# Agricultural Safety Systems

## Implementing and developing industry standards

**By E.A. "Tony" McKenzie Jr., Mahmood Ronaghi, John R. Powers Jr. and Timothy J. Lutz**

TRACTOR OVERTURNS have been identified as a leading cause of work-related fatalities in the agricultural industry (Myers & Snyder, 1995). Research has also found that the combination use of a rollover protective structure (ROPS) in conjunction with a seatbelt has been shown to be effective in reducing fatalities (Myers & Snyder). Although ROPS use is increasing (Zwerling, Burmeister, Reynolds, et al., 1997), the number of overturn-related fatalities per year has not declined significantly (NSC, 1997)—with more than 100 fatalities continuing to occur each year (Myers, 2003). Between 1992 and 2005, Bureau of Labor and Statistics (BLS) reported 2,869 agricultural fatalities associated with tractor-related events with 1,412 directly related to tractor overturns, for an annual average of 101 fatalities (BLS, 2006).

One impediment to ROPS use is low-clearance situations, such as orchards and animal confinement buildings. Many smaller tractors are now equipped with manually extending or foldable ROPS for use in such situations. However, 10 to 20% of new tractors are reported to be operating without ROPS (Myers & Snyder, 1995). Decreased use or nonuse of manually extending or foldable ROPS may occur because of a need to operate tractors in low-clearance situations. ROPS will only provide protection if the operator properly deploys it.

Current data on injuries and fatalities related to failure to manually deploy adjustable ROPS are absent. To address the need for structures that are easily adapted to low-clearance situations, NIOSH has adopted the innovative technology used to protect drivers and passengers from overturn hazards when operating convertible automobiles (Mowry, 1999; Mercedes-Benz AG, 1995; U.S. Department of Transportation, 1989).

NIOSH's Division of Safety Research (DSR) has developed a prototype telescoping ROPS system that automatically deploys (AutoROPS). AutoROPS is a passive device consisting of a retractable ROPS that is normally latched in its lowered position for day-to-day use and a sensor that monitors the tractor's operating conditions. If the sensor detects an overturn condition, the retracted ROPS deploys and locks in the full upright position before the overturning tractor contacts the ground.

Static load testing and field upset tests of the device have been conducted in accordance with SAE J2194. Additionally, timed trials of the deployment mechanism were performed. The system has successfully completed each required test, meeting or exceeding industry standards.

### General Description

The NIOSH AutoROPS is an electronically controlled deployable system consisting of the base (stationary) section, which contains the latching system, the crossbar (deployable) section and the electronic control section (Powers, Harris, Etherton, et al., 2000). The system is normally operated in its retracted position, at a height in the proximity of the operator's shoulder; it remains in this position until the electronic rollover sensor initiates deployment of the AutoROPS. The deployed height of the structure is approximately equal to the height of a commercial fixed ROPS. The height of the AutoROPS in the retracted position was established based on the sitting midshoulder height for a 5th percentile female (NASA, 1978). This ensures that operators can see over the crossbar.

### Initial Concept & Design

The concept was to create a passive device that could be constantly in the retracted (or armed) posi-

**E.A. "Tony" McKenzie, Ph.D., P.E.,** *works at NIOSH, where his research focuses on the agricultural sector and rollover protective structures, and on fall prevention in the construction sector. McKenzie is a graduate of West Virginia University (WVU), where he is an adjunct professor in the Mechanical and Aerospace Engineering Department. He is a member of ASSE's Northern West Virginia Chapter.*

**Mahmood Ronaghi** *is a research safety engineer with NIOSH's Protective Technology Branch (PTD), which is part of the agency's Division of Safety Research in Morgantown, WV. Ronaghi holds an M.S. in Aerospace Engineering from University of Colorado, Boulder, and an M.S. in Mechanical Engineering from North Carolina A&T State University.*

**John R. Powers Jr.** *is an electrical engineer and team chief with NIOSH's PTD in Morgantown, WV. He holds a B.S. in Electrical Engineering from Pennsylvania State University.*

**Timothy J. Lutz, P.E.,** *is a mechanical engineer with NIOSH's Mining Injury Prevention Branch in Pittsburgh, PA. He holds a B.S. in Mechanical Engineering from Pennsylvania State University.*

Photo 1 (above): Ford 4600 when purchased in 1998.

