MEASUREMENT OF “RIDER ACTIVE” EFFECTS ON
ATV PERFORMANCE

DRI-TR-14-04

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19 February 2014
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EXECUTIVE SUMMARY

Exploratory experimental measurements were conducted during 2000 to 2004 of the effects of “rider-active” positioning (i.e., the rider shifting his/her pelvis side-to-side on, fore-and-aft on and vertically off the seat) on eight different attributes of All Terrain Vehicle (ATV)\(^1\) performance, comprising objective and/or subjective measurements of:

- Mobility (objective, subjective)
- Stability (objective roll, subjective roll and pitch)
- Overall handling quality (subjective)
- Task difficulty (subjective)
- Ride discomfort (subjective)
- Traction (subjective)
- Ergonomics/external (objective) reach
- Forward visibility (objective)

A mixture of objective and subjective measurements was used in this exploratory study to quantify the effect of “rider active” body movement because many of the aforementioned performance attributes are highly complex (e.g., overall handling quality, ride discomfort), and at the current time not readily quantified by one or more objective indices that have been previously demonstrated to be strongly correlated with rider subjective ratings or with incidents (e.g., loss of path control, overturn, collision, etc.). Generally, correlations against subjective data can only be conducted on the basis of suitably designed experiments involving vehicles in which only one attribute at a time is changed, and in which suitably controlled experiments are done based on objective and subjective measurements, tasks, subject

\(^1\) An ATV is defined as “A motorized off-highway vehicle designed to travel on four low pressure tires, having a seat to be straddled by the operator and handlebars for steering control. ATVs are subdivided into two types as designated by the manufacturer. Type I – A Type I ATV is intended for use by a single operator and no passenger. Type II – A Type II ATV is intended for use by an operator or an operator and a passenger. It is equipped with a designated seating position behind the operator designed to be straddled by no more than one passenger.” according to ANSI/SVIA 1 (2010).
protocols, and extensive data reduction and statistical (i.e., correlation) analyses, which was beyond the scope of the reported studies. Likewise, correlation against accident data requires measuring the objective attributes of numerous accident-involved vehicle make-model-years, which was beyond the scope of these studies.

Instead, a sample of existing, exemplar production ATVs was used for the exploratory studies described in this report. Many of the design parameters and performance attributes of these production ATVS varied simultaneously, so that it was not possible to isolate the effect of any one design parameter or attribute. Rather, the goal was to assess and quantify the “range” of objective and subjective measurements occurring for a set of realistic riding tasks.

Likewise, as the emphasis of the studies was on collecting objective and subjective data for a “range” of tasks and exemplar vehicles, the focus was not on measuring variations due to rider skill level or training. Accordingly, three ATV expert riders were used for the tests, in an attempt to control for the effects of skill, training and learning. By using only expert riders, there was less inter-rider variability (due to skill and training effects) and less effect of learning during the tests as would occur with novice or less experienced riders. Past experience has indicated that under suitably controlled experimental conditions, expert riders are more consistent in terms of performance outcomes and subjective ratings (i.e., less variable) than would otherwise be the case with, for example, novice or less experienced riders. By using three expert riders, some effects of inter-rider variability were included in the data, albeit at one (expert) skill level.

The evaluations were conducted in several phases spanning several years, overall including up to eight ATVs, up to nine tasks (including terrain, instructions and conditions) and up to three expert test riders. In all tests only one person (i.e., the operator) was present on the vehicle.
Data resulting from the objective and subjective (rider-centered) measurements were used to estimate the “rider active percentage” for each performance attribute, task, vehicle and rider. This was defined as the percentage change in each performance index, when “rider active” body movement was used. Mean, minimum and maximum “rider active percentages” were determined and reported for each of these, as well as for groups of tasks, vehicles and riders.

The results of the evaluations indicated that the “rider active percentage” varied widely (i.e., from 0% to 310% (absolute value)), by an amount which was dependent on the particular performance attribute, the task (including the terrain, the instructions and the conditions) and the specific vehicle and rider. The data indicated that “rider active” positioning on average has a large (i.e., greater than or equal to 30%) “mean” beneficial effect on:

- Forward Visibility Obstructed Distance (-62%);
- Ride Discomfort subjective rating (42%);
- Dynamic Roll Stability subjective rating (38%);
- Dynamic Pitch Stability subjective rating (31%);
- Left Hand Reach volume objective index (30%).

Across all subjective ratings and objective indices, expert riders, vehicles, and off-highway courses, “rider active” positioning had a substantial 26% average mean beneficial effect. This beneficial effect is not available to operators of non-“rider-active” vehicles.

Such advantages are not small and can provide important operating margins or advantages for ATV users in these types of conditions.

The magnitude, importance and advantages of the “rider active percentage” depends on the circumstances (i.e., the task (including the terrain, the mission and the conditions), the specific vehicle and the specific rider, and the importance of a particular performance attribute to that
circumstance (e.g., a vertical drop-off, embankment or cliff not being visually obscured by a forward obstacle would be an example of an important advantage of “rider active” (i.e., ability to stand on the footrests to improve visibility of the forward path, in the presence of vegetation and other obstructions) in a potentially critical circumstance).

For many other types of vehicles in which the operator represents a small fraction of the vehicle weight and in which the operator is restrained inside the vehicle and sitting on a seat with a seat back, the “driver-active percentage” is typically (and often negligibly) small, close to, if not effectively equal to, zero. “Rider active” advantages, including adaptability to conditions and having operating “margins”, are not available to operators of those vehicles.

Some non-rider-active vehicles may conceivably have some advantages over ATVs in some attributes (e.g., baseline static stability, or baseline ride discomfort); however, ATVs represent a unique combination of high off-highway mobility, with moderate levels of static stability and cargo capacity and adaptability to conditions (via “rider active” positioning).

Among off-highway vehicles, the “rider active percentage” of ATVs in some cases provides substantial performance advantages, adaptive capability and adaptive performance “margins,” which can be important or safety related in some circumstances, and which are not available in non-“rider-active” vehicles. “Rider active” positioning, which is an inherent feature and advantage of ATV design involving elongated straddle seats, footrests and handlebar control, enables the rider to shift position laterally, longitudinally and vertically to enhance and to adapt to the current task and conditions, if/when desired, the vehicle’s performance envelope (including enhancing mobility, stability, handling qualities, traction, ergonomics/external reach, and forward visibility, and/or reducing task difficulty and ride discomfort). “Rider active” operation is a key part of training courses provided by the ATV Safety Institute (www.atvsafety.org); and mandatory warning labels on all ANSI/SVIA 1-compliant ATVs warn users “Never operate without proper
training or instruction”. Many US states require training for ATV operation; and in the US, ATV manufacturers provide free training with purchase of any new ATV.
This report describes experimental evaluations of the effects of rider-active positioning (i.e., the rider shifting his/her pelvis side-to-side on, fore-and-aft on and vertically off the seat) on eight different attributes of All-Terrain Vehicle (ATV) performance.

A. BACKGROUND

An “ATV” is a particular type of standardized off-highway vehicle, which is defined by (among other factors specified in ANSI/SVIA-1-2010 (2010)) its “straddle seat-handlebar-controlled-helmet-required” configuration. The elongated straddle seats, the footrests and handlebars enable the rider to shift position as instructed in training courses and in ATV owner’s manuals, in a way often referred to as rider body movement or “rider active” positioning. Due to the rider’s mass being a substantial fraction of the vehicle mass, these rider body shifts can have substantial effects on vehicle performance, extending the performance envelope of the vehicle, which can be useful in utility as well as in recreational applications.

“Rider active” effects are an inherent feature and advantage of ATVs, and allow the rider to enhance and adapt the vehicle’s performance envelope to the current task and conditions. These adaptations include enhancing mobility, stability, handling qualities, traction, ergonomics/external reach, and forward visibility, and/or reducing task difficulty and ride discomfort.

2 The ANSI/SVIA 1-2010 Standard defines an ATV as “A motorized off-highway vehicle designed to travel on four low pressure tires, having a seat to be straddled by the operator and handlebars for steering control. ATVs are subdivided into two types as designated by the manufacturer. Type I – A Type I ATV is intended for use by a single operator and no passenger. Type II – A Type II ATV is intended for use by an operator or an operator and a passenger. It is equipped with a designated seating position behind the operator designated to be straddled by no more than one passenger.”

3 Weir and Zellner, SAE 860225, 1986.

Adaptive body positioning is instructed in ATV training courses and user manuals.

Unique among small vehicles, ATVs are also equipped with low pressure tires that, in general, exert less pressure than a human foot, so that they can operate on a virtually all types of ground such as snow, mud, loose or hard sand, ice, gravel, bogs, marshes, tundra and virtually all other off-highway surfaces. The unique combination of their “rider active” configuration and low pressure tires enable ATVs to fill a unique, highly adaptive, high mobility niche in the off-highway vehicle fleet.

B. OVERVIEW OF METHODS

Several experimental investigations of the magnitude and nature of “rider active” positioning effects were conducted during 2000 through 2004, using up to seven example ATVs available during that period.

The performance attributes that were evaluated were:

- Mobility (objective, subjective)
- Stability (objective static roll stability, subjective dynamic roll stability and subjective dynamic pitch stability)
- Overall handling quality (subjective)
- Task difficulty (subjective)
- Ride discomfort (subjective)
- Traction (subjective)
- Ergonomics/external reach (objective)
- Forward visibility (objective)

These are some but not all of the performance attributes of importance in ATV operation, be it recreational or utility operation. Other important performance attributes were not evaluated in this study, including:

- Utility (for various specific applications)
- Power/weight ratio
- Clearance (e.g., overhead, side, ground, break-over angle, approach angle, departure angle)
- Mount/dismount ease
- Seating comfort
- Transportability (in other vehicles)
- Cargo capacity
- Towing capacity
- Ability to be manually moved
- Other performance attributes

A variety of objective and subjective (rider-centered) measurements was collected for these performance attributes evaluated, and the results were used to estimate the “rider active percentage” for each performance attribute and each example vehicle, which was defined for purposes of this study as:

\[
\text{RA\%} = \frac{\text{Performance index value with rider active}}{\text{Performance index value with rider passive}} - 1 \times 100\% \quad (1)
\]

So, for example, an RA\% value of +30\% for (for example) “Ride Discomfort” means that “rider active” positioning improved the Ride Discomfort subjective rating (or objective index, as the case may be) by 30\%.

