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February 20, 2007 *CTC*/DP-CL0942-07

Environmental Information Technology Management Office
ASA (I&E-ESOH) (Mr. Thomas Moran)
1235 Clark Street
Crystal Gateway 1, Suite 307
Arlington, VA 22202-3263

SUBJECT: Draft Technical Report: Tactical Rollover Alert Device for Tactical Vehicle Monitoring

REFERENCE:
(1) Task No. 0438, "Development, Demonstration, Evaluation and Implementation of Defense Safety Oversight Council (DSOC) Workplace Mishap Reduction Initiatives to Promote Sustainability and Enhance Mission Readiness Across the Department of Defense", approved September 27, 2005
(2) Subtask 2, Defense Safety Oversight Council Initiatives
(3) Contract Number W74V8H-04-D-0005

Dear Mr. Moran:

Concurrent Technologies Corporation (*CTC*) is pleased to submit one (1) copy of the Subject Deliverable in accordance with the Reference (1) Task and (2) Subtask under the Reference (3) Contract. The Contractor, *CTC*, hereby declares that, to the best of its knowledge and belief, the technical data delivered herewith under the Reference (3) Contract is complete, accurate, and complies with all requirements of the contract. If you should require technical clarification, please call Mr. Robert Gardiner at (703) 310-5656. For contractual issues, please call the undersigned at the above direct dial number.

Very truly yours,

Darnella Parker
Manager, Contract Resources

/bem

Enclosures: as stated

cc: Mr. Ryan Leirvik, OSD, Readiness Programming and Assessment
Ms. Darlene Bader-Lohn, SFIM-AEC-PCT

RESEARCH, DEVELOPMENT, DEMONSTRATION, EVALUATION, AND IMPLEMENTATION OF DEFENSE SAFETY OVERSIGHT COUNCIL (DSOC) WORKPLACE MISHAP REDUCTION INITIATIVES TO PROMOTE SUSTAINABILITY AND ENHANCE MISSION READINESS ACROSS THE DEPARTMENT OF DEFENSE

TASK No. 0438

Draft Technical Report: Tactical Rollover Alert Device for Tactical Vehicle Monitoring

February 20, 2007

Requests for this document shall be referred to:

Office of the Assistant Secretary of the Army
for Installations and Environment
ASA (I&E) - ESOH
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Prepared by
National Defense Center for Environmental Excellence (NDCEE)

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The focus of this project was to identify and test a device that was capable of providing drivers of the HMMWV, Highly Mobile Multi-purpose Wheeled Vehicle, a visual and audible warning of potential rollover conditions. The need for this proof of concept arose from the escalation of injuries and deaths occurring in Operation IRAQI FREEDOM (OIF) and Operation ENDURING FREEDOM (OEF), resulting from the rollover of up-armored HMMWVs. Personnel at the Aberdeen Test Center installed the equipment, conducted initial baseline testing and issued a Safety Release so the device could be used in operational follow-on tests at Fort McCoy, Fort Polk, and Fort Benning.

Operational testing results indicated the XM2 Rollover Warning Device demonstrated the potential to be a useful tool for helping drivers operate their vehicles more safely through the early identification of potential rollover conditions. Follow-on testing is recommended.

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ACRONYMS AND ABBREVIATIONS

ADOCS	Advanced On-Board Computer System
ASA (I&E)	Office of Assistant Secretary of the Army for Installations & Environment
ASDT	Army Safe Driver Training
ATC	Aberdeen Test Center
AVTP	Allied Vehicle Testing Publication
BG	Brigadier General
CG	Center of Gravity
COTS	Commercial Off-The-Shelf
CRC	Combat Readiness Center
CTAD	Commercial, Off-the-shelf, Tactical Awareness Device
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
DOTF	Deployment and Operations Task Force
DSOC	Defense Safety Oversight Council
EO	Executive Order
FY	Fiscal Year
G-Force	Gravitational Force
GVW	Gross Vehicle Weight
HMMWV	Highly Mobile Multi-purpose Wheeled Vehicle
LED	Light Emitting Diode
LG	LG Electronics "Lucky Goldstar"
MPH	Miles Per Hour
MTTF	Military Training Task Force
NATO	North Atlantic Treaty Organization
NDCEE	National Defense Center for Environmental Excellence
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
RAD	Rollover Alert Device
UAH	Up-Armored HMMWV
U.S.	United States
USACRC	United States Army Combat Readiness Center

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Defense Safety Oversight Council Integration Group, Mr. Joseph Angello, Chair
DSOC Military Training Task Force, Mr. James Gunlicks, Chair
DSOC Deployments & Operations Task Force, Brig Gen Maury Forsyth, Chair

Military Vehicle Safety Working Group (DOTF/MTTF)

- Lt. Col. Paul Guemmer, USAF, J-3 Readiness, Chair
- Lt. Col. John Wanant, USMC Safety Center
- LTC Randall Cheeseborough, USACRC
- Dr. Elizabeth Rodriquez-Johnson, OSD-AT&L
- MSG Charles Timms, HQ DA, G-3/5/7
- Mr. Mike Barksdale, USACRC
- Mr. Keith Lane, IMCOM Safety
- Mr. Edward Talbott, USAF Safety, AETC/SEG

Mr. Tim Hoy and Aberdeen Test Center staff

Staff from each of the Service Safety Centers

Test installations personnel

- Fort McCoy, WI
- Fort Polk, LA
- Fort Benning, GA

Support Contractors

- Stability Dynamics
- Mr. Al Rice, J-3 Readiness

EXECUTIVE SUMMARY

The National Defense Center of Environmental Excellence (NDCEE) was engaged by the Defense Safety Oversight Council (DSOC) to perform as the integrating contractor for the various DSOC initiatives, including the Tactical Rollover Alert Device for Tactical Vehicle Monitoring. The focus of this project was to perform a proof-of-concept test of a device that was capable of providing drivers of the Highly Mobile Multi-purpose Wheeled Vehicle (HMMWV) a visual and audible warning of potential rollover conditions.