Photo 2 (right): Ford 4600 after refurbishing with remote control and AutoROPS in 1999.

**Abstract:** *The use of rollover protective structures (ROPS) on farm tractors, along with operator seatbelt use, is the best known method for preventing fatalities caused by tractor overturns. One impediment to universal ROPS use is low-clearance situations. To address this, NIOSH researchers developed a passive safety device—the automatically deploying telescoping ROPS—to protect tractor operators in an overturn event. Adoption of a new agricultural safety device such as this is based upon compliance with existing industry standards and development of new performance standards when necessary.*

tion until a rollover was detected; it would then be deployed into the protective position. At the time of initial concept (1995), no similar agricultural device existed, but some automakers had similar devices.

Acceptance by agricultural manufacturers required that applicable industry safety standards be satisfied. The most applicable ROPS standard was for wheeled agricultural equipment—SAE J2194. This standard allows three methods for acceptance: 1) static laboratory testing; 2) field upset testing; or 3) dynamic laboratory testing. The nature of the AutoROPS required that two parts of SAE J2194 be used. The static laboratory test would be used to satisfy the strength and energy absorption of the device and the field upset test would be used to satisfy its functionality and performance (ASABE, 2002).

The design of the static testing laboratory design was awarded to West Virginia University (WVU) under a government contract, while the initial design of the first generation AutoROPS was performed at NIOSH. The field upset testing site was located at NIOSH's Pittsburgh Research Laboratory (PRL) because of the availability of space for the two required test pits—one for the rear upset test and the second for the side upset test.

A Ford 4600 tractor was selected for the prototype design. Two tractors were purchased: one for laboratory testing and one for field testing. The field-testing tractor had to be modified for remote control operation as well as to protect against structural damage so that it could be used in repeated upset tests. It took nearly 2 years to prepare the tractor before the first upset test was conducted in spring 1999. Photo 1 shows the tractor at the time of purchase and Photo 2 shows it after it was refurbished with the remote controls, first-generation AutoROPS and the protective structure.

## AutoROPS Development

The device has undergone three major design changes in the past 10 years, each of which are briefly discussed to highlight the obvious changes and the design philosophy for each.

### *First-Generation AutoROPS*

The first design was created to prove a concept, and most of the effort focused on having a successful detection of an overturn event and a successful deployment of the AutoROPS. This design was constructed of telescoping round steel tubes with a deployable crossbar tube (inside tube) and a stationary base (outside tube). The deployment energy was supplied by stored energy of compressed springs inside the tubes.

The device was retracted using internal hydraulic cylinders and deployed by means of a pyrotechnic squib system. The pyrotechnic squib is a small explosive bolt. When electrical current was applied to the squib, a small explosion took place in an expansion chamber. The explosion heated the air and increased the pressure in the expansion chamber, which forced the release pin outward from the AutoROPS. Once the release pin was displaced, the stored energy in the compressed springs was released and deployed the AutoROPS. The first-generation system is shown in Figure 1 (p. 60). The first-generation is shown in the deployed position on the Ford 4600 in Photo 2.

### *Second-Generation AutoROPS*

Latching the first-generation design in the retracted position or releasing it to the deployed position was a labor-intensive process. The aim of the second-generation design was to reduce the labor required to prepare the AutoROPS for service. The other area of emphasis was to eliminate the single use of the system. The goal was to create a multiuse design, and to eliminate the cost and danger related to the use of the pyrotechnic squibs (McKenzie & Etherton, 2002).

To achieve this, the system needed a reusable latch-and-release mechanism. The rest of the system remained virtually unchanged. The second-generation design is shown in the retracted position (Photo 3, p. 60) on a Ford 4600 in the laboratory setting.