In this report, “rider active” refers to the rider being free to move his/her pelvis laterally and/or longitudinally on the seat, or vertically off the seat; whereas “rider passive” refers to rider keeping his/her pelvis centered on the seat at all times, but allowing the upper body to lean in any direction (e.g., in order to maintain rider comfort).

The “rider active percentage” (RA\%) provides an index of the magnitude of the “rider active” effect by comparing the “rider active” to the “rider passive” rating or index. The magnitude of the “rider active” effect is in
general dependent on the task (including the course and the terrain), the conditions (e.g., speed), the specific rider and the specific vehicle. The goal of these studies was to assess the range of “rider active percentage” values observed for typical operating tasks. The tasks and conditions used in this study were intended to be representative of realistic recreational or utility usage in this regard; however, they are not inclusive of all possible tasks or usages.

Section II of this report provides a summary of the test methods, including the test vehicles, riders, courses and tasks, with further details provided in Appendices A through D. Section III describes the results in terms of the measured “rider active percentage” for the various ATV performance attributes. Section IV provides a summary and conclusions. Appendices A thought D describe the test results in terms of the raw objective and subjective measurements. Appendix E provides a further discussion of vehicle mobility indices.

C. DEFINITIONS

For purposes of this study, the following definitions apply.

All Terrain Vehicle (ATV) – A motorized off-highway vehicle designed to travel on four low pressure tires, having a seat to be straddled by the operator and handlebars for steering control. ATVs are subdivided into two types as designated by the manufacturer. Type I – A Type I ATV is intended for use by a single operator and no passenger. Type II – A Type II ATV is intended for use by an operator or an operator and a passenger. It is equipped with a designated seating position behind the operator designated to be straddled by no more than one passenger.” (ANSI/SVIA 1-2010).

Rider active – varying the riding position, by moving the pelvis laterally and longitudinally on the seat, or raising it off the seat (i.e., rider
“posting”), while keeping both hands on the handlebars and both feet on the footrests throughout a maneuver. For example, on rough terrain the rider may stand in order to enable his legs to absorb or attenuate some of the terrain irregularities (as commonly done in, e.g., off-highway motorcycling, horseback, personal watercraft, or snowmobile riding, etc.).

Note: in most, if not all, of the maneuvers used in these evaluations (as well as in real world ATV usage), “rider active” body positioning is inherently dynamic in nature, in response to continuously changing soil traction, terrain slope and irregularities, and vehicle lateral, longitudinal and vertical accelerations.

Rider passive – fixed riding position, in which the pelvis remains in a centered location on the seat (also described as “rider-centered” in the instructions given to the test riders in this report), and in which the rider may lean the upper body longitudinally and/or lateral about the waist, keeping both hands on the handlebars and both feet on the footrests throughout a maneuver.

Static – vehicle is stationary

Dynamic – vehicle is moving
A. TEST VEHICLES

A total of eight different example ATVs were used during the tests, which were accomplished in several phases during 2000 to 2004. The test vehicles are described in Table 1.

Table 1. Test vehicle description

<table>
<thead>
<tr>
<th>Vehicle Descriptor</th>
<th>Model Year</th>
<th>Engine Size (cc)</th>
<th>Approximate Weight with fluids-lb (kg)</th>
<th>ATV Type (see ANSI/SVIA 1-2010)</th>
</tr>
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<tr>
<td>V1</td>
<td>1997</td>
<td>300</td>
<td>527 (240)</td>
<td>I</td>
</tr>
<tr>
<td>A</td>
<td>2004</td>
<td>350</td>
<td>513 (233)</td>
<td>I</td>
</tr>
<tr>
<td>V2</td>
<td>1995</td>
<td>400</td>
<td>553 (251)</td>
<td>I</td>
</tr>
<tr>
<td>B</td>
<td>2004</td>
<td>400</td>
<td>564 (256)</td>
<td>I</td>
</tr>
<tr>
<td>V3</td>
<td>2000</td>
<td>600</td>
<td>598 (272)</td>
<td>I</td>
</tr>
<tr>
<td>V4</td>
<td>1999</td>
<td>500</td>
<td>660 (300)</td>
<td>I</td>
</tr>
<tr>
<td>C</td>
<td>2004</td>
<td>400</td>
<td>750 (340)</td>
<td>II</td>
</tr>
<tr>
<td>D</td>
<td>2004</td>
<td>500</td>
<td>776 (352)</td>
<td>II</td>
</tr>
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</table>

In all of the tests, only the rider (i.e., the operator) was present on each of the ATVs.

Note that as related to the multi-phase nature of the evaluations, not all ATVs were used in all evaluations. Instead, one or more of these ATVs were used in the evaluation of each performance attribute. For some performance attributes (e.g., overall mobility, as subjectively rated over a test course) four vehicles (i.e., V1 through V4) and all three expert riders were used. As
described subsequently, evaluation of one of the 2004 model year vehicles (i.e., Vehicle A) in terms of hand reach and forward visibility was performed by one expert rider; evaluation of the 2004 model year vehicles (i.e., A through D) in terms of maximum tilt table angle was performed by a second expert rider; and a rider group comprising all three expert riders was used for the other model year vehicles (i.e., V1 through V4), because, as previously noted, several separate and independent studies were involved. The use of different riders for different evaluations may not be crucial in the current study, as the current purpose is to compare the typical range of “rider active percentages”, rather than any vehicle-centered differences in “rider active percentage”.

Also note that the example ATVs varied substantially in their specific designs, mechanical features, relative performance in various terrains and maneuvers, cargo capacities and intended usage (except that they all conformed to the applicable version of the ANSI/SVIA 1 Standard). Again, the purpose of these evaluations was to assess the typical range of “rider active” effects, rather than any vehicle-centered differences in “rider active” effects. Any apparent differences that might appear to be associated with a given variable, e.g., engine size or vehicle weight as indicated in Table 1, may be purely coincidental, as many other co-varying design features (e.g., drive configuration, tires, suspension configuration, load capacities, seating height, weight distribution, etc.) may also influence such trends. In other words, due to the large number of variables which differ among the test vehicles, it is not possible to ascribe any particular performance difference or trend to any one of the variables in Table 1, or to any other single design variable.

B. TEST RIDERS

All tests were done with a single expert ATV operator riding on the ATV (and in no test was a passenger present (which would be a “warned against” behavior for the Type I ATVs)). Depending on the evaluation being done, subjective and/or objective measurements were made with those test riders
participating in each riding task. Two of the expert riders were expert engineering test riders; and one of the expert riders was an SVIA expert ATV training instructor. Use of such expert riders was intended to reduce the potential effects of learning, training and inter-rider differences that might otherwise occur during the course of any one study, or between studies, as all of three test riders were fully competent highly experienced ATV riders. All three test riders were close to 50th percentile adult male in stature and weight.

In particular, all three riders participated in the off-highway evaluations of the non-2004 group of vehicles; one of the engineering test riders participated in the tilt table tests of the 2004 group of vehicles; and the other engineering test rider participated in the visibility and ergonomic evaluation of one of the 2004 model year vehicles, as reported herein.

The expert test riders were considered to be generally representative of expert ATV riders and highly experienced ATV riders. Use of novice or less experienced ATV riders would, in general, be expected to introduce lower repeatability and greater variability, as well as learning (i.e., time-varying effects) during the course of such a study, requiring use of other protocols, including a larger rider sample size.

C. COURSES, TASKS, INSTRUCTIONS

The off-highway evaluations were conducted at the El Mirage Off-Highway Recreational Vehicle Area, located in the Mojave Desert, California, USA. The terrain in the area includes rocky hills with trails and rock climbs, dry creeks (washes), sloped and level sandy areas, and level dirt roads with various series of long wavelength sinusoidal bumps formed over time by typical sprung mass resonance of off-highway vehicles using the area.

Figures 1 through 5 illustrate the physical appearance of the five courses.
Figure 1. Photo of portion of Sinusoidal Bumps course

Figure 2. Photo of portion of Closed Circuit Turns course
Figure 3. Photo of portion of Dry Creek Bed course

Figure 4. Photo of portion of Upslope Sand course
Table 2 summarizes the several off-highway courses used, as well as the defined riding tasks, the instructions read to the test riders, and the measurements made. Note that many of the task instructions were that a given course was to be ridden in “minimum time maintaining safety”. This was done in order:

(a) to specify, to some extent, a standardized speed “profile” that would be relatively uniform among the expert riders;

(b) to improve the repeatability/reproducibility of the task (i.e., allowing riders to ride at any arbitrary speed would mean that the evaluation conditions tend not to be repeatable between runs or reproducible between riders);
(c) to recognize that some ATVs do not have speedometers, and that posted speed limits do not exist in most off-highway situations, and that, in any case, speed needs to be continuously varied by the rider so as to be “safe for conditions”;

(d) to relate to how the vehicles may sometimes be operated, recreationally or in utility applications (i.e., covering a distance in minimum time while maintaining safe operation); and

(e) to relate to how users/consumers may in practice evaluate a vehicle (e.g., a vehicle that can only be operated across a given terrain/course at very low speeds due to ride discomfort, traction limits, stability limits, etc. may be down-rated in comparison to a vehicle that can be operated at a somewhat greater speed).

For those tasks that were to be done in “minimum time maintaining safety”, elapsed time was used as the performance index quantifying to what level “minimum time maintaining safety” was achieved. Elapsed time (or average speed) is a common performance index used to describe vehicle mobility over a specified path and terrain (See Appendix E).