The need for this proof-of-concept arose from the escalation of injuries and deaths occurring in Operation IRAQI FREEDOM (OIF) and Operation ENDURING FREEDOM (OEF) resulting from the rollover of up-armored HMMWVs. An immediate response to prevent these rollovers was paramount, and this technology was one part of the multi-faceted approach used by DoD to address this issue. The XM2 Rollover Warning Device, developed by Stability Dynamics, appeared to have potential in helping drivers identify potential rollover conditions early, therefore react before rollover occurs, serving as an intermediate retro-fit solution to rollover hazards. Testing was completed to validate this potential.

Personnel at the Aberdeen Test Center installed the equipment, conducted initial baseline testing and issued a Safety Release so the device could be used in operational follow-on tests at Fort McCoy, Fort Polk, and Fort Benning.

Based on feedback from testing personnel, overall device performance was satisfactory. Installation was relatively easy and users felt the product had value. Device cost was a key concern of the DSOC Integration Group, especially if this product would be used to outfit the entire tactical vehicle fleet. Those concerns stemmed primarily from the first units purchased, which were in excess of $ 6,000.00 each. Follow-on purchases were significantly lower at $2,000.00 each. Stability Dynamics indicated that the cost for additional units would decrease as more devices are purchased. Other black boxes were examined, but the XM2 device incorporated all of the required features and included a design that appeared strong enough to withstand the rigors of a battle environment.

Differences in vehicle weight, weight distribution, and ground surface can affect the device's response, and if the sensitivity settings are too high or low, the driver may not receive the appropriate warnings. Preliminary results indicated that this could be a continuing concern requiring personnel to re-calibrate the devices as loads and terrain changed. Further testing could provide answers on the magnitude of this potential concern.

1.0 INTRODUCTION AND BACKGROUND

According to data provided by the Office of the Secretary of Defense, preventable mishaps are reducing DoD operational readiness and costing the Department over $3.5 billion dollars annually. Nearly 1.2 million military personnel are injured each year with over 30 thousand of the injured requiring hospitalization or assignment to quarters. Former Defense Secretary, Donald Rumsfeld issued a memo addressing this issue on May 19, 2003, stating "World-Class Organizations does not tolerate preventable accidents" and directed a 50% department-wide mishap reduction. This challenge led to the establishment of the Defense Safety Oversight Council (DSOC). The Secretary later increased this goal to a 75% mishap reduction effort.

The Service Safety Centers and the Deployment & Operations Task Force (D&O TF) identified tactical vehicle rollovers as a key concern. Between FY02 and FY06 tactical vehicles had been involved in nearly 500 accidents in Operation IRAQI FREEDOM (OIF) and Operation ENDURING FREEDOM (OEF), and according to data provided by service safety centers, these rollovers killed nearly 100 service members. In response to this alarming situation the D&O TF formed a tactical vehicle working group that suggested "black box technology" as a potential risk mitigation solution.

1.1 Purpose

The purpose of this task was to validate if black boxes could demonstrate potential as a tactical vehicle mishap intervention solution. It is important to note the term "black box" is a generic term for a Commercial Off-The Shelf (COTS) electronic device that in this case is designed to provide early warning of an impending rollover condition. During field testing and in project documentation, additional terms and acronyms were used to refer the same device, including:

- XM2 Rollover Warning Device
- LG Alert Rollover Warning Device
- Stability Dynamics XM2 Rollover Warning Device
- CTAD - Commercial, off-the-shelf, Tactical Awareness Device
- RAD – Rollover Alert Device

1.2 Subtask Rationale and Report Focus

Tactical vehicle rollovers escalated dramatically after HMMWVs were up-armored. Though no formal study results are available yet, notional data indicates the causes of many of the rollovers could be from driving too fast for road conditions and/or due to distraction/failure to remain alert. Feedback from leadership in the field indicated that another factor affecting the increasing rollovers was that many incidental drivers were inexperienced and unfamiliar with the elevated center of gravity associated with the increased weight of the up-armored vehicles, a condition that made them more susceptible to rollovers. Figure 1 provides an image of a HMMWV.

Figure 1. M1114 HMMWV with Outriggers

2.0 PROJECT OVERVIEW

Project team members and an overview of the project's technical approach are outlined in this section.

2.1 Project Team

The Government project team for this effort consists of, but is not limited to, the following organizations:

<u>Government Stakeholders</u>
OSD RP&A
DSOC Deployment & Operations Task Force
Joint Tactical Vehicle Working Group
U.S. Army Combat Readiness Command
U.S. Army Test and Evaluation Command, Aberdeen, MD
Fort McCoy, WI
Fort Polk, LA
Fort Benning, GA

Other Team Members include the NDCEE and its subcontractor, Stability Dynamics. The NDCEE's primary role in this sub-task was as overall project manager and to provide sub-contractual oversight. The NDCEE worked closely with government stakeholders to identify the technical and procurement requirements associated with this technology as well as interfacing with the DSOC Task Forces and OSD RP&A.

2.2 Technical Approach

Elements associated with this task included:

- Identification and procurement of COTS product.
- Coordination of the Safety Release Testing.
- Implementation of the pilot program to assess Rollover Alert Device (RAD) performance.
- Evaluation of Results and Presentation of findings to the DSOC and DSOC Task Forces.

3.0 PROCUREMENT, TEST AND EVALUATION RESULTS

3.1 Identify and Procure Black Box Product

The NDCEE researched a number of commercially available black box devices as part of the due diligence process, which included technologies identified by:

- Stability Dynamics
- US Department of Transportation Intelligent Vehicle Report
- Frost and Sullivan Commercial Vehicle Report
- Federal Highway Administration report on Technology Practices in Europe.
- US Insurance Industry
- Altra Technologies Incorporated
- Competitive Technologies Incorporated

The XM2 Rollover Warning Device manufactured by Stability Dynamics was selected for safety release testing based on its "hardening" for military combat environments and on the recommendations provided by the US Army and the DSOC Deployment and Operations Task Force. Two XM2 Rollover Warning Devices were initially procured and directly shipped to the U.S. Army Aberdeen Test Center (ATC), Aberdeen Proving Grounds, Maryland, for the safety release testing. Upon successful testing and a signed safety release, six additional devices were ordered and delivered to the approved follow-on test facilities. The configuration and specifications of the devices were identical in all tests.