### *Third-Generation AutoROPS*

The previous two designs were effective but did not resemble an actual commercial ROPS. The major emphasis of the third iteration was to produce an AutoROPS that represented a finished product rather than a prototype design. This was accomplished by eliminating the hydraulic cylinders, which reduced the weight, using square tubing, switching the deployable crossbar tube (outside tube) and the stationary base (inside tube), and allowing the latch-and-release mechanism to be on the deployed section rather than the fixed section. This design (Photo 4, p. 61) is dramatically different in appearance, material and fabrication from its proof-of-concept predecessor (McKenzie, Etherton, Harris, et al., 2003). This same design was adapted for use on a zero-turn commercial lawn mower (Photo 5, p. 61).

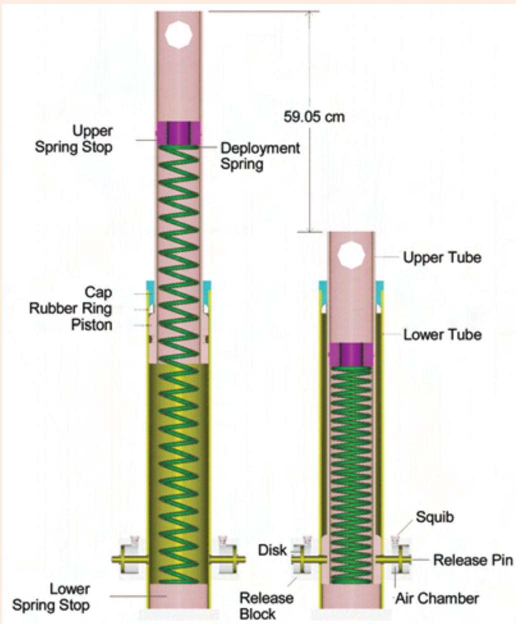
## Composite Materials Use in the AutoROPS

Proper use of ROPS effectively reduces the danger inherent in tractor overturns. Reducing the

Figure 1

## First Generation AutoROPS

NIOSH first generation AutoROPS in deployed and retracted positions.




cost of the structures while maintaining their protective performance is a meaningful strategy for increasing the use of ROPS (Kelsey & Jenkins, 1991). Composite materials that have excellent mechanical properties and that can be more efficiently fabricated offer such an avenue. NASA has reported that composite materials are ideal for structural applications where high strength-to-weight and stiffness-to-weight ratios are required.

The fabrication methods for making ROPS from composite materials present strong possibilities for offsetting higher material costs with lower-cost fabrication methods. By replacing steel with a composite material, strength, stiffness, corrosion resistance, wear resistance, weight and fatigue life of the AutoROPS could be greatly improved.

**Photo 3: Second-generation AutoROPS on Ford 4600 in lab.**

NIOSH researchers conducted a study to evaluate the use of composite materials for ROPS construction. The main advantage of using composite materials is that it would reduce the overall weight of ROPS. This weight reduction would make the devices (manual or automatic) easier to operate and increase their acceptability. It would also lower the tractor's center of gravity and increase its stability. The scope of this research involved identifying candidate materials for the deployable AutoROPS, performing computer model tests of these materials, conducting laboratory tests and identifying a low-cost method for fabricating a prototype composite ROPS.

### *Static Testing*

The static testing requirements, dictated in SAE J2194, were followed and applied to the composite ROPS. Testing to the ultimate load, a normal practice with composite structures, was implemented. Load pads were used to prevent local crushing. Testing composite elements differs from testing isotropic material (metal) beam elements in that shear stresses (or strains) and deformations that depend on fiber orientation must be taken into consideration. An adequately slow rate of loading must be used for static tests and the composite joint must be cured and properly bonded before testing. The static test was applied to a single-post composite and compared with the results from a computer model. The results were very comparable and validated the modeling effort (Figure 2).

Using this information, a full fixed ROPS was built and tested. The composite structure did not deflect, so it did not absorb the required energy as stated in SAE J2194. The loads for this test exceeded nearly twice the weight of the tractor, and the force applied to a steel ROPS for the same tractor. These results indicated that the static test was not an option for the composite ROPS; therefore, dynamic testing would be required for SAE J2194 compliance. The composite ROPS before application of the test load is shown in Photo 6 (p. 62); the composite ROPS after the applied load is shown in Photo 7 (p. 62).