Note that in Table 2, the “typical speed” listed is for informational purposes only, and was recorded by means of a speed sensor mounted on the test vehicle.
Table 2. Detailed Description of Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Task</th>
<th>Instructions to test rider</th>
<th>Measurements</th>
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<tr>
<td>Sinusoidal Bumps</td>
<td>Course comprising a series of sinusoidal bumps on compacted sand, averaging approximately 1 m peak to peak. Long wavelength, varies. Path marked by cones (El Mirage). 278 m course length. Typical speed: &lt; 19 mi/h Soil: compacted dry sand</td>
<td>Ride through the marked course, both directions, in minimum time.</td>
<td>Begin with the front wheels between the start cones. When given the start signal, accelerate and ride through the course as quickly as possible. At the end of the course turn around and run the course in the opposite direction in the minimum time</td>
<td>Elapsed time from vehicle start until front wheels pass start cones in opposite direction. Subjective ratings</td>
</tr>
<tr>
<td>Course</td>
<td>Description</td>
<td>Task</td>
<td>Instructions to test rider</td>
<td>Measurements</td>
</tr>
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<td>---------------------</td>
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<tr>
<td>Closed Circuit Turns</td>
<td>A series of small radius linked turns through bushes, in flat relatively sandy soil (El Mirage)</td>
<td>Maneuver through two laps of the course (marked with small cones) in the minimum time.</td>
<td>Begin with the ATV situated at the starting point with the front wheels between the starting gate cones. Upon the start signal, accelerate and negotiate 2 laps of the marked course.</td>
<td>Elapsed time from vehicle start until front wheels pass start cones in opposite direction, after the second lap. Subjective ratings</td>
</tr>
<tr>
<td>Course</td>
<td>Description</td>
<td>Task</td>
<td>Instructions to test rider</td>
<td>Measurements</td>
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<tr>
<td>Dry Creek Bed</td>
<td>Dry creek bed on the side of a small mountain comprising a short climb over medium and large size rocks and boulders. The course was narrow in some areas. (El Mirage)</td>
<td>Maneuver through the creek bed course in the minimum time.</td>
<td>Begin with the ATV situated facing uphill with the front wheels between the starting gate cones. Upon the start signal, accelerate and negotiate the marked course up the incline. At the top of the course turn around and return to the bottom, staying on the course at all times.</td>
<td>Elapsed time from vehicle start until front wheels pass start cones in opposite direction. Subjective ratings</td>
</tr>
<tr>
<td>Course</td>
<td>Description</td>
<td>Task</td>
<td>Instructions to test rider</td>
<td>Measurements</td>
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<tr>
<td>Upslope sand</td>
<td>Increasing slope on tall sand dune, steepest portion in excess of 30 degrees. (El Mirage)</td>
<td>Maneuver through the course in the minimum time.</td>
<td>Begin with the front wheels between the start cones.</td>
<td>Elapsed time from vehicle start until front wheels pass start cones until the front wheels pass through the finish cones. Subjective ratings</td>
</tr>
<tr>
<td>Course</td>
<td>Description</td>
<td>Task</td>
<td>Instructions to test rider</td>
<td>Measurements</td>
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<td>------------</td>
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</tr>
<tr>
<td>3 Ditches</td>
<td>Perpendicular traversal of three irregular, dry ditches, depth 1-2 m, width at top 5-10 m, steeply sloping sides. (El Mirage)</td>
<td>Maneuver through the course in the minimum time.</td>
<td>Begin with the front wheels between the start cones. When given the start signal, accelerate and ride through the course as quickly as possible. At the end of the course turn around and run the course in the opposite direction in the minimum time.</td>
<td>Elapsed time from vehicle start until front wheels pass start cones in opposite direction. Subjective ratings</td>
</tr>
</tbody>
</table>
For the laboratory tests of roll (i.e., cross-slope) static stability, a tilt table was used. Vehicle manufacturers and others have used various test methods and indices to characterize the static stability of vehicles. One simple measurement of static stability, as described in Lenkeit and Broen (2006), is measured by placing a vehicle on a table, covered with a high friction material, which tilts about an axis and raises one side of the vehicle higher than the other. As the table continues to tilt, it eventually reaches an angle at which the “high side” tires lift from the table, and the vehicle tips over if not restrained. Figure 6 shows an example tilt table test in progress, with one of the engineering test riders using “rider passive” body positioning.
The advantages of the tilt table method include:

- It is relatively simple to perform;
- Typical measurement equipment is simple and inexpensive;
- It accounts for tire and suspension deflection characteristics;
- It provides a metric for making comparisons of vehicles and loading conditions.

One limitation of this method is that the tilt table measurements represent an idealized condition in which the forces acting at the center of gravity of the vehicle system are a result of gravity only, rather than other dynamic forces which nearly always are present in the real world. Another dynamic effect that cannot be reproduced on a tilt table is the effect of vehicle side slip angle. Dynamically, a vehicle side slip angle is required in order to operate a vehicle across a cross slope (i.e., in order to generate side forces on the tires that prevent the vehicle from sliding down the slope), and side slip angle increases the effective track width of the vehicle (as it yaws relative to its path). For ATVs on many off-highway surfaces, this effect can be quite large. Another limitation is the limited repeatability and reproducibility of the tilt table measurement when a human rider is used, in regard to rider-to-rider differences and variations of such factors as stature, weight, mass distribution, limb lengths, etc.; and (regardless of whether a human rider or a surrogate rider is used) necessarily detailed positioning procedures for the rider’s torso, limbs, pelvis, etc. In addition, it would be extremely difficult (and therefore rare) to find a real, flat, constant sloped, planar surface that has the same characteristics as the idealized tilt table.

Therefore, as with all of the measurements in this report, the tilt table results reported herein are intended to be representative of the range of rider active effects that might be observed, rather than establishing a comprehensive database of what occurs in the field, which would be
relatively difficult to measure, due to variations in the aforementioned variables.

D. OBJECTIVE MEASUREMENTS

The primary objective measurements collected in these evaluations were:

- Elapsed time required to perform a specified task (for most of the off-highway tests);
- Maximum tilt table angle for the static (for the roll static) stability test at which tilt angle the two uphill tires lifted from the table;
- Maximum and minimum fore/aft, lateral and vertical left hand reach distance (from the ergonomic test);
- Eye height above ground (for the forward visibility test)

E. SUBJECTIVE MEASUREMENTS

Subjective ratings of vehicle response and performance attributes, when suitably designed and administered, can provide sensitive and repeatable indices of operator-centered vehicle performance, i.e., vehicle performance as viewed from the operator’s perspective.

A substantial literature and technology exists describing vehicle subjective rating systems and methodologies, which evolved since World War II in, for example, the field of military aircraft handling qualities. For example, McDonnell (1968) reviews some of this history and the various subjective rating methods in use at that time. As stated by McDonnell (1968):

“...The suitability of a manually controlled vehicle to serve its intended purpose is ultimately assessed by a series of judgments. Perhaps the most difficult portion of such an assessment is the evaluation of the vehicle’s handling qualities, which play such a key role in the overall
suitability of the vehicle, and yet have in the past been perplexing even to define satisfactorily.”

McDonnell (1968) defined “handling qualities” as “those characteristics which determine the control nature and behavior of pilot/vehicle systems.”

McDonnell (1968) describes the development of a rating methodology based on psychometric and psychophysics methods, i.e.:

“Psychometric methods provide an approach to these problems, and in this study were used to scale several phrases descriptive of vehicle handling qualities. Thus, quantitative characteristics were derived for contemporary [handling qualities rating] scales through the use of a scaling technique known as the “Method of Successive Intervals,” where data for the method were obtained from a survey experiment.”

In this survey experiment:

“...the rater was instructed to read over a list of phrases arranged in random order. Then each phrase was presented one at a time. The rater was to imagine he were reading a handling qualities report where the test pilot has used the presented phrase in describing a vehicle. The rater was then instructed to indicate his impression of the vehicle, as gained from the phrase, on a graphic scale with end points “most favorable” and “least favorable.”

By analyzing the positioning of each adjective on a blank scale, McDonnell (1968) developed an interval adjectival (i.e., unnumbered, labeled with only verbal descriptors) rating scale, where the scale was anchored to adjectives, and the adjectives were selected and spaced according to a small and uniform “discriminal dispersion” criterion, as further described below.

5 McDonnell (1968), p1.
Generally speaking, and as discussed by McDonnell (1968), definition and application of a suitable rating scale for handling qualities evaluation requires:

- Clarification of the task, to the extent practicable;
- Quantization of the psychometric continuum, between “most favorable” and least favorable” extremes;
- Consideration of discrimination thresholds, i.e., “just noticeable differences” (JNDs), both in terms of linguistic description and physical performance;
- Goal of constant discriminability across the psychometric continuum;
- Application of the methods of successive intervals.

Beyond these requirements, McDonnell (1968) describes how a suitable subjective rating scale can be constructed which:

(a) Is interval in nature (as opposed to an ordinal, cardinal or other non-continuous type);

(b) Is labeled along its span with adjectives rather than numbers;

(c) Uses adjectives which have been previously “tested” using samples of human subjects, wherein they are “placed” by the subjects on a blank linear scale between “most favorable” and “least favorable” extremes; and

(d) For which the resulting selected adjectives:

i. display a tight consensus of meaning (i.e., display small standard deviation (i.e., “discriminal dispersion”) when each adjective is “placed” by a sample of test subjects on a blank
linear scale between “most favorable” and “least favorable” extremes); and

ii. are subsequently positioned on a linear scale according to the average position as “placed” by a sample of test subjects on a blank linear scale between “most favorable” and “least favorable” extremes; and

iii. are relatively evenly spaced between the “most favorable” and “least favorable” extremes of the scale.

Note that in general the adjectival positions resulting from this procedure are not evenly spaced along the scale, as (in any language) the measured psychometric distance between adjacent consensus meanings is not necessarily evenly spaced (e.g., the psychometric “distance” between “Bad” and “Poor” as placed by samples of subjects whose first language is American English is smaller than the psychometric “distance” between “Good” and “Highly Desirable”).

Based on this approach, McDonnell (1968) proposed a “global rating scale for handling qualities evaluation” as illustrated in Figure 7.
During the last several decades, the McDonnell global rating scale has been applied in a series of studies of vehicle handling qualities (e.g., McRuer, et al. (1975)); and has been generalized and extended to the rating of other...
performance attributes (e.g., ride qualities) by removal of the “nearly uncontrollable” adjective.