3.1.1 Device Functional Description

The XM2 Rollover Warning Device is intended for use as an early warning system to alert drivers when they are on the verge of exceeding the maximum mobility limits of the vehicle based on calibration inputs for the specific vehicle characteristics, loads and terrain. This rollover device can be used on many different types of vehicles but in this case was designed specifically for installation on HMMWVs.

Accelerometers measure lateral gravitational force (g-forces) perpendicular to the vehicle's direction in real time. If the pre-defined operator limits are exceeded an audible alarm will sound. Vertical g-forces perpendicular to the road surface also are displayed for driver monitoring purposes. This function can aid in surface grade determinations as well provide audible warnings. But in this test no audible alerts were associated.

Lateral and vertical sensitivity can be adjusted using digital push buttons on the front of the base unit. “00” is the least sensitive setting and “99” is the most sensitive setting.

The accelerometers are housed in the base unit and comprise the passive rollover sensor (see Figure 2).

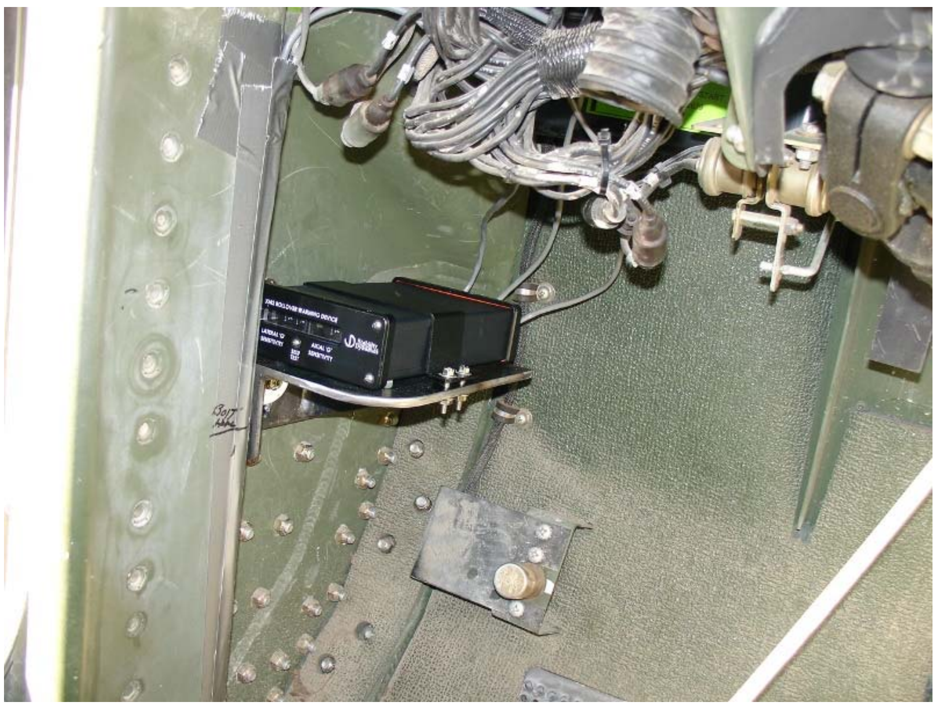


Figure 2. Base Unit Mounted on Inside Left Panel in Front of Driver’s Side Door

The driver’s display consists of ten Light Emitting Diodes (LEDs) for each lateral direction (left and right) and ten LEDs for each vertical direction (up and down). For each lateral and vertical direction, the six LEDs closest to the zero point (center of display) are green. The seventh and eighth LEDs are yellow, and the ninth and tenth LEDs are red. The eighth and tenth lateral LEDs are accompanied by audible warnings. A picture of the display is shown in Figure 3.

Figure 3. Rollover Warning Device Driver's Display

Figure 4. Driver's Display Mounted in Top Left Corner of M1114 Cab

The above picture of the display illustrates the display mounting point located in the top left corner of a M1114 HMMWV cab. This location was initially chosen by the test facility due to ease of installation. However, the indicator is located out of the normal driver field of view in this configuration requiring the driver to shift vision from the road to read the display. The Combat Readiness Center (CRC) recognized this hazard and had the indicator relocated toward the center. A Safety Confirmation Test will be required to determine the ideal location for the device.

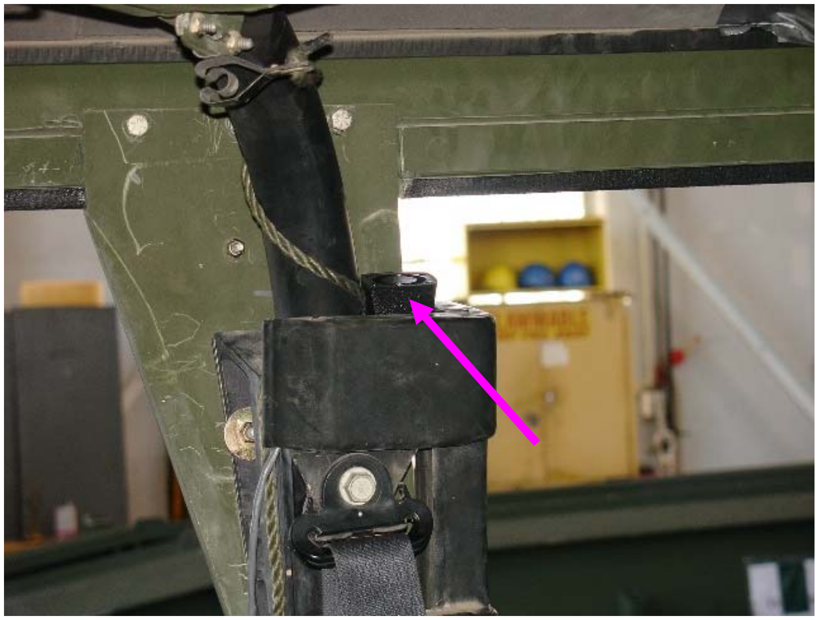


Figure 5. Warning Siren Mounted Above the Driver's Seatbelt Shoulder Mount)

The audible alarm, shown above in Figure 5, is the final component of the Warning Device. The alarm will emit a high volume and pitch squawk when the preset sensitivity setting is exceeded; in this case, LED 10. This alarm warns the driver that the lateral acceleration limit has been reached. A speaker built into the LG Alert Base Unit also emits a moderate beeping warning when the driver's display reaches its preset sensitivity setting; in this case LED 8 and LED 9.

