Proceedings of IMECE04
2004 ASME International Mechanical Engineering Congress and Exposition
November 13-20, 2004, Anaheim, California USA

IMECE2004-59070

COMMERCIALIZING AN AUTOMATICALLY DEPLOYABLE ROLLOVER PROTECTIVE STRUCTURE (AUTOROPS) FOR A ZERO-TURN RIDING MOWER: INITIAL PRODUCT SAFETY ASSESSMENT CRITERIA

J.R. Etherton, E.A. McKenzie Jr., and J.R. Powers
National Institute for Occupational Safety and Health, Morgantown, WV

ABSTRACT
Fatal injuries have occurred to operators of zero-turn riding mowers when these machines rolled over during high speed sharp turns or on uneven terrain. These mowers are frequently operated in low clearance conditions such as around trees and when loaded onto low-roofed trailers. The automatically deployable rollover protective structure (AutoROPS) can provide both protection during rollover events and the capability to operate a mower in low clearance conditions. Until recently, AutoROPS technology development has occurred only in a government laboratory. In the current phase of development, private industry has taken an interest in the AutoROPS technology and is pursuing, with NIOSH, the product testing and development needed to commercialize the AutoROPS on a zero-turn riding mower. The government's role, as a partner with private industry in bringing new safety technology into practical application, is discussed.

Importantly, for the AutoROPS product to be as effective as possible, it should not introduce additional, unacceptable risks. Previous product safety assessments led by government laboratories are reviewed. These assessments were made to minimize hazards in products developed in government labs. A product safety assessment was performed on the AutoROPS during its design phase. In addition to minimizing the severity and frequency of operator injury resulting from an accidental rollover, the assessment considered 1) environmental factors such as corrosion, electromagnetic interference, and vibration; 2) human error avoidance; and 3) safeguard reliability analysis. This assessment was a cooperative effort between the safety engineering design team at the Division of Safety Research of the National Institute for Occupational Safety and Health; a ROPS manufacturer; and a zero-turn riding mower manufacturer. Design features are being incorporated into the prototype AutoROPS to address hazards encountered in normal use of these machines.

INTRODUCTION
Zero-turn riding mowers (Z-mowers) are used by workers in the landscape and horticultural services industry to care for large lawn areas. They provide high speed and precise maneuverability. Unfortunately, some of these mowers have been involved in fatal overturn incidents. The U.S. Bureau of Labor Statistics reports that an average of four riding mower related fatalities occurred annually to workers in the landscape and horticultural services industry between 1992 and 2002. This makes up a majority of the average of six annual deaths (many of which are overturn-related) to riding mower workers in all private industry. Rollover protective structures (ROPS) used with seatbelts have been proven effective in reducing work-related deaths. However, fixed ROPS can become a significant hazard when Z-mowers are used under trees and when they are being loaded into low-roofed trailers.

An automatically deployable rollover protective structure (AutoROPS) concept was conceived at NIOSH's Division of Safety Research in Morgantown, WV in the late 1990's as an innovative way to provide protection to operators of utility tractors that are used in low-clearance work. Successive projects funded by NIOSH have completed the proof-of-concept and early design revisions. The current stage of development involves commercial partnerships with a ROPS manufacturer and a Z-mower manufacturer who are working with NIOSH toward equipping a Z-mower with an AutoROPS.

Figure 1 A "Z-mower"

The NIOSH AutoROPS is a passive safety device that can deploy to provide ROPS protection in the event of an accidental rollover of agricultural farm equipment or a riding mower. This technology consists of an automatically deploying protective structure and a roll-over sensor that can be mounted on a vehicle to provide a functional ROPS for the operator in the event the vehicle is about to overturn. The sensor monitors the operating angle and angular velocity of the vehicle and determines the likelihood of vehicle roll-over. If such a condition exists the sensor will provide a signal to deploy the protective structure. This device provides a level of protection that does not rely on operator action. It automatically senses an overturn condition and deploys the structure to provide the standards-specified ROPS operator clearance zone. This paper addresses the process for AutoROPS commercialization and the vital requirements for a successful commercial product to perform its function correctly and reliably.

Federal Laboratory Innovation

> "To capitalize on the nation's investment in federal research, expertise and technology must be brought to the marketplace. This commercialization enhances not only the nation's socioeconomic well-being in the global marketplace, but also secures its security and prominence."
> Ed Linsenmeyer (Federal Technology Transfer, 2004)

Commercializing new technology products that were developed in or spun off from research at federal labs is being strongly emphasized in the 21st century management of these labs (DOT, 2004).