Examples of rating scales for several performance attributes developed and applied in past ground vehicle studies, and used in the current ATV studies, are illustrated in Figures 8, 9 and 10. Note that those scales for which the adjectival spacing varies is a result of their being based on psychometric surveys done with samples of subjects; whereas those scales for which the adjectival spacing is equal and uniform were ad hoc in nature and not based on psychometric surveys.
Figure 8. Example Rating Form (Task Difficulty, Ride Discomfort and Overall Mobility)
ATV Study Subjective Rating Form

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Rider name</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Rider:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Difficulty</th>
<th>Overall Handling Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ NA</td>
<td>☐ NA</td>
</tr>
</tbody>
</table>

- Effortless
- Easy
- Moderate
- Difficult
- Impossible

- Perfect
- Very Good
- Good
- Fair
- Mediocre
- Poor
- Terrible

<table>
<thead>
<tr>
<th>Ride Discomfort</th>
<th>Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ NA</td>
<td>☐ NA</td>
</tr>
</tbody>
</table>

- None
- Trace
- A Little
- Some
- Moderate
- Annoying
- Strong
- Severe

- Perfect
- Very Good
- Good
- Fair
- Mediocre
- Poor
- Terrible

<table>
<thead>
<tr>
<th>Overall Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ NA</td>
</tr>
</tbody>
</table>

- Perfect
- Very Good
- Good
- Fair
- Mediocre
- Poor
- Terrible

Figure 9. Example Rating Form (Task Difficulty, Overall Handling Quality, Ride Discomfort, Visibility and Overall Mobility)
ATV Study Subjective Rating Form
(Page 3)

Subjective effect of rider body motion on:

- **Pitch Stability**: ☐ NA
  - Large Effect
  - No Effect

- **Roll Stability**: ☐ NA
  - Large Effect
  - No Effect

- **Traction**: ☐ NA
  - Large Effect
  - No Effect

- **Comfort**: ☐ NA
  - Large Effect
  - No Effect

Comments:

Figure 10. Example Rating Form (Subjective Effect of Rider Body Position on Pitch Stability, Roll Stability, Traction and Comfort)
In the “rider active” evaluation tests, rating scales were provided to each ATV expert rider after he completed each type of maneuver, and the rider was instructed to bear in mind the specific task (including the task instructions and any special definitions of terms on the rating scales, read by or to him prior to the maneuver). Each expert rider recorded his rating by inscribing a horizontal tick mark at a position on each adjectival scale (and positioned in relation to the adjectives on the scale) that best represented his subjective impression of the particular attribute being rated. The ratings so recorded were subsequently digitized by an analyst using a 100-point scale, and processed in order to determine mean, minimum and maximum values.

Note that if such ratings were appropriately administered and collected for a larger number of subjects, the resulting data could have been more extensively analyzed in terms of their statistical characteristics. In the current evaluations, which involved a limited number of expert riders, the rating data is intended to be mainly indicative of the range of ratings that occurred for each condition, for the small sample of expert test riders used.

Further descriptions of specific rating term definitions as well as task instructions are given in Appendix A for each performance attribute.
Section III
“RIDER ACTIVE PERCENTAGE” RESULTS

A. DEFINITION OF “RIDER ACTIVE” PERCENTAGE

As the purpose of the current tests was to determine the magnitude of “rider active” effects for a small sample of expert riders, vehicles and courses, for each performance index, the “Rider Active Percentage” was defined and calculated as:

\[
RA\% = \frac{\text{Performance index value with rider active}}{\text{Performance index value with rider passive}} - 1 \times 100\% \quad (1)
\]

This provides a convenient non-dimensional index that expresses the magnitude of the “rider active” effect, which is normalized by the performance index with “rider passive” positioning.

Note that an exception to Equation 1 was made for the three subjective rating scales entitled “Effects of Rider Body Position on Traction”, “Effects of Rider Body Position on Roll Stability” and “Effects of Rider Body Position on Pitch Stability”, respectively. Although the tasks and instructions were essentially the same as for the other subjective rating scales, the rating scales themselves were designed (for no particular reason) to require a direct rating by the test rider of the magnitude of the “rider active” effect, after riding each course, first five times in a “rider passive” manner, and then five times in a “rider active” manner. For graphical display purposes, in order to enable the results to be reported in the same units (i.e., RA\%), for purposes of these bar graphs only, it was arbitrarily assumed that “Large Effect” on these particular three scales (which is at the upper end of the respective scales) was equivalent to \(RA\% = 100\%\) (i.e., a doubling of the “passive” rating).
B. RESULTS

Based on the results presented in Appendices A through D, Figures 11 through 21 present the change in objective and subjective indices between the “rider active” and “rider passive” conditions in terms of the “Rider Active Percentage” for the five off-highway courses/tasks, in accordance with Equation 1.

For purposes of consistency in the discussion, the following terms are used to describe the relative magnitude of the rider active (i.e., RA%) effect for each off-highway course and vehicle configuration:

- Small - RA% less than 10%:
- Substantial - RA% from 10% to 30%:
- Large - RA% from 30% to 100% (i.e., up to double the “rider passive” rating):
- Very large - RA% more than 100% (i.e., more than double the “rider passive” rating)

1. Effect of “Rider Active” on Mobility, Elapsed Time, Five Courses

Figure 11 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the elapsed time Mobility index, for the five off-highway courses. The data indicate that “rider active” positioning can have substantial effects on Mobility-Elapsed Time for the Sinusoidal Bumps, Dry Creek Bed and the 3 Ditch Traversal (with descending magnitude), which were the courses having the largest vertical terrain disturbances. For these courses, the “rider active” effect did not vary strongly with vehicle mass or engine capacity. “Rider active” positioning had mixed effects in the Upslope Sand, increasing the climbing speed with one ATV, and having little or even slowing effects with the other three ATVs. “Rider active” positioning had
very small beneficial effects on Mobility-Elapsed Time in the Closed Circuit
Turns course.
Figure 11. Effect of “Rider Active” on Mobility - Elapsed Time, for 5 courses, 4 ATVs, 3 expert riders, in terms of “Rider Active Percentage”
2. Effect of “Rider Active” on Overall Mobility, Subjective Rating, Five Courses

Figure 12 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Overall Mobility subjective rating, for the five off-highway courses. The data indicate that “rider active” positioning can have substantial beneficial effects on the Overall Mobility subjective rating for the 3 Ditch Traversal and the Sinusoidal Bumps, with some variations due to vehicle. “Rider active” positioning had a large effect on Dry Creek Bed (i.e., up to 50% RA%). “Rider active” positioning had mixed effects on Overall Mobility subjective rating in the Upslope Sand and Closed Circuit Turns, which also varied with vehicle.
Figure 12. Effect of “Rider Active” on Overall Mobility, Subjective Rating
Comparing the subjective results in Figure 12 with the objectively measured elapsed time results in Figure 11, the data suggest that rider subjective perceptions of Overall Mobility – and the effects of “rider active” positioning on it – are somewhat similar in terms of relative ratings to (and therefore may be influenced by) the Mobility-Elapsed Time. However, the Overall Mobility subjective ratings may also be influenced by other subjective variables, since (for example) “rider active” effects are more evident in the Overall Mobility subjective ratings in the Closed Circuit Turns, and less evident in the Sinusoidal Bumps, than they are for Mobility-Elapsed Time.

3. Effect of “Rider Active” on Task Difficulty, Subjective Rating, Five Courses

Figure 13 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Task Difficulty subjective rating, for the five off-highway courses. The data indicate that, depending on the vehicle, “rider active” positioning can have substantial beneficial effects on Task Difficulty for four of the five courses: the Sinusoidal Bumps, 3 Ditch Traversal, the Dry Creek Bed and the Closed Circuit Turns (in order of descending magnitude), and for these courses, the “rider active” effect varied with vehicle. “Rider active” positioning had mixed effects on Task Difficulty in the Upslope Sand, which also varied with vehicle.
Figure 13. Effect of “Rider Active” on Task Difficulty, Subjective Rating
The Upslope Sand results indicate that with vehicle V2, when the expert riders were instructed to use “rider active” positioning (rather than choosing themselves when to use it), the Task Difficulty increased (whereas “rider active” had little effect on Task Difficulty with the other vehicles). This suggests that for vehicle V2, and for this particular Upslope Sand course, shifting the pelvis made the task more difficult. This adverse effect was a relatively rare outcome, and in the majority of courses, vehicles and performance attributes, “rider active” was observed to have beneficial effects, in many cases substantial and in some cases large or very large in magnitude. It is possible that in the Upslope Sand course the riders may have shifted position in order to try to improve traction and dynamic pitch stability of vehicle V2 (which Figures 16 and 18 indicate) but this may have degraded objective and subjective mobility and task difficulty with vehicle V2 (which Figures 11, 12 and 13 indicate).