Further description is provided in the Stability Dynamics' XM2 User/Installation Manual, which is located in Appendix B.

3.2 Coordination of Safety Release Testing

ATC personnel conducted the initial testing of the black boxes to gauge effectiveness of the rollover device in a controlled testing environment. Results of these tests were used to develop a safety release for units participating in the follow-on operational testing.

According to the ATC test plan, Appendix C, parameters including safety and health, physical characteristics, tilt table, side slopes, steering and handling, and endurance were examined.

This project portion of the test began on October 3, 2005. ATC completed their assessment of the device on April 25, 2006 and subsequently issued a recommendation for safety release to support the use of the Stability Dynamic's rollover alert device for follow-on testing. An overview of the testing protocol and results is provided below. A copy of the safety release recommendation is located in Appendix D.

3.2.1 Tests Conducted and Results

ATC conducted testing on the device installed on M1114 HMMWVs. Various parameters of automotive performance and human factors engineering were assessed, and the results of each parameter were summarized from the safety release recommendation.

3.2.2 Automotive Performance – Physical Dimensions

The M1114 HMMWV was equipped with Goodyear Wrangler MT 37x12.5R16.5LT radial tubeless tires; all testing was conducted with the front tires inflated to 30 pounds per square inch (psi) and the rear tires inflated to 40 psi. The physical dimensions of the M1114 HMMWV at gross vehicle weight (GVW) are presented in Table 1.

Table 1. Physical Dimensions, M1114 HMMWV with LG Alert Rollover Sensor at GVW

Parameter	Location	Measurement	
		in.	cm
Overall Length	Front frame rails to pintle bracket	185.4	470.9
Overall Width	Front door handles	90.3	229.4
Overall Height	Gun mount (no gun installed)	73.0	185.4
Wheelbase	Axle No. 1 to Axle No. 2	130.2	330.7
Tread Width	Axle No. 1	71.3	181.1
Effective Length*	Front of Axle No. 1 tire to rear of Axle No. 2 tire	169.2	429.8
Effective Width*	Front tire bulge	84.0	213.4

***Measured at 0.5 meters above ground or lower in accordance with Allied Vehicle Testing Publication (AVTP) 03-160W**

3.2.3 Automotive Performance – Weight Distribution

Weight distribution data were taken with the vehicle fully fueled and the operator in the vehicle. The weight distribution of the M1114 HMMWV at GVW is presented in Table 2.

Table 2. Weight Distribution, M1114 HMMWV at GVW

Axle	Weight					
	Left side		Right side		Total	
	kg	lb	kg	lb	Kg	lb
Front	1,285	2,830	1,300	2,870	2,585	5,700
Rear	1,440	3,180	1,440	3,180	2,880	6,360
Total	2,725	6,010	2,740	6,050	5,465	12,060

3.2.4 Automotive Performance – Center of Gravity (CG)

The lateral and longitudinal orthogonal CG locations were determined using the weight distribution, wheelbase, and tread measurements of the vehicle. The vertical CG component of the M1114 HMMWV was determined utilizing the reaction method outlined in TOP 2-2-800, Center of Gravity. The CG results for the M1114 HMMWV at GVW are presented in Table 3.

Table 3. Center of Gravity Locations, M1114 HMMWV at GVW

Plane	Reference	Measurement	
		In	cm
Vertical	Above level ground	35.5	90.2
Longitudinal	Forward of the rear axle centerline	61.5	156.2
Lateral	Right of longitudinal centerline	0.1	0.3

3.2.5 Automotive Performance – Tilt Table

The static rollover threshold of the vehicle was measured using the ATC Tilt Table. The vehicle was positioned on the table and tilted about its roll axis until the rollover threshold was achieved. Restraining straps with enough slack allowed the vehicle to move freely but prevented the vehicle from rolling off the table. Maximum side slope angle and simulated lateral acceleration were determined with both the curbside (right) and roadside (left) of the vehicle positioned upslope. A photograph of the M1114 HMMWV on the tilt table is presented in Figure 6.

Figure 6. M1114 HMMWV on the Tilt Table

Static rollover results for the M1114 HMMWV at GVW are presented in Table 4. A comparison of the static rollover results with the LG Alert Box preset tilt angle thresholds for activation of LED 8 and LED 10 is presented in Table 5. The preset tilt angle thresholds for LED 8 and LED 10 were obtained from the LG Alert Box User/Installation Manual.

Table 4. Rollover Threshold Results, M1114 HMMWV at GVW

Side Upslope	Axle	Tilt Angle, degree	Simulated Lateral Acceleration, *g's*	LG Alert Box Warnings
Left	-	20.6	0.38	Yellow LED 8
	-	26.7	0.50	Red LED 10
	2	37.9	0.78	
	1	38.3	0.79	
Right	-	26.3	0.49	Yellow LED 8
	-	31.6	0.62	Red LED 10
	2	39.1	0.81	
	1	39.3	0.82	

Table 5. Comparison of Rollover Threshold Results and LG Alert Box Preset Thresholds for Activation of LED 8 and LED 10

LG Alert Box Warning Light	Preset Tilt Angle for Activation, degree	Measured Tilt Angle at Activation, degree	
		Left Side Upslope	Right Side Upslope
LED 8	25.9	20.6	26.3
LED 10	33.3	26.7	31.6

As previously mentioned, lateral and vertical sensitivity can be adjusted using digital push buttons on the front of the LG Alert Box Base Unit, with “00” being the least sensitive setting and “99” the most sensitive setting. Tilt table testing was used to establish a safe sensitivity setting for the device. The above results were obtained with the sensitivity set to “20.” The number of display LEDs activated increased in a linear fashion as tilt angle increased. LED 10 (and its accompanying audible warning) activated at a tilt angle equivalent to 70 percent of the M1114 HMMWV rollover threshold (38.3 degrees) with the left side upslope and 80 percent of the rollover threshold (39.3 degrees) with the right side upslope.

