BEFORE THE
UNITED STATES CONSUMER PRODUCT SAFETY COMMISSION

JOINT COMMENTS OF
AMERICAN HONDA MOTOR CO., INC., AMERICAN SUZUKI MOTOR CORPORATION, ARCTIC CAT INC., BOMBARDIER RECREATIONAL PRODUCTS INC., DEERE & COMPANY, KAWASAKI MOTORS CORP., U.S.A., POLARIS INDUSTRIES INC., and YAMAHA MOTOR CORPORATION, U.S.A.

VOLUME II

All Terrain Vehicles; **Advance Notice of Proposed Rulemaking;** **Request for Comments and Information** **70 Fed. Reg. 60,031 (Oct. 14, 2005)**	**ATV ANPR**

December 13, 2005

Dynamic Research, Inc.

TECHNICAL ANALYSIS IN RESPONSE TO CPSC ANPR QUESTIONS 3, 4, 5, 6 and 13

12 December 2005

355 Van Ness Ave • Torrance • California 90501 • 310-212-5211 • Fax 310-212-5046 • www.dynres.com

This document provides a review and analysis of a series of questions raised in the recent CPSC Advanced Notice of Proposed Rulemaking (ANPR) in regard to All Terrain Vehicles (ATVs) of October 2005.

The response to each ANPR question begins with a restatement of the question, a discussion of clarifying points and any assumptions needed in order to answer the question, and technical discussion of the topic.

ANPR Question 3: "Technical reports of testing, evaluation and analysis of the dynamic stability, braking and handling characteristics of ATVs currently on the market," including non-ANSI ATVs.

A global literature search and review found no recent published reports (after 2000) describing testing, evaluation and analysis of the dynamic stability, braking and handling of ATVs currently on the market.

A small additional amount of recent data was found regarding ATV static stability measurements for current models. In addition, further static stability characteristics for current ATV models were measured for purposes of this response to the ANPR, which are described below.

1) Published current ATV static stability data

A technical report by Rechnitzer et al[1] (2003) reports on the lateral static stability index, Kst (or SSF), based on tilt table measurements of a 2002 Honda TRX 350. A detailed review and critique of this report by Zellner, et al[2] (2004) indicated errors in the Rechnitzer, et al, measurements and associated conclusions regarding ATV static stability, and presented alternate tilt table based Kst measurements for the same vehicle in an appendix.

Lenkeit, et al[3] (2005) recently measured for the US Bureau of Land Management the static stability of a sample of ATVs and other small utility vehicles, using tilt table methods, for up-slope, down-slope and cross-slope directions. For the most part, the purpose of that study was to develop simple field evaluation methods for measuring the effects on static stability of accessory and cargo loads, and therefore most of the measurements are oriented toward that purpose. A 200 lb "surrogate rider" ballast device and seating procedure were proposed in order to represent the effects of a large, centered rider on static stability. Table 1 lists some of the data from the

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[1] Rechnitizer, et al, All Terrain Vehicle Injuries and Deaths, Monash University Accident Research Centre, March 2003.

[2] Zellner, et al, Review and Analysis of MUARC Report: "ATV Injuries and Deaths," and Additional Simulations and Initial Testing of MUARC ATV Rollover Protection System (ROPS), Technical Report 04-01, Volumes I, II and III, Dynamic Research, Inc, 2004.

[3] Lenkeit, J. F., et al, Pilot Study for ATV Tilt Table Procedure Development, Dynamic Research Inc. Technical Memorandum 05-45-2, for US Bureau of Land Management, December 2005.

study, for a few ATV examples. This is based on the "Tilt Table Ratio" (see ANPR Question 5 below), which is defined as the tangent of the maximum tilt table angle when 2-wheel lift occurs.

Generally speaking, for the procedure with the 200 lb "rider surrogate" ballast in place, the up slope TTR values are the greatest, followed by the down slope TTR values, followed by the cross slope TTR values.

Table 1. Tilt Table Ratio measurements for small sample of ATVs (Lenkeit, et al (2005)

ATV			TTR value with 200 lb rider surrogate		
Make	Model	Year	up slope	down slope	cross slope
Yamaha	YFZ450	2004	0.89	1.11	0.66
Honda	TRX300	2003	0.97	1.13	0.65
Honda	TRX400	2003	0.98	1.10	0.58

2) Additional sample of ATV Tilt Table Ratio (TTR) measurements

In order to respond to the ANPR, a sample of current and recent production ATVs was measured using the Tilt Table Ratio method (see ANPR Question 5 below). The sample included both ANSI-defined ATVs and non ANSI-defined ATVs.

Table 2 presents Tilt Table Ratio (TTR) results for the sample of current and recent production ATVs. Generally speaking, the up-slope TTR values are the greatest, followed by the down-slope TTR values, followed by the cross-slope TTR values. As noted in the discussion under ANPR Question 5 below, these values are for a 200 lb "surrogate rider" ballast placed 6 inches above the un-deformed seat surface, centered above the centers of the left and right footrests. It was not determined whether a 200 lb rider is suitable or typical for all of these vehicles (i.e., such a rider perhaps would not be for the TRX90 youth model, for example). In addition, the results do not reflect "rider active" displacement of the rider's body, including for example, instinctive uphill lean by virtually all riders, and shifting the hips on the seat in the uphill direction by trained and experienced riders. These rider-active effects, some of which are always present in real riding, would result in larger values for TTR. The amount by which the TTR would become larger would vary depending on rider size and weight, the amount of rider-activity, and ATV weight and seating layout.

Table 2. Tilt Table Ratio results for sample of current and recent production ATVs

No.	Make	Model	Year	Weight (lb) no rider	Tilt Table Ratio		
					Up-Slope	Down-Slope	Cross-slope
1	Honda	TRX90	2006	248	0.75	1.06	0.57
2	Honda	TRX500 FE	2006	626	0.99	1.08	0.62
3	Honda	TRX500FA	2006	628	0.97	1.01	0.62
4	Honda	TRX680 FGA	2006	629	0.92	0.94	0.63
5	Honda	TRX250 EX	2006	380	0.76	1.05	0.58
6	Honda	TRX450 ER	2006	392	0.81	1.11	0.68
7	Honda	TRX400 FGA	2006	585	0.95	1.07	0.59
8	Honda	TRX250 TE	2006	434	0.85	1.04	0.55
9	Honda	TRX300 EX	2006	392	0.74	1.06	0.58
10	Honda	TRX400 EX	2005	391	0.76	1.08	0.66
11	Yamaha	Kodiak 450 4x4	2005	583	1.04	1.01	0.56
12	Suzuki	Eiger Quadrunner 4x4	2004	624	1.01	1.01	0.58
13	Bombardier	Outlander XT 800 4x4	2006	771	0.93	1.06	0.57
14	Alpha Sports	Kolt 90	2005	256	0.64	0.86	0.55
15	Yamaha	YFZ 450	2006	376	0.84	1.13	0.69
16	Kymco	Mongoose 250	2006	441	0.84	0.98	0.55
17	Yamaha	Grizzly 600 4x4	2006	644	0.94	1.04	0.60
18	Polaris	Sportsman 500 HO 4x4	2006	763	0.90	1.04	0.63
19	Suzuki	King Quad 700 4x4	2005	668	1.01	1.07	0.67
20	Yamaha	Raptor 80	2002	252	0.80	1.08	0.51
21	Bombardier	Outlander Max XT 400 4x4 (1 up)	2004	750	1.15	1.11	0.64
22	Bombardier	Outlander Max XT 400 4x4 (2 up)	2004	750	0.91	1.08	0.54
23	Arctic Cat	500 4x4 Auto (1 up)	2003	780	1.19	1.15	0.72
24	Arctic Cat	500 4x4 Auto (2 up)	2003	780	0.94	1.11	0.62

ANPR Question 4: "Technical reports or standards that describe minimum performance requirements for stability, braking and handling characteristics for ATVs".

1) Minimum performance requirements for ATV stability and braking

a) ANSI (1990, 2001), static pitch stability and dynamic braking tests[4]

The original version and the first revision of the ANSI Standard for ATVs included two relevant tests for stability and braking, namely static pitch stability (Kp) and dynamic braking performance.

The Kp test is described elsewhere in this report, and is basically the ratio of the wheelbase, to 2 times the c.g. height, measured without the rider. The ANSI Standard requirement is that ATVs have a Kp value of at least 1.0.

The ATV service braking test is a dynamic braking test based on a simplified version of the post-burnish brake effectiveness test for motorcycles, specified in US/FMVSS 122. The ANSI Standard requirement is that ATVs with maximum speeds capability greater than 18 mph be able to achieve an average braking deceleration of 0.6g or greater.

2) Minimum performance requirements for ATV handling characteristics

Currently, worldwide, there are no known minimum performance requirements for handling characteristics of ATVs, or of any on-road or off-road vehicle, despite more than 50 years of research and testing development in this area.

There are literally hundreds of objective and subjective handling test procedures in use worldwide, yet no public domain performance standards for handling exist. This is because customer preferences and design tradeoffs play major roles in vehicle handling. In addition, it is relatively complex, multi-variable and with many diverse aspects, therefore making it a difficult area to standardize. In addition, it has historically been extremely difficult to extract from accident data evidence that one or another type or range of handling qualities is over- or under-represented in accident statistics. Additionally complicating is the fact that the handling

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[4] American National Standard, Four Wheel All-Terrain Vehicles-Equipment, Configuration, and Performance Requirements, ANSI/SVIA-1-1990, 1990; Revised ANSI/SVIA-1-2001, 2001.

characteristics of accident involved vehicles cannot be described by one or two variables, but rather those for each vehicle can include, for example, as described by Kunkel and Leffert (1988) for passenger cars in the discussion under ANPR Question 5 below, at least 24 different handling parameters.

Perhaps the closest thing to "handling criteria" in the US was the 1975 Interim Experimental Safety Vehicle (IESV) Specification. This comprised some approximately 13 handling tests, and response boundaries or criteria that were based on an "envelope" of characteristics measured for a sample of vintage 1973 passenger cars. This specification was used as a way to ensure "baseline" or "typical" car handling characteristics were included the new, innovative vehicles constructed under the "Experimental Safety Vehicles" program of the US/DOT/NHTSA in the 1970s. Many of these ESV vehicle prototypes were built by small companies with little or no automotive design background. As a consequence, it cannot be said that the IESV performance criteria were safety-related, or were able to discriminate safe from unsafe vehicles. The types of tests included were arguably safety-related, in some cases.

Further discussion of some of the extensive past and current research into passenger car, light truck and ATV handling test procedures and metrics is provided under the discussion for ANPR Question 5 below.

Several papers were found that discussed ATV handling and stability criteria, and these are mentioned here and in ANPR Question 5.

a) Allen, et al (1989b), criteria for ATV static, steady state and transient steering stability[5]

This report presents limited amounts of tire data, theoretical discussion and ATV circle test data, as well as recommendations regarding ATV handling criteria.

Unfortunately, various erroneous, misleading and baseless statements are made. These include:

- "The oversteer characteristics of three wheelers can lead to spin out during hard transient maneuvering...(p 21)," yet no data or

[5] Allen, R.W., et al, Task 1 Report: Definition of Static, Steady State and Transient Steering Stability Criteria for ATVs, Systems Technology Inc. Report 1255-1, Contract CPSC-C-87-1237, October 1989.

account is given which shows that ATV "spin out" ever occurred. In fact, not only during this study, but during thousands of test runs during the Voluntary Standards development, as well as during the tests underlying the CPSC Engineering Report, no occurrence of any actual ATV "spin out" was ever reported. "Oversteer" is not equivalent to "spin out," and this is a false inference that the authors repeatedly make in the report.

- "...this large lateral acceleration exceeds the vehicle's roll stability threshold thus inducing rollover (p 21)," yet no data are presented and there is not indication in the report, that a rollover due to "side slip" and "large lateral acceleration" was ever "induced" during the tests. In fact, not only during this study, but during thousands of test during the Voluntary Standards development, as well as during the tests underlying the CPSC Engineering Report, no occurrence of any actual ATV rollover due to "side slip" and "large lateral acceleration" was ever reported, and this is an unsupported inference that the authors repeatedly make in the report. ATVs (as well as any other wheeled vehicle) can roll over, but experience indicates that is often due to obstacle encounters at excessive speeds, or attempting to ride on excessively steep slopes.

- "...oversteer can lead to loss of control," yet no data are presented and there is not indication in the report, that a "loss of control" due to oversteer ever occurred. In fact, not only during this study, but during thousands of test during the Voluntary Standards development, as well as in the tests underlying the CPSC Engineering Report, no occurrence of any actual ATV "loss of control" was ever reported, and this is an unsupported inference that the authors repeatedly make in the report. ATV riders (as well as drivers of any other wheeled vehicle), can experience "loss of control," but experience indicates that is most likely due to riding at excessive speeds for the terrain or conditions, or attempting to ride on excessively steep slopes, not from "excessive oversteer."

The report stops short of making any other recommendations for handling "criteria," other than these false inferences about oversteer, and concludes by stating that "independently suspended four wheeled ATVs provide the most flexibility for making design tradeoffs in order to achieve optimum vehicle handling."

b) Wright, et al (1991), stability and maneuverability aspects of ATVs[6]

This paper describes a literature review of some of the other work in this area, and a simple static stability analysis. Unfortunately, the paper also includes a series of erroneous, baseless and misleading statements which include:

- "Increases in rolling resistance or motion resistance by as much as 300 percent when a solid axle (no differential) ATV is put into a tight turn act as a braking mechanism and may be sufficient to precipitate a pitch or rollover due to instability of the machine," is a statement for which no basis can be found in the paper or in reality. In fact, the magnitude of such "resistance" to motion is extremely small, particularly on typical off-road surfaces, and on off-road soils, ATVs can turn very tightly without extraordinary effort. There is no known evidence that a pitch over or rollover has ever been precipitated by such small drag forces, and both CPSC and the ATV industry have investigated and rejected such baseless assertions by the authors.

- "Kp value [with rider]....should be at least unity." The authors present absolutely no rational basis for this statement. Note this is the same value (i.e., Kp = 1.0) used in the ANSI standard, although in the ANSI standard it is measured without a rider and with no connection whatsoever to this paper.

- "Kst cosine alpha should be at least unity." Again, the authors present absolutely no rational basis for this statement.

- "The current ANSI/SVIA standard for 4 wheel ATVs is inadequate because it does not address lateral stability of ATVs," yet the authors do not mention, or apparently are not even aware of, the enormous efforts made during the Voluntary Standards process to try to do so, nor the reasons why eventually it was not included.

- The [ANSI] pitch stability criterion is not acceptable," yet the authors present absolutely no rational basis for this statement.

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6 Wright, R.R., et al, "Stability and Maneuverability Problems of ATVs," SAE Paper 911944, 1991.

ANPR Question 5: "Technical information on test and evaluation methods for defining ATV characteristics that are specifically relevant to the vehicles' stability", and including factors involved in trying to develop a dynamic stability standard for ATVs, based on previous work in this area.

In general, it is assumed that this refers to "roll stability." There is some technical literature which pertains to "yaw" stability, and roll and yaw stability can interact, and yaw stability is described toward the end of this section.

1) History of US/DOT/NHTSA research and actions on light passenger vehicle roll stability

As indirectly related to the topic of ATV stability test and evaluation methods, the US National Highway Traffic Safety Administration (NHTSA) has pursued the topic of passenger car, light truck and van rollover stability since the early 1970s. A summary of the history of this research and regulatory actions is given in a NHTSA Request for Comment published in 2000.[7] A summary and excerpts from this are provided here as follows.

"In 1973, NHTSA issued an Advance Notice of Proposed Rulemaking (ANPRM) on resistance to rollover (38 FR 9598; April 18 1973)...Research project were undertaken to investigate handling and stability of different types of vehicles in severe steering maneuvers associated with untripped rollovers. The relevant conclusions of the research were that "vehicle rollover response is dominated by the vehicle's rigid body geometry (with dynamic contributions from suspensions effects)," and that "untripped rollover, even on high skid-resistance surfaces, is difficult to predict and accomplish." The research recommended computer simulation of dynamic testing as a more repeatable alternative to full-scale track testing. Further work on untripped rollover was discontinued in the late 70's."[8]

"In September 1986, Congressman Timothy Wirth petitioned NHTSA to establish a standard for rollover resistance by setting a minimum allowable Static Stability Factor (SSF) of 1.2. The agency denied the petition in December of 1987 (52 FR 49003, December 29, 1987) stating that

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[7] National Highway Traffic Safety Administration, Request for Comments, Consumer Information Regulations, Federal Motor Vehicle Safety Standards, Rollover Prevention, Docket No. NHTDS-20000-6859, Federal Register, Vol. 65, No. 106, June 1, 2000.

[8] Op cit, p 35000, col 1

"...while a vehicle's stability factor can reasonably predict whether a vehicle which is already involved in a single-vehicle accident will roll over, it does not accurately determine its likelihood of becoming involved in an accident that includes rollover.: An SSF of 1.2 "...would neither adequately encompass the causes of vehicle rollover nor satisfactorily ameliorate the problem." *In order to consider a minimum standard*, the agency believed it was necessary to understand vehicle characteristics making a single-vehicle crash more likely as well as those predictive of the outcome of a single-vehicle crash [emphasis added]."[9]

"In June 1988 the Consumers Union (CU) petitioned NHTSA to establish a safety standard to protect occupants against "unreasonable risk of rollover." CU did not suggest a specific remedy. The agency granted the petition in September 1988. From 1988-1993 NHTSA undertook the most comprehensive analysis in its history, studying over 100,000 single-vehicle rollover crashes. This study eventually focused on two vehicle static measurements which seemed promising: Tilt Table Angle and Critical Sliding Velocity. Tilt Table Angle is the angle at which a vehicle will begin to tip off a gradually tilted platform. Critical Sliding Velocity is the minimum velocity needed to tip a vehicle which is sliding sideways. Both of these measurements address the situation in which a vehicle encounters something that trips it into a rollover, such as a curb, soft dirt, or its own tire rim digging into the pavement."[10]

"The NHTSA Authorization Act of 1991 (the Act) (part of the Intermodal Surface Transportation Efficiency Act) required the agency to address several vehicle safety subjects through rulemaking. One of the safety subjects was protection against unreasonable risk of rollovers of passenger cars and light trucks.'[11]

"On January 3, 1992 NHTSA fulfilled the first mandate of the Act by publishing an ANPRM (57 FR 242)...The ANPRM discussed the agency's statistical analyses of the interaction of driver characteristics, vehicle stability metrics, roadway and environmental conditions. The notice described the following vehicle stability metrics as having a potentially

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[9] Op cit, p 35000, col 2

[10] Op cit, p 35000, col 2

[11] Op cit, p 35000, col 2

significant role in vehicle rollover: center of gravity height; static stability factor; tilt table ratio; pull ratio; wheelbase; critical sliding velocity; rollover prevention metric; braking stability metric; and percent of total vehicle weight on the rear axle."[12]

"During the development of the ANPRM and after analyzing comments to ANPRM, it became obvious that no single type of rulemaking could solve all, or even a majority of, the problems associated with rollover. This view was strengthened by the agency's review and analysis of the comments on the ANPRM. To emphasize this conclusion and inform the public further about the complicated nature of the light duty vehicle rollover problem, the agency released a document entitled "Planning Document for Rollover Prevention and Injury Mitigation" at a Society of Automotive Engineers (SAE) meeting on rollover on September 23, 1992."[13]

"In June 1994 NHTSA terminated rulemaking to establish a minimum standard, fulfilling the second mandate of the Act, because it found (using statistical simulation of crash outcome) that increasing several vehicle rollover metrics to a higher level than is currently seen in most compact sport utility vehicles would not appreciably decrease fatalities and injuries in rollovers (59 FR 33254). In the termination notice NHTSA said, "The agency believes that no single type of rulemaking or other agency action could solve all, or even a majority of, the problems associated with rollover. Accordingly, it is pursuing a broad range of activities to address those problems." The notice discussed the wide range of ongoing agency activities to address the rollover problem and referred to the Planning Document."[14]

"In May 1996 NHTSA issued the "Status Report for Rollover Prevention and Injury Mitigation" (NHTSA-1996-1811-2). This document updated the progress of the programs discussed in the Planning Document and added the description of a planned project: development of a dynamic test for rollover and control stability in light vehicles."[15]

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[12] Op cit, p 35000, col 3

[13] Op cit, p 35000, col 3

[14] Op cit, p 35001, col 1

[15] Op cit, p 35001, col 1

"In August 1996 NHTSA received a request from Consumers Union (CU) asking the agency to develop a test of vehicle emergency handling capability and to provide test results on new vehicles to the public as consumer information. The type of rollover test that would be addressed by such a tests is known as on-road, untripped rollover, or maneuver-induced rollover. This type of rollover was believed to represent approximately 10 percent of annual rollovers."[16]

"Since the vast majority of rollovers are tripped, we have now decided that primary consumer information should be based on factors relevant to tripped as well as untripped rollovers, and we have reconsidered the merits of Static Stability Factor as an indicator of rollover risk for consumer information."[17]

"Unfortunately, as we reported in 1994, no vehicle measurement that can be used in a minimum vehicle safety standard that would decrease the risk of rollover involvement without necessitating drastic design changes to a vehicle type that is sought after by consumers, namely compact SUVs. This is because the rollover rate of an individual make/model is not very sensitive to small changes in metrics, and larger changes in metrics that would positively influence rollover rate would necessitate dimensional changes that would prevent the manufacture of current designs of compact light trucks (pickups and SUVs)."[18]

Ultimately, as a result of the analysis of responses to this Request for Comment, NHTSA incorporated SSF as part of their Consumer Information New Car Assessment program, in particular by providing a "Star Rating" associated with SSF levels, and associated rollover accident rates.