4. Effect of “Rider Active” on Ride Discomfort, Subjective Rating, Five Courses

Figure 14 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Ride Discomfort subjective rating, for the five off-highway courses. The data indicate that, depending on the vehicle, “rider active” positioning can have very large beneficial effects on Ride Discomfort for the Dry Creek Bed (e.g., with one rider/vehicle, as much as 300% of (i.e., four times) the “rider passive” rating in terms of the “Rider Active percentage”). The Dry Creek Bed course involved a very rough surface interspersed with sandy sections with multiple uphill, down-hill and small radius turn transitions. In addition, depending on the vehicle, “rider active” positioning was observed to have small to large beneficial effects on Ride Discomfort for the Sinusoidal Bumps; and small to substantial beneficial effects on Ride Discomfort for the 3 Ditch Traversal and Upslope Sand courses.
Figure 14. Effect of “Rider Active” on Ride Discomfort, Subjective Rating
5. Effect of “Rider Active” on Overall Handling Quality, subjective rating, five courses

Figure 15 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Overall Handling Quality subjective rating, for the five off-highway courses. The data indicate that, depending on the vehicle, “rider active” positioning can have large beneficial effects on Overall Handling Quality for the Sinusoidal Bumps (i.e., as much as 95% for one vehicle and rider) and Dry Creek Bed. “Rider active” positioning can have substantial beneficial effects on Overall Handling Quality for the Closed Circuit Turns course, depending on the vehicle; and was observed to have small or mixed effects for the 3 Ditch Traversal and Upslope Sand courses.
Figure 15. Effect of “Rider Active” on Overall Handling Quality, Subjective Rating
6. Effect of “Rider Active” positioning on Traction, subjective rating, five courses

Figure 16 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Traction subjective rating, for the five off-highway courses. Note that for purposes of these bar graphs, it was arbitrarily assumed that “Large Effect” on these particular three scales (which is at the upper end of the respective scales) was equivalent to RA% = 100% (i.e., a doubling of the “rider passive” rating). The data indicate that “rider active” positioning can have large beneficial effects on Traction in the Upslope Sand and 3 Ditch Traversal (both of which involved uphill slopes on loose sand), which was not strongly dependent on the vehicle. “Rider active” positioning can have substantial beneficial effects on Traction in the Closed Circuit Turns and Dry Creek Bed and small effects on Traction in the Sinusoidal Bumps course, in which traction was not a major factor.
Figure 16. Effect of “Rider Active” positioning on Traction, Subjective Rating
7. Effect of “Rider Active” positioning on Dynamic Roll Stability, subjective rating, five courses

Figure 17 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Dynamic Roll Stability subjective rating for the five off-highway courses. Note that for purposes of these bar graphs, it was arbitrarily assumed that “Large Effect” on these particular three scales (which is at the upper end of the respective scales) was equivalent to RA% = 100% and “No Effect” equivalent to 0%. The data indicate that “rider active” positioning can have large beneficial effects (RA% = 30 to 100%) on Dynamic Roll Stability for four of the five courses: the Closed Circuit Turns, Sinusoidal Bumps, 3 Ditch Traversal and the Dry Creek Bed (in order of descending magnitude), and for these courses, the “rider active” effect varied somewhat with the vehicle. “Rider active” positioning had small to substantial effects on Dynamic Roll Stability in the Upslope Sand, which varied with the vehicle.

Based on the comments of the expert riders, the riders were apparently quite aware of the roll (lateral lean) displacement of the vehicles during the “minimum time maintaining safety” riding task on all five courses, and preferred to be able to move their pelvis away from the direction of the vehicle lean. The predominantly large effect of “rider active” positioning on Dynamic Roll Stability showed the strongest consensus among the expert riders, across all courses and all vehicles.
Figure 17. Effect of “Rider Active” positioning on Dynamic Roll Stability, subjective rating
8. Effect of “Rider Active” positioning on Dynamic Pitch Stability, subjective rating, five courses

Figure 18 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Dynamic Pitch Stability subjective rating, for the five off-highway courses. Note that for purposes of these bar graphs, it was arbitrarily assumed that “Large Effect” on these particular three scales was equivalent to RA% = 100%. The data indicate that “rider active” positioning can have large beneficial effects on Dynamic Pitch Stability for the Sinusoidal Bumps, 3 Ditch Traversal and Upslope Sand courses, which varied somewhat with the vehicle. “Rider active” positioning had substantial effects on Dynamic Pitch Stability in the Closed Circuit Turns and Dry Creek Bed. As with Dynamic Roll Stability, these substantial to large beneficial effects of “rider active” on Dynamic Pitch Stability did not vary strongly with the vehicle.
Figure 18. Effect of “Rider Active” positioning on Dynamic Pitch Stability, subjective rating
9. Effect of “Rider Active” on Static Roll Stability, tilt table angle

Figure 19 shows the effect of “rider active” positioning in terms of the “Rider Active Percentage” for the Static Stability tilt table angle index, for the three directions of tilt, based on the measurements described in Appendix B. The data indicate that “rider active” positioning can have substantial beneficial effects (i.e., 10 to 20% RA%) on lateral (roll) static stability maximum tilt angle, depending somewhat on the vehicle. Note that the latter value is corroborated by the example results of Rechnitzer, et al. (2003) who found 19% beneficial effect in the direction of lateral tilt.8 “Rider active” positioning had small beneficial effects on uphill and downhill tilt table maximum angle, which also varied somewhat depending on the vehicle.

Note that these effects on objective static stability indices are smaller in magnitude than those observed for the expert rider subjective ratings of Dynamic Roll Stability and Dynamic Pitch Stability in the off-highway riding courses. The latter involve more typical, realistic and complex motions, potentially involving the dynamic roll and pitch displacements of the vehicle (relative to the ground); and (based on the expert riders’ comments) the rider’s sensing of these displacements.

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Figure 19. Effect of “Rider Active” on Static Uphill Stability, Downhill Stability and Cross-slope Stability, Objective Tilt Table Angle

10. Effect of “Rider Active” on Left Hand Reach

Figure 20 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Left Hand Reach volume index, for one example vehicle, based on the measurements and calculations in Appendix C. The data indicate that “rider active” positioning had a substantial to large effect on the left hand reach volume (i.e., 30% RA%). This substantial to large “rider active” effect can be important for utility tasks (e.g., crop spraying, orchard tending, etc.) depending on the specific utility task. Non-rider active vehicles generally have very limited left hand reach volume for such tasks if attempted from within partially or fully enclosed vehicles.
11. Effect of “Rider Active” on Forward Visibility

Figure 21 shows the effect of “rider active” riding in terms of the “Rider Active Percentage” for the Forward Visibility Obstructed Distance objective index, based on one example vehicle and the measurements and calculations in Appendix D. The data indicate that “rider active” positioning (i.e., standing on the footrests) had a large beneficial effect on the Forward Visibility Obstructed Distance (i.e., 45% to 90% RA%). This substantial effect can be important for off-highway route selection, as well as search activities, and provides an advantage that only off-highway vehicles with the highest seating positions may equal. Smaller non-rider active off-highway vehicles have more limited forward visibility Obstructed Distances, due to the lower eye height of the driver. This can be important in identifying drops offs, embankments, ditches or other off-highway hazards, particularly in areas with vegetation and/or terrain visual obstructions.
C. SUMMARY OF RESULTS

Table 3 summarizes the mean, minimum and maximum “rider active percentages” for each subjective rating and objective index, across all expert riders, vehicles, and off-highway courses. The data indicate that “rider active” positioning on average has a large (i.e., greater than or equal to 30%) “mean” beneficial effect on:

- Forward Visibility Obstructed Distance (-62%);
- Ride Discomfort subjective rating (42%);
- Dynamic Roll Stability subjective rating (38%);
- Dynamic Pitch Stability subjective rating (31%);
- Left Hand Reach volume objective index (30%);

Across all subjective ratings and objective indices, expert riders, vehicles, and off-highway courses, “rider active” positioning had a substantial 26% average mean beneficial effect. This beneficial effect is not available to operators of non-rider active vehicles.
In terms of the maximum “rider active percentages” observed, recognizing that single extreme values are not highly reliable indicators, the data in Table 3 indicate that for selected expert riders, vehicles, courses and subjective ratings, “rider active” positioning can in some cases have very large effects, i.e., on:

- Overall Handling Quality (133%);
- Ride Discomfort (310%);
- Overall Mobility (119%).

Finally, in terms of the minimum “rider active percentages” observed, and again recognizing that single extreme values are not highly reliable indicators, the data in Table 3 indicate that for selected expert riders, vehicle, courses and subjective ratings, “rider active” positioning can in some cases have apparent adverse effects. In some cases, this could be the result of tradeoffs that “rider active” positioning may have had on different subjective performance attributes, e.g., “rider active” improving traction and dynamic pitch stability while degrading task difficulty and mobility, as found for vehicle V2 on Upslope Sand in Section III.B.3. The largest apparent adverse effects observed were (each of these for one particular rider, vehicle and course):

- Overall Handling Quality (-40%);
- Task Difficulty (-42%);
- Ride Discomfort (-49%);
- Overall Mobility (-29%).
Table 3. Summary of maximum mean “rider active percentage” for each attribute, index and task

<table>
<thead>
<tr>
<th>Rider Active Percentage</th>
<th>Subjective Ratings</th>
<th>Objective Measurements</th>
<th>Mean$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall Handling Quality</td>
<td>Task Difficulty</td>
<td>Ride Discomfort</td>
</tr>
<tr>
<td>Mean</td>
<td>11</td>
<td>11</td>
<td>42</td>
</tr>
<tr>
<td>Min</td>
<td>-40</td>
<td>-42</td>
<td>-49</td>
</tr>
<tr>
<td>Max</td>
<td>133</td>
<td>77</td>
<td>310</td>
</tr>
<tr>
<td>Count$^2$</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

$^1$ Row-wise mean calculation used the negatives of the “Mobility-Elapsed Time” and “Forward obstructed visibility distance” values, due to improved values being negative for those variables.

$^2$ “Count” refers to the number of measurements, e.g., 5 courses x 3 riders x 4 ATVs = 60.

$^3$ Specific rating categories may comprise fewer than 60 measurements, due to missing data (e.g., failure of a rider to complete all rating scales in some cases).
Section IV
SUMMARY AND CONCLUSIONS

A. SUMMARY

Exploratory experimental objective and subjective measurements were conducted during 2000 to 2004 of the effects of “rider-active” positioning (i.e., the rider shifting his/her pelvis side-to-side on, fore-and-aft on and vertically off the seat) on eight different attributes of All-Terrain Vehicle (ATV)\(^9\) performance, comprising objective and/or subjective measurements of:

- Mobility (objective, subjective)
- Stability (objective static roll stability, subjective dynamic roll stability and dynamic pitch stability)
- Overall handling quality (subjective)
- Task difficulty (subjective)
- Ride discomfort (subjective)
- Traction (subjective)
- Ergonomics/external (objective) reach
- Forward visibility (objective)

A mixture of objective and subjective measurements was used in this exploratory study to quantify the effect of “rider active” body movement because many of the aforementioned performance attributes are highly complex (e.g., overall handling quality, ride discomfort, task difficulty), and at the current time not readily quantified by one or more objective indices.