3.2.6 Automotive Performance – Steering Geometry

The steering wheel rotated three complete turns and one quarter turn from one steering bump stop to the other for a total of 1,170 degrees. The wheel angles at full left and right steer for the M1114 HMMWV are presented in Table 6. The steering ratio for M1114 HMMWV was calculated to be 16.0:1 (16.0 degrees of steering wheel travel to 1 degree of tire travel).

Table 6. Steering Geometry, M1114 HMMWV at GVW

Steered Wheel Angle, degrees			
Full left steer		Full right steer	
Left wheel	Right wheel	Left wheel	Right wheel
36.5	27.0	28.0	36.5

3.2.7 Automotive Performance – Steady-state Circular Steer (Skid pad) Testing

The steady-state cornering characteristics of the vehicle were determined on a clean, dry, level, and bituminous-concrete surface. The vehicle was operated at a constant speed around a circular test course with a diameter of 200 feet. Testing was conducted in both the left and right steer directions starting at 5 mph and continuing to a maximum attainable safe speed. The vehicle was fitted with an outrigger system for safety during testing.

At each discrete road speed, the vehicle's steering wheel angle, yaw rate, longitudinal and lateral speed were recorded on the ATC developed Advanced On-Board Computer System (ADOCS) to assess the handling characteristics. These data can be used to determine whether the vehicle under steers, over steers or exhibits neutral steer characteristics at a given level of lateral acceleration.

To maximize safety and controllability, a vehicle that under steers is highly desirable at all levels of lateral acceleration. More easily controlled by an average driver, an under steering vehicle is inherently directionally stable and will tend to continue in a straight line when the traction limit is exceeded. Conversely, an over steering vehicle moves toward directional instability and tends to tighten its turn when the traction limit is exceeded.

A comparison of the LG Alert Box preset lateral acceleration thresholds and the measured lateral accelerations for activation of LED 8 and LED 10 is presented in Table 7. A comparison of the lateral accelerations at which LED 10 was triggered and the maximum sustained lateral accelerations for each steer direction is presented in Table 8.

Table 7. LG Alert Box Preset Lateral Acceleration Thresholds and Measured Lateral Accelerations for Activation of LED 8 and LED 10

Steer Direction	Lateral Acceleration for Activation of LED 8, *g*'s		Lateral Acceleration for Activation of LED 10, *g*'s	
	Preset	Measured	Preset	Measured
Left	0.44	0.36	0.55	0.42
Right	0.44	0.36	0.55	0.48

Table 8. Lateral Acceleration Corresponding to Activation of LED 10 and M1114 HMMWV Maximum Sustained Lateral Accelerations

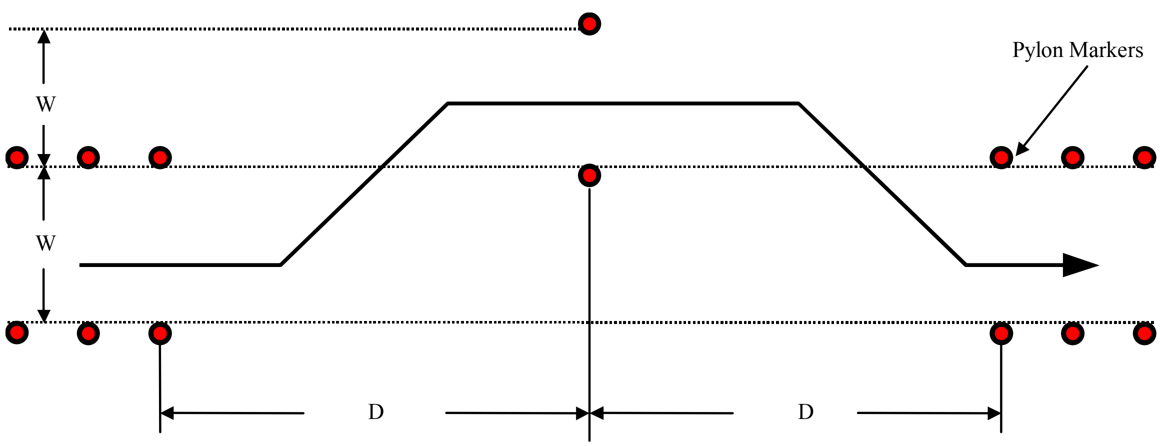
Steer Direction	Lateral Acceleration at Activation of LED 10, *g's*	Maximum Sustained Lateral Acceleration, *g's*
Left	0.42	0.50
Right	0.48	0.49

The M1114 HMMWV generally exhibited slight under steer characteristics throughout the speed range tested in both steer directions; no significant over steer characteristics were shown throughout testing.

During the skid pad test, LED 8 and LED 10 activated at lateral acceleration levels that were lower than the preset thresholds. Activation of LED 10 occurred at a lower lateral acceleration (0.42 g's) in the left steer direction than in the right steer direction (0.48 g's). LED 10 activated at 84 percent and 98 percent of the maximum sustained lateral acceleration in the left and right steer directions, respectively. Activation of LED 8 occurred at 72 percent and 73 percent of the maximum sustained lateral acceleration in the left and right steer directions, respectively. The performance of the LG Alert Box was considered adequate because the first audible alarm (LED 8) activated at lateral accelerations low enough to give the driver sufficient time to reduce speed and avert an unstable situation.