Subsequently, in 2001, NHTSA issued another ANPRM on dynamic rollover resistance testing, and this is discussed below.

a) Description of static stability metrics used by NHTSA

"The agency, vehicle manufacturers and others have used various "metrics" and driving maneuvers to characterize the rollover resistance of vehicles in particular situations. Metrics are usually measurements of dimensional,

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[16] Op cit, p 35001, col 2

[17] Op cit, p 35001, col 2

[18] Op cit, p 35001, col 3

mass, and inertial properties of vehicles or calculations combining these properties in ways intended to represent rollover resistance. They have also taken the form of the results of simple static tests such as tilt table ratio or the combination of static measurements and simple driving maneuver tests such as "stability margin." In its ongoing rollover studies, the agency has used several metrics including Static Stability Factor, Tilt Table Angle or Ratio, Critical Sliding Velocity and Side Pull Ratio and various driving maneuvers including J-turn and Fishhook maneuvers and sinusoidal steering.

Each of these descriptors of rollover resistance has both advantages and disadvantages, and several would be acceptable candidates for comparative consumer information. The agency favors static stability factor because unit is applicable to both tripped and untripped rollover."[19]

"The Static Stability Factor (SSF) of a vehicle is one half the track width, t, divided by h, the height of the center of gravity above the road...The factor of two in the computation "t over 2 h" makes SSF equal to the lateral acceleration in g's [due to cornering, rapid steering reversals, or striking a tripping mechanism, like a curb, when sliding laterally] at which rollover begins in the most simplified rollover analysis of a vehicle represented by a rigid body without suspension movement and tire deflections. In this form, it is easy to compare to the related metrics, Tilt Table Angle and Side Pull Ratio which are similar except for the inclusion of suspension movement and tire deflection [in the latter metrics]."[20]

"A simple test of rollover resistance is to place a vehicle entirely on a table which tilts about a longitudinal axis and rises one side of the vehicle higher than another. As the table continues to tilt it eventually reaches an angle at which the high side tires lift from the table and the vehicle rolls over if not restrained. The critical angle is called the Tilt Table Angle. The trigonometric function, tangent, of this angle is the Tilt Table Ratio (TTR), which is the ratio of the component of the tiled vehicle's weight which acts laterally to overturn it, to the component perpendicular to the table which resists overturning. For idealized vehicles without suspension movements,

[19] Op cit, p 35006, col 3

[20] Op cit, p 35007, col 2

the TTR is the same as the SSF. The suspension movements of actual vehicle reduce the TTR about 10 to 15 percent relative to the SSF."[21]

"The Side Pull Ratio (SPR) is the lateral force acting at the vehicle's c.g. necessary to cause two wheel lift, divided by the vehicle's weight. It is determined by a test which is conceptually identical to the tilt table test but which uses an externally applied lateral force to cause the wheels on one side of a vehicle parked on a horizontal surface to lift up. It exercises the vehicle suspension more realistically because the whole weight of the vehicle remains on its suspension. In the tilt table test, the vehicle can rise somewhat relative to the table surface because the component of the vehicle weight which compresses the suspension springs steadily diminishes as the angle of the table increases. For an idealized vehicle without suspension movements, the SPR also is the same as the SSF. Again, the suspension movements of actual vehicles reduce the SPR relative to the SSF by about 10 to 15 percent."[22]

"Critical Sliding Velocity (CSV) is a metric tied directly to tripped rollover. It is a calculation of the lateral velocity necessary to cause a rigid body representation of a vehicle to overturn upon impact with a rigid tripping mechanism. It includes c.g. height, track width, mass and roll moment of inertia of the vehicle in the calculation."[23] As for the other static metrics, it is abstract and oversimplified in the sense that it ignores the effective height or center of pressure height of the tripping object above the road surface, which may vary from vehicle to vehicle for the same struck object.

"Stability Margin is a metric directed toward on-road untripped rollover. It is the difference between the Side Pull ratio of a vehicle and its maximum lateral acceleration in g's, as measured in a steady state cornering test."[24] "...the subtraction of the maximum on-road acceleration limits the applicability of the [Stability] Margin to untripped rollover. Simply fitting the

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[21] Op cit, p 35007, bottom

[22] Op cit, p 35008, top

[23] Op cit, p 35008, col 1

[24] Op cit, p 35008, col 2

same vehicle with low traction tires increases the stability margin without making any differences when a tripping mechanism is encountered."[25]

b) NHTSA decision to terminate rulemaking on a minimum standard

"The action contemplated by this notice follows a decision by the agency (59 CFR 33254) to terminate rulemaking on a minimum standard for rollover resistance and to pursue the consumer information approach instead. In the analysis leading to the decision, the agency concluded that both Tilt Table Angle and Critical Sliding Velocity were causally related to rollover and had a strong statistical relationship to rollover frequency. However, the benefits achieved by setting a minimum level for a rollover metric, even well beyond that of truck-based SUVs or full size vans, were not great enough to compel the costs of fundamental vehicle changes and the loss of attributes desired by customers. Also the redesign could result in the elimination of some classes of vehicles, such as compact SUVs."[26]

c) NHTSA dynamic rollover resistance test procedure and consumer information regulation

As noted previously, NHTSA had an ongoing, long-term research program to address dynamic untripped rollover by means of developing full-scale test procedures.

In 2001, NHTSA described its intentions for the next phase of its dynamic rollover resistance test development in its Request for Comments (NHTSA-2001-9663-1). NHTSA received responses from various members of the automotive industry and consumer groups, and published the responses in Docket (NHTSA-2001-9663-2 through 2001-9663-26).

The documentation provided for some of the test procedures was sufficiently specific as to fully define the method proposed. However, for other test procedures, the documentation only outlines the method, and lacks important details. In these cases, the undocumented details have been inferred and are noted below.

Several categories of dynamic test were proposed as follows:

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[25] Op cit, p 35009, col 2

[26] Op cit, p 35011, col 3

- Defined path methods
- Defined steering methods
- Laboratory test methods

i) Defined Path Methods

Defined path methods require a driver (or special Automatic Vehicle Controller) to steer within a defined course or to follow a prescribed path.

VDA Course Test

The VDA Course Test is supported by many of the major European automobile manufacturers. The course is shown in Fig 1. The driver increases the vehicle speed from run to run until a limit is reached, as defined by rollover or unavoidably hitting cones (e.g., spin out, plow out).

- Entry speed: start at a "reasonable" speed (e.g., 30 mph). From run to run, increase speed by 1 mph increments.
- Throttle: close throttle 15m before the end of the entry lane.
- Steering wheel angles, rates, and reversal timing: determined by driver, as appropriate.
- Metrics: entry speed, behavior at limit (rollover, plow out, spin out)
- Advantages of Test Procedure: applies to untripped rollover; includes the effects of roll momentum for some vehicles; is easy for consumers to understand; has international acceptance as a "handling" course, and provides some indication of vehicle's handling; easy and low cost testing; is supported by several manufacturers (i.e., DaimlerChrysler, VW, BMW, Mitsubishi)
- Disadvantages of Test Procedure: does not apply to tripped rollover; repeatability is poor; does not provide a "worst case" for all vehicles. That is, it maximizes roll momentum for some vehicles, but not other vehicles, because it is a fixed course, and steering inputs are at the same frequencies for all vehicles; the limit condition includes the limit vehicle speed and the limit vehicle response (e.g., plow out, spin out, rollover, or power steering limit). So, results may be confusing to consumers. For example,

if the limit condition is plow out at 60 km/h for vehicle #1, spin out at 65 km/h for vehicle #2, and rollover at 70 km/h for vehicle #3, which vehicle should be considered the best. The answer may not be clear; it is difficult to conduct the test for large vehicles, such as SUVs.

Consumers Union Course

The Consumers Union (CU) course is shown in Fig 2. The test is run identically to the VDA course.

- Entry Speed: start at a "reasonable" speed (e.g., 30 mph). From run to run, increase speed by 1 mph increments.

- Throttle: close throttle 15m before the end of the entry lane.

- Steering wheel angles, rates, and reversal timing: determined by driver, as appropriate.

- Metrics: entry speed, behavior at limit (rollover, plow out, spin out)

Ford Dynamic Weight Transfer Method

The Ford Dynamic Weight Transfer Method (DWTM) involves driving on four sinusoidal paths (Fig 3) that are set up to provide maximum lateral acceleration of 0.7g at 45 mph. Since this is somewhat below the maximum lateral acceleration for most vehicles, rollovers are not expected (even for vehicles that may roll over using other test procedures). Rather, results are compared using measurements of the maximum dynamic weight transfer, as discussed below.

- Entry Speed: defined to be 45 mph for all courses.

- Throttle: it is not known what Ford does with the throttle position during the test, however, it may be reasonable to assume that Ford drops the throttle just prior to the initial steering (e.g., 10m, which corresponds to 0.5 sec at 45 mph).

- Steering wheel angles, rates, and reversal timing: determined by Automatic vehicle controller (AVC), as appropriate.

- Metric: the dynamic weight transfer (DWT) is defined as the maximum percentage of weight transferred away from the inside tires during the steering reversal, using a 0.4 sec moving average. In equation form,

$$DWT = \left(1 - \frac{Fz_{RF\ Dynamic} + Fz_{RR\ Dynamic}}{Fz_{RF\ Static} + Fz_{RR\ Static}}\right)$$

where,

RF denotes the right front

RR denotes the right rear

F_Z denotes a normal load

Note that the right side tires are the inside tires during a reversal turn to the right.

ii) Defined Steering Methods

Defined steering methods require an automatic vehicle controller (AVC) for precise and repeatable steering. With this method, there are no cones or prescribed path. All of the defined steering methods proposed by NHTSA were of the "Fishhook" type. Various forms of the Fishhook Test were supported primarily by some of the major Japanese automobile manufacturers in the comment period.

The general form of the steering input for all of the Fishhook Test variations is shown in Fig 4. For all of the Fishhook Tests used by NHTSA, the initial vehicle speed was increased from run to run until "major 2 wheel lift" (rollover) occurred or until 50 mph was reached.

Some of the details of the procedures were not described by NHTSA and are assumed herein based on previous NHTSA documents or reasonable estimations.

Below are common elements of the three types of Fishhook Tests proposed by NHTSA, followed by the unique features of each type.

<u>Common Elements of NHTSA Fishhook Tests</u>

- Entry Speed: NHTSA did not describe its beginning entry speed or speed increments from run to run. A reasonable approach would be to start at 30 mph and increase speed by 2 mph increments from run to run, until rollover occurs, or until some maximum speed is reached. To reduce the number of runs required, one alternative would be to increase speed by 4 mph from run to run. Then, if rollover occurs, reduce speed by 1 mph on successive runs until rollover does not occur.

- Throttle: in the ANPRM NHTSA did not describe the time at which the throttle is to be dropped. 0.5 sec prior to the initial steering input would be a typical value.
- Steering Wheel Angles: the initial steering wheel angle is determined by a ramp steer pretest. The pretest involves measurements of lateral acceleration and steering wheel angle, and slowly ramping the steering wheel angle while keeping the vehicle at a fixed speed. NHTSA does not describe precisely how the steering wheel angle is selected. The steering wheel angle at 0.3g is linearly extrapolated to the maximum lateral acceleration, as shown in Fig 5. The angle corresponding to the extrapolation is then used as the initial steering wheel angle. NHTSA proposed that the reversal steering wheel angle would be in the range of 500 – 600 deg.
- Steering rates: NHTSA proposed 720 deg/sec for both the initial turn and the steering reversal.
- Metrics: NHTSA only proposes to use entry speed at two wheel tip up as a metric.

Timing of Steering Reversal - Fishhook #1

NHTSA proposed that the steering reversal would occur after a fixed dwell time (see Fig 4), however, the proposed dwell time was not given. A reasonable assumption would be a dwell time of 0.5 sec

Timing of Steering Reversal - Fishhook #2

NHTSA proposed the use of roll rate sensor feedback in real time, with the initiation of the steering reversal to be triggered by the first zero crossover of roll rate. Note that this is the same as the first relative maximum roll angle.

Timing of Steering Reversal - Fishhook #3

Nissan proposed a technique not fully described by NHTSA. It involves the use of a fixed dwell time, as determined by a step steer (J-turn) pretest.

The step steer pretest is conducted using the same steering rate (720 deg/sec) and angle (as determined from the ramp steer pretest) that are to be used in the Fishhook Test. It is described in the NHTSA RFC as follows:

"The roll rate is measured to determine the time of the maximum roll angle of the second oscillation. Nissan believes that the most severe fishhook for each vehicle is the one in which the lateral acceleration zero crossing during counter steering in the fishhook occurs at the second oscillation peak time as measured in the J-turn maneuver. The dwell time from initial steer to counter steer would be adjusted accordingly." NHTSA goes on to say that, *"Nissan's...technique appears to produce a counter steer timing similar to that produced by roll rate feedback."*

One interpretation of this paragraph is that the step steer data are analyzed to determine both the third zero crossing of roll rate (the "time of the maximum roll angle of the second oscillation", t_3) and the lateral acceleration response time (t_r). Then, the time of the steering reversal would be calculated to be t_3 minus one half of the lateral acceleration response time (one half of the lateral acceleration response time may correspond to the time necessary for lateral acceleration zero crossover from a peak value). In equation form,

$$t_{\mathrm{Reversal}} = t_3 - \frac{t_r}{2}$$

iii) Laboratory Test Methods

Several test devices were also proposed in response to the ANPRM. These devices do not involve on-road testing.

Centrifuge Test

The Centrifuge was supported by General Motors and several consumer advocate groups in the U.S. It involves a turntable device, such as is shown in Fig 6. The vehicle is positioned at a 50 ft radius from the center of the turntable. The outside tires are blocked (presumably with blocks of some minimum height, e.g., 2 in) to prevent the vehicle from sliding.

The test involves slowly (quasi-statically) increasing the rotational speed of the turntable until the vehicle rolls over.

The primary metric is the lateral acceleration at rollover, also known as the Static Rollover Threshold. A second measure, which involves incorporating the results of the Maximum Lateral Acceleration test (discussed below), is called Stability Margin. The Stability Margin is the difference between the Static Rollover Threshold and the Maximum Lateral Acceleration. This method does not address untripped rollover.

Maximum Lateral Acceleration Test

The Maximum Lateral Acceleration Test involves driving on a fixed radius circle (e.g., 100 ft), slowly (quasi-statically) increasing speed and steering to maintain the vehicle's path along the circle. The metric is the Maximum Lateral Acceleration that can be achieved while the path is maintained.

Lateral Sled Test

The Lateral Sled Test was proposed by Exponent. In this test, the vehicle is mounted laterally on a sled which itself is mounted on rails (Fig 7). The sled is decelerated from 25 mph, using step-like braking to defined levels of deceleration. From run to run, the levels of deceleration are increased by 0.05g. The "inside" tires are blocked, similar to the Centrifuge tests, to prevent the vehicle from sliding.

The metric is the deceleration level that caused the vehicle to roll over. This method does not address untripped rollover.