### *Dynamic Testing*

A study on graphite composite laminates indicated that due to rate sensitivity issues, the dynamic testing generated better results than quasi-static (static) testing (Aymerich, Priolo & Vacca, 1999). This information supported the choice for dynamic testing.

A dynamic testing system was designed by a WVU graduate student under a government contract. It was constructed and placed into service at PRL. Initial testing on a fixed steel ROPS indicated that this system was constructed in accordance with SAE J2194 and would give an acceptable level of evaluation of the composite ROPS when tested.

## Intellectual Property

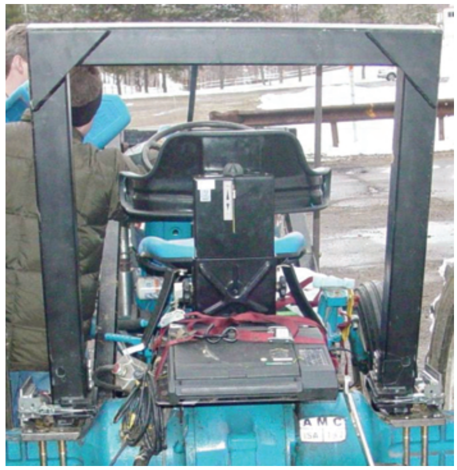
NIOSH researchers are encouraged to have intellectual property (IP) patented. IP can be valuable to a private company as it can be sold for licensing rights and gives the company leverage if someone tries to copy its product(s). NIOSH chose to pursue the patent process for the AutoROPS technology to protect it from being consumed by a larger entity and to make it an available passive safety device for the user. The AutoROPS technology was believed at its inception to have patentable IP; however, the patent process was long and expensive—and it was eventually abandoned (see sidebar on p. 62).

## Partnerships

When the patent process was abandoned, the search for partners began. To date, NIOSH has partnered with three organizations on the development of AutoROPS.

The first partnership (2003) came as a letter of agreement with FEMCO, an established ROPS manufacturer in McPherson, KS. This company offered engineering expertise, cost evaluations and manufactured parts for the AutoROPS.

The second partnership (2003) was with Scag Power Equipment, Mayville, WI. Scag is a manufacturer of lawn and turf care equipment, including walk-behind zero-turn and riding zero-turn commercial mowers. The company offered manufactur-



ing expertise and a zero-turn commercial lawn mower for design and testing.

The third partnership (2004) was a funding partnership with the Office of Technology Transfer and Commercialization (OTTC) at California State University at San Bernardino. NIOSH researchers competed for and was awarded a prototype development, testing and evaluation (PDTE) grant, and a marketing study grant to commercialize the AutoROPS and ultimately bring the technology to market. The PDTE efforts were handled by NIOSH and its partners, and the marketing study was contracted to Emerging Growth Enterprises LLC (EGE), a partner with OTTC. EGE was awarded follow-on support for 2005-07 from OTTC to help NIOSH researchers complete the project.

Much of the effort of EGE and NIOSH focused on identifying potential partners to integrate the AutoROPS into the commercial arena. Through an extensive marketing study, EGE identified industry's main concerns with AutoROPS and confirmed that the commercial lawn and garden market was the most willing to adopt this new technology. The main area identified in these efforts was the need to have an industry standard for the deployment requirements of the AutoROPS.

### Standards Activities

The sponsoring organization for agricultural standards is the American Society of Agricultural and Biological Engineers (ASABE). In 2006, a proposal was filed with the ASABE standards committee to evaluate the need and relevance of a proposed AutoROPS standard. A working group was created to assess the need for a standard and draft one if necessary.

The working group voted in favor of the standard and it was assigned to the PM-52 (Power Machinery) committee for lawn and turf. The proposed standard was designated X-599 and the proposed title was Standardized Deployment Performance of an Automatic Deployable ROPS for Agricultural and Turf and Landscape Equipment. Most of the standard was written by NIOSH researchers and EGE staff. It is in the final stages and was voted on by the PM-52 and PM-23 (ROPS for wheeled agricultural tractors) committees in fall 2007. Based on that process, corrections were made and the vote was submitted to the ASABE X-599 Committee. Following that, the draft standard is to be posted by ANSI for a 45-day comment period. Once that process is complete, it is anticipated that the standard will be published as ASABE S-599.