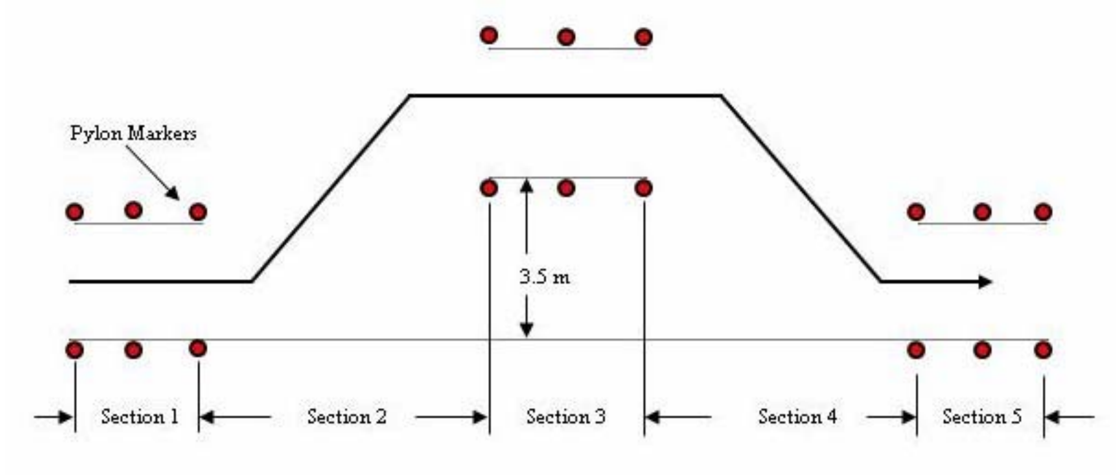
3.2.8 Automotive Performance – Emergency Lane Change

The emergency handling characteristics of the vehicle were determined on the TOP and NATO Lane Change Courses, which were set up on the main runway at Phillips Army Airfield. Course boundary limits were defined using traffic pylons. Throughout each lane change maneuver, the driver attempted to maintain a constant speed while applying the smoothest steering inputs necessary to successfully negotiate the course. Testing began at 20 mph through each course, with small speed increases for subsequent runs until the vehicle achieved its maximum, stable speed (no wheel lift off/excessive vehicle slide) while staying within the course limits or until the driver could no longer negotiate the course without striking pylons. Diagrams of the TOP and NATO Lane Change Courses are presented in Figures 7 and 8, respectively.



W = 3.7 meters (12.0 ft)
D = 1.5 x turning circle diameter of the vehicle = 21.6 meters (71.0 ft)

Figure 7. TOP Lane Change Course Dimensions, M1114 HMMWV



Sections 1 and 5:	Length = 15.0 meters (49.2 ft)
	Width = 1.1 x vehicle width* + 0.25 meters = 2.6 meters (8.6 ft)
Sections 2 and 4:	Length = Overall length of vehicle* + 24 meters = 28.3 meters (92.7 ft)
Section 3:	Length = 25.0 meters (82.0 ft)
	Width = 1.2 x vehicle width* + 0.25 meters = 2.8 meters (9.3 ft)

*Measured at 0.5 meters above ground or lower.

Figure 8. NATO Lane Change Course Dimensions, M1114 HMMWV

The maximum average speeds and peak lateral accelerations achieved by the M1114 HMMWV at GVW, through the NATO and TOP Lane Change Courses, are presented in Table 9.

Table 9. Lane Change Results, M1114 HMMWV at GVW

Lane Change Course	Maximum Average Speed, mph	Peak Lateral Acceleration, *g*'s	
		Minimum	Maximum
TOP	36.0	-0.90	0.72
NATO	40.1	-0.39	0.46

The M1114 HMMWV successfully completed the TOP Lane Change Course at a maximum average speed of 36 mph. The lateral acceleration levels measured through the TOP course were significantly higher than the levels measured through the NATO course. This was expected, because the length of the TOP course was significantly shorter than the NATO course. LED 8 was activated during every run at target speeds of 32 mph and above. LED 9 was activated during six of nine runs at target speeds of 32 mph and above. LED 10 was activated during two of nine runs at target speeds of 32 mph and above.

The M1114 HMMWV successfully completed the NATO Lane Change Course at a maximum average speed of 40.1 mph. Neither LED 9 nor LED 10 (red alerts) was triggered during any run through the NATO Lane

Change Course. LED 7 and LED 8 (yellow alerts) were activated during nine of the fourteen runs at target speeds of 38 mph and above.

The M1114 HMMWV lane change results indicate that the LG Alert Box sensitivity needed to be adjusted so the alarm activates at lower lateral acceleration levels. LED 10 should have been triggered during each of the higher speed (34-36 mph) TOP lane change runs, because front and rear tire slide was observed during those runs. The LG Alert Box must activate the alarm prior to loss of traction to effectively alert the driver to vehicle instability that could lead to a rollover. Drivers reported that only the audible alarm was effective in alerting them to instability during a lane change maneuver, because the visual warnings required them to take their eyes off the road.

3.2.9 Human Factors Engineering – Usability

The LG Alert Box system was comprised of one driver's display (Figure 3), one base unit (Figure 2), and one warning siren (Figure 5).

The driver's display was mounted to the left front roof attachment bolt as seen in Figure 4. The driver's display was mounted so as not to disrupt the driver's field of vision and was close to eye level for safer viewing. The driver's display was large enough for the driver to distinguish the number of lights that were on, but doing so was more difficult while operating the vehicle.

The base unit was mounted against the driver's side kick panel inside the vehicle. While the driver had no need to access the base unit, technical personnel could easily reach the unit for adjustment.

The warning siren was mounted behind the driver's seat belt shoulder attachment on the turret ring support bar, which made it very easy for the driver and passengers to hear.

3.2.10 Human Factors Engineering – Safety

The driver's display was noted as being somewhat distracting during dynamic testing due to the changing display lights, especially during movements like the double lane change steering and handling test. The placement of the driver's display requires minimal movement of the driver's eyes from the road to the display, but at the same time introduces a minor distraction during highly dynamic maneuvers.

The warning siren, programmed to sound when the driver's display reaches LED 10, is placed in close proximity to the driver's left ear and may adversely startle the driver during aggressive maneuvers. However, no problems were noted by the driver during testing when the warning siren sounded.

3.2.11 Human Factors Engineering – Ingress and Egress

The base unit was mounted such that it protruded approximately 3 inches into the driver's leg area. This placement may cause the driver to catch clothing on the unit or may cause the driver to strike his or her leg during ingress or egress. While no problems were reported during testing, a soldier with combat gear could experience difficulty.