When a new technology looks to have a promising use as a commercial product, but needs further development, then collaboration with private industry is appropriate. Federal labs can partner with private industry through a variety of technology transfer mechanisms, e.g., letters of agreement, grants, and consortia. Private industry partners have the market expertise to refine a prototype to make it a product ready for the general public. They also have technical capabilities that are a part of their own development and production activities. As partners, federal laboratories can assist with marketing the effectiveness of technology, so that intended users will see that it serves their needs.

Examples of Commercializing Federal Laboratory Research Products

Commercial products that have evolved from technology transfer initiatives by federal laboratories include new medical devices and automobiles using new fuels.

Smart Surgical Sensor Research at the National Aeronautical and Space Administration (NASA) produced a smart sensor technology, under exclusive license in 2004, that will give surgeons finer control of surgical instruments during delicate brain operations. The probe will enter the brain gently under robotic control and will locate the edges of tumors while preventing damage to critical arteries. The "neural net/fuzzy logic" software will provide real-time tissue identification, thus improving diagnostic accuracy and precision of surgery. Overall, the new technique will increase the safety, accuracy, and efficiency of surgical procedures. (Federal Technology Transfer, 2004)

Cryogenic Catheter The National Institute for Standards & Technology (NIST) builds and sustains technology partnering activities between its laboratories and mission-related organizations. A new procedure for treating abnormal uterine bleeding is a result of cooperative research between NIST and CryoGen Inc., of San Diego. The Food and Drug Administration (FDA) recently approved the procedure, which uses a catheter based on NIST technology that can reach temperatures of -150 to -190 degrees Celsius at the tip. The catheter is inserted into the uterus where it freezes problem tissue. According to a review in *Family Practice News*, the treatment was successful in clinical trials, with patients typically discharged 30 minutes after the procedure and with nearly all returning to work the following day.

Automobiles using new fuels The Department of Transportation (DOT) performs safety performance evaluations on transportation equipment for the automotive industry. The California Fuel Cell Partnership is a unique collaboration of auto manufacturers, energy companies, fuel cell technology companies, and the DOT. This partnership is advancing a new vehicle technology that could move the world toward practical and affordable environmental solutions. The partnership is exploring the path to commercializing fuel cell electric vehicles by examining such issues as fuel infrastructure requirements, vehicle and fuel safety, market incentives, and consumer acceptance. The partnership will increase public awareness of fuel cell vehicle technology and the benefits it can offer through a number of outreach tools, including hands-on exhibits, vehicle demonstrations and school presentations.

Ensuring the Safety of Federal Lab Partnership Products Unlike the case for new medical devices needing approval by the FDA, there is no approving agency for safety equipment used in the workplace. ROPS must meet OSHA requirements, which currently require that a ROPS have a label indicating that it satisfies ASAE requirements for wheeled agricultural tractors. In the absence of an approval process, product safety criteria for the AutoROPS have been developed at NIOSH based on Safety Analysis and Risk Assessment. Four initial criteria are:

1) The AutoROPS design shall include features that provide for the timely deployment of the AutoROPS when exposed to environmental factors such as corrosion, electromagnetic interference, and vibration.

2) The AutoROPS design shall include features that prevent the unexpected deployment of the AutoROPS if a person places part of their body in the AutoROPS deployment path.

3) The AutoROPS shall be designed so that safety-critical mechanical and electrical components are reliable. A single component failure in the control system shall not prevent operation of the AutoROPS in a rollover.

4) An AutoROPS shall only be used on a mower equipped with a seatbelt.

Protection from Environmental Factors

Metal Corrosion Consensus corrosion test requirements exist for only a few mechanical product components such as jacks for agricultural machines (ASAE 5485, 2003) and road vehicle brake linings (ISO 6315, 1980). In general, practice is set forth on testing apparatus and procedures for its use, but the type and number of test specimens, exposure periods, and interpretation of test results is established by the product manufacturer (ASTM B117, 2003).

Corrosion test planning, (Spence, 1995) for the AutoROPS will involve the five following steps:

1) Define Goals & Objectives: The purpose of the initial test will be for corrosion screening. A screening test will help to eliminate obvious design limitations. Then a tailored corrosion test will be used that simulates expected corrosion environments that would compromise the reliable response of the AutoROPS for rollovers of Z-mowers.

2) Design Corrosion Test: A salt spray test (ASTM B117) will be used for the initial screening to identify areas for coating, sealing, or enclosing. Tests that mimic insecticides and fertilizer dust will be later tests.

3) Develop Test Protocol: A test for agricultural jacks requires a life of 250 cycles after a 48-hour salt spray exposure. One unit will be used in the screening test that has these criteria.

4) Engineer Test Plan: Engineering the test will involve designing the fixtures for mounting the AutoROPS in the test chamber and designing a mechanism for cycling the AutoROPS through several hundred deployments after exposure in the test chamber.

5) Modify Test Plan: Modifications will depend on the results of the initial tests.