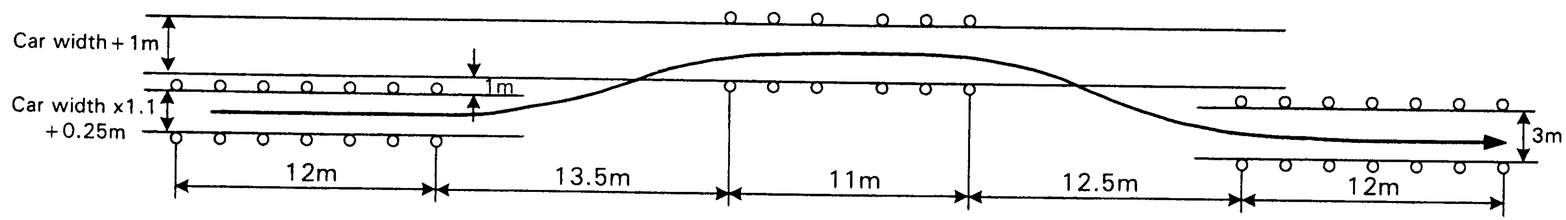

Figure 1. VDA Course Layout

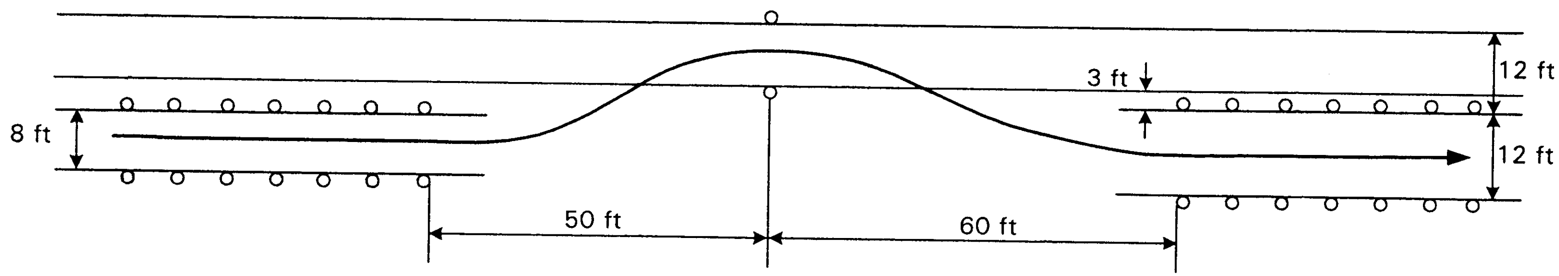

Figure 2. Consumers Union Course Layout

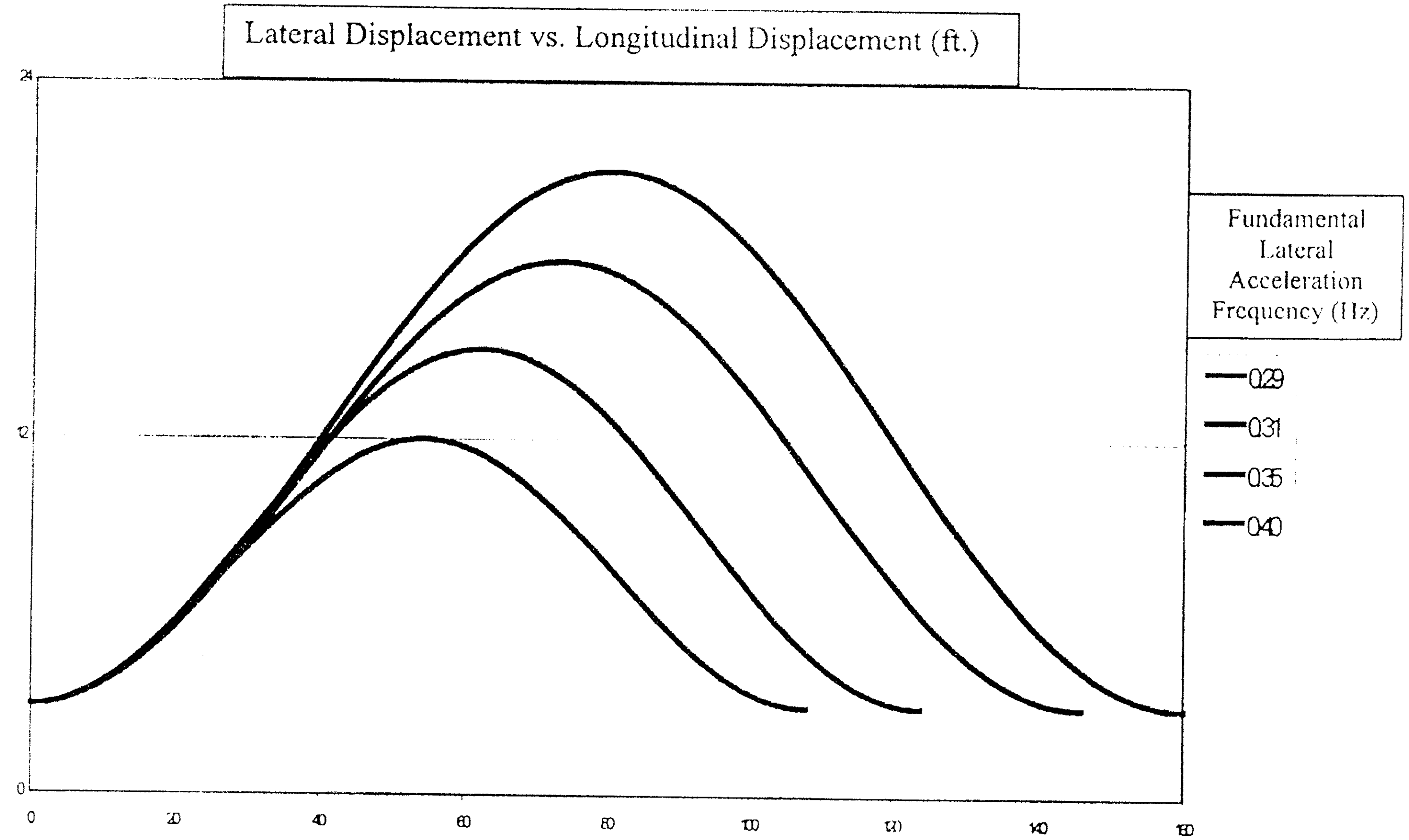

Figure 3. Ford DWTM Paths

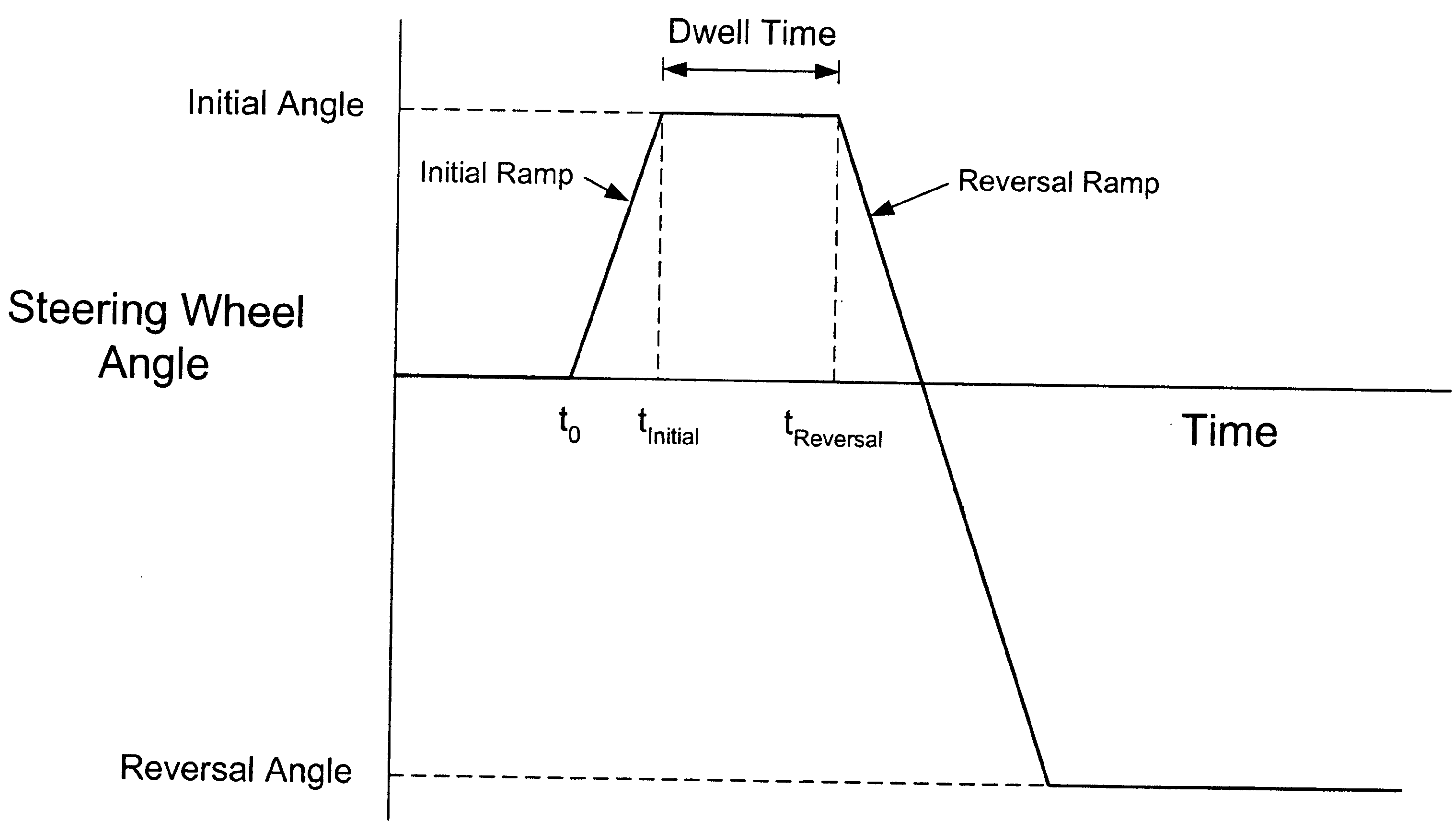

Figure 4. Steering Input for Fishhook Tests

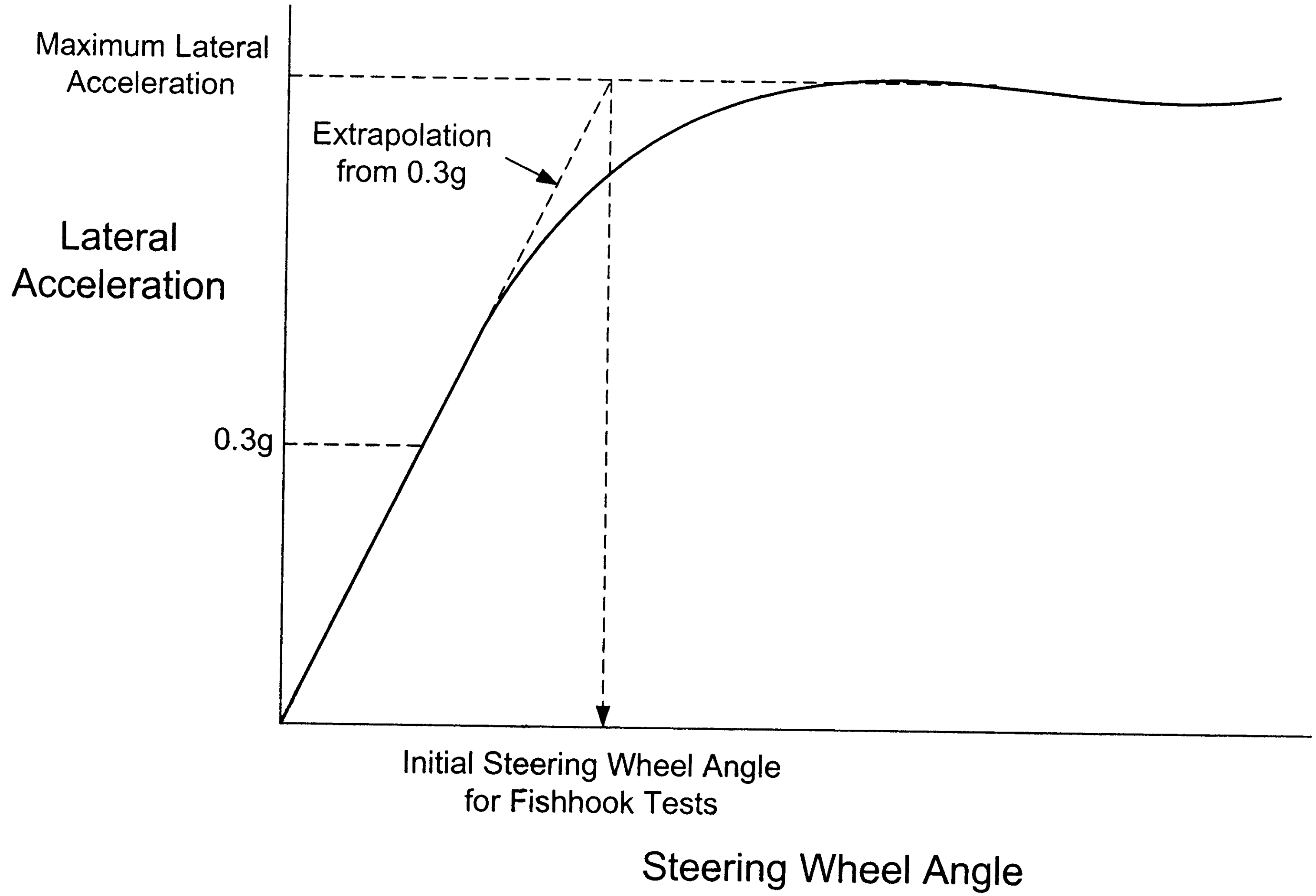

Figure 5. Method of Identifying Steering Wheel Angle for Fishhook Tests

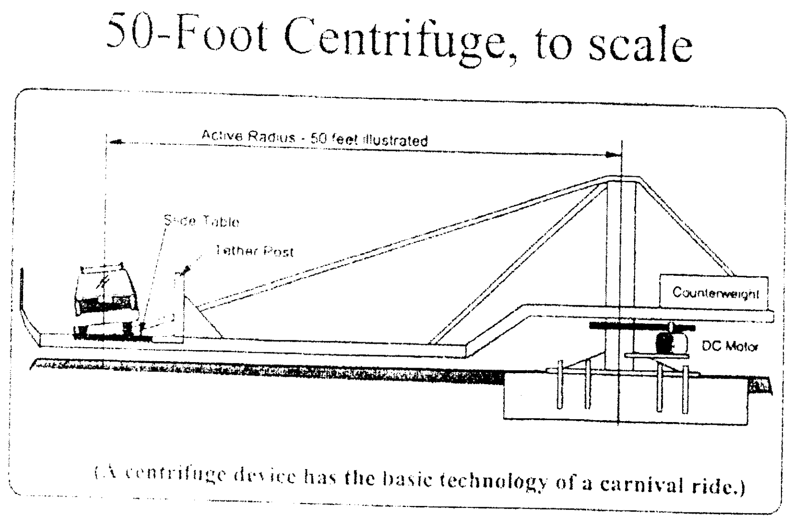

Figure 6. Centrifuge Test Concept

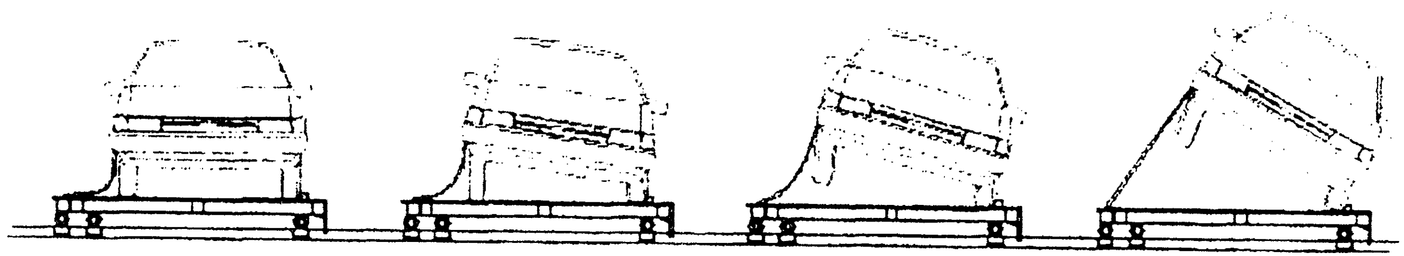

Figure 7. Sled Test Concept

iv) Summary of comments on the dynamic test methods.

Table 3 summarizes the dynamic test candidates, and which organization supported each test.

Table 3. Summary of Dynamic Test Types and Supporters of Each

	VDA Course (ISO 3888 Part 2)	Centrifuge Sled, Side Pull	Fishhook	Dynamic Weight Transfer Method
Organizations Supporting	Toyota (tripped) Mitsubishi VW BMW DaimlerChrysler Continental Teves	Centrifuge: UMTRI GM (w/ Stability Margin and Min Lateral Accel) AHAS Public Citizen Consumers Union (as SSF substitute) Side Pull: H-D Sled: Exponent (Dynamic Rollover Test)	Nissan Toyota (untripped) TRW Chassis Honda	Ford
Method	- Driver controlled steering - Defined path, turning from right lane to left lane and back to right lane - Tight lane widths - 'Entry speed incremental from run to run - Metric: entry speed, behavior at limit (plow, spin, roll)	- Done with centrifuge, side pull, or sled apparatus - Tires blocked to prevent sliding, vehicle tethered - Apparatus accelerated until rollover occurs - Metric: lateral acceleration at rollover - Other variations to simulate effects of roll momentum	- Done with AVC - +270/-600 deg SWA - 720 deg/sec steering rate - Reversal timing determined according to pretests (Nissan) - Entry speed incremented from run to run - Metric: entry speed, lateral accel at rollover (Toyota)	- Done with path following AVC - A group of defined double lane change paths, encompassing a range of frequencies - 45 mph, 0.7 g - Metric: maximum percent weight transfer over a specified minimum duration

Table 4 summarizes the tests recommended by commenting organization, along with a summary of the main point of the comments.

Table 4. Recommended Dynamic Test procedures, by Commenting Organization

Organization	Document	Closed Loop - Path Following			Open Loop - Defined Steering				Non-Road Tests				Comments Made by Organization
		VDA (ISO 3888-2)	CU Short Course	DWTM (also, PCLLC)	Open Loop Pseudo-DLC	Fishhook #1	Fishhook #2	Fishhook #3	Centrifuge	Sled (DRT)	Side Pull	Comp Sim	
NHTSA	RFC	X	X	X	X	X	X	X					
UMTRI	9663-2, -3								X				4 tests: Static, Straight Tether, Inboard Tether, Curb Trip Separate handling test needed, also, to determine effects of ESC and quantify overall yaw controllability
Nissan	9663-4							X					Find worst case reversal time via pretests. Should also consider Centrifuge Test
Toyota	9663-5	X				X							VDA for "tripped" rollover, with peak-to-peak yaw rate as criterion. Fishhook #1 for "untripped" rollover, with lateral acceleration at rollover (LAR) as criterion.
GM	9663-6								X				Use Centrifuge result along with Maximum Lateral Acceleration to compute Stability Margin. Recommends standard, with minimum values for Centrifuge result (0.9) Maximum Lateral Acceleration (0.6g), and Stability Margin (0.2 or 1.5/wheelbase[2], whichever is larger).
TRW Chassis	9663-7						X						Computer simulation methods should also be explored. ESC should be shown as benefit by test selected.
Mitsubishi	9663-8	X											
VW	9663-9	X											Recommends combination of SSF and VDA. Supports additional handling test.
AHAS, Public Citizen	9663-10, -20								X				NHTSA is only studying untripped rollover.
Suzuki	9663-11, -12, -13, -14, -22												NHTSA maneuvers do not address real problem - tripped rollover. Should develop test to evaluate the risk of rollover if the vehicle leaves the roadway.

Table 4. Recommended Dynamic Test procedures, by Commenting Organization (cont'd)

Organization	Document	Closed Loop – Path Following			Open Loop – Defined Steering				Non-Road Tests				Comments Made by Organization
		VDA (ISO 3888-2)	CU Short Course	DWTM (also, PCLLC)	Open Loop Pseudo-DLC	Fishhook #1	Fishhook #2	Fishhook #3	Centrifuge	Sled (DRT)	Side Pull	Comp Sim	
BMW	9663-15	X											Criterion: maximum entry speed. Does not think that any single test is enough, but VDA is best available.
Harley-Davidson	9663-16										X		
NADA	9663-17												Lacks expertise to recommend particular test. NHTSA must focus on appropriate consumer information.
Daimler Chrysler	9663-18	X											NHTSA should simply publish results, w/o a star system. Results are maximum entry speed and failure mode (spin out, plow out, rollover).
Exponent	9663-19									X			Sled is decelerated from 25 mph at defined step levels (0.05g increments). Criterion: Lateral acceleration at tip up. Representative of soft soil (furrowing) tripped rollover.
IIHS	9663-21												No specific test recommended, but test must correlate with rollover accident data.
Continental Teves	9663-23	X											Criterion: Maximum entry speed
Ford	9663-24			X									4 specified paths (wide variety of frequencies), and path-following robot. Recommended vehicle speed of 72 km/h and 0.7g lateral acceleration. Criterion: Maximum percent of dynamic weight transfer. Additional handling tests needed to more fully define handling and stability.
Trindal	9663-25												Use SSF only. Dynamic tests cannot be made to be repeatable.
Consumers Union	9663-26												Need a suite of tests. Static (Centrifuge or SSF), Rollover (no specific test recommended, but steering reversal is critical), Handling (various).

Table 5 summarizes comments on each of the three main categories of dynamic test procedure. These were mostly identified by NHTSA as important criteria for evaluation, and include the relationship of each type of test to tripped and untripped rollover accidents, test repeatability, effect of pavement and tire condition, whether influence by roll momentum, whether the procedure can identify the "worst case" dynamic condition for a given vehicle, whether the test has "face validity," whether there is international acceptance of the test as a vehicle handling test procedure, whether the test can measure the effectiveness of electronic stability control (ESC) which was an important NHTSA goal, whether the test accounts for the likelihood of the vehicle leaving the road (i.e., path response), whether manufacturers would be tempted to use "slippery tires" as a countermeasure, ease and low cost of testing, and insensitivity to vehicle size.