### Conclusion

The NIOSH AutoROPS efforts for the past 12 years (1995-2007) have been challenging from the perspective of the design engineer, marketer and safety advocate. Through dissemination of NIOSH's research information to all levels of involved parties, these efforts have raised the awareness in ROPS usage.


**Photo 4 (above, left): NIOSH AutoROPS third-generation design.**

**Photo 5: AutoROPS on a commercial mower.**

**Figure 2**

**Comparison of One-Post FE Model vs. Laboratory Testing Results**

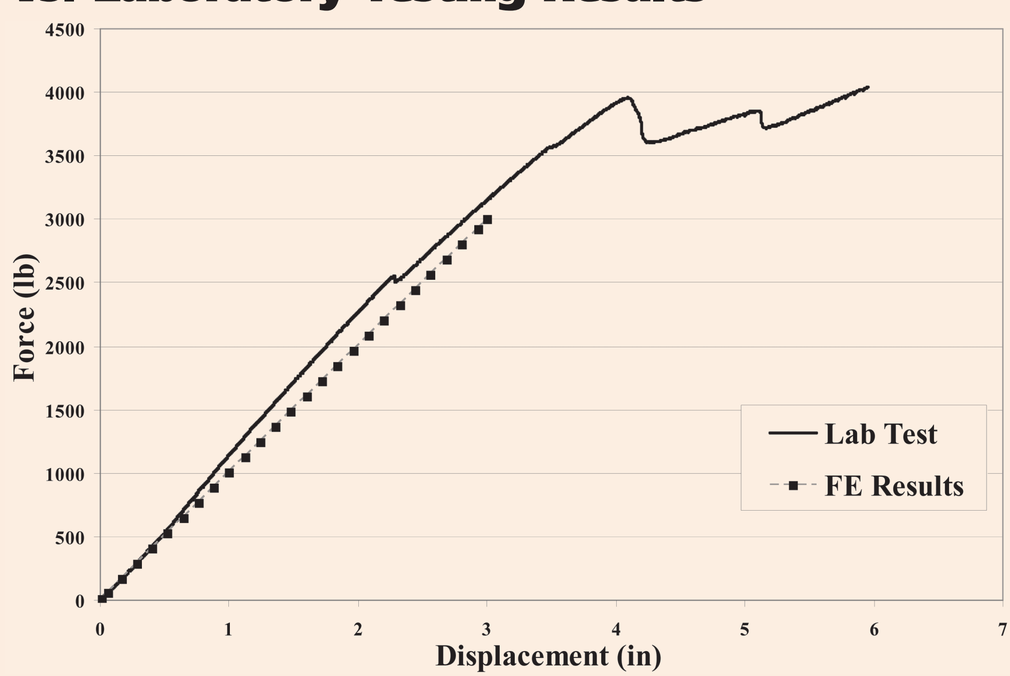


**Photo 6 (left): Composite ROPS condition shown before static testing load was applied.**

**Photo 7 (right): Composite ROPS condition shown after static testing load was applied.**

The major outcome was always expected to be a partnership with a major company in the agricultural industry producing and offering the AutoROPS as an optional safety device in low-clearance environments. At project inception, it was not conceived that the major company would be a zero-turn commercial lawn mower manufacturer and the major outcome would be an industry safety standard for the deployment of the AutoROPS. The final path was dictated by combined efforts of NIOSH and its partnerships with FEMCO, OTTC and Scag Power Equipment. NIOSH is excited about the expected acceptance of the ASABE standard. Once the standard is ratified this technology will be available for manufacturers to implement into new and existing safety products. ■

## References


**American Society of Agricultural & Biological Engineers (ASABE).** (2002). Rollover protective structures (ROPS) for wheeled agricultural tractors (SAE J2194). St. Joseph, MI: Author.

**Aymerich, F., Priolo, P. & Vacca, D.** (1999). Static loading and low-velocity impact characterization of graphite/PEEK laminates. *The E-Journal of Nondestructive Testing & Ultrasonics, 4.*

**Bureau of Labor Statistics (BLS).** (2006). *Census of fatal occupational injuries.* Washington, DC: Author.

**Etherton, J.R., Ronaghi, M. & Current, R.S.** (2007). Development of a pultruded FRP composite material ROPS for farm tractors. *Journal of Composite Structures, 78*(2), 162-169.