Agricultural Electronics Environmental Testing
The standard for agricultural electronics is ANSI/ASAE EP455 (2003), "Environmental Considerations in Development of Mobile Agricultural Electrical/Electronic Components." This standard sets forth tests for the conditions shown in Table 1.

Guul-Simonsen and Jacobsen (1999) report that boxes that satisfy IEC standards for protecting electronics from dust and water cannot be expected to provide resistance against penetration of gases such as water vapor and hydrogen sulfide. Water vapor and hydrogen sulfide are aggressive environmental factors, but are typical to agricultural environments in Europe and the US.

Vibration and Ruggedness Tests
Tests are planned to examine the effects of vibration and other physical abuse on the AutoROPS mechanical components.

Protection from Unexpected Deployment

A hazard exists from potential human contact with high speed deployment motion of the upper AutoROPS structure mass. Exposure to the hazard could be when: a second person rests a hand on or has a hand above the AutoROPS while talking to the operator; or the operator rests a hand on or has a hand above the AutoROPS while inspecting the mower; or the operator has their head above the AutoROPS while inspecting the mower. The energy transfer that is available in normal deployment motion is:

$$\text{Energy in each spring} = \tfrac{1}{2} kx^2 = \tfrac{1}{2}\,(7\ \text{lb/in})(24\ \text{in})^2 = 2016\ \text{in-lb}$$

$$\text{Energy with both springs} = 4032\ \text{in-lb.}$$

The protected zone (Figure 2) should exceed the full distance of deploying structure travel. Human motion toward the travel path may be as high as 100in/s. The protective zone would be at least triangular in form with the point of the triangle on the deployable structure in its low position. At the top of travel, the perpendicular distance away would be 100in/s x 0.1s = 10in. Other precautions against inadvertent release of the AutoROPS would be controls that prevent the AutoROPS from deploying if the mower is not operating with the operator seated with the seatbelt engaged.

A capacitance device is being developed to prevent contact during inadvertent release. The initial device is a touch-sensitive bar on the top of the AutoROPS. If someone has their hands or head in contact with the top of the AutoROPS, then the AutoROPS will not deploy. In its final configuration the capacitive field will emanate in a zone above the crossbar. This capacitance device will be tested by a variety of subjects typical of mower users and on a variety of terrains (grass, dirt, concrete...) and testing will be on these surfaces both wet and dry.

Component Reliability

While the objective of a failure modes effect and criticality analysis (FMECA) is to identify all modes of failure within a system design, its first purpose is the early identification of all catastrophic and critical failure possibilities so they can be eliminated or minimized through design correction at the earliest possible time. The earlier that potential failures are identified, analyzed, and corrected, the greater the total savings to all concerned. (Bellinger, 1988; MILSTD 1629, 1980)

Mechanical reliability In the early FMECA (Table 2) it is evident that the free motion of both release arms is critical. The failure of other single mechanical elements will be offset by the function of its parallel component, but if either release arm fails to swing out when a deployment signal is sent, then the AutoROPS cannot deploy.

Control reliability The requirement for control reliability will be met by ensuring that, in the electrical system that controls deployment, the failure of a single component will not prevent the AutoROPS from deploying when an overturn is imminent. Issues to be addressed include: component selection, construction standards and control logic.

Seatbelts

A seatbelt will be used that meets ASAE/SAE seatbelt requirements for agricultural vehicles. Operator willingness to use seatbelts will be considered.

Table 1 Itemization of ANSI/ASAE EP455 Environmental Factors

Temperature Operating temperature Storage temperature Thermal shock	Salt Exposure Electrical steady state conditions Operating voltage	Humidity Exposure Soak
Altitude Operating Storage	Over-voltage Reverse Polarity Short circuit protection	Mechanical shock Operational Handling Shipping
Dust	Memory retention Starting voltage	Mechanical vibration Random
Solar radiation Ultraviolet effects Readability	Power-up operational requirements	Sinusoidal Resonance Search
Immersion	Electrical transient conditions Accessory noise Alternator field decay	Electromagnetic compatibility Susceptibility
Wash	Batteryless operation Inductive load switching	(component level) Open-field emissions
Particle impact	Load dump Mutual coupling	
Chemicals Spray Exposure Brush Exposure	Electrostatic discharge Surface Connectors	50/60 Hz "E" field susceptibility Combined environments