Table 5. Comparison of Proposed Dynamic Roll Resistance Test Procedures

Objectives	Method		
	Laboratory Device (e.g., Centrifuge)	Defined Steering (e.g., AVC-controlled Fishhook)	Defined Path (e.g., VDA course)
Direct connection to tripped rollover, explores excitations beyond range of tire-pavement friction	Yes	No	No
Direct connection to untripped rollover	No	Yes	Yes (although it depends on specific vehicle)
Repeatable	Yes	Yes	No
Not affected by pavement friction and tire wear characteristics	Yes	No (could be addressed)	No (could be addressed)
Includes effects of roll momentum	No (except partially with "catapult" version)	Yes	Yes (but only for some vehicles)
Identifies "worst case" for each vehicle	No (excludes suspension resonance)	Yes	No
Has obvious "face validity", is not abstract	No	Yes (to the extent that it is a worst case)	Yes

Table 5. Comparison of Proposed Dynamic Roll Resistance Test Procedures (cont'd)

Objectives	Method		
	Laboratory Device (e.g., Centrifuge)	Defined Steering (e.g., AVC-controlled Fishhook)	Defined Path (e.g., VDA course)
International acceptance as a "handling" test procedure	No	No	Yes
Measures effects of ESC systems (yaw or roll)	No	Yes	Yes (except for some roll-prevention ESC systems)
Does not disproportionately favor ESC systems with simple braking intervention	Yes	Yes	No (due to use of entry speed as metric)
Accounts for likelihood of vehicle leaving roadway	No (partial, if maximum lateral acceleration test included)	No (partial, if maximum lateral acceleration test included)	Yes (partially, except for vehicles which do not reach a maximum lateral accel limit)
Manufacturers would not be tempted to use "de-powered" (i.e., slippery) OEM tires	Yes	No	Yes
Easy and low cost testing	No	No	Yes
Is insensitive to vehicle size	Yes	Yes	No

NHTSA analyzed the comments, and concluded that SSF should be used as a predictor of (and had a relatively strong correlation to) tripped rollover; and that the Fishhook test (supplemented by J-Turn tests) conducted with an Automatic Vehicle Controller (AVC) should be used as a predictor of (and had some correlation to) tripped rollover.

The SFF and Fishhook were subsequently incorporated in 2002 into NHTSA's New Car Assessment Program (NCAP) 5-Star Rating Consumer Information system. A sample of the most popular (approximately 40) light trucks and vans, as well as some passenger cars, are tested each year by NHTSA using the SSF and Fishhook methods, and results are published.

The SSF measurements are performed using a special device which measures vehicle center of gravity and other vehicle parameters, as described by Heydinger, et al 1995.[27]

The NCAP rollover resistance NCAP tests were initially conducted for NHTSA by the Transport Research Center (TRC) of Ohio, and as of 2005 are being conducted by Dynamic Research, Inc. in California.

2) Candidate stability test procedures for ATVs

In addition to the static and dynamic test procedures discussed above for passenger cars and light trucks, other dynamic stability test methods have been considered for ATVs. To date none of these except Kp (which is a static, i.e., not a dynamic, pitch stability test in the ANSI Standard) have been formalized into a standardized procedure, nor have they been correlated with overturn accident rates, or assessed for the discriminating power, repeatability at a given site, reproducibility across different sites, their effects on existing vehicle designs and the many other aspects of a vehicle dynamic test procedure that need to be assessed in order to determine the feasibility and suitability of a standardized test.

Candidate test procedures considered in the past are summarized below, along with some of the related technical issues, advantages, and limitations of each.

There are two overarching technical difficulties with dynamic stability tests for ATVs, which are discussed next.

a) Test soil deformation and deterioration

In reality, a fundamental difficulty in applying any such test methods to off-road vehicles, including ATVs, is that the results depend largely on the soil characteristics, and the interaction of the tires with the soil.

Conceptually, a paved surface might be suggested as a test surface, to improve repeatability and consistency. However ATVs and their tires are not designed to be operated on paved surfaces and the results (i.e., maximum lateral acceleration, nature of the limit, and understeer/oversteer characteristics) obtained through measurement on a paved surface would not

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[27] Heydinger, et al, "The Design of a Vehicle Inertia Measurement Facility," SAE Paper 950309, 1995.

be representative of the characteristics that would be measured on many or most off-road soils. This is in part because more tire drive force (i.e., traction) is required to propel the ATV on soils than on pavement, and it is well-known that for any pneumatic tire, for example, the lateral force output depends on the amount of tire drive force applied. In addition, the interaction of the lugs with the soil, the specific interaction of the tire material compound with soil, the deformation of the tire carcass in soil, and so on, are different from the interaction with a paved surface, and the latter is not generally indicative of the results on soil (except perhaps in special cases).

More specifically, in regard to soils, the challenges involved in conducting such dynamic tests with off-road vehicle tests include:

- Most off-road surfaces need constant "grooming" to prevent development of ruts, "berms" and/or layers of loose soil. If ruts develop, they have the effect of acting like "rails" on or in which the ATV tires operate, and which move the tire/ground contact point up the sidewall of the tire (i.e., reducing the effective c.g. height). If berms are allowed to develop it also has the effect of creating a "banked" curve that is unrepresentative of operation on a horizontal surface. A layer of loose soil on top of compacted soil introduces a low friction, "ball bearing" shear layer, which is slippery and varies in its consistency across the test surface and during the test period.

- In many cases, the shear characteristics of the soil change once it is disturbed, even if it is groomed.

- The moisture content of the soil, which may vary depending on recent precipitation, ground water, relative humidity, disturbance of the soil and air temperature, can have a large effect on the shear characteristics of the soil and therefore on the test results. For example, dry sand is quite different from wet sand.

- The range of terrain, soils and surfaces on which ATVs operate varies greatly. These include muddy swamps, agricultural fields, sand dunes, forest trails, packed dirt, snow, etc. Each of these could be expected to produce a different result, and none could be considered to be "representative" of a “typical” surface.

Table 6 summarizes some of the main soil types and their composition, mechanical characteristics and technical factors in relation to vehicle dynamic testing. All except gravel have mechanical characteristics which are highly sensitivity to moisture. This implies either some yet-to-be-defined method to control moisture in a test soil within a certain range, or else use (and maintenance) of "dry" soils.

In addition, assuming that the listed soil types are maintained in a dry condition, then their mechanical characteristics are generally "plastic"[28] in nature, which leads to the previously mentioned issues with rutting, berms and tire sinkage, except for clayey soils. Clayey soils are generally "cohesive"[29] because of their small particle size and surface tension when moist. When they are substantially wet, they tend to be extremely slippery. When they are maintained in a dry condition, they tend to be extremely hard, durable and of high friction coefficient (all of which is why they may be used on tennis courts). However, repeated large shear forces acting along their free surfaces, as in vehicle dynamic testing, can loosen and build up a dust layer, which can become inconsistent and slippery, even when dry. Conceivably, some method of surface cleaning or re-location to a new surface might ameliorate this problem.

Table 6. Main classes of typical off-road soil types

Soil type	Composition	Mechanical characteristics		Dynamic test issues
		Moisture sensitivity	Force characteristics	
Sandy	Fine sediments	High	Plastic	Ruts, berms, sinkage
Clayey	Super fine sediments	High	Cohesive	Slippery residue
Gravel	Coarse sediments	Low	Plastic	Ruts, berms, sinkage
Loamy	Organic fibers	High	Plastic, hysteresis	Ruts, berms, sinkage

28 "Plastic" refers to the fact that typical soils, under loading, "fail" by shearing, and do not restore to their original geometry, when the load is removed.

29 "Cohesive" refers to soils which, because of their composition, can have a substantial tensile strength (as well as compression and shear strength).

b) Rider-active nature of ATVs

Another fundamental difficulty in applying such tests to ATVs, related to ATVs being "rider active" vehicles, is that the results also very much depend on rider size, weight, position and posture on the ATV. For an ATV, the rider represents a significant portion of the total mass, and in addition, the rider can move around on, and stand above, the seat. How to standardize these effects and how to be able to repeat and reproduce them from a test procedure viewpoint is not evident.

The following ATV stability test procedures were all considered by the ATV industry and the SVIA, in the course of attempting to develop a Voluntary Standard for ATVs. With only one exception, Kp, they were rejected, for the two aforementioned reasons, in addition to other procedural difficulties.

c) ATV candidate stability test procedures and metrics

iv) Kp (pitch stability factor)

This is the procedure developed and incorporated into the ANSI Standard for ATVs. It is analogous to the SSF defined by NHTSA for light duty on-road vehicles, except that it applies to the fore-aft pitch (rather than the sideward roll) direction. It is equal to the wheelbase divided by 2 times the c.g. height.

The c.g. height is determined by rotating the vehicle about its rear axle, and balancing it, a somewhat unique procedure feasible for ATVs because of their relatively light weight and small size. This procedure also improves the repeatability of the c.g. height measurement for ATVs, which have soft, low inflation pressure tires.

v) Kst (roll stability factor)

This is identical to NHTSA's SSF, and is equal to the average front and rear track divided by half the c.g. height.

This metric was discussed and eventually rejected in the Voluntary Standard discussions in the late 1980s for a long list of reasons. These included the facts that:

- ATV roll stability typically has more to do with tire/soil interaction and slippage than does pitch stability (e.g., large vehicle sideslip angles occurring at limit lateral accelerations tend to stabilize the vehicle in roll);

- Lack of accident data indicating the relative frequency with which rollovers (as opposed to pitchovers, or pitch-rolls, etc.) occurred in accidents;

- Lack of accident data indicating the relative frequencies of tripped versus untripped rollover (which as indicated in the NHTSA research, have different metrics associated with them); and

- The relatively larger effect of rider-active body displacement, with regard to roll stability, which cannot be readily accounted for in a Kst type measurement.

- Kst does not account for tire and suspension deflection effects which can be significant in lateral measurements.

vi) Steady state turn test

Conceptually, a dynamic "steady state turn" test procedure can be used to measure the maximum lateral acceleration capabilities of an ATV, the nature of its limit and its understeer/oversteer[30] characteristics. For an ATV, there are a number of ways in which such a test might be implemented. These are described and discussed below.

There are several basic considerations relevant to steady state turn tests, using any of these test methods, which are discussed as important background.

<u>Interpretation of understeer/oversteer and limit characteristics</u>

Although the understeer/oversteer characteristics of ATVs can be measured by means of a dynamic steady state turn test procedure, for ATVs there is no generally accepted or desirable range of understeer/oversteer

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[30] "Understeer/oversteer characteristic" refers to a standardized (Society of Automotive Engineers) vehicle dynamics methodology for describing the relationship between vehicle steer angle, forward speed and radius of turn. With the steer angle held fixed, if the radius of turn increases as speed is gradually increased, the vehicle is said to be understeering: if the radius of turn decreases as speed is gradually increased, the vehicle is said to be oversteering; and if the radius of turn remains constant as speed is gradually increased, the vehicle is said to be neutral steering.

characteristics as there may be for road vehicles.[31] Likewise the desirable nature of the turning limit for ATVs is not clear[32].

For ATVs and other off-road vehicles which may operate on tightly curved, low friction paths, path-following is extremely important, as many such off-road (or dirt road) paths have downhill embankments, hills and escarpments present, with obviously no guardrails. It is common experience of off-road drivers and riders to prefer some level of oversteer (i.e., decreasing path radius as speed increases) rather than understeer (i.e., increasing path radius as speed increases) which can result in departure from the path. In addition, if the throttle is closed or brakes applied with an oversteering/large sideslip vehicle, it will tend to scrub off additional speed by virtue of its sliding sideways. In addition, if throttle is applied to an oversteering vehicle (which tend to operate with larger sideslip angles), the thrust can be vectored into the turn, assisting to keep the vehicle on, and moving toward the inside of, the curved path.

Need for a standardized rider

A dynamic steady state turn maneuver would require either a standardized rider positioning (and measuring) procedure, or a "robot rider" to control the vehicle. While the latter is technically feasible and has been demonstrated (see below) it may be cost prohibitive, and introduces an additional level of complexity and standardization challenges. Assuming a human rider is used, issues of test rider size and weight also need to be addressed. In addition, ATVs are universally operated in a "rider-active" manner (i.e., at a minimum, virtually all riders "lean into" a turn) and the rider-to-rider and run-to-run variability of rider-activity tend to increase the variability in the results

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[31] Generally, for passenger cars, it is considered that a medium amount of understeer is preferred, up to the limit of lateral acceleration. Although there is no standard in any nation for such a practice, it is the typical practice in most regions. The basic rationale is that excessive understeer can result in inability to remain on to turn tightly enough on a curved path at limit conditions; and oversteer can result in yaw instability above a certain critical speed, meaning that the vehicle will turn left when steered right, above a certain speed.

[32] For passenger cars, traditionally it has been considered that it is desirable for the nature of the limit condition to be a so-called "plow-out" (or "nose-out") attitude where incrementally greater speeds would result in a larger turn radius, and the vehicle leaving its initial curved path in a "nose-first" attitude. The traditional rationale for this is that cars have more effective impact protection systems for frontal impact than for side impact. This reasoning is not valid for ATVs, motorcycles and other vehicles, for obvious reasons.

obtained. Currently, no simple objective means exist to specify, reproduce, measure or control for rider-active effects.

Steady state turn test methods

In general, for wheeled vehicles, there are a number of methods for conducting "steady state turn" tests. These fall into the categories of constant steering, constant speed or constant radius as shown in Table 7. In all cases, the steer angle, forward speed, yaw rate and lateral accelerations would be instrumented and recorded. The understeer/oversteer characteristics can be calculated from these measurements, and where a limit behavior is reached, the nature of that limit can be noted.

Table 7. General categories of steady state turn tests

Method	Steering	Speed	Radius
1	Fixed	Ramp	-
2	Trapezoidal	Fixed (at series of increasing speeds)	-
3	Ramp	Constant	-
4	Fixed (at series of increasing steer angles)	Fixed	-
5	-	Fixed	Fixed
6	-	Fixed (at series of increasing speeds)	Fixed

Method 1-Fixed steer, increasing ramp of speed

Procedure:

- Hold the steering constant by means of a "check chain" or similar device.
- Gradually accelerate the vehicle, holding the steering constant, until a limit condition is reached.

Application:

- Measure understeer/oversteer characteristics.

- Can assess the nature of the limit condition (i.e., tail-out, nose-out or tip), as the limit would typically be approached slowly.

Limitations:

A large area is needed for this type of test, and it is difficult to predict just what the path of the vehicle will be. In actual off-road areas it is difficult to find an area that has consistent soil, smoothness, flatness and slope characteristics over the large area required.

The use of check chains helps to maintain a constant steering angle, but can be unsafe as it restricts the rider's ability to make corrections if needed for safety reasons.

Method 2-Trapezoidal steer, fixed speed

Procedure:

- Approach the maneuvering area on a straight line path at constant speed.
- Apply the steering input, up to a specified amplitude, in a trapezoidal waveform, while maintaining a constant speed. A check chain or similar device is used to establish and maintain the specified steering input amplitude.
- Maintain the indicated speed and steer angle for several seconds after any initial transients subside.
- Repeat the procedure at incrementally initial higher speeds until a limit condition is reached.

Application:

- Measure understeer/oversteer characteristics.
- It may be difficult to use this method to assess the nature of the limit condition unless the speed increment is kept very small.

Limitations:

A large area is needed for this type of test, and it is difficult to predict just what the path of the vehicle will be. In actual off-road areas it is difficult to find an area that has consistent soil, smoothness, flatness and slope characteristics over the large area required.

The use of check chains helps to maintain a constant steering angle, but can be unsafe as it restricts the rider's ability to make corrections if needed for safety reasons.

Maintaining the indicated initial speed is difficult especially at large steer angles, because large vehicle sideslip angles may develop, and large tire drag forces may occur, greatly increasing the throttle input needed to maintain a constant indicated speed. Substantial longitudinal tire slippage may also occur, which results in the indicated (drive train) speed begin a poor descriptor of forward speed. Specification of which sensor to use to control forward speed can have a large effect on the test result. In addition, increased throttle input typically affects the steering response (i.e., yaw response) of any wheeled vehicle.

Method 3-Ramp steer, fixed speed

Procedure:

- Approach the maneuvering area in a straight line at constant speed.
- Increase the steering input quasi-statically until a limit condition is reached.
- Maintain a constant speed as the steering is applied.

Application:

- Understeer/oversteer characteristics.
- Limit condition can be assessed as the limit would typically be approached slowly.

Limitations:

A large area is needed for this type of test, and it is difficult to predict just what the path of the vehicle will be. In actual off-road areas it is difficult to find an area that is consistent over the large area required.

Method 4-Trapezoidal steer (series of increasing angles), fixed speed

Procedure:

- Approach the maneuvering area in a straight line at constant speed

- Apply the steering input, in a trapezoidal waveform while maintaining a constant speed. A check chain or similar device is used to maintain the final fixed steer angle.

- Maintain the speed and steer angle for several seconds after any initial transients subside.

- Repeat the process at incrementally steering angles until a limit condition is reached.

Application:

- Understeer/oversteer characteristics

- It may be difficult to use this method to assess the limit condition unless the steer angle increment is kept very small.

Limitations:

A large area is needed for this type of test, and it is difficult to predict just what the path of the vehicle will be. In actual off-road areas it is difficult to find an area that is consistent over the large area required.

The use of check chains helps to maintain a constant steering angle, but can be unsafe as it restricts the rider's ability to make corrections if needed for safety reasons.

Method 5-Fixed radius, increasing ramp of speed

Procedure:

- A circular path is marked on the ground. The vehicle must follow this path throughout the evaluation.

- The vehicle is accelerated quasi-statically, steering as needed to maintain the prescribed path, until a limit condition is reached.

Application:

- Understeer/oversteer characteristics.
- Limit condition can be assessed as the limit would typically be approached slowly.

Limitations:

As multiple laps of the circle are generally required, the course will tend to develop a berm.

Method 6-Fixed speed (series of increasing angles), fixed speed

Procedure:

- A circular path is marked on the ground. The vehicle must follow this path throughout the evaluation.
- The vehicle is accelerated to the target speed as the circle is approached. The steering is manipulated until the vehicle follows the path at the target constant speed.
- The process is repeated at incrementally increasing speeds.

Application:

- Understeer/oversteer characteristics
- It may be difficult to use this method to assess the limit condition unless the speed increment is kept very small.

Limitations:

- As multiple laps of the circle are generally required, the course will tend to develop a berm.
- Some small closed loop steering is typically needed to maintain the path.

iv) "Dynamic lateral stability test" feasibility study

In connection with the development of the original SVIA (ANSI) Voluntary Standard for ATV's c. 1988, a "dynamic stability test" feasibility study was conducted by Dynamic Research Inc. (DRI) under contract to the SVIA. In order to attempt to overcome the two previously mentioned difficulties (i.e., soil variation, and rider position variation) the test procedure was developed at El Mirage Dry Lake in Southern California, which has a (usually) dry, hard clayey soil surface; using an automatic servo-steering (or "robot") rider device to control the ATV test vehicle.

Test procedure objective

The objective of the study was to assess the feasibility of a dynamic steady state turn test, based on a "constant radius turn" method (Methods 5 or 6 above). The reason for use of the constant radius method was that it was believed that this would enable a more robust "control-by-wire" (rather than radio control). The other methods were possible, and could have been attempted, but were not, given the limited time and scope of the study.

El Mirage Dry Lake

This test site comprised a dry lake which had a roughly 3 mile by 1 mile nominally flat unobstructed central section often used for filming car commercials and occasionally for vehicle testing. During perhaps 8 months of the year the clayey surface was relatively dry and hard. If subjected to repeated passage of maneuvering vehicles in for example steady state turn tests, a fine powdery residue can build up on the surface, which may become slippery or inconsistent in friction level. This generally required moving to another area after some number of passes.