---

\(^9\) A Type I ATV is defined as “Any motorized off-highway vehicle designed to travel on four low pressure tires, having a seat to be straddled by the operator and handlebars for steering control. ATVs are subdivided into two types as designated by the manufacturer. Type I – A Type I ATV is intended for use by a single operator and no passenger. Type II – A Type II ATV is intended for use by an operator or an operator and a passenger. It is equipped with a designated seating position behind the operator designated to be straddled by no more than one passenger”, according to ANSI/SVIA 1 (2010).
that have been previously demonstrated to be strongly correlated with rider subjective ratings or with incidents (e.g., loss of path control, overturn, collision, etc.). Generally, correlations against subjective data can only be conducted on the basis of suitably designed and controlled experiments involving vehicles in which only one attribute at a time is changed, and which involve objective and subjective measurements, tasks, subject protocols and extensive data reduction and statistical analyses, which was beyond the scope of the reported studies. Likewise, correlation against accident data requires measuring the objective attributes for numerous accident-involved vehicle make-model-years, which was beyond the scope of these studies.

Instead, a sample of existing, exemplar production ATVs was used for the studies. Many of the design parameters and performance attributes of these production ATVs varied simultaneously, so that it was not possible to isolate the effect of any one design parameter or attribute. Rather, the goal was to assess and quantify the “range” of objective and subjective measurements occurring for a set of realistic off-highway riding tasks.

Likewise, as the emphasis of the studies was on collecting objective and subjective data for a “range” of tasks and exemplar vehicles, the focus was not on measuring variations due to rider skill level or training. Accordingly, three ATV expert riders were used for the tests, so that the effects of skill, training and learning effects were controlled for. Past experience has indicated that under suitably controlled experimental conditions, expert riders are more able to follow specified tasks and to report subjective ratings that are more repeatable (i.e., less variable) than would otherwise be the case. By using three expert riders, some effects of inter-rider variability were included in the data, albeit at one (expert) skill level.

The evaluations were conducted in several phases spanning several years, overall including up to eight ATVs, up to nine tasks (including terrain, instructions and conditions) and up to three expert test riders. In all tests, only one person (i.e., the operator) was present on the vehicle.
The objective and subjective (rider-centered) measurements were used to estimate the “rider active percentage” for each performance attribute, task, vehicle and rider. This was defined as the percentage change in each performance index, when “rider active” body movement was used. Mean, minimum and maximum “rider active percentages” were determined and reported for each of these, as well as for groups of tasks, vehicles and riders.

The results of the evaluations indicated that the “rider active percentage” varied widely (i.e., from 0% to 310% (absolute value)), by an amount which was dependent on the particular performance attribute, the task (including the terrain, the instructions and the conditions) and the specific vehicle and rider. The data indicated that “rider active” positioning on average has a large (i.e., greater than or equal to 30%) “mean” beneficial effect on:

- Forward Visibility Obstructed Distance (-62%);
- Ride Discomfort subjective rating (42%);
- Dynamic Roll Stability subjective rating (38%);
- Dynamic Pitch Stability subjective rating (31%);
- Left Hand Reach volume objective index (30%).

Across all subjective ratings and objective indices, expert riders, vehicles, and off-highway courses, “rider active” positioning had a substantial 26% average mean beneficial effect. This beneficial effect is not available to operators of non-rider active vehicles.

Such advantages are not small and can provide important operating margins or advantages for ATV users in these types of conditions.

B. CONCLUSIONS

The magnitude, importance and advantages of the ATV “rider active percentage” depends on the circumstances (i.e., the task (including the
terrain, the goal and the conditions), the specific vehicle and the specific
rider, and the importance of a particular performance attribute to that
circumstance (e.g., a vertical drop-off, embankment, obstacle, ditch or cliff
not being visually obscured by a forward obstacle would be an example of an
important advantage of “rider active” in a potentially critical circumstance).

For many other types of vehicles in which the operator represents a
small fraction of the vehicle weight and in which the operator is restrained
inside the vehicle and sitting on a seat with a seat back, the “driver-active
percentage” is typically (and often negligibly) small, close to, if not
effectively equal to, zero. “Rider active” advantages, adaptability to
circumstances or “margins” are not available to operators of those vehicles.

Some non-rider-active vehicles may conceivably have some advantages
over ATVs in some attributes (e.g., baseline static stability, or baseline ride
discomfort); however, ATVs represent a unique combination of high off-
highway mobility, with a moderate level of static stability and cargo capacity
and adaptability to conditions (via “rider active” positioning).

Among off-highway vehicles, the “rider active percentage” of ATVs in
some cases provides substantial performance advantages, adaptive capability
and adaptive performance “margins,” which can be important or safety
related in some circumstances, and which are not available in non-“rider-
active” vehicles. “Rider active” positioning, which is an inherent feature and
advantage of ATV design involving elongated straddle seats, footrests and
handlebar control, enables the rider to shift position laterally, longitudinally
and vertically, as instructed in training courses and in ATV owner’s manuals,
to enhance and to adapt to the current task and conditions, if/when desired,
the vehicle’s performance envelope (including enhancing mobility, stability,
handling qualities, traction, ergonomics/external reach, and forward visibility,
and/or reducing task difficulty and ride discomfort). “Rider active” operation
is a key part of training courses provided by the ATV Safety Institute
(www.atvsafety.org); and mandatory warning labels on all ANSI/SVIA 1-
compliant ATVs warn users “Never operate without proper training or
instruction”. Many US states require training for ATV operation; and in the US, ATV manufactures provide free training with purchase of any new ATVs.

C. LIMITATIONS

This was an exploratory study of the effects of “rider active” body positioning on several aspects of ATV performance and was not intended to be comprehensive. It was based on a relatively small set of vehicles, riders, courses, soils/terrains, tasks, performance attributes, and categories of subjective ratings and objective indices. Nevertheless, the samples used were considered to be representative of the ATV market. Larger sets of these factors would be needed for a comprehensive study of “rider active” effects including more robust statistical analyses. The results reported provide a rough indication of the relative magnitude of “rider active” effects, relative to a non-“rider active” condition; and the resulting magnitudes were found to be substantial or large for some tasks, conditions, vehicles and expert riders. Further more specific identification of the magnitude of “rider active” effects would require expansion of the test matrix, protocols, indices and data set.
REFERENCES


Anon., Department of Defense Dictionary of Military and Associated Terms; Joint Publication 1-02; 8 November 2010 (As Amended Through 15 March 2013).


APPENDIX A
DESCRIPTION OF FIVE OFF-HIGHWAY RIDING COURSES, TASK DESCRIPTIONS, RIDER INSTRUCTIONS AND RESULTS

1. COURSE DESCRIPTIONS

Test riders completed a series of five defined courses and tasks, alternatively using “rider active” and “rider passive” body positions. Each maneuver was designed to focus on a particular aspect of mobility, for instance roll stability while turning, ride discomfort while traversing a particular type of rough terrain and pitch stability and traction when climbing steep sandy slope. As previously summarized in Table 2, the off-highway test courses comprised:

- Sinusoidal bumps
- Closed circuit turns
- Dry creek bed
- Upslope sand
- 3 ditch traversal

The courses were delineated by existing terrain features as well as by marking cones at the start and finish, and for some of the courses at intermediate points to assist in route guidance.

All of the courses were ridden under dry soil conditions with a single person (i.e., the operator) on the ATV.

2. TASK INSTRUCTIONS

The expert riders were instructed to traverse each course “as quickly as possible while maintaining safe operation.” This required each expert test rider to exercise judgment so as to traverse each course in minimum time.
while maintaining full control of the vehicle. This may be similar to what occurs in some recreational and utility riding. As discussed in Section II.C, in the current evaluations, this was done to provide some level of experimental repeatability and reproducibility.

The elapsed time required to complete each maneuver, and test rider subjective ratings of various attributes, were recorded.

3. RATING INSTRUCTIONS

For each riding course, the subjective attributes considered most relevant to the given course were rated by each expert rider. Table A.1 lists the subjective attributes that were rated for each course.

Table A.1. Subjective attributes rated for each riding course

<table>
<thead>
<tr>
<th>Course</th>
<th>Overall Mobility</th>
<th>Task Difficulty</th>
<th>Ride Discomfort</th>
<th>Overall Handling Quality</th>
<th>Effect of Body Position on:</th>
<th>Traction</th>
<th>Roll Stability</th>
<th>Pitch Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Bumps</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Closed Circuit Turns</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Dry Creek Bed</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Upslope Sand</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3 Ditch Traversal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Following completion of each course, each expert rider was instructed to mark the relevant subjective rating scale with a horizontal line relative to the adjectives spanning the scale that best described his impression in regard to the respective attribute for the given vehicle, course and riding position (i.e., active or passive).

Each expert rider was instructed before and after riding each course that the following attribute definitions were to be used when making the respective evaluation and recording the rating:

“Overall Mobility - subjective speed or ease with which the vehicle traverses the given terrain. [Overall] Handling [Quality] and [R]ide [D]iscomfort may affect this rating, but do not necessarily affect it.”

“Task Difficulty - how difficult it was to perform the specified task. The specified task includes the course that you are to negotiate, and the manner in which you are instructed to perform the task, for example, rider centered or rider-active position.”

“Ride Discomfort - Physical discomfort due to vertical, pitching, rolling or fore/aft vehicle motions.”

“Overall Handling Quality – overall quality of the vehicle’s steering response in keeping the vehicle on the intended path.”