3.3 Implement Pilot Program to Assess Black Box Performance

Rollover Alert Devices were installed in HMMWVs at designated bases. The pilot program then subjected soldiers to extreme driving environments similar to those the HMMWVs would experience in theater. Participants were first trained in the use of the devices, and then conducted operational driving tests. Test drivers were asked to complete an evaluation survey on their experiences with the device at the end of the testing period. Summary results of the survey are noted in section 3.4 of this report and the survey roll-up is located in Appendix H.

The U.S. Army Combat Readiness Center (USACRC) oversaw this follow-on operational black box testing at the following three military installations.

- Fort McCoy, WI – July 24-28, 2006
- Fort Polk, LA – August 14-18, 2006
- Fort Benning, GA – October 16-18, 2006

A summary of test procedures and results for each installation is provided below.

3.3.1 Fort McCoy

Commercial, off-the-shelf, Tactical Awareness Device (CTAD / black box) testing was conducted at Fort McCoy from July 24-28, 2006, and was integrated into their Up Armored HMMWV (UAH) driver training program. In preparation for the testing, seven alert devices were installed in HMMWV M1025/1026 vehicles. The following overview is taken from Fort McCoy's trip report, which may be found in Appendix E.

Before the sixteen students and instructors started training, the Tactical Safety Manager briefed them on how the device works, what to expect from the device, and the hazards and controls outlined in the safety release.

For the on-road skill based training in the UAH course, the students received classroom instruction on emergency vehicle operation and then practiced these skills at the Wisconsin State Patrol Training Academy. The Training Academy course included an s-curve, increasing radius curves, decreasing radius curves, and an open area for other exercises. The UAH course used the curves to reinforce proper cornering techniques and other skill-based exercises such as a serpentine, threshold-braking, and a swerve to avoid an obstacle.

The initial sensitivity setting of "22" on the devices proved to be too sensitive for the M-1025/1026 vehicles used in the UAH course in these exercises. These vehicles have add-on armor kits and weigh approximately 9,800 pounds. After adjusting the lateral sensitivity to "17," the devices provided feedback that was useful.

The UAH course also included off-road training and an "advanced mobility course," also off-road. Much of this driving focused on brake-throttle modulation techniques and was conducted at slow speeds. This phase of the training did very little to test the capability of the CTAD.

The Tactical Safety Manager observed that the device was more sensitive to maneuvers conducted to the left and plans to validate this observation during the next test event at Fort Polk. He also suggested that the device should be mounted as low as and as close to the front axle as possible, which was not always accomplished on the seven vehicles used in the UAH course.

All sixteen students and instructors completed the CTAD operational assessment. All of the students felt the device was useful and, in their opinions, would help to reduce the incidents of rollover crashes in HMMWVs.

3.3.2 Fort Polk

Fort Polk soldiers participated in black box testing on August 14-18, 2006. This testing was integrated into their Army Safe Driver Training (ASDT) course at the Joint Readiness Training Center Intermediate Staging Base, Alexandria, LA. The following overview is taken from Fort Polk's trip report, which may be found in Appendix F.

To prepare for the testing, the ASDT team installed CTADs on five HMMWV M1025/1026 vehicles and set up the driver training course. On each vehicle, CTAD base units were installed on the right side of the radio shelf even though the CTAD manual calls for mounting the device as low on the vehicles and as close to the front axle as possible. After consulting with John Luckock of Stability Dynamics, the ASDT team decided that mounting the base units on the radio mounts would not degrade the device's effectiveness.

Based on feedback from the Fort McCoy test, the display unit was mounted in three different locations. Soldiers were asked to provide specific feedback on the locations of the display units.

The Tactical Safety Manager briefed soldiers and instructors on how the CTAD works and what to expect from the device. The ASDT team demonstrated what the display looked like and the tones emitted when the device sensed lateral and axial acceleration by tilting a base unit connected to a display unit.

The ASDT team conducted five, four-hour training sessions for 96 soldiers. The training consisted of six ASDT exercises including skid control, evasive steering, controlled braking, serpentine, and straight line backing. All exercises except for skid control were conducted in HMMWVs.

Testing began with lateral and axial sensitivity settings at “20.” The axial sensitivity of “20” was fine, but the lateral sensitivity setting of “20” did not provide much feed back with the standard M1025 on the ASDT course. With the lateral sensitivity set at “28,” the soldiers received sufficient feedback to get the full experience of how the device works. At this setting, any abrupt steering input on the braking exercise, serpentine exercise, or the evasive exercise would generate an alert and warning. Twelve soldiers tested the devices with settings of “20” and “20” and another 12 received training with the base unit set at “24” and “20.” Seventy-five soldiers tested the devices with the settings of “28” and “20.”

The soldiers started the evasive steering and controlled braking exercises at 30 MPH and most progressed to 45 mph. Maximum speeds in the serpentine exercise were 30 mph.

During the training program, ten soldiers lost complete control of the HMMWV while driving the controlled braking exercise, and three soldiers lost control on the evasive steering exercise. Each incident occurred during the soldier's initial attempt at the exercises.

At the conclusion of the testing, all 96 participating soldiers completed the survey form and provided verbal feedback. Most of the verbal feedback received from the soldiers was positive for both ASDT and the CTAD. Many soldiers commented that the CTAD gave them a better understanding of how the vehicle reacted to their steering inputs and how hard they were "pushing" the vehicle. The location of the display unit is still an issue for many of the soldiers who participated in the test. Several soldiers recommended a location on the center post (below the windshield wiper motor) where all of the crew can monitor the display. One soldier commented that if the display had a "fish eye" glass, it would be easier for all of the crew to see the display. Soldiers commented that at the 90%-

100% full-scale g force where the device currently emits the loudest alert that it would be better if the device announced “rollover, rollover, rollover” as an initial alert for the crew to start their rollover drill.

3.3.3 Fort Benning

The rollover alert device (RAD) final testing session was conducted at Fort Benning, GA from October 16-18, 2006. This testing differed from the others, as it was not conducted as part of a driver training course. A copy of Fort Benning’s test plan may be found in Appendix G.

The USACRC test monitors divided the drivers into two groups, one being the control group and the other the test group. Both groups performed the same driving exercises – the NATO lane change, the TOP standard lane change, and a braking test – but only the test group used the RAD. Test monitors directed all vehicle movement and recorded RAD display data.