Servo (or robot) rider and signal tether device

An electric servo-actuator motor was mounted on the main frame of the ATV, and in such a way that its output shaft applied a specifiable torque to the steerable front assembly of the ATV, using on-board torque and angle sensors and feedback control systems.[33]

An additional servo-motor was mounted to the throttle, the position of which was sensed by a potentiometer. A closed loop control circuit was implemented such that the remote operator could command throttle position.

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[33] Lenkeit, J.F., "A Servo Rider for the Automatic and Remote Path Control of a Motorcycle," SAE Paper 950199, 1995.

A pneumatic piston-cylinder acted on the brake pedal of the ATV to enable one-shot braking to be applied, to bring the ATV to rest. This was actuated by an electrically controlled solenoid valve at the outlet of an non-board air reservoir.

The steer angle, throttle and brake command signals were input by a human operator standing near the center of the test circle, via an approximately 50 ft long electrical cable. In order to minimize cable forces acting on the ATV, the cable was carried on a pivoting boom, having a counter-balance weight, rotating about the center of the test circle.

The test circle was delineated by marking cones on an approximately 50 ft circle on the dry lake test surface.

The ATV was fitted with sensors for steer angle steer torque, forward (front wheel) speed, yaw rate and lateral acceleration, which are the variables needed to measure understeer/oversteer characteristics, maximum lateral acceleration and nature of the limit. The sensor data was transmitted by the tether cable and recorded by means of a ground-fixed data acquisition system.

The ATV was ballasted with adjustable position weights, so that the total of the ballast weights and the equipment weights totaled 170 lb (i.e., a 50th percentile adult male) rider, and the weight distribution was initially that of a centered rider on the ATV. The ballast was then further adjusted to match the lateral rider c.g. offset (e.g., about 8 inches lateral shift) for a rider-active near-limit riding position.

Feasibility test procedure

The test procedure for the feasibility study involved the human operator applying a fixed throttle input, resulting in a fixed forward speed, and then adjusting the steer angle input so that the ATV would approximately follow the cone-delineated constant radius curve. The steer angle was then held constant at this condition for several seconds.

The throttle input was then incrementally increased for a greater speed, and the steer angle adjusted to follow the curve, in a series of steps up to the maximum lateral acceleration achievable.

Data were able to be recorded in order to measure understeer/oversteer characteristics, maximum lateral acceleration and nature of the limit. The test data from these feasibility tests were not retained.

Comments on the feasibility test procedure

The required efforts and initial investment in hardware in order to establish a repeatable standardized "steady state turn" test method, based on servo-rider test device and tests on a dry lake, were substantial.

Despite these significant technical efforts, there appeared to still be substantial sources of variability in the results, due to the ability and precision of the human operator in steering the ATV to follow the curved course marked by cones; and the deterioration of the dry lake test surface over repeat passes; as well as from month to month with weather effects.

Further efforts could potentially ameliorate the human operator limitations. These could include for example, use of an automatic lane- (or cone-) sensing guidance system (based on currently emerging passenger car technologies); use of open loop controller (e.g., fixed steer rather than fixed radius input); fully on-board electronics, including guidance and control functions; programmed repeatable control; and other features.

Other maneuver types, such as the NHTSA rollover resistance fishhook test could also be attempted, but how to implement rider-active behavior (i.e., natural reflexive postural leaning of a (robot) rider when subjected to time-varying lateral g-forces) would be a substantial technical challenge.

The costs to implement, and to standardize any such complex procedure, and the practicability for manufacturers, the Government and others to reproduce such equipment and procedures, would be open to question.

v) Wide open throttle acceleration (rearward pitch stability)

This was a test procedure considered in the early Voluntary Standards process c. 1984.

Methods

This test involves applying a series of increasing magnitude "step open throttle" inputs to the ATV, in first gear, from a stop; and measuring any pitch up motion of the vehicle.

Advantages

This procedure is relatively realistic worst-case scenario that might occur in the real world. It includes effects of tire/soil interaction.

Disadvantages

This procedure is highly depending on the engine driveline characteristics, their state of tune and adjustment, atmospheric conditions and other engine/driveline related variables. In addition rider variation in applying the step throttle, and rider body reflective action, may unduly influence the results. There are also potential safety issues in the event of a pitch-up, if the test rider is not suitably skilled. Soil standardization is a difficulty.

vi) Maximum braking test (forward pitch stability)

This test procedure was considered in the Voluntary Standards development activity c. 1986.

Methods

This test involves applying a large (e.g., maximum allowable FMVSS 122) step-like brake lever control force input, and measuring any pitch forward motion of the vehicle.

Advantages

This procedure is relatively realistic worst-case scenario that might occur in the real world. It includes effects of tire/soil interaction.

Disadvantages

This procedure is highly depending on the brake system and suspension characteristics, and their state of adjustment. In addition rider variation in applying the step brake, and rider body reflective action, may unduly influence the results. There are also potential safety issues in the event of a pitch-forward. Soil standardization is a difficulty.

vii) Increasing up/down/cross slope operation

This was a test procedure considered in the Voluntary Standards development c. 1985.

Methods

These tests involved construction of an artificial (wooden) hill, with a parabolic increasing slope, and about 20 m from edge to edge across the slope. It was covered with high friction non-skid (sand emulsion) material. The increasing slope could be invoked by riding forward in the uphill direction; riding in reverse in the uphill direction; or riding across the slope, in a series of traverses, each at increasing cross slope, until a wheel lift condition was attained.

Advantages

These test allowed continuous, smooth and dynamic transition from small slopes, to large slopes, and a gradual attainment of the maximum slope condition. It allowed rider-active body movements. Attempts were made to specify the latter, and to record them by means of instrumentation.

Disadvantages

The hill surface was not a real soil. There were significant safety aspects that required "belaying" the rider and ATV with safety ropes. It was difficult to specify and repeat rider-active body position.

viii) Obstacle encounters (pitch stability)

This was a test procedure considered in the Voluntary Standards development c. 1985. The CPSC Engineering Report included a similar set of tests on artificial and natural bumps at Aberdeen Proving Ground.

Methods

This involved a series of different artificial triangular profile bumps of various heights and lengths. These were ridden across at a series of increasing speeds, until a stability (or physical discomfort) limit was reached.

Advantages

This procedure is relatively realistic worst-case scenario that might occur in the real world.

Disadvantages

Rider body-active movement, particular standing and absorbing shock as would normally be done by riders in this situation, was extremely difficult to specify, repeat and measure. The bump was not constructed from real soil, and had unrealistic rebound and damping characteristics. Throttle inputs had very large effects on the results, and a fixed or locked throttle had to be used to avoid repeatability problems. Often the limit was a discomfort limit rather than a stability limit. When it was a stability limit, there were significant safety issues. It was not clear how such a test could be specified and repeated, or how to avoid rider skill effects, which were large.

3) Other static stability test and evaluation methods

a) Etkin, static margin[34]

The concept of vehicle "static stability" measurement probably emerged in the early 1900s in the aeronautical field, when it was discovered that static stability was absolutely essential for achieving flight, and wind tunnels were devised to make such measurements.

The principle of pitch static stability has long been expressed in the aeronautical field as the distance between the center of gravity and the center of (vertical) pressure (the latter sometimes called the "stick fixed neutral point"). The "static margin" is equal to this distance divided by a characteristic length, which for aircraft is taken as the wing root chord length. To achieve static pitch stability in an airborne vehicle, the center of vertical pressure must be behind the center of gravity.

An exactly analogous formulation is used for static stability in yaw, based on the distance between the center of gravity and the center of (lateral) pressure, for sideslip conditions. For static yaw stability of a vehicle, the center of lateral pressure must be behind the center of gravity.

b) Weir and Zellner, ATV "stability margin"[35]

Weir and Zellner extended the aeronautical concept to ATVs operating in accelerating or sloped terrain conditions. For static stability, they stated that the vector describing the resultant acceleration (including gravity), acting through the center for gravity, had to lie within the area bounded by the centers of pressure of the tires (i.e., the acceleration vector had to lie within the wheelbase and track of the vehicle). For sufficiently large slopes or accelerations, it was possible that the acceleration vector would project outside the wheelbase or track, and in this case the vehicle would be statically unstable.

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[34] Etkin, Dynamics of Flight, John Wiley and Sons, Inc., 1957.

[35] Weir, D. H. and Zellner, J. W., "An Introduction to the Operational Characteristics of All Terrain Vehicles," SAE Paper 860225, 1986.

The distance in the ground plane between the acceleration vector and the edge of the tire "footprint" was referred to as the "stability margin." On flat and level terrain at steady speed, the stability margin was large, while on steep slopes or under large longitudinal or lateral accelerations the stability margin could decrease, or become zero or negative (unstable).

The paper also describes how the ATV rider can increase the stability margin by shifting or leaning his body in the uphill direction or in the direction of acceleration, which is a natural reflexive behavior further enhanced by the ATV's straddle seat.

4) Other dynamic stability test and evaluation methods

a) Allen, et al., ATV bump computer simulation model[36]

This paper includes, among half a dozen or so examples for other larger vehicles, an example computer simulation of an ATV and rider encountering a triangular profile bump and a circular profile bump. Despite the title of the paper, there is no discussion of ATV stability in this maneuver, and it is known that this very much depends on rider-vehicle interaction and in particular rider body movement and throttle and brake inputs.

Interestingly, the mode does include a vertical rider spring-mass-damper model, and the model is adjusted so that it compares quite closely to one particular test run on each bump. The authors comments, however, that the human test rider exhibited large run-to-run variability in his body movement, despite efforts to keep this constant, and this implies that the simulation model is a descriptive rather than a predictive model. This again highlights why this type of dynamic test is difficult to standardize.

b) Renfroe and Fleniken, ATV bump computer simulation and suspension design suggestions[37]

This paper describes a simple simulation model of an ATV traversing a bump (assuming that the rider mass is part of the ATV), and examining the vertical and "maximum difference in [ATV] pitch angle" (while traversing the bump).

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[36] Allen, R. W., et al., "Validation of Ground Vehicle Computer Simulations used for Dynamic Stability Analysis," SAE 920054, 1992.

[37] Renfroe, D. and Fleniken, G. L., "Designing for Pitch and Bounce Motion of Single Passenger Off-Road Vehicles, SAE Paper 940273, 1994.

The paper does not mention stability. However the reported maximum difference in pitch angle across the bump in some cases exceeds 180 degrees, and physically this seems highly questionable. The paper makes suggestions regarding preferred ratios of front/rear spring rate and damping rate, but given the apparent inconsistencies in the data these might have questionable validity.

c) Zellner, et al. (2004), increasing slope computer simulations[38]

In addition to the static stability measurements described earlier in this section, this report describes computer simulations of ATV mobility over rough terrain, and dynamic stability on increasing slopes. This includes increasing up-slopes, down-slopes and cross-slopes. The rider's hips are shifted in the uphill direction, and the rider's torso is leaned in the uphill direction, in order to simulate rider-body active movement. The throttle and brake are controlled in order to maintain a constant forward speed.

The accompanying animations illustrate how these types of maneuvers would be hazardous to conduct in full-scale tests, as the limit of stability is reached, and this is similar to the findings described previously in the "wooden hill" increasing slope full-scale test feasibility study.

5) Vehicle handling test and evaluation methods

The field of ground vehicle handling qualities is an enormous one, and the literature includes literally thousands of papers over the last 50 or more years. A few examples which may have some relevance to ATVs are included here.

a) Weir and DiMarco, passenger car directional handling test procedures and criteria[39]

This report describes a large-scale analysis for the NHTSA of passenger car handling and directional control test procedures, metrics and criteria. Detailed analysis of test data from a variety of sources was conducted, and

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[38] Zellner, et al, Review and Analysis of MUARC Report: "ATV Injuries and Deaths," and Additional Simulations and Initial Testing of MUARC ATV Rollover Protection System (ROPS), DRI-TR-04-01, Volumes I, II and III, Dynamic Research, Inc, 2004.

[39] Weir, D.H., DiMarco, R.J. and McRuer, D.T., Evaluation and Correlation of Driver/Vehicle Data, Contract DOT-HS-5-01200, Systems Technology, Inc. Report TR-1068-1, April 1977.

some recommendations were proposed with regard to useful objective test procedures and metrics. These included a single lane change; step steer; pulse steer; and describing function determination (using quasi random sum-of-sine steering input). Useful metrics included the vehicle yaw rate-to-steering wheel angle gain and effective time constant; and peak sideslip angle rate. The report includes a comprehensive bibliography of the seminal literature in vehicle handling prior at that date.

b) Kunkel and Leffert, passenger car directional response tests[40]

This paper describes General Motors handling metrics which had been developed and implemented over previous years. These included the Control Response (step steer) Test, Frequency Response (swept sine) Test, Maximum Lateral Acceleration (circle) Test, On-Center (small sine) Handling Test, Lift-Dive (acceleration and braking) Test, and Center of Gravity (tilt table with scales) Test. Similar SAE and ISO test procedures are also reviewed.

Twenty-four different response parameters were measured using the six test procedures. For example, the Control Response Test was used to measure vehicle lateral acceleration-to-steering gain, roll-to-lateral acceleration gain, understeer gradient and lateral acceleration response time.

Frequency histograms of GM passenger cars' parameter values for 1980 to 1988 model years are represented. No information is given in regard to criteria for these parameters.

c) Allen, et al, ATV steady state and dynamic handling characteristics[41]

This paper describes a computer simulation model and full-scale tests of 3 and 4 wheel ATVs. The steady state test and model data compare reasonably well, but the dynamic data indicate large differences between model and tests.

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[40] Kunkel, D.T. and Leffert, R.L., "Objective Directional Response Testing," SAE Paper 885008, 1988.

[41] Allen, et al, "Steady State and Dynamic Properties of All Terrain Vehicles related to Directional Handling and Stability," SAE 891105, 1989.

The steady state (circle) test data indicate that both the 3 and 4 wheel ATVs are understeering at low lateral accelerations, and become oversteering at high lateral accelerations.

Unfortunately the paper then draws several erroneous, misleading and/or baseless conclusions. These include that:

- "...at higher speeds, ATV response becomes sluggish," yet the only evidence for this is the dynamic results from the computer simulation, which the test data indicate is highly inaccurate. In fact, in general, ATV steering is not sluggish but rather quite responsive at high speeds.

- "ATV steering dynamics seem to degrade at lighter cornering conditions than for automobiles," yet this wrongly assumes that the transition to oversteer is a "degradation" instead of a desirable quality in any off-road vehicle, as discussed elsewhere herein.

- "...under rear axle force saturation (due to braking or acceleration) ATVs are directionally unstable," yet no supporting test data is presented in the paper, or in any other known published paper before or since this paper was published.

d) Allen, et al (1989b), ATV transient handling and stability[42]

This paper is mostly a review of other papers by the authors, with some new data on instrumented tests in an S-curve maneuver. The paper makes several misleading statements, including:

- "Handling deteriorates under hard cornering to an oversteer condition...," whereas for off-road vehicles it is well-known, as discussed elsewhere herein, that oversteer is preferable to understeer (for a variety of reasons) when trying to stay on winding dirt trails and roads without guardrails. The authors seem to assume that what may hold for on-road vehicles should

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[42] Allen, et al, "Transient Analysis of ATV Lateral Directional Handling and Stability," SAE Paper 891109, 1989.

somehow also hold for off-road vehicles, but this demonstrably is not the case.[43]

- "This condition can lead to dynamic instability and potential spinout which could also precipitate rollover," yet no such events were measured or recorded in the tests described, or in any of the other tests conducted by the ATV industry or its contractors in the Voluntary Standard development or by the CPSC or its contractors in its Engineering Report.

e) Allen, et al (1990), effect of load transfer distribution on ATV handling[44]

This report describes test and computer simulations to assess the affects of increasing the front suspension roll stiffness on ATV handling. The data indicate that, as would be expected, ATV oversteer is decreased and under steer is increased by increasing the front roll stiffness. However, various baseless, misleading and self-conflicting conclusions are stated, including:

- "As a practical matter, from the rider's point of view, the constant describing function result means that roll stiffness does not affect the vehicle response in terms of closed loop steering regulation (i.e., maintaining a steady path trajectory (p40)" seems to be in conflict with "...ATV steering response behavior is determined by load transfer characteristics which can be significantly influenced by relative roll stiffness between the front and rear axles p 42)."

- "When front axle roll stiffness is increased...causes ATV steering response to move...away from a spin out prone oversteer condition (p42)," yet no "spin outs" were recorded in these tests, or in any other tests reported by the authors, or CPSC or the ATV industry or their various contractors. In addition, in an off road vehicle, unlike an on-road vehicle, oversteer, especially at the limit

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[43] That oversteer is preferable and the given rule for off-road vehicles can be observed in any of hundreds of off-road rallies and racing events worldwide each year. Virtually all such vehicles can be seen to have substantial amounts of oversteer in turns, yet few ever "spin out."

[44] Allen, et al, Effects of Load Transfer Distribution on ATV Directional Handling and Stability, Systems Technology Inc. Report 1257-1, Contract CPSC-C88-1219, January 1990.

is more desirable than understeer, because of superior ability to stay on (and not drive off) winding dirt paths and roads.

In this report, the authors state that "Dynamic response test show that ATVs are very responsive to steering inputs, with time lags considerably less than typical cars." This is accurate, but is in direct conflict with what the authors reported in earlier publications, which was based on their simulation models rather than test data.

The authors also fail to mention or address that excessively stiff front axle roll stiffness can result to harsh shock prone steering on bumps, loss of steering control on bumps, and adverse ride characteristics.

f) Forouhar (1997), ATV frequency response to steering and rider control[45]

This paper review previous circle test and J-turn tests, and then describes a frequency domain steering model of an ATV and rider. Using 60 seconds of recorded winding path test data, a yaw response model of the ATV is measured. This is combined with a theoretical model of a rider. The conclusions are that the ATV "low frequency gain is about 3.55 deg/s/deg and it bandwidth is about 5 rad/s, implying good response for low frequency rider steer inputs and attenuation of high frequency disturbances." In addition, when combined with a typical rider model, the rider-vehicle system has a good (2 rad/s) responsiveness and large (8 db) gain margin, which means it the system stability is not overly sensitive to the rider's exact choice of gain.

g) Forkenbrock (2005), handling tests for electronic stability control[46]

This presentation describes recent NHTSA development of handling test applicable to passenger car and light truck electronic stability control (ESC) testing. The goals of the ESCs and related handling tests are to verify that, with ESC, and in maneuvers specially designed to induce yaw instability, the

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[45] Forouhar, F. A., "ATV Frequency Domain Response Analysis and Rider Behavior," Proceedings of the 1997 IEEE International Conference on Control Applications, October 1997.

[46] Forkenbrock, G. J., "Overview of NHTSA's 2005 ESC Research Program," Presentation to 19th International ESV Conference, Washington, D.C., http://dmses.dot.gov/docimages/pdf91/312464_web.pdf, June 2005.

vehicle does not spin out; it is able to achieve a minimum lateral displacement; it does not experience 2-wheel lift; and it does not experience rim-to-ground contact or tire debeading. It is notable that, at least conceptually, some of these might also be desirable for ATV handling tests. Again, the challenge with ATV handling tests is standardization and measurements of soil, and rider body motions.

The preferred maneuver is a "0.7 Hz sine plus dwell" steering input, applied by means of an automatic steering controller (AVC). NHTSA is collaborating with the car industry to apply and further develop this handling test method. A decision has not yet been made as to whether the test will become a Consumer Information (NCAP) test or a Federal Motor Vehicle Safety Standard.

h) Alliance of Automobile Manufacturers (2005), ESC handling test data[47]

This presentation collects a large amount of test data, and their statistical distribution, resulting from full-scale tests with approximately 50 passenger cars and light trucks, and based on NHTSA's "0.7 Hz sine plus dwell" handling test.