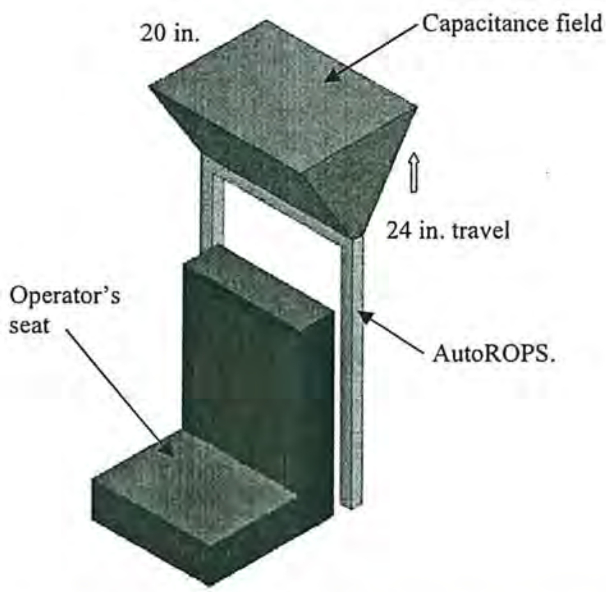

Figure 2 Protective volume above the AutoROPS (shown in its lowered position)

Subsystem: Latch and release mechanisms System: AutoROPS Probability Interval: 15 Yrs					Sheet: ___ of ___ Date: ________ Prep. by: ________ Rev. by: ________ Approved by: ________
Item/Functional Ident.	**Failure Mode**	**Failure Cause**	**Failure Effect**	**Risk Assessment** Cat=catastrophic Med=mediun Lo=low	**Action Required/Remarks**
				SEV PROB RISK	
Release Arm	Catch Fails	Shear Stress	Release of that side	Lo Lo Lo	Ample safety factor
Release Pivot	Jams	Corrosion	No Release	Cat Lo Med	Seals, Self lubricate
Main Spring	Wire shear	Shear Stress	Minimal effect	Lo Lo Lo	Ample safety factor
Latch Pin	Pin Breaks	Shear Stress	That side does not catch	Lo Lo Lo	Ample safety factor
Latch Pin	Jams	Clearance/ corrosion	That side does not catch	Lo Lo Lo	Ample clearance, well sealed
Latch Spring	Breaks	Manufacturing Defect	That side does not latch	Lo Lo Lo	Ample safety factor
Latch Spring	Permanent set	Incorrect material	Both sides do not latch	Cat Lo Med	Select proper spring material
Solenoid	Bent rod	Human misuse	No Release	Cat Lo Med	Protective cover
Solenoid	Jams	Corrosion	No Release	Cat Lo Med	Protective cover , well sealed

Table 2 Failure modes, effects, and criticality analysis for AutoROPS mechanical components

DISCUSSION

A variety of requirements must be satisfied in getting the AutoROPS ready for use by workers in the landscape and horticultural services industry. Having a plan for what test requirements need to be met is an important step toward commercializing the AutoROPS.

REFERENCES

ANSI/ASAE EP455 [2003] Environmental Considerations in Development of Mobile Agricultural Electrical/Electronic Components, New York, NY.

ASAE S417.1 [2003] Specifications for Alarm Systems Utilized in Agricultural Structures, New York, NY.

ASAE S485 [2001] Implement Mounted, Screw-Type Jacks, New York, NY.

ASTM B117 [2003] Standard Practice for Operating Salt Spray (Fog) Apparatus, West Conshohocken, PA.

Bellinger, D [1988] Failure Analysis Technologies and Applications in WG Ireson and C Coombs (ed.) Handbook on Reliability Engineering and Management, McGraw Hill, New York, NY.

DOT [2004] A Guide to Transportation Technology & Innovation, John A. Volpe, National Transportation Systems Center, Cambridge, MA.

Federal Technology Transfer Act [1986] H.R.3773 Public Law: 99-502, Washington, D.C.

Federal Technology Transfer [2004], a web-based publication at: www.federallabs.org

Fuel Cell DOT [2004]
www.drivingthefuture.org/

Guul-Simonsen, F; Jacobsen, P [1999] Corrosion Protection By Assembly Boxes For Agricultural Electronics, Applied Engineering in Agriculture. 15(2): 165-168.

ISO 6315 [1980] Road Vehicles Brake Lining - Corrosion Test Procedure, International Organization for Standardization, Geneva.

MIL HDBK-781A [1996] Handbook For Reliability Test Methods, Plans, and Environments For Engineering, Development Qualification, and Production, Washington D.C.

MILSTD 1629A [1980] Procedures for Performing a Failure Mode, Effects , and Criticality Analysis, Washington D.C.

Powers, JR; Harris, JR; Etherton, JR; Snyder, KA.; Ronaghi, M; Newbraugh, BH [2001] Performance of an Automatically Deployable ROPS on ASAE Tests, Journal of Agricultural Safety and Health 7(1): 51-61.

SBIR and STTR Success Stories
http://grants.nih.gov/grants/funding/sbir_successes/sbir_successes.htm

Spence, J, Cramer, S, and Haynie, F [1995] Planning and Design of Tests in R. Baboian (ed.) Corrosion Tests and Standards, ASTM, Philadelphia, PA.