wider and about twice as high as a typical ATV and thus requires significantly more space for transport and storage. In addition, the approximately 55% greater weight makes this 765 lb vehicle difficult to load, unload or maneuver by one person. The Pilot is similarly affected.

## CONCLUSIONS

Advocating significant design modifications for presumed safety benefits without considering the adverse effects of those changes on the total product is not an appropriate design methodology. When considering operator protection, all accident modes need to be considered. Based on the authors' testing it appears that the Johnson vehicle lacks the balance of design parameters mentioned above. It has the potential to offer some protection to belted, helmeted riders in some accidents. But, evaluated in the context of the overall product and its intended use there are incompatibilities, inconsistencies, omissions, and degradation of performance. Some of the major shortcomings are:

- Introduces new accident modes.
- Introduces new injury modes.
- Reduces mobility.
- Reduces visibility.
- Renders logistics more difficult.
- Eliminates rider activity.
- Wheel weights lead to larger unsprung mass.
- Added weight requires reevaluation of tire requirements.

- Requires adjustable seat. Even large operators have difficulty reaching handlebars while reclined against seat back. Smaller operators cannot reach handlebars while reclined.
- Seating posture and inability to post results in decreased ride quality.
- Suspension redesign required to improve ride quality.
- Difficult to switch gears with stock footpeg position and shift lever rotated upward.
- Restraint system is partially elastic and provides inferior characteristics.
- Longer tow bar needed for towing trailers/vehicles as must clear wheelie bar.

The Consumer Product Safety Commission (1990, 1991) has evaluated several ROPS systems for ATVs and agrees that ROPS in general are inappropriate for light-weight rider-active vehicles. A ROPS becomes especially dangerous to have in light of the predicted low restraint usage rates.

If introduced as a commercial product, the utility and mobility problems of this design will significantly reduce the vehicle's practicality. Its recreational use would decrease dramatically (too heavy, not enough power, not maneuverable). Its utilitarian uses would also decrease (not enough power, entry/egress very difficult, no designed cargo area). A prospective consumer will likely see it as a one person vehicle that is not easily operated or transported by one person.

It is not intended by the authors of this paper to discourage innovation or creativity in design. Designs must be evaluated in the context of the overall product and its intended use by consumers. Advocating a modification to an ATV without testing and evaluating the modification in the entirety of expected ATV environments and uses is not sound design practice.

*Acknowledgments* – Significant contributions were made to this research program on ROPS by Celia Oakley and Dan Girvan. The authors wish to acknowledge and thank Honda North America, Inc. for their support in this research effort.

## REFERENCES

- Bowman, B. L. and Rounds, D. A. (1988) "Restraint System Usage in the Traffic Population." 1987 Annual Report. National Highway Traffic Safety Administration, DOT HS-807-342.
- Consumer Product Safety Commission (1990) "All-Terrain Vehicle Voluntary Standards/Lateral Stability Status Report," September 1990.
- Consumer Product Safety Commission (1991a) "Briefing Package on All-Terrain Vehicles," March 1991.
- Consumer Product Safety Commission (1991b) "All-Terrain Vehicles: Termination of Rulemaking Proceeding", Federal Register, Vol. 56, September 18, 1991, 47166-47173
- Harill, E.D. (CPSC Director Congressional Relations) (1990) letter to Honorable Doug Barnard, Jr. in response to Johnson ROPS.

- IASS (1985) "Maneuver Analysis: A Safety Program for Fork-lift Truck Operator Protection", Institute For Advanced Safety Studies (IASS), prepared for Allis-Chalmers Industrial Truck Division.
- Johnson, F.H. (1991) deposition in *Hagelsieb v. Honda*, February 18, 1991.
- Johnson, F.H., Wright, R.R., Carpenter, T.G. and Nelson, R. (1991) "A Safer ATV," SAE Paper #911945.
- Ouellet, J.V. (1990) "Appropriate and Inappropriate Strategies for Injury Reduction in Motorcycle Accidents," *Rider-Passenger Protection in Motorcycle Collisions*, SAE #SP-827.
- Piziali, R. L., Paver, J.G., Merala, R., Fries, R., Fowler, G.F. and McCarthy, R.L. (1992) "Evaluation of an Occupant Protection System for All-Terrain Vehicles," *Proceedings of the ASME Winter Meeting*
- Piziali, R. L., Ayres, T.J., Paver, J.G., Fowler, G.F. and McCarthy, R.L. (1993) "Investigation of the Net Safety Impact of an Occupant Protection System For All-Terrain Vehicles," SAE Paper #930208
- Takeuchi, O. (1989) deposition in *O'Berg v. Honda*, April 18, 1989.
- Weir, D.H. and Zellner, J.W. (1986) "An Introduction to the Operational Characteristics of All-Terrain-Vehicles," SAE Paper #860225.
- Wong, J. Y., *Theory of Ground Vehicles*, John Wiley & Sons, New York, 1978.
- Woodward, J. L. and Swan, S. (1980) "ROPS Field Performance – A Status Report." SAE Paper No. 800679