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[47] Alliance of Automobile Manufacturers, "Preliminary Result of ESC Performance Test Evaluations," http://dmses.dot.gov/docimages/pdf92/337256_web.pdf, 23 June 2005.

ANPR Question 6: "Technical information on motion sensing technology that can be used to measure the displacement, velocity and acceleration of both the test [rider] and test vehicle.

Table 8 presents a summary of five different types of motion measurements systems, which have found application in the vehicle (and crash) dynamics fields. These are:

- 3D video analysis systems
- 3D optic analysis systems
- Inertial measurement systems
- Differential GPS with post-analysis systems
- Differential GPS with real time analysis systems

Each of these is further discussed in Table 8 and below.

i) Previous system investigated by CPSC

In the late 1980's, CPSC investigated a 3D video analysis system with multiple reflective targets placed on the rider and vehicle. It is unknown how useable this system was, however it is known that such early 3D systems were not very user-friendly terms of their setup, calibration and extensive post-processing requirements. It is also unknown what the ultimate accuracy and resolution of the system investigated by CPSC was.

j) Other current measurement systems

For each of the five types of system, Table 8 summarizes the type of equipment, the software, the sampling and data rates, the estimated costs of parts and integration, past use in vehicle studies, post-test analysis requirements, some of the prevalent error sources, feasibility of vertical distance , velocity and acceleration measurement, other comments, the technical risk involved in integrating the system, whether the system is available as a commercial-off-the-shelf system (COTS) and examples of typical brand names.

A typical sampling rate for high speed high resolution video recording is 1000 samples per second for displacement measurement, and applying typical rules of thumb for digital differentiation and smoothing yields reliable velocity data rates of about 200 Hz, and reliable acceleration data rates of about 40 Hz.

Inertial measurement units recording at 1000 samples per second can achieve filtered data rates of 100 Hz for displacements, velocities and accelerations, which is their advantage. The limitations include larger parts costs if more than about 15 measurement locations are desired, and the possibility of sensor drift and noise as possible issues, depending on the amplitude and frequency ranges of the motions being recorded.

Differential GPS offers another method for motion measurement and analysis, but with generally lower data rates owing to the lower sampling rates available. COTS packages offer 1 Hz data rates, but with limited or no vertical and pitch motion capability. Customized packages can output 10 Hz data rates with vertical and pitch motion capability, but this comes at the expense of a higher signal noise level.

All of these methods except traditional inertial measurement have significant technical risk associated with integrating the hardware, software and achieving the desired tradeoffs between accuracy, noise levels, range, and number of measurement locations. The inertial measurements and high data rate differential GPS also involve significant system integration efforts, which depend on the specific system accuracy, channels, range, etc. requirements.

Table 8. Summary of vehicle and occupant measurement systems

Process	Equipment	Software	Estimated		Estimated Cost		Past use on:			Post Test Analysis	Error Sources	Vertical Measurements	Other comments	Technical Risk	COTS	Equipment Sources
			Sample Rate	Data Rate	Parts	Integration	ATV	Vehicle	Rider							
3D Video	3 to 6 High Speed Video Cameras Minimum; Multiple high-contrast targets; Controlled lighting environment	3D Analysis	1000 Hz	40 Hz	$150K	Low	unknown	unknown	Yes	Results available after extensive post test analysis	Target locations; Poor lighting conditions, may not work well in outdoor lighting situations	Yes	Data quality is largely dependant on the ability to control the lighting environment and the effectiveness of object targets. Ruggedized system would need to be developed.	Moderate	Yes	Cameras: Redlake, ViconPeak Software: Xcitex 3D analysis package, APAS
3D Optical	3 to 6 High Speed Video Cameras Minimum; Optoelectronic or electromagnetic marker systems	3D Analysis	1000 Hz	40 Hz	$150K	Low	unknown	unknown	Yes	Results available after extensive post test analysis	Target locations; Poor lighting conditions, may not work well in outdoor lighting situations	Yes	Data quality is largely dependant on the ability to control the lighting environment and the effectiveness of object targets	Moderate	Yes	Polhemus; WATSMART; Ascension Technology; Northern Digital
Inertial Measurement	Solid State inertial units	Data Acquisition	1000 Hz	100 Hz	$10k per measurement location; DAS $25k	Moderate to High	Yes	Yes	unknown	Results can be available in "Real Time"	Sensor drift, noise level	Yes	The smallest and most desirable units require processing of serially formatted data. This solution would require the development of an embedded system.	Low	Yes	Crossbow, Systron Donner, Memsense, Xsens, Etc.
Differential GPS	Multiple differential GPS receivers	Standard Surveyor Package	100 Hz	1 Hz	$120k	Low	Yes	Yes	unknown	Results available after extensive post test analysis	Multipath distortion; atmospheric; constellation availability	No	Height measurements are significantly more problematic and error prone than XY; roll and pitch may be impossible	Very High	Yes	Trimble, Garmin, Magellen, Etc.
	Multiple differential GPS receivers	DRI "Real Time" Software	100 Hz	10 Hz	$150k	Moderate	No	Yes	No	Results available via Matlab	Same as surveyor GPS with higher noise level due to higher sample rate	No	"Real Time" is used loosely in this case for the 10 Hz output rate contains significant levels of anomalies	Very High	Yes	Trimble

ANPR Ques 13: "Information about the applicability of sensor technology to improve the safety of ATVs"

Table 9 summarizes emerging car-based sensor technologies and their potential application to future, potential car-based safety systems.[48] The categories of sensors are reviewed; and then the categories of potential car-based safety systems are reviewed, along with commentary in regard to their applicability to improve the safety of ATVs.

1) Car sensor technology

Emerging sensor technologies are being developed, demonstrated and to a limited extent introduced on prototype and production cars. To date, few of these have been introduced in production cars, and there is little or no data available on their actual in-use safety effectiveness at the current time.

General comments on the relevant differences between ATVs and cars in relation to sensors are followed by a brief summary of technical challenges for their application to ATVs.

In general, as related to their off-road usage, ATVs are exposed to much more severe operating environments than passenger cars, and this affects the information gathered by as well as the operability and suitability of safety–related sensors. These differences include:

- Their much smaller mass, which results in proportionally greater accelerations of their sprung body, which can adversely affect the operability, signal quality and durability of many sensors;
- The far rougher and more complex off-road terrain on which they operate, which can result in "false" impact or rollover signals, for example;
- The much greater exposure of vehicle parts to noise, vibration, mechanic shock, electromagnetic interference, water dust and other contaminants, which adversely affect both the operability and the durability of sensors;

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[48] US Department of Transportation National Highway Traffic Safety Administration, Crash Prevention Technologies Matrix, 2004.

- The much smaller space on the vehicle for properly mounting and housing sensors.

- In some cases, substantially greater costs to the consumer, with unknown or potentially small or no benefits for some systems.

In addition, the variable being sensed can be much more difficult to sense, or not possible to sense, on an ATV. Some of the reasons for this include:

a) For "lane delineation" (e.g., lane edge) sensors, absence of lane delineation markers or boundaries in virtually all off-road environments;

b) For "radar/IR distance and direction" sensing, these are primarily being explored in the car filed for sensing of other cars, whereas for ATVs proximity of an opposing car represents a rare misuse condition. Moreover, it is unclear how such radar or IR sensing systems would detect or be useful in a typical off-road environment, involving relatively low speeds, and situations where rocks, boulders, trees and the like may normally be in close proximity to the ATV, without being a threat. In such situations, the rider's normal vision would seem to be the most reliable means to detect obstacles.[49]

c) For driver "eye-open" sensing, the need to cover the eyes with various types of eye protective gear;

d) For "occupant position sensing" as related to active rollover or impact protection (e.g., airbags, etc.) , the much greater range of ATV rider movement and position on and off the seat, in comparison to a car occupant;

e) For "roll angle and roll rate" sensing, the capability of ATVs to operate routinely on relatively steep and complex slopes and terrains which almost never result in a rollover, but which may be falsely interpreted by typical car rollover sensors as "impending rollovers;"

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[49] Exploratory research and development of autonomous off-road vehicles by the US/DOD/DARPA has resulted in several prototype vehicles which can apparently operate in using automatic obstacle sensing, steering and speed control; but such prototype "robot" vehicles are extraordinarily expensive and do not fulfill the purposes of ATVs as low cost, general purpose recreational and utility vehicles for personal transport.

f) In addition, for "roll, yaw and lateral acceleration" sensing, the prevalence of large three-dimensional terrain features and obstacles over which ATVs may operate which cause strong interactions amongst these motions, and which make such signals far more difficult to separate and interpret. In addition, ATVs may sometimes be dropped and overturned during loading onto a truck or trailer, and presumably this sort of relatively common event should not trigger a rollover warning, crash notification to rescue services, or automatic steering or braking actions, for example.

g) For "steer angle and steer angle rate" sensing, such sensors exist in some car systems, but these have been designed from more benign environments and exposures than those of typical ATVs;

h) For "crash acceleration" and "lateral acceleration" sensing, as noted previously, ATVs have lighter mass, and are also exposed to much greater terrain roughness and shock and vibration environments. As a results, although is feasible to sense accelerations, it would be extraordinarily difficult to distinguish those associated with a "crash" from those lateral (or longitudinal) ones associated with maneuvering, from those associated with the terrain and surface roughness.

i) For "wheel speed sensing," such sensors exist for on-road motorcycles, yet these have been developed for a much more benign and less exposed environment. In addition, as noted below, such sensors are used in antilock braking and traction control systems, and it is unclear what if any advantages such systems would have for off-road vehicles such as a ATVs;

j) For "brake pressure sensing," such sensors exist for on-road motor vehicles, but they are used primarily in power-assisted brake systems, which in general ATVs do not have or need.

k) The one sensing technology that is finding and may find further application on ATVs is "GPS" sensing. To date, use of GPS on ATVs has not been in connection with safety systems, but rather with navigation systems.[50] Potentially, if (by means of other sensors) there

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[50] A navigation system is not primarily a safely device but could have safety-related applications such as assisting users with safe route finding; or assisting in guiding rescue teams, once the rescue team has been notified of an incident.

were separate means for reliably transmitting a "crash" notification message to rescuers (either by voice-radio or automatically), then GPS sensing could support rescue operations, which could have some benefits for ATV accidents in remote off-road areas.

l) IR cameras for night vision might also have some applications for ATVs, however it seems likely that OE or aftermarket high intensity lighting systems could be equally effective for ATVs. This is not the case for on-highway passenger cars, which must avoid exposing other road users to "glare." In addition, that the displays for ATV night vision systems would almost certainly have to be helmet-mounted, as ATVs in general do not have windshields required for head-up displays; and head-down displays or displays on a stalk would be too distracting, dangerous and probably not useable.

2) Car safety enhancement systems

In addition to the generally large differences in sensor applicability" for cars versus ATVs, there are also major differences with respect to use of the sensor information in potential safety enhancement systems. There are at least three categories of sensor-based potential safety systems for passenger cars, ranging from systems that are more passive in nature to systems that are more active or intervening. These include:

- Active occupant protection systems
- Driver warning systems
- Driver assistance systems
- Rescue information systems
- Crash avoidance and mitigation systems

Some of the more frequently studied car safety enhancement systems are described in the following section, along with commentary regarding their applicability to ATVs.

a) Active occupant protection systems

Examples of active occupant protection systems in passenger cars include radar-actuated (or roll sensor-actuated) seatbelt pre-tensioners and airbags, and automatically deployable rollover protection systems (ROPS).[51]

In regard to seatbelts on ATVs, seatbelt should only be used on any vehicle if and when a ROPS is present. However, for ATVs, to date there have been numerous studies[52] of ROPS, with and without seat belts, and these studies have found that such systems would *increase* injuries to ATV riders. This is due to several mechanisms, including:

- Decreased overturning stability of such a small vehicle, due to the ROPS having a relatively large mass on such a vehicle, resulting in a significantly higher center-of-gravity and more overturning tendency;

- Impact against and crushing by the ROPS itself, with ROPS that loosely restrain the rider, or which do not restrain the rider at all;

- With ROPS that tightly restrain the rider, interfering with rider-active body movement (reducing the terrain and operating capabilities of the vehicle); and transmitting large, brain-injuring g-forces to the rider on a vehicle with such a small mass and high accelerations during overturns.

Therefore and ATV fitted with, for example, roll sensor-actuated seatbelt pre-tensioners (along with a fixed ROPS) would have the same injurious effects as this third type of (tightly restrained) ROPS system, and would not be viable.

In regard to use of radar- or roll sensor- actuated airbags on ATVs, in addition to the all the significant problems involved in sensing ATV crashes or rollovers, as described above, for ATVs it is unclear against what surface an airbag would act. Passenger car frontal airbags act between the

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[51] Examples of automatically deployable ROPS include Mercedes Benz and BMW convertibles, which sense impeding rollover and deploy a roll-protection structure behind the driver and front seat occupant.

[52] For example, Zellner, et al, Review and Analysis of MUARC Report: "ATV Injuries and Deaths," and Additional Simulations and Initial Testing of MUARC ATV Rollover Protection System (ROPS), Technical Report 04-01, Volumes I, II, and III, Dynamic Research, Inc., 2004.

occupant and either the steering column (for driver airbags) or the dashboard (for passenger airbags). Passenger car side airbags[53] act between the occupant and the door surfaces and/or the opposing vehicle's impacting surfaces. The motorcycle frontal airbag announced by Honda in 2005[54] acts between the rider and the motorcycle windshield and also opposing vehicle in motorcycle frontal impacts. For an ATV, these reacting surfaces (windshield, steering column, opposing vehicle) are typically not present. To the contrary, ATV accidents are typically single vehicle accidents involving entirely different types of injury mechanisms, such as impact between the rider and the ground. More importantly, ATVs have fuel tanks in front of the rider, and there are obvious potential hazards in mounting a pyrotechnic device such as an airbag on a fuel tank.[55]

The concept of an inflatable, airbag-type "ROPS," deployed from an area to the rear of the ATV seat has been mentioned as a concept, but it too would have to address the "sensor" feasibility issues discussed above, as well as its relative injury risks and benefits in typical ATV accidents.

Deployable rigid ROPS, such as used on some production convertible passenger cars, and as prototypes on agricultural tractors,[56] would be bound to have similar injurious effects as previously studied ATV rigid ROPS prototypes.

b) Driver warning systems

Sensor-based warning systems for car drivers that have been studied and in some cases introduced in passenger cars include:

- Lane departure warning

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[53] Van Auken, R.M., and Zellner, J.W., "Preliminary Analysis of the Effects of ATV ROPS on Rider Injury Potential, Second Revision," Dynamic Research, Inc., Technical Report 96-4B, February 1997.

[54] Honda press release, http://world.honda.com/news/2005/2050908.html, 8 September 2005.

[55] The Honda motorcycle airbag system is mounted on a GL1800, a very large touring motorcycle in which the fuel tank is located beneath the seat. The airbag is deployed from a shroud located in front of the rider.

[56] Powers, et al, "Performance of an automatically deployable ROPS on ASAE Tests," J. of Agricultural Safety and Health 7(1):51-61. 2001.

- Drowsy driver warning
- Collision warning
- Rollover warning
- (Side) blind zone warning
- Backup warning
- Curve over-speed warning

These are briefly described in their passenger car context, along with comments on their applicability to ATVs.

In regard to "Lane departure warning," this uses video or IR camera sensing to detect when a passenger car is departing a lane marked by lane delineation lines, in order to transmit a warning to the driver. For ATVs operating in an off-road environment, there are no lane delineation lines, and often no clear path boundaries of any sort (e.g., field, beach, etc.) from which to detect a "departure." Moreover, it is unknown whether and to what extent this type of accident occurs with ATVs.

In regard to "Drowsy driver warning," this uses driver open-eye video or IR sensing to detect when a car drivers eyes are closed, in order to transmit a warning to the driver. For ATV riders, it is important that eye protection, which comes in various types and forms, is worn, it is unlikely that an ATV-mounted senor could be developed that would work with all types of eye protection. In addition, such a device would have to work with a larger range of ambient lighting conditions present with a rider in essentially outdoor lighting conditions. Moreover, it is unknown whether and to what extent this type of accident occurs with ATVs.

In regard to "Collision warning," this uses radar or IR sensing of the distance and direction (and rates thereof) to opposing motor vehicles, to calculate a probability of and "time to" collision, in order to transmit a warning to the driver. These systems are not able to detect small objects. For ATVs, the opposing objects typically present and which may be associated with "ATV impacts" tend to be either small, or low-lying ground features, such as bumps, ditches, irregularities, trees, fences and the like. None of the listed objects is detectable by existing radar or IR sensors. In addition, ATV opposing objects are in extremely close proximity and it is unclear that such a system would be able to detect for which objects there is a high probability of collision, and if detected whether the rider would have sufficient time to react. It is also unclear whether an ATV-mounted audio or visual warning could be sensed by the rider, given the presence of engine and wind noise, helmet, the bright sunlit conditions in which a visual warning would need to be effective and the lack of ATV structures in the rider's field of view, on which to mount a visual warning. In addition, there is a general lack of data describing the frequency and types of objects ATVs collide with, and whether they could be reliably sensed by electronic means.

In regard to "Rollover warning," passenger car systems use solid-state roll rate sensors[57] and integrate this signal to obtain roll angle and probability of rollover in order to transmit a warning to the driver. For passenger cars, such systems are only now being considered. Given the complexity and quickness of passenger car and light truck rollover events, it is unclear at this time whether typical drivers would be able to detect the warning, then to determine the proper steering and/or braking inputs to use, and then to apply the proper steering or braking input, with sufficient quickness and accuracy to avoid an impending rollover. For ATVs, in addition to these significant uncertainties, there is the additional fact that, ATV rollover, once begun, can progress much more quickly than that of passenger cars, due to ATV's smaller masses and moments of inertia. In addition, it is also unclear whether an ATV-mounted audio or visual warning could be sensed by the rider, given the presence of engine and wind noise, helmet, the bright sunlit conditions in which a visual warning would need to be effective and the lack of ATV structures in the rider's field of view, on which to mount a visual warning. In addition, there is a general lack of data describing the direction and source of ATV rollovers (i.e., whether a "rollover" accident was in the forward, side or rearward direction; whether it was due to an obstacle or ground impact or rider control input, and if so, of what type and magnitude etc.), and whether any of these events could be reliably sensed by electronic means, and reacted to by a typical rider.

In regard to "(Side) blind zone warning," this uses radar or IR sensing of the distance and direction (and rates thereof) to nearby motor vehicles, in or approaching the "blind spot," to calculate a probability of and "time to" collision, in order to transmit a warning to the driver. These systems are not able to detect small objects. For ATVs, it is unclear whether "blind spot"

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[57] There are several different types of solid state senor used, including accelerometer arrays (which are further processed), induced current devices, so-called solid state rate gyros and others.

accidents occur, and if so what types of vehicles are involved in passing the ATV. Even if such accidents did occur, and sensors could be designed to detect the overtaking vehicle and ignore other stationary objects, it is unclear whether an ATV-mounted audio or visual warning could be sensed by the rider, given the presence of engine and wind noise, helmet, the bright sunlit conditions in which a visual warning would need to be effective and the lack of ATV structures in the rider's field of view, on which to mount a visual warning.

In regard to "Backup warning," this uses video (or in some cases IR) sensing of the presence and distance and (and rate thereof) to objects to the rear or a passenger car or light truck, in order to transmit a warning to the driver. For ATVs, it is unclear whether backing up "blind spot" accidents occur, and if so what sizes of person, animal, object, etc. are involved, and what are the severities of such accidents. Even if such accidents did occur, and sensors could be designed to detect the person, animal or object, it is unclear whether an ATV-mounted audio or visual warning could be sensed by the rider, given the presence of engine noise, helmet, the bright sunlit conditions in which a visual warning would need to be effective and the lack of ATV structures in the rider's field of view, on which to mount a visual warning.