“Effect of Rider Body Positioning on Traction” – how effective “rider active” positioning was in comparison to “rider passive” positioning in enabling the vehicle to move forward (to be completed after two series of five runs each, under “rider passive” followed by “rider active”)

“Effect of Rider Body Positioning on Roll Stability” - how effective “rider active” positioning was in comparison to “rider passive” positioning in increasing resistance of the vehicle to overturning to the left or right (to
be completed after two series of five runs each, “rider passive” followed by “rider active”)”

“Effect of Rider Body Positioning on Pitch Stability” - how effective “rider active” positioning was in comparison to “rider passive” positioning in increasing resistance of the vehicle to overturning to the left or right (to be completed after two series of five runs each, “rider passive” followed by “rider active”)”

4. RESULTS

The subjective ratings of each expert rider for each attribute, each course/task, and each vehicle were digitized using a 100 point scale. The data, along with the objectively measured elapsed time, were analyzed in order to calculate the mean and the maximum and minimum values for each attribute, course/task and vehicle. The results are presented subsequently.

a. Mobility, elapsed time

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum elapsed time for the various courses/maneuvers, vehicles and rider active versus rider passive positioning are shown in Figure A.1.

The elapsed time data indicate substantial effects of rider active positioning, particularly for the Sinusoidal Bumps, the Dry Creek Bed and the 3 Ditch Traversal courses. The elapsed time data indicate substantially lower objective Mobility on these courses when the riders remained seated and centered on the seat.
Figure A.1. Effect of “Rider Active” Position on Mobility, Elapsed Time, Five Courses
b. Mobility, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum Mobility subjective rating for the various courses/maneuvers, vehicles and rider active versus rider passive positioning are shown in Figure A.2. In the Mobility subjective rating data, the vertical numerical scale of 0-100 corresponds to the full range of the adjectival scale used on the rating forms.
Figure A.2. Effect of “Rider Active” Position on “Overall Mobility”, Subjective Rating, Five Courses
c. Task Difficulty, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum Task Difficulty subjective rating for the various courses/maneuvers, vehicles and rider active versus rider passive positioning are shown in Figure A.3.
Figure A.3. Effect of “Rider Active” Position on “Task Difficulty”, Subjective Rating, Five Courses
d. Ride Discomfort, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum Ride Discomfort subjective rating for the various courses/maneuvers, vehicles and rider active versus rider passive positioning are shown in Figure A.4.
Figure A.4. Effect of “Rider Active” Position on “Ride Discomfort”, Subjective Rating, Five Courses
e. Overall Handling Quality, subjective rating

Vehicle handling qualities (in relation to aircraft and other vehicles) refer to "those qualities or characteristics which govern the ease and precision with which an operator is able to perform the tasks required in support of the vehicle role."\textsuperscript{10} Often for ground vehicles, it can be more narrowly defined as "the way wheeled vehicles perform transverse to their direction of motion, particularly during cornering and swerving. It also includes their stability when moving in steady state condition."\textsuperscript{11} "Overall Handling Quality" refers to the vehicle’s response to steering (at all speeds and magnitudes) and to lateral/directional disturbances (e.g., especially terrain irregularities for off-highway vehicles).

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum Task Difficulty subjective rating (across riders) for the various courses/maneuvers, vehicles and “rider active” versus “rider passive” positioning are shown in Figure A.5.

Figure A.5. Effect of “Rider Active” Position on “Overall Handling Quality”, Subjective Rating, Five Courses
f. Effect of Rider Active Positioning on Traction, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum subjective rating for the Effect of Rider Active Positioning on Traction for the various courses/maneuvers and vehicles are shown in Figure A.6.
Figure A.6. Effect of “Rider Active” Position on “Traction”, Subjective Rating, Five Courses
g. Effect of Rider Active Positioning on Dynamic Roll Stability, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum subjective rating for the Effect of Rider Active Positioning on Roll Stability for the various courses/maneuvers and vehicles are shown in Figure A.7.
Figure A.7. Effect of “Rider Active” Position on “Dynamic Roll Stability”, Subjective Rating, Five Courses
The results indicate relatively large effects of “rider active” positioning on Dynamic Roll Stability in those courses involving lateral maneuvers and/or terrain inputs (i.e., the Dry Creek Bed, the Closed Course Turns and the 3 Ditch Traversal, for some ATVs); and on Pitch Stability in those courses involving longitudinal maneuvers and/or terrain inputs (e.g., the Sinusoidal Bumps and Upslope Sand for some ATVs.

h. Effect of Rider Active Positioning on Dynamic Pitch Stability, subjective rating

Bar graphs comparing the mean (across riders) as well as the maximum and the minimum Effect of Rider Active Positioning on Pitch Stability subjective rating for the various courses/maneuvers and vehicles are shown in Figure A.8.
Figure A.8. Effect of “Rider Active” Position on “Dynamic Pitch Stability”, Subjective Rating, Five Courses
1. DESCRIPTION

Stability is defined as “the property of a body that causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments that restore the original condition”.\textsuperscript{12} Stability can be further subdivided into “dynamic stability” wherein the forces and moments restore the “previously established steady motion”;\textsuperscript{13} and “static stability” wherein the forces and moments restore the previously established “at rest” condition.

As an objective measurement of “static stability”, the following index of ATV static stability was evaluated (with an amount and type of Rider Active positioning, using an expert rider, that was subjectively selected by the expert rider):

- Maximum lateral Tilt Table Angle (TTA), with rider active and rider passive) at which three or more tires remain in contact with the surface

This involved using tilt table test methods to objectively measure the effects of rider-active positioning on the static stability of example ATVs, and in particular how rider pelvis positioning affects static stability as measured statically on a tilt table.

\begin{itemize}
  \item \textsuperscript{12} \url{http://www.merriam-webster.com/dictionary/stability}, definition 1(b), accessed 25 October 2013.
  \item \textsuperscript{13} \url{http://www.dictionaryofengineering.com/definition/dynamic-stability.html}, accessed 25 October 2013.
\end{itemize}
2. EVALUATION CONDITIONS

For the tilt table measurements, one simple measurement of static stability, as described for example in Lenkeit, et al. (2009) for ATVs and in ANSI/ROHVA 1-2011 for side-by-side vehicles, is accomplished by placing a vehicle entirely on a table which tilts about an axis and raises one side of the vehicle higher than the other. As the table continues to tilt, it eventually reaches an angle at which both “high side” tires lift from the table, and the vehicle will begin to tip if it is not restrained. The procedure is repeated for both leftward and rightward tilts.

Generally, for vehicles which have seats with a seatback and restraint belts, it is possible and repeatable to place a surrogate mass representing each occupant at standardized centered locations on the seats, as in, for example, the ANSI/ROHVA 1-2011 standard.

For vehicles such as ATVs, which are designed to enable rider active positioning, there is currently no standardized method for positioning such a surrogate mass in a way that would represent “rider passive” or “rider active” positioning. In addition, since ATVs are relatively light weight, the exact mass and mass distribution (e.g., head/neck, upper torso, lower torso, upper extremities, and lower extremities) of the individual test rider can influence the results. Therefore, and especially because the purpose of the current evaluations was to assess the effects of “rider active” positioning, an actual (engineering test) rider, with mass and stature close to 50th percentile adult male, was used for the tilt table tests. In this way, it was at least ensured that the positioning represented realistic human positioning, corresponding to that selected by at least one test rider on the occasion of these tests.

As the tilt table angle was increased, the expert rider was instructed to shift his pelvis so as to attempt to keep the uphill tires in contact with the surface of the table, with the only constraints being that each hand was gripping the respective handgrip so as to be able to operate the hand...
controls in a normal manner and each foot was placed on the respective footrest.

Figure 1 illustrates an example tilt table test in progress with the engineering test rider, using the procedures that define “rider passive” positioning, as discussed in Section I. Again, there may be issues with the repeatability and reproducibility of this method (e.g., due to an individual rider’s exact body part weight distribution, and due to exact flexion angles of the head, neck, shoulders, elbows, waist, hips, knees and ankles). However, the purpose of the current study was to assess the approximate magnitude of the “rider active” effect, rather than to determine any statistical distribution of such effects.

3. RESULTS

Bar graphs comparing maximum lateral Tilt Table Angle for three of the vehicles and for “rider active” versus “rider passive” positioning are shown in Figure B.1. The height of each bar represents the average maximum tilt angle for left and right tilt.
Figure B.1. Effect of “Rider Active” Positioning on Lateral Tilt Table Results
1. DESCRIPTION

“Ergonomics/Left Hand Reach” refers to the ability of an ATV rider to use his left hand to perform a variety of tasks, including utility tasks, that could include, for example, accomplishing various crop (including orchard or vineyard tending, etc.) tasks and/or equipment related (e.g., weed or crop sprayer) tasks. For such “reach” tasks, in practice the vehicle may be stopped; or potentially it may be proceeding at very low speed, controlled by the right hand which operates the throttle control, one of the brake controls and the steering grip, as well as by the right foot brake. In addition, the ATV rider can be sitting (i.e., “rider passive”) or standing (i.e., “rider active”).

2. TEST PROCEDURES

A series of measurements were made to quantify the left hand reach of a 50th percentile male engineering expert rider under “rider passive” (seated centered) and “rider active” (standing on footrests, right hand on handgrip) conditions. These measurements were previously reported in Zellner, et al. (2004).

Figures C.1 (top view) and C.2 (rear view) show multiple exposure photographs of the left hand reach of a 50th percentile male rider seated on the baseline ATV, in the horizontal and vertical transverse planes.

Figure C.3 (rear view) shows multiple exposure photographs of the left hand reach of a 50th percentile male rider standing on the footrests of the baseline ATV, in the vertical transverse plane. For the analysis, the top view standing reach was assumed to be the same as the top view sitting reach.
Figure C.1. Top View of Left Hand Reach in Horizontal Plane, Baseline ATV, Rider Sitting
Figure C.2. Rear View of Left Hand Reach in Vertical Transverse Plane, Baseline ATV, Rider Sitting
Figure C.3. Rear View of Left Hand Reach in Vertical Transverse Plane, Baseline ATV, Rider Standing
3. RESULTS

Table C.1 summarizes the approximate measurements of left hand reach, and the estimated area and semi-spherical volume of reach for the “rider passive” (seated) position and the “rider active” (standing) position. From this it is observed that the left hand reach volume is increased by approximately 30 percent when the rider is able to use both the seated and standing reach volumes.