During the first phase of testing, drivers conducted a baseline run of each exercise without receiving a briefing on the device. The groups made three runs with the first run at 25mph, second run at 30mph, and the last run at 35mph.

Upon completion of the baseline run, test monitors briefed the test group on the RAD. They explained how the RAD measures lateral and axial acceleration and how the driver can use this feedback to improve their control inputs while driving the vehicle. Each driver, including those in the control group, then had 15 minutes to practice driving through the various exercises; no data were recorded for the test group.

The final test runs were conducted in the same format as the baseline runs, only the test group had the benefit of using the RAD to guide their driving inputs. Readings were recorded throughout the run.

The 22 drivers in the test group completed surveys at the conclusion of the testing session. Some soldiers in the test group reported the RAD helped them control side-to-side swaying (decrease in lateral g-forces) during the driving exercises; 40% of the inexperienced drivers showed significant improvement in driving skills using the RAD. Drivers in the control group (without access to the RAD) did not show improvement.

3.4 Evaluate Results

The NDCEE received combined driver survey responses from Fort McCoy, Fort Polk, and Fort Benning. The NDCEE notes that some questions may have allowed multiple answers, while some questions requiring a single answer tallied more or less than the number of respondents (134). Survey questions and responses are summarized below. The full survey rollup may be found in Appendix H.

1. How would you rate the usefulness of the previous training you received to current job?

    - 83.6% of respondents felt the usefulness of previous training was applicable to their current job.

2. Were vehicle rollover issues addressed in your previous training?

    - 66.4% of respondents reported that rollover issues had been addressed.

3. What type (M4, M025, etc) of HMMWV was the rollover device used in?

    - 46.3% drove M1025 vehicles, with the M114 vehicle a distant second at 17.2%.

4. How would you rate the effectiveness of the rollover warning device in completing your mission with the rollover warning device than with out it?

    - 88.1% of respondents felt the warning device was effective in completing their mission.

5. What do you like about the rollover warning device?
   *More than one response may be given. (140 total responses)

    - Of the 20 different responses given to this question, 29.3% of respondents felt the device helped to show the vehicle's limits. In the next highest ranked response, 10% of respondents liked the sound and light feature.

6. What do you dislike about the rollover warning device?

    - Of the 15 different responses given to this question, 29.1% of respondents reported they disliked nothing about the device, 14.2% thought the device was too loud, and 11.2% felt the device was too sensitive.

7. How would you rate the placement of the rollover warning device display screen?

    - 69.4% of respondents thought the display screen was very easy or easy to see.

8. How would you rate the effectiveness of the audible warning siren while driving?

    - 87.4% of respondents found the warning siren to be very effective or effective.

9. Was the audible warning siren a negative distraction or did it result in an unsafe reaction while performing a maneuver?

   - 64.2% of respondents rated the siren as "very safe, great warning" or "safe, good warning." 15.7% had a neutral opinion.

10. How accurately do you feel that the warning thresholds were set?

   - 91.2% of respondents felt the warning thresholds were accurate to some degree.

11. What type of training on the rollover warning device did you receive (e.g., instruction card, video, classroom)?

   - Sixty-five percent of the respondents received either a brief training class (36.6%) or, hands-on training (28.4%); another 12.7% had both a training class and hands-on training. Nineteen percent of the respondents provided no answer.

12. How would you rate the adequacy of the training?
   *Total responses 135, anomalies in survey tally

   - 89.7% of respondents found the training very adequate or adequate.

13. How greatly did the rollover warning device influence you to correct your driving behavior?

   - 78.4% of respondents felt the warning device was influential on their driving behavior.

14. List the best attributes of the rollover warning device that helped you accomplish your mission.
   *likely more than one answer possible

   - Of the 18 various answers given, 18.2% of respondents thought the audio warning was the best attribute, while 10.6% liked knowing how far they could push the vehicle's capabilities.

15. List the attributes of the rollover warning device that, in your opinion, distracts or hinders your mission.

   - Twelve various answers were given to this question, and 23.9% felt that no attributes distracted or hindered their mission. 15.7% of respondents thought that noise level was a distraction, and 10.4% did not like the location of the display indicator.

16. Provide any recommendation for improving the operational effectiveness of the system.
*Total responses 133, anomalies in survey tally

- Twenty recommendations were provided for enhancing the system's effectiveness. 24.6% of respondents had no recommendations, with 12% of respondents suggesting improved placement of the device.

17. In your opinion, should the Army investigate further use of the system and similar systems into operational settings?

- 76.1% of respondents felt a rollover warning system warranted further investigation.

The majority of drivers surveyed thought the device was effective and useful. Over 88% rated the RAD as an effective tool. More than78% believed the device influenced their driving behavior in a positive manner. Approximately 76% of the soldiers thought the U.S. Army should investigate further use of this or similar devices in an operational setting.

4.0 CONCLUSIONS & RELATED FINDINGS

- The XM2 Rollover Warning Device demonstrated the potential to be a useful tool in helping drivers operates their vehicles more safely through the early identification of potential rollover conditions.

- The majority of drivers surveyed upon completion of operational testing indicated that they felt the device was a worthwhile addition to vehicle safety features and that its use positively influenced their driving behavior. Additionally, most test participants felt the Army should further investigate the use of this or similar systems in operational settings.

- Proper calibration of the device's sensitivity settings was critical in providing accurate driver feedback. Differences in vehicle weight, weight distribution, and ground surface can affect the device's response, and if the sensitivity settings are too high or low, the driver may not receive the appropriate warnings. More testing will be required to evaluate whether these settings may have a significant impact on operation and if so to identify appropriate mitigation protocols.

APPENDIX A

Military Vehicle Safety Working Group Meeting Minutes and Power Point Presentation, November 30, 2006

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APPENDIX B

Stability Dynamics'' XM2 User/Installation Manual

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APPENDIX C

ATC Test Plan

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APPENDIX D

Safety Release Recommendation

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APPENDIX E

Fort McCoy Trip Report

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APPENDIX F

Fort Polk Trip Report

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APPENDIX G

Fort Benning Test Plan

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APPENDIX H

Driver Survey Rollup Results

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APPENDIX I

Fort Benning Trip Report

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