In regard to "Curve over-speed warning," there are a variety of these systems which have been discussed but not yet implemented for passenger cars. The simplest involve solid-state accelerometers that sense when a vehicle is cornering at a lateral acceleration greater than a certain level, in order to transmit a warning to the driver. The difficulty is in sensing pavement friction conditions, i.e, what might be a safe speed and lateral acceleration for dry high friction conditions might not be for icy conditions. This is even more complicated for ATV's which basically should never be operated on any type of paved surface, and which are almost always operated on some type of non-standard off road surface. Passenger car systems under development may use wheel speed and radar ground speed sensors to detect when a large amount of vehicle sideslip is present, in order to determine whether the limit of adhesion is being approached. It is unclear whether such sensing would be feasible for ATVs, given in particular the wide diversity of terrains, soils and conditions on which ATVs are operated. It is also unclear whether an ATV-mounted audio or visual warning could be sensed by the rider, given the presence of engine noise, helmet, the bright sunlit conditions in which a visual warning would need to be effective and the lack of ATV structures in the rider's field of view, on which to mount a visual warning. Even if the warning was detected it is unclear that a typical

ATV rider would know what steering throttle or brake input to use, and whether this would be quick enough or of sufficient amplitude to avoid an "over-speed" type accident. Moreover, it is unknown how frequently this type of "over-speed" or "high sideslip" type accident occurs with ATVs.

c) Rescue information systems

For passenger cars, this typically uses airbag deployment signals to transmit a radio (or other frequency) message and GPS coordinates to rescue services (e.g., examples are the GM On-Star and other similar networks). For ATVs, there are no existing "crash detection" sensors present, in order to determine that a crash has occurred. Hypothetically, these could involve a rollover sensor of some type, as mentioned above; however in loading or unloading an ATV from a truck, and in other operations, ATVs may be overturned without a rider on board, and it would be undesirable to deploy rescuers for such relatively common events. Therefore, at a minimum, such a system would need a "rider on-board" sensor. Yet, this is made complicated by the fact that ATV riders may frequently stand on the footrests (rather than sit of the seat) during operation. In addition, it is unclear in what fraction of ATV accidents late notification of rescuers is a significant factor.

d) Crash avoidance and mitigation systems

For passenger cars, this uses similar sensor technology as for "Collision warning" and "Rollover warning" described above, but linked through suitable logic to braking and/or steering actuators. There are currently only a few such systems which have been deployed in production passenger cars.[58] For passenger car systems, typically this involves providing a first-stage warning to the driver, and then if the collision or rollover continues to be imminent, applying brakes (and/or steering) to reduce the speed of (or if possible avoid) a collision or rollover. For passenger cars, such automatic (or intervening) strategies are more possible because of the presence of antilock brake system braking actuators and/or power steering systems. Neither of these are present (or perhaps even advisable) on ATVs. In addition, "collision" and "rollover" sensing on ATVs have associated difficulties that were previously described.

[58] For example, the 2005 Acura RL with Collision Mitigation System.

Car-based Sensor Technology	Potential Safety Technology																			
	Lane departure warning	Drowsy driver warning	Collision warning	Rollover, warning	Blind zone warning	Backup warning	Curve over-speed warning	Automatic crash notification	Active lighting	Night vision	Adaptive restraints	Rollover active protection	Brake Assist	Antilock braking	Traction Control	Yaw stability control	Curve over-speed control	Collision mitigation	Automatic cruise control	Rollover prevention
Lane Delineation Sensing Cameras	X						X										X			
Radar/IR Distance Sensing						X							X						X	
Driver Eye-Open Sensing		X																		
Occupant Position Sensing											X									
Radar/IR Distance and Direction Sensing			X		X								X					X		
Roll Angle and Roll Rate Sensing				X								X								X
Yaw Rate Sensing							X									X				
Steer Angle and Steer Angle Rate Sensing									X								X			
Crash Acceleration Sensor								X												
Global Positioning System								X												
IR Cameras										X										
Wheel Speed Sensors														X	X					
Brake Pressure Sensing													X							
Lateral acceleration sensing							X										X			

PROGRAM DETAILS:

Distribution:
Middle Schools and High Schools nationwide.

Quantity:
20,000 programs sent to mainly rural area teachers.

Components:

- A two color dual sided teacher guide / community leader letter
- Thirty 5-1/2 x 8-1/2 eight page four color student activity booklets
- Thirty dual sided letter folded parent take home brochures.
- A four color 17 x 22 wall poster
- A one-color teacher response card
- A program survey
- A jiffy mailing envelope

Estimated reach:
52,200 teachers (2.61 teachers per program on average)
2,483,400 students (124.17 students per program on average)

EDUCATORS' FEEDBACK:
Based on 110 surveys and 135 response cards

Utilization of the Program:
The *Protect Yourself, Protect the Planet* program was used primarily by middle school and high school teachers mainly in the areas of Social Studies and US History. 67% of the teachers had already used the program when they completed the survey. The remainder plan to use the program the following semester. 59% planned to share the program with other educators in their schools. Of those who shared the program, 24% had shared with one colleague, 43% had shared with two colleagues, 13.7% had shared with three colleagues, 11.8% had shared with more than three colleagues, and 7.5% had shared with more than six colleagues.

Teacher Pass-Along:
On average, the program was used with 124.17 students and 2.61 teachers. Student counts ranged from 30 to 720. Teacher counts ranged from 1 to 38.

Student Usage:

- 26.11% used the materials with up to 30 students
- 23.96% used the materials with 31 to 40 students
- 13.54% used the materials with 41 to 60 students
- 16.67% used the materials with 61 to 100 students
- 19.72% used the materials with more than 100 students

Teacher Usage:

- 25.49% indicated two teachers used the program
- 43.14% indicated three teachers used the program
- 13.73% indicated four teachers used the program
- 5.9% indicated five teachers used the program
- 11.76% indicated six or more teachers used the program

Program Evaluation:
The components of *Protect Yourself, Protect the Plane* program were all rated "Excellent" or "Above Average" by over two-thirds of the educators completing the surveys. The Activity 4: *Sun Poetry* was rated highest, and all components received average ratings between 4.42 and 4.58 on the 5-point rating scale (5 = excellent, 1 = poor).

- The student activity booklet received an average score of **4.26**
- The parent guardian take home pamphlet received an average score of **4.18**
- The letter to educators and community leaders received an average score of **4.01**
- Activity 2: *Fun and the Sun* received an average score of **4.51**

- The wall poster received an average score of **4.38**

Components' Rating	Student Activity Booklet	Parent/Guardian Take Home Pamphlet	Leader/Educator Letter	Wall Poster
Excellent	51.07%	43.16%	35.56%	52.53%
Above Average	30.21%	37.89%	37.89%	35.36%
[redacted]				
Average	16.71%	16.84%	24.43%	12.13%
Below Average	2.01%	2.11%	2.12%	0.00%
Poor	0.00%	0.00%	0.00%	0.00%

Component Utilization:

86.74% of the educators indicated they displayed the wall poster in their classroom.

47.83% of the respondents tell us all of their students completed the activity booklets. 22.64% tell us some of their students did, but not all. 29.53% of the educators tell us all of their students have yet to complete the books at the time of the survey.

78.67% of the educators indicated they distributed the take-home pamphlet.

81.44% of the educators encouraged their students to visit the ATV web sites mentioned in the program.

Program Effectiveness:
As a result of using the program, 52.75% of the educators thought their students were definitely more aware of ATV safety practices, while the remaining 47.26% of the educators indicated their students had somewhat developed a better awareness of these issues.

In addition, 46.07% of the educators thought their students were definitely more aware of the importance of ATV riding styles being environmentally friendly, while 49.46 where somewhat more aware of these implications. The remaining 3.29% of the educators indicated their students' awareness level had not changed.

97.89% of the educators indicated they found the materials and resources helpful in enhancing ATV safety and environmental awareness.

95.24% of the educators found the "Fun in the Sun Safety Certificate" valuable.

Sampling of Teacher Comments

"Great Materials - Students were very interested!" Grade 6th Teacher, Beaverton, MI

"This seems like a great program for parents and students alike. Please keep me on your mailing list and send more information!" Grade 7th & 8th Teacher, Stanton, MI

"Very good information – kid friendly!" Grade 7th Teacher, Havana, FL

"Very good and timely program!" Grade 9-12 Teacher, Gilbert, WV

"Many of my students have ATV's and they were very interested in reading the pamphlets. I shared the materials with a teacher in the Technology Education Department, too! Thank you!" Grade 10-12 Teacher, Spring Church, PA

"Valuable information. Would be great if it was available on video!" Grade 8-12 Teacher, St. Elmo, IL

"I think anything that makes our children more aware of their responsibilities is a very worthwhile program!" Grade 5-8 Teacher, Morenci, MI

"Excellent materials well put together!" Grade K-6 Teacher

"The information helped to open up students eyes to both sides of the issue!" Grade 7-8 Teacher, Athens, MI

"Being a "country school" this information was very important to our community!" Thank you. Grade 7-10 Teacher, Melissa, TX

"Thanks for getting the word out on this important issue. This information was very useful to a lot of my students!" Grade 5-8 Teacher, Wellsburg, WV

"Thank you. This material is relevant to this area and class. We had just covered snow machine safety!" Grade 7th Teacher, Kenai, AK

"Thanks, ATV's are extra popular in our area. We have many ATV trails in national forest in our county!" Grade 8 Teacher, Logan, OH

"Thanks the ATV material was very useful for this area and the students appreciated the printed materials!" Grade 9-12 Teacher, Mogadore, OH

"Thank you, you always send valuable information. I appreciate all that you send"! Grade 7th,8th & 12th Teacher, New Wilmington, PA

"Great very informative!" Grade 8-12 Teacher, Fletcher, OK

"Any program that helps students to understand the importance of safety is always valuable!" Grade 7-12 Teacher, Keokuk, IA

"The large print is good for students. The booklets were well organized and visual are good!" Grade 6-8 Teacher, Monvovia, CA

"Very high interest for the students. They enjoyed reading and discussing it!" Grade 8 Teacher, Grass Lake, MI

"These pamphlets came at a "timely" place in our lessons/discussions. With Christmas coming up the students may be getting an ATV and other vehicles so they can use "caution" tips." Grade 5-8 Teacher, Selma, NC

"Thank you!" Grade 10 Teacher, Rockport, IN

"Great information and easy for students to read and understand!" Grade 8-12 Teacher, Dola, OH

"Excellent!" Grade 6-8 Teacher, Spring Creek, NV

"I can use this information in my unit on Personal Safety!" Grade 6-8 Teacher, Wilmington, DE

"Very informative valuable information for this age group. Thanks!" Grade 6 Teacher, Savannah, MO

"Good information. I liked the ATV IQ quiz." Grade 6-8 Teacher, Pella, IA

"Due to the subject area, the students were very interested!" Grade 6-8 Teacher, Murray, KY

"The ATV safety program was very appropriate for my group. It started many conversations, experiences & comments. Most of my students have 4 wheelers – we are in a extremely rural county in Western Kentucky!" Grade 9-12 Teacher, Morganfield, KY

"Kids in this area are avid riders of ATV's, so this was great information for them to have. We've had some accidents on ATV's so reminding students of the hazards is very important. Thank you for sending this information out!" Grade 7-12 Teacher, Stoneboro, PA

"The information is pertinent and in a form that makes it easy to present!" Grade 10-12 Teacher, Lindale, TX

"This was very interesting and useful information that I presented to my Drivers Ed classes. Most of them have ATV's so it was very relevant information for them!" Grade 9-12 Teacher, Winchester, IL

"Thanks so much for great materials!" Grade 9-12 Teacher, Jay, OK

"Excellent, really geared toward young people!" Grade 9-12 Teacher, Columbia, AL

"This was an excellent topic to cover. So many young people are injured or killed with ATV's. A good video would also be effective!" Grade 9-12 Teacher, Andover, OH

"I found the materials accurate, attractive and well organized. More importantly, the students found the information relevant. It generated great discussion and persuasive essays on their take on the information presented. We used the material on parent night and distributed the supplementary information. I thought it was great!" Grade 8 Teacher, Barnwell, SC

"Very helpful - easy to organize!" Grade K-8 Teacher, Macon, GA

"Great safety tip, informative!" Grade 9-12 Teacher, Bedford, OH

"Valuable information – thanks!" Grade 8 Teacher, La Mirada, CA

"Great program. Quick and easy to present with good leads for discussion. I especially liked the brochure for parents/guardians. That is where we need to focus the ATV safety issue. I've been a D.N.R. ATV instructor since the beginning of the program in Wisconsin and taught for A.S.T for 13 years. I've seen a wide variety of materials and find this to fit the "general " population very well." Grade 6-7 Teacher, Richland center, WI

"Excellent material!" Grade 9-12 Teacher, Gibson City, IL

"We were able to use the information for state competition in FCCLA!" Grade 9-12 Teacher, Brush, CO

"Good information relevant to teenagers!" Grade 9-12 Teacher, Clinton, SC

"Your materials were well received by my students!" Grade 9-12 Teacher, Buchanan, MI

"Very informative and extremely useful in our rural community!" Grade 9 Teacher, Catlin, IL

"Thanks for this information. We are a rural school and a lot of our students have ATV's. There is a real need for this program. Thank you so much for providing the free materials. I will use them in my Health and Safety classes. Grade 6-8 Teacher, Conway, SC

"Very timely information. We've had several students recently injured due to ATV accidents!" Thank you. Grade 9-12 Teacher, Council Grove, KS

"My students enjoyed learning about things that pertained to their immediate lives." Grade 6 Teacher, Hannibal, MO

"The program was very teacher and student friendly. It will be a valuable resource throughout the school year. Thanks!" Grade 10 Teacher, Littlestown, PA

"Great information and lay-outs. High interest for my students and very valuable. Please keep me on your list to receive future materials!" Grade 9-12 Teacher, Fairbanks, AK

Response to U.S. CPSC Suggestion to Consider a Transitional Category of ATV

J. Paul Frantz, Ph.D., C.P.S.M., CPE
Stephen L. Young, Ph.D.
Timothy P. Rhoades, Ph.D., P.E., CPE
Raina J. Shah, M.S.E.
Julia K. Diebol, B.S.E.

APPLIED SAFETY AND ERGONOMICS, INC.

3909 Research Park Dr. • Suite 300 • Ann Arbor, Michigan 48108
Tel: 734.994.9400 • Fax: 734.994.9494
www.appliedsafety.com

I. Introduction

Applied Safety and Ergonomics, Inc. (ASE) was asked by American Honda Motor Co., Inc., American Suzuki Motor Corporation, Arctic Cat Inc., Bombardier Recreational Products Inc., Deere & Company, Kawasaki Motors Corp., U.S.A., Polaris Industries Inc., and Yamaha Motor Corporation, U.S.A. to consider youth-model ATV issues included in the United States Consumer Product Safety Commission's (CPSC's) Advance Notice of Proposed Rulemaking (ANPR) at 70 FR 60031 and related CPSC staff reports. More specifically, we have been asked to consider the potential benefits of further consideration of a new category of ATV. [Biographical sketches of the project participants are provided at the end of this document.]

By way of background, in April 1988, major ATV manufacturers entered into a Consent Decree that established uniform CPSC age restrictions related to ATV engine sizes. The CPSC system of categorization was and continues to be: 1) "Y-6" ATVs are intended for children 6 years and older and have a maximum engine displacement of 50ccs. 2) "Y-12" ATVs are intended for children 12 years and older and have a maximum displacement of 90ccs, and 3) "adult-size" ATVs are intended for riders 16 years and older. The Consent Decree expired in April, 1998, and five manufacturers initiated "Action Plans" whereby they agreed to continue many of the provisions of the Consent Decree, including adhering to age-related guidelines and continuing to discourage children under 16 from operating adult-size ATVs. Arctic Cat Inc., Bombardier Recreational Products Inc., and Deere & Company have also entered the U.S. ATV market and initiated substantially similar Action Plans. There are a number of other ATV manufacturers (i.e., "new entrants") that were not part of the Consent Decree and have not committed to such Action Plans with the CPSC.

II. Information and Materials Considered

In responding to this request, we have taken into consideration numerous documents, publications, and literature related to ATVs, in addition to our education, training and professional experience. A sampling of materials considered and/or activities related to this request include:

- ATV accident data, in-depth investigations (IDIs), and related human factors, medical, and other literature
- ATV product literature, including manuals, labels, point-of-purchase information, training materials, and public education program materials
- Review of internet sites and communications with vendors selling ATVs for use by children
- Visits to ATV dealerships in Michigan and Ohio and inspections of ATVs of various sizes
- Communications with national, state, and local 4-H leaders involved in ATV training program development and assessment
- 4-H Community ATV Safety Program and child development materials

- Federal Consent Decrees and information regarding subsequent Action Plans
- ANSI/SVIA. (2001). ANSI/SVIA–1–2001: American National Standard for four-wheel all-terrain vehicles—equipment, configuration, and performance requirements. Irvine, California: Specialty Vehicle Institute of America.
- Various sources of literature and data regarding physical, psychomotor, psychological, temperamental/affective, and social development and characteristics of children as well as young and older adults
- Materials associated with CPSC Petition No. CP-01-4/HP-02-1, Request to Ban All-Terrain Vehicles Sold for Use by Children under 16 Years Old, such as:
  - Consumer Federation of America. (2002). Petition to the U.S. Consumer Product Safety Commission (CP-01-4/HP-02-1) to ban all-terrain vehicles for use by children under 16 years old and to provide refunds for consumers.
  - Testimony from members of the American Academy of Pediatrics (AAP) at the West Virginia Hearing and related materials and AAP publications regarding ATVs.
  - Consumer Product Safety Commission. (2005). Briefing Package, Petition No. CP-01-4/HP-02-1, Request to Ban All-Terrain Vehicles Sold for Use by Children under 16 Years Old. Washington, D.C.: Author. February.
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  - Giemsoe, H. (Undated.) Arizona ATV Riders.

- Materials associated with CPSC Advance Notice of Proposed Rulemaking—Request for Comments and Information (70 FR 60031-60036)
  - Consumer Product Safety Commission. (2005). Ballot Vote Sheets for ANPR; All Terrain Vehicles: Request for Comments and Information. Washington, D.C.: Author. September 15.
  - Consumer Product Safety Commission. (2005). All terrain vehicles; advance notice of proposed rulemaking; Request for comments and information. 70 FR 60031-60036. October 1.
  - Stratton, H. (2005). CPSC memo to Patricia Semple, Executive Director re: Review of ATV standards. June 8.

III. Background Related to the Suggestion of a New ATV Category

Concern has been raised by the CPSC about the number of children under 16 years of age operating "adult-size" ATVs as specified by current CPSC age restrictions. The CPSC has suggested that there could be safety benefits associated with reducing the frequency with which children under 16 ride ATVs currently categorized as adult size. In addition, suggestions have been made at CPSC-sponsored meetings that a better-fitting ATV for larger children under age 16 would be desirable. The CPSC has suggested consideration of "a transitional ATV geared to larger children and/or small adults" (Consumer Product Safety Commission, 2005; p. 60036). This new type of ATV would be "appropriate for 14-year-olds" (Consumer Product Safety Commission, 2005; p. 60033). Due to the transitional nature of such a category, this conceptual type of ATV will be referred to here as T-14.