Table C.1. Estimates of left hand reach zones

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Baseline ATV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seated:</strong></td>
<td></td>
</tr>
<tr>
<td>Horizontal plane angle (deg)</td>
<td>200</td>
</tr>
<tr>
<td>Horizontal plane extent (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>Horizontal area (m²)</td>
<td>3.9</td>
</tr>
<tr>
<td>Vertical plane angle (deg)</td>
<td>170</td>
</tr>
<tr>
<td>Vertical plane extent (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>Vertical arc area (m²)</td>
<td>3.3</td>
</tr>
<tr>
<td>Estimated Volume (fractional sphere)(m³)</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>Standing:</strong></td>
<td></td>
</tr>
<tr>
<td>Horizontal plane angle (deg)</td>
<td>200</td>
</tr>
<tr>
<td>Horizontal plane extent (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>Horizontal area (m²)</td>
<td>3.9</td>
</tr>
<tr>
<td>Vertical plane angle (deg)</td>
<td>170</td>
</tr>
<tr>
<td>Vertical plane extent (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>Vertical arc area (m²)</td>
<td>3.3</td>
</tr>
<tr>
<td>Vertical cylinder height (standing-seated)(m)</td>
<td>0.5</td>
</tr>
<tr>
<td>Estimated Volume (fractional sphere plus fractional cylinder) (m³)</td>
<td>8.6</td>
</tr>
<tr>
<td>Percentage increase in reach volume (%)</td>
<td>30.</td>
</tr>
</tbody>
</table>
In addition, it is obvious that when standing, the rider may be able to reach higher when standing (e.g., to 9.3 ft (2.85 m) in this example) than when sitting (e.g., to 8.0 ft (2.85 m) in this example). This might be important for some utility (e.g., orchard tending, forestry, overhead structure maintenance) tasks.

Note that, as reported in Zellner et al. (2004), the left hand reach volume is substantially smaller (e.g., by 94%) if the ATV was to be modified with, for example, a ROPS with a torso-lap belt restraint system.
APPENDIX D
OBJECTIVE FORWARD VISIBILITY EVALUATION

A. DESCRIPTION

“Forward Visibility” refers to the operator’s range of (directly) forward vision, as determined by his eye height relative to visual obstructions that may lie in front of him/her. Forward visibility is related to safety, and is also important in some utility applications (e.g., route finding, livestock round-up, search and rescue, etc., in hilly terrain, and in particular in the presence of ground vegetation and/or obstructions). Lowering the operator’s eye point can adversely affect the range of forward visibility; and conversely, raising the operator’s eye point (e.g., by standing, i.e., “active riding” positioning) can extend forward visibility. This functional behavior can be observed among ATV riders in the real world.

A simplified geometric analysis was conducted of the visibility range for a 50th percentile adult male rider and typical (i.e., Vehicle 2) ATV dimensions. This was derived as a function of eye height, obstacle distance from the ATV and obstacle height above ground level. These results were previously reported in Zellner, et al. (2004).

B. RESULTS

Table D.1 presents measurements of the eye height of a 50th percentile rider while seated and while standing on the baseline ATV; and while seated in an ATV fitted with a prototype ROPS.
Table D.1. Measured rider eye height data

<table>
<thead>
<tr>
<th>Vehicle /position</th>
<th>Eye Height for 50th Percentile male (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline ATV, rider seated</td>
<td>1.59</td>
</tr>
<tr>
<td>Baseline ATV, rider standing (in riding position)</td>
<td>1.90</td>
</tr>
</tbody>
</table>

In order to assess the effects of these differences on visibility range, a simple geometric model of an obscured visibility zone was developed, which was then used to compare rider visibility in these conditions.

Figure D.1 illustrates the rider’s eye point, at a height $h_R$ above the ground, in relation to a typical obstacle of height $h_o$, which is located at a distance $d_o$ from the rider. The zone behind the obstacle is obscured, out to a distance $d_o$ from the rider. Beyond a distance of $d_v$, the rider is able to see the terrain (assuming in this example that it is level and flat). The zone (or distance) that is obscured by the obstacle is $d_v$ minus $d_o$, which can be calculated from simple geometry, knowing the height of the rider and obstacle, and distance of the obstacle.

Figure D.1. Simple model of zone obscured by an obstacle as affected by rider eye height

Figure D.2 shows the effect of obstacle height and driver eye height on obscured visibility zone, for a modified ATV which was lowered and fitted.
with ROPS as described in Zellner, et al. (2004) and for the baseline ATV, for an obstacle positioned 10 m in front of the rider. For all obstacle heights, the “obscured visibility zone” is greater for the ROPS ATV than for the baseline ATV for the rider seated, and especially for the rider standing. For an obstacle height of, for example, 1.4 m, the obscured zone is about 100 m long for the ROPS ATV, 75 m long for the Baseline ATV with rider seated, and 30 m long for the Baseline ATV with rider standing. It can be seen that the “rider standing” position has a substantial benefit in terms of obscured distance across the range of obstacle heights; and that the differences are greater when the obstacle is about the same height as the seated driver’s eye position, as would be expected.

These differences in visibility, although seemingly self-evident, are important for farm and other off-highway work environments, where safe route-finding on cross country terrain, and the need to search for people, animals, objects or terrain hazards can be frequent tasks.

![Obstructed Visibility Zone Beyond Obstacle as a Function of Obstacle Height (Obstacle at 10 m)](image)

Figure D.2. Effect of obstacle height on obscured visibility zone, for ATV ROPS and baseline ATV, for obstacle at 10 m distance
Figure D.3. Effect of obstacle distance on obscured visibility zone, for ATV ROPS and baseline ATV, for 1.5 m obstacle height

Figure D.3 shows the effect of obstacle distance and driver eye height on obscured visibility zone, for a 1.5 m high obstacle, as another example. Here, the obscured visibility zone is 4 times as long (i.e., 300% longer) for the seated rider, as it is for the standing rider. For example, for an obstacle distance of 10 m, the obscured zone is 500 m long for the seated position, whereas it is 125 m long for the standing position.

This difference in visibility can be of substantial importance in many off-highway situations, and indicates a benefit of “rider active” positioning in off-highway operation.
APPENDIX E
DISCUSSION OF VEHICLE MOBILITY AND RELATED FACTORS

Mobility can be defined as the capacity of a vehicle to traverse a given course over a given terrain. This capacity can be described in terms of a “Go/No Go” capability (as in early military evaluations); or as the average maximum speed over the defined course and terrain (see Appendix A.4.a). It can also be based on subjective ratings by trained evaluators based on operation over specified courses.

Vehicle mobility can be influenced by a wide variety of factors, including:

- Task difficulty (i.e., generally, mobility tends to decrease as the “task difficulty” (i.e., the severity) of the course and terrain increases);

- Stability (i.e., if a vehicle cannot climb, descend or traverse steeply sloped terrain due to its pitch or roll stability limits, its mobility on such terrain will be limited);

- Overall Handling Qualities (i.e., vehicle’s path-following capability (which is a component of mobility) can be affected by factors such as minimum turning radius, steering response, etc., in following narrow, winding off-highway paths);

- Ride Discomfort (i.e., extremely rough terrain or limited operator/vehicle capability to absorb motion and vibration inputs (e.g., approaching subjectively “painful” limits) can limit mobility on such terrain (e.g., Go/No Go, and/or the speed at which such terrain can be traversed));
- Traction (i.e., particularly under low traction conditions (e.g., loose sand, gravel, mud, wet grass, etc.) mobility may be limited by traction);

- Forward visibility (i.e., if forward visibility is significantly obstructed by whatever factor (e.g., low seating position, overhead and forward vehicle structures and/or equipment) the mobility (e.g., speed over terrain) can be reduced)

- Other factors

The above factors influencing mobility – and the effects of rider active positioning on them – were also evaluated, in some cases using the same test courses and tasks, as described in Appendices A and D of this report.

While there are numerous factors that affect vehicle mobility, a typical composite objective index of mobility is the average speed at which a vehicle can travel over a given terrain, or equivalently, the elapsed time to complete a specified course. A portion of this study implemented methods for conducting evaluations of ATV mobility, using time over specified courses as a mobility index.

Mobility has been of high importance to military planners for more than a century. For example, the US Department of Defense currently defines mobility as “A quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission.”\(^{14}\) With regard to ground vehicles, this can include the capability to traverse various types of terrain, where a commonly accepted index of mobility is the average maximum speed at which a vehicle can traverse a specific course or terrain. For example the NATO Reference Mobility Model (NRMM) is a computer-based simulation tool that is widely accepted in the

\(^{14}\) Anon., Department of Defense Dictionary of Military and Associated Terms; Joint Publication 1-02; 8 November 2010 (As Amended Through 15 March 2013)
mobility community as a means to predict a vehicle’s steady-state operating capability (i.e., maximum effective speed) over specified terrain. The NRMM can perform predictions of a vehicle’s effective maximum speed on-road and cross-country. The NRMM is a mature technology that was developed and proven by the U.S. Army Waterways Experimental Station (WES) and the U.S. Army Tank-Automotive and Armaments Command (TACOS) over several decades.\textsuperscript{15}

Mobility is an important factor when evaluating the utility of ATVs, especially when design changes are being considered that could affect mobility. Mobility provides access to off-highway terrain, whether it is for recreational or utility purposes. For example:

- Making an ATV wider may limit the capability of an ATV to maneuver between trees, vegetation, rocks or on narrow trails;

- Making an ATV wider or longer may limit the ability of the ATV to traverse large mounds, rocks, embankments, “crowns” or banks (due to grounding the vehicle under its center);

- Making an ATV lower may likewise limit the ability of the ATV to traverse large mounds, rocks, embankments or “crowns”;

- Requiring a rider to remain seated during operation can limit the speed at which the ATV can be comfortably (or tolerably) operated on rough terrain, which is another type of mobility limit, which limits the operating range of the vehicle during a given time interval (e.g., per hour or per day), and which also adversely affects rider discomfort.

– Making an ATV lower or requiring the rider to remain seated can increase the obscured visibility distance, reducing the average operating speed when route-finding when the terrain is obscured by vegetation and/or obstacles.