**Kelsey, T. & Jenkins, P.** (1991). Farm tractors and mandatory roll-over protection retrofits: Potential costs of the policy in New York. *American Journal of Public Health, 81*(7), 921-923.

**McKenzie, E.A. & Etherton, J.R.** (2002). NIOSH AutoROPS latch and release mechanism: Second generation. *Proceedings of 2002 American Society of Mechanical Engineers Congress and Exposition, USA.*

**McKenzie, E.A., Etherton, J.R., Harris, J.R., et al.** (2003). NIOSH AutoROPS third-generation static testing and human interaction element. *Proceedings of 2003 American Society of Mechanical Engineers Congress and Exposition, USA.*

**Mercedes-Benz AG.** (1995). The automatic rollover bar: Unique the world over [News release]. Stuttgart, Germany: Author.

**Mowry, G.** (1999). Rollover sensor technology and sensing strategies. *Passenger Car Rollover Workshop: TOPTEC—Cause and Prevention.* Warrendale, PA: Society of Automotive Engineers.

**Myers, J.** (2003, Feb. 13). Update on NIOSH statistics on tractor-related injury and fatality. Paper presented at the NIOSH Agricultural Safety Centers Tractor Safety Meeting, Pittsburgh, PA.

**Myers J.R. & Snyder, K.A.** (1995). Rollover protective structure use and the cost of retrofitting tractors in the United States, 1993. *Journal of Agricultural Safety and Health, 1*(3), 185-197.

**NASA.** (1978). *Anthropometric source book* (NASA Publication No. 1024). Washington, DC: Author, Scientific and Technical Information Office.

**National Safety Council (NSC).** (1997). *Accident facts.* Itasca, IL: Author.

**OSHA.** Rollover protective structures (ROPS) for tractors used in agricultural operations (29 CFR 1928.51). Washington, DC: U.S. Department of Labor, Author.

**Powers, J.R., Harris, J.R., Etherton, J.E., et al.** (2000). Performance of an automatically deployable ROPS on ASAE tests. *Journal of Agricultural Safety and Health, 7*(1), 51-61.

**U.S. Department of Transportation.** (1989). Automatic rollover bar design for the new Mercedes-Benz convertibles 300 SL/500 SL. Washington, DC: Author.

**Zwerling, C., Burmeister, L., Reynolds, S., et al.** (1997). Use of rollover protective structures: Iowa, Kentucky, New York and Ohio, 1992-1997. *Morbidity and Mortality Weekly Report, 46*(36), 842-845.



### Acknowledgment

The authors thank T.G. Bobick, Ph.D., P.E., CSP, CPE, for reviewing this document. Thanks also to the NIOSH staff in Morgantown, WV, and Pittsburgh, PA, who have contributed to the success of this project, especially the late Dr. Karl A. Snyder.


***Disclaimer:*** *The findings and conclusions in this report are those of the author(s) and do not represent the views of NIOSH. In addition, the mention of company names or products does not imply endorsement by NIOSH.*

## The Patent Process

The AutoROPS project began in 1995 with the approval of two separate projects: one to design a structure and the second to design a sensor. The two projects developed independently for several years until both were ready to be tested as a complete system. An unsuccessful attempt to patent the technology was initiated within NIOSH in 1996. At this time, the technology did not have the level of the maturity required to pursue a patent, so the process was delayed until 1999, after further research and development were completed.

A U.S. provisional patent application and a Patent Cooperation Treaty international application were then filed. Because of the lack of patentable claims, NIOSH decided to abandon the case and the patent application lapsed in 2003. At the end of the patent efforts, it was ensured that this safety device would be available.

This process lasted more than 4 years. During that time, disclosure had to be performed in a manner that would not jeopardize the ongoing patent process. The inability of full disclosure of the research efforts limited and sometimes hindered the research efforts. In retrospect, this was the most responsible path to ensure success of the AutoROPS technology.