Based on our investigations, the CPSC's suggestion is supported by groups experienced in promoting youth development and ATV safety. For example, the assessment of 4-H, a nationally recognized youth development organization that has developed youth ATV training materials and programs, is that "the reality in the U.S. is that many youth under the age of 16 already are operating and will continue to operate adult-sized ATVs on a regular basis" (Halley Research, 2002, p. xv). This statement in a "Special 4-H Community ATV Safety Program Notice" indicates the conflicting situation that 4-H experiences as they: 1) focus on increasing the safe practice behaviors of youth who already operate ATVs (adult-size or not), 2) assist adults in making decisions about the readiness of their child to operate a particular ATV, and 3) support the position of the U.S. CPSC and the ATV industry regarding age of operators. Implicit in this Program Notice is an acknowledgment that many children under age 16 are capable of operating some adult-size ATVs and that it is worthwhile to make 4-H Community ATV Safety Programs available to them. Furthermore, we spoke with several 4-H Leaders at the national, state and local level involved in the development, dissemination, and conduct of youth ATV training materials and programs. These individuals had experience with youth in various parts of the country including Louisiana, Kentucky, Alaska and Utah and all of them recognized a variety of reasons for the tendency of larger 14 and 15 year olds to be on adult-size ATVs and they all supported further consideration of a new category of ATV.

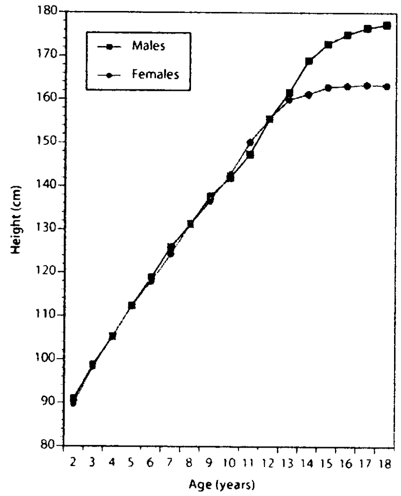
There is also evidence that children who participate in state required training programs seldom arrive for training with a youth-size ATV. More specifically, according to Dr. Kevin Kesler the Director of 4-H and Youth Programs for the State of Utah, during this year Utah 4-H has instructed approximately 1,000 children and the majority of those children were between 12 and 15 years old. Of those children, he could recall only three arriving with ATVs of 90ccs or less, and the vast majority of those operating "adult-size" ATVs successfully completed the training.

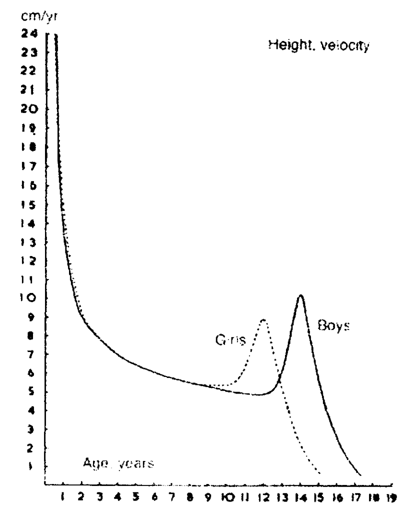
The CPSC's suggestion for consideration of a transitional category is also well founded from a human factors perspective. That is, from a variety of human performance and child development perspectives, many 14 and 15 year olds will have characteristics (e.g., strength, reach, stature, agility, balance, cognitive skills, etc.) that are either basically the same as many young adults or more similar to young adults than to younger children. Also, from a risk perception/appraisal perspective, again the literature indicates that many 14 and 15 year olds perform either basically the same as many older children/young adults or more similar to this group than to younger children.

IV. Factors Related to 14 and 15 Year Old Operation of Adult-Size ATVs

Based on our analysis, there are a number of factors that may contribute to the prevalence of 14 to 15 year olds riding adult-size ATVs:

- **The size of many 14 and 15 years olds will be more similar to that of older siblings and adults than to many children under age 14.** Many girls and boys attain their "adult" or "near-adult" height by age 14 or 15 (see figures below). Practically, this means that there will be a perception that many children in the 14 and 15 year age group will "fit" a machine that also fits an adult better than they will fit a machine that also fits much of the 12 and 13 year old population.
- **In addition to the physical size of the child at the time of ATV purchase, many children, especially boys, will be growing rapidly around ages 14 and 15.** The rate of growth in terms of height increases significantly for girls at around age 11 through 13 and for boys at around age 14 through 15 (see figures below). Practically, this translates to purchasers making accommodations for growth spurts that can give one the impression that a child will soon outgrow a Y-12 ATV even if it may provide an appropriate or acceptable fit at the time of purchase. When factoring in the projection of a child's growth, it not unreasonable to anticipate economic disincentives to purchasing a Y-12 model ATV as well as interest in avoiding the time and effort associated with having to trade in or purchase another larger ATV in a relatively short period of time.





The height figure (left, above) was obtained from the National Center for Health Statistics, Division of Health Examination Statistics (1998). The height velocity figure (right, above) is from Tanner, Whitehouse and Takaishi (1966) and it represents the height velocity of the typical boy and girl in their study.

- **Age is not expected to be the definitive factor in assessing a 14 to 15 year old's readiness to engage in numerous other activities.** Parents and caregivers routinely make assessments regarding the extent to which their children are capable of performing various activities or using different products. By the time children are 14 or 15, parents have had many years of experience assessing the readiness of their child to perform many activities and/or use many different products, including riding a bicycle in the driveway, on a sidewalk, on a street with a cul-de-sac, across town and through busy intersections, alone or with friends, etc.; using kitchen appliances such as toasters, mixers, microwaves, gas stoves, electric knives, and ovens with and without parental supervision; using tools such as scissors, hammers, screwdrivers, electric drills, and power saws; using outdoor power equipment such as string trimmers, lawn mowers, and riding tractors; and using other recreational products such as snow skis, snow boards, skate boards, roller blades, go-carts/fun-karts, sleds, and canoes. The vast majority of these activities and products do not come with specific age recommendations or requirements. It is widely recognized that there is no specific age, set of characteristics, or formula to definitively determine one's readiness to use all sorts of products or participate in any number of activities. Parents of 14 to 15 years olds typically have a wealth of experience indicating, to them, that chronological age of a child and/or age recommendations/requirements are just two factors among many in determining readiness. Thus, if a Y-12 model appears to be a questionable fit for a child, a parent could question the relevance of the current limited age categories as they relate to his/her child.

- **The experience of 14 to 15 year olds operating other vehicles may provide converging evidence to some parents that their child is reasonably suited to something other than a Y-12 model.** Some examples of other vehicles include cars, trucks, off-road motorcycles, etc. ATVs are used in many farming communities and it is common for younger teenagers to operate vehicles and machinery in that setting. Regarding automobiles, it is also noteworthy that many states allow motor vehicles to be operated by children under age 16. For instance, all states allow children to drive a car, in at least some circumstances, between the ages of 14 and 16, with 42 states allowing children to enter a "learner stage" under the age of 16 and nine states allowing children under age 15. It is also the case that, for decades, children under 16 have operated off-road motorcycles.

- **The current Y-12 category may be socially unattractive to larger 14 and 15 year old children.** There is a potential stigma associated with an ATV that does not also accommodate some older children and adults to be viewed as "child-like." Not unlike items on the "kids menu" at a restaurant, 14 and 15 year old children may view such ATVs as socially less desirable.

- **The power available in current Y-12 ATVs has been effectively reduced and may be considered too low for larger 14 and 15 year olds.** It is our understanding that for emissions purposes, a transition is occurring from 2-stroke to 4-stroke engines in ATVs. This practically reduces the available power and increases the weight of an ATV with a given engine displacement, which effectively means that the CPSC system of categorizing ATVs that was developed many years ago has resulted in a lowering of available power for many Y-12 models. Considering this change in light of the previous discussions related to fit and perceptions of Y-12 ATVs versus some adult-size ATVs, this transition to 4-stroke engines could be expected to make the Y-12 category less desirable to larger 14 and 15 year old operators.

- **Options for child operation of ATVs are limited compared to options available for off-road motorcycles.** The limitations on youth ATV sizes combined with the limited age categories for youth ATVs are easily contrasted with off-road motorcycles typically available at the same dealerships. The credibility of the current youth ATV scheme may be strained in light of the many off-road motorcycle options available to youth and adults that are not linked to a specific and limited set of age restrictions. Thus, for off-road motorcycles, the initial focus of selection may be on goodness of fit in terms of size, skills, etc., whereas with ATVs, age may be the initial focus and may limit or be in conflict with a consideration of goodness of fit.

Newer market entrants that have not partnered with the CPSC have been increasingly supplying the demand for more youth ATV options. These sellers supply ATVs targeted at youth under age 16 that the CPSC would currently classify as adult-size. In recent years, there have been many new brands of ATVs that have models that exceed 90cc and we have seen considerable evidence that many models are promoted for sale to children under 16. Our investigations have involved conversations with people selling ATVs at used car lots, other retail outlets, and via the internet stores. For example:

- In personal communication with a person selling Kazuma ATVs, we asked "What size ATVs do you have?" She replied "We don't care about the laws." Thus, even before there was a discussion of child age or size, the seller wanted to make it clear that "laws" regarding age would not be pertinent to our selection of an ATV.

Internet vendors also provide indications of the reasons for selling larger ATVs for use by children.

- DFWScooters.com provides the following information related to a 110cc ATV (buyatwholesaleprice.com, 2003):

> **Why 110CC ATV ?**
> Our customers asked us for 110CC atv and also asked us to remove the alarm and the remote starter. When we asked them why they wanted 110CC VS 70CC or 90CC they said 110CC has more power and it also can be regulated to go slower, hence kids wont out grow it sooner.

- Another vendor includes a running list of questions and answers about ATV models that it sells via the internet (1trail.com, 2005). A sampling of comments for several 150cc models include:

> **QUESTION:** Hi. I am 11 years old. How long do you think this Trail ATV-150 will last me? And I am 76 pounds.
> **ANSWER:** Unless you have really good riding skills and need more power, this one is going to last couple years before you need a bigger one.
>
> **QUESTION:** I am a 11 year old and about 5 feet how long well this atv last me? me and my dad are thinking about getting one. Would you prefer the brand Kazuma? Thanks Rob
> **ANSWER:** Kazuma and Redcat are the same and as you are only 11, 150 will last you a very long time and so will the 110.
>
> **QUESTION:** i am a thirteen year old that is 5ft 7in and i weigh 130 pounds. Would this be the right size atv for me?
> **ANSWER:** I will say yes but you have to keep in mind they can go fast so your parents have to be comfortable with you on a 150, if not a 110 will be a good choice too.

- For a 250cc model, one of the questions and answers was:

> **QUESTION:** i am a 12 year old boy and can handle 1 of these 250 atv's and my mom told me i can get 1 for christmas so what is the latest she and my dad could order 1 so that it can be here for christmas.
> **ANSWER:** This Atv has a lot of power and as of when you should order, all depends on how many we have in stock and the color you want. Last Christmas we sold out way before Christmas. I will think you might want to order it sometimes close to Thanksgiving.

- The position of this internet vendor is not the result of lack of knowledge of CPSC recommendations regarding rider age. This same vendor includes a web page that lists the CPSC's age/engine size categorization scheme.

> SAFETY TIPS
>
> For your safety:
> An ATV IS NOT A TOY AND CAN BE HAZARDOUS TO OPERATE
>
> - Always wear a helmet and other protective gear.
> - Never ride on public roads -- another vehicle could hit you.
> - Never ride under the influence of alcohol or other drugs.
> - Never carry a passenger.
> - Ride an ATV that's right for your age. The guidelines are:
>
> | | |
> |---|---|
> | Age 6 and older | Under 70cc |
> | Age 12 and older | 70cc - 90cc |
> | Age 16 and older | Over 90cc |
>
> - Supervise riders younger than 16; ATVs are not toys.
> - Ride only on designated trails and at a safe speed.
> - Take an approved training course
>
> For more safety tips, check out these website:
>
> http://www.atvsafety.org/
> http://www.nohvcc.org/html/ohv_safety.htm
> http://www.atv-youth.org/

This increasing number of offerings by manufacturers/sellers who do not follow CPSC-approved practices demonstrates a market interest in an expanded offering of youth ATV options. Of course, with increasing sales of such ATVs comes an increase in buyers who are not provided with the system of warnings, instructions and training that are made available to those who purchase from the established companies who conform to Action Plan practices approved by the CPSC.

V. Characteristics of a Possible T-14 Model

The characteristics of such a transitional ATV would presumably address many of the issues that have been cited as deterrents to the purchase of youth ATVs for use by many 14 and 15 year olds, while maintaining some of the features of current youth ATVs. The details of this new category of ATV are not defined as yet, but it is anticipated that it would share traits in common with both youth- and adult-size ATVs. For example:

- A T-14 model would address fit issues with this age group better than current youth ATVs.
- A T-14 model would be more powerful than current youth models, but less powerful that many of the larger adult-size ATVs.
- A T-14 model would have some provision for limiting speed and/or establishing some maximum power parameters.
- A T-14 model would include a system of warnings and instructions that would address intended use by children age 14 and older. These materials would be:
    - provided in various modes/media (e.g., point-of-purchase, on-product, accompanying literature, etc.)
    - targeted to the various different audiences (e.g., parents, dealers, and youth).

In addition to these design and warning characteristics of the T-14 ATV itself, it is anticipated that such a category would also likely be associated with other things that would promote ATV safety for 14 and 15 year olds, as well as ATV safety generally. For example:

- Training courses would be available nationwide to 14 and 15 year olds who have T-14 model ATVs through the SVIA network of instructors. Presently, SVIA training is not open to 14 to 15 year olds on anything other than a Y-12 ATV.
- There is the potential for increased consideration of "goodness of fit" between operator and ATV. If a transitional category was available, it would present greater opportunities for discussion of factors other than age. For example, if there were two categories of ATVs available to 14 and 15 year olds (Y-12 and T-14), there would be greater opportunity to introduce ATV fit guidelines, like those used by 4-H, at the point of purchase and 1) help parents and prospective riders understand and appreciate the connection between proper fit and ATV risk, 2) increase parents' and childrens' understanding of the rider-active nature of ATVs and behaviors related to directional control and stability, and 3) help parents to better appreciate the importance of proper training and instruction and making "house rules" that keep unprepared or improperly fitting riders off ATVs that they own.

- The availability of such models could help to reduce the frequency of 14 and 15 year olds operating larger adult-size ATVs.

VI. Conclusions

We support the CPSC's suggestion to further consider a transitional ATV. In summary, further consideration of expanding the selection of ATVs available to youth under 16 by adding a category of product that accommodates larger 14 and 15 year olds and many adults is consistent with:

- human factors data and human performance literature
- the experience and desire of a nationwide youth development organization (4-H) that has been actively involved in ATV training
- real-world ATV training of 14 to 15 year olds riding adult-size ATVs
- a desire to address trends in market demand while simultaneously addressing the CPSC's desire for a system that supports proper age recommendations, warnings and instruction at the point-of-purchase and during use, as well as suitable ATV training programs
- a desire to enhance the credibility and relevance of CPSC age messages to parents and children
- a desire to enhance the credibility of other ATV safety messages that the CPSC has emphasized and that the established ATV manufacturers have provided over the years
- a desire for greater parental involvement at the point-of-purchase and elsewhere in assessing a child's readiness to operate an ATV
- a desire for greater parental appreciation for the rider-active nature of ATVs
- a desire for greater parental awareness of the connection between good fit and operation of an ATV
- a desire for greater parental awareness of and child participation in ATV training programs
- a desire to reduce the frequency of 14 to 15 year olds riding larger adult-size ATVs

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Biography of the Authors

J. Paul Frantz is a Principal Research Engineer and a founder of Applied Safety and Ergonomics, Inc. (ASE) in 1994. Since 1993, he has also served as an adjunct faculty member at the University of Michigan teaching product and occupational safety management. His consulting activities, research, and teaching address a wide variety of issues and applications in the areas of human factors/ergonomics, product and occupational safety, and warnings and instructions. He holds a Ph.D. in Industrial and Operations Engineering from the University of Michigan and a B.S.E. in Human Factors Engineering from Wright State University. Dr. Frantz is a Certified Professional Ergonomist (CPE) and a Certified Product Safety Manager (C.P.S.M.). Dr. Frantz is a member of various professional societies, including the Human Factors and Ergonomics Society, the American Society of Safety Engineers, the Society for Technical Communication, and the Institute for Industrial Engineering. He also serves as the American Society of Safety Engineers' representative to the American National Standards Institute's (ANSI) Committee Z535 on warning signs, labels, symbols, tags and colors and he chairs the ANSI Z535.6 Subcommittee for Safety Information in Product Manuals, Instructions and Other Collateral Materials.

Stephen L. Young is a Senior Research Scientist and Director of Research and Development at ASE. Dr. Young holds a Ph.D. in Engineering Psychology from Rice University and has lectured at Harvard University and the University of Michigan on topics including human error, warnings and safety communications and design of displays and controls. Prior to joining ASE, Dr. Young served as a Senior Research Associate at the Liberty Mutual Research Center for Safety and Health. Dr. Young has authored numerous publications related to warnings, hazard communication, and risk perception, and he has served as a reviewer for various scientific journals including Ergonomics, Applied Ergonomics, and the Journal of Safety Research. Dr. Young serves on the ANSI Z535 Committee Z535 on warning signs, labels, symbols, tags and colors and was a leading author of the new draft standard Z535.6 Standard for Safety Information in Product Manuals, Instructions and Other Collateral Materials.

Timothy P. Rhoades is a Principal Research Engineer and a founder of ASE. He is a professional engineer and certified professional ergonomist (CPE) specializing in human factors engineering and ergonomics. He also serves as an adjunct faculty member at the University of Michigan. His research, design, and consulting interests include occupational and consumer safety, product use behaviors, warnings, vehicle visibility, and human movement. He holds B.S.E., M.S.E., and Ph.D. degrees in Industrial and Operations Engineering from the University of Michigan. He has served as a member of several consensus standards committees involved with vehicle visibility, biomechanics, and other ergonomics and safety issues, and he served in a standards management role as a member of Standards Development Committee of the American Society of Safety Engineers. He currently serves on the American National Standards Institute (ANSI) Z535.6 Subcommittee on Product Safety Information in Product Manuals, Instructions, and Other Collateral Materials. He is a professional engineer and certified professional ergonomist (CPE). Dr. Rhoades is also a member of various professional societies, including the Human Factors Society, the Society of Automotive Engineers, the American Society of Safety Engineers, and the Institute of Industrial Engineers.

Raina J. Shah is a Human Factors Specialist and holds a Master's degree in Industrial and Operations Engineering from the University of Michigan. She also holds two Bachelor's degrees from the University of Michigan, one in Psychology and another in Industrial and Operations Engineering. Her professional activities include the design and evaluation of hazard communications, analysis and investigation of product and occupational accidents, analysis and evaluation of standards and regulations, and research activities related to user processing of information. She has participated in numerous projects involving recreational products, communications to parents regarding risks to children, and assessing child readiness for product use. Ms. Shah also has experience in job analysis and driver performance issues. Ms. Shah is a member of the Human Factors and Ergonomics Society and the Society for Chemical Hazard Communication. She is also a member of the American National Standards Institute (ANSI) Z535.4 Subcommittee on Product Safety Signs and Labels. Prior to joining ASE, Ms. Shah assisted with research at the University of Michigan Center for Ergonomics in the area of biomechanics and human motion simulation. She also worked in the Human Factors Division of the University of Michigan Transportation Research Institute where she studied human factors issues related to the design of driver interfaces.

Julia K. Diebol is a Project Analyst in the Human Factors and Product Safety Group. She holds a Bachelor's degree in Industrial and Operations Engineering from the University of Michigan. Her professional activities include analysis of technical literature, standards and regulations related to risk communication, human performance and product safety. Prior to joining ASE, Ms. Diebol conducted graduate-level research related to measuring driver workload at the Human Factors Division of the University of Michigan Transportation Research Institute.