

# Preventing tractor rollover fatalities: performance of the NIOSH AutoROPS

J R Powers, J R Harris, J R Etherton, M Ronaghi, K A Snyder, T J Lutz, B H Newbraugh

## Abstract

Approximately 132 agricultural tractor overturn fatalities occur per year. The use of rollover protective structures (ROPS), along with seat belts, is the best known method for preventing these fatalities. One impediment to ROPS use, however, is low clearance situations, such as orchards and animal confinement buildings.

To address the need for ROPS that are easily adapted to low clearance situations, the Division of Safety Research, National Institute for Occupational Safety and Health (NIOSH), developed an automatically deploying, telescoping ROPS (AutoROPS). The NIOSH AutoROPS consists of two subsystems. The first is a retractable ROPS that is normally latched in its lowered position for day-to-day use. The second subsystem is a sensor that monitors the operating angle of the tractor. If a rollover condition is detected by the sensor, the retracted ROPS will deploy and lock in the full upright position before ground contact.

Static load testing and field upset tests of the NIOSH AutoROPS have been conducted in accordance with SAE standard J2194. Additionally, timed trials of the AutoROPS deployment mechanism were completed. The design of the retractable ROPS and sensor, as well as the results of the different testing phases are discussed.

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**Keywords:** tractor safety; rollover protective structures (ROPS); overturn; occupational injury

Tractor overturns are the leading cause of fatalities in the agricultural industry. Approximately 132 fatalities occur per year.<sup>1</sup> The use of rollover protective structures (ROPS), in conjunction with seat belts, is the best known method for preventing these fatalities. 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, these ROPS will only provide protection if the operator chooses to raise them. Available data do not indicate the number of injuries or fatalities due to the failure to raise adjustable ROPS. Approximately 8% of new tractors are reported to be operating without ROPS.<sup>1</sup> Some of these may be due to a need to operate these tractors in low clearance situations.

To address the need for ROPS that are easily adapted to low clearance situations, the Division of Safety Research, National Institute for

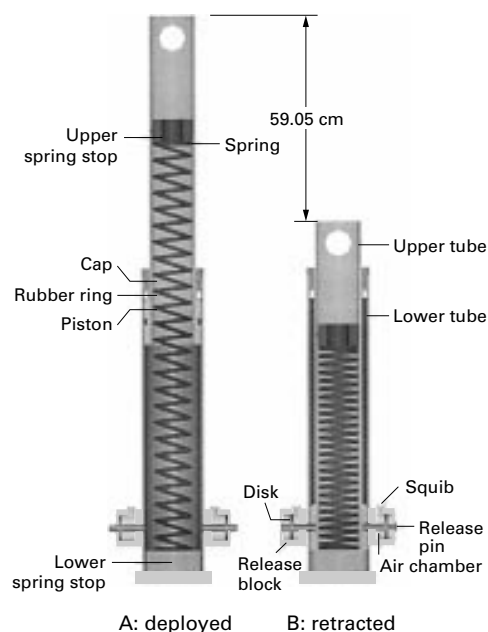


Figure 1 Structure and mechanism of AutoROPS, an automated rollover protective system which fires the release pins to activate the mechanism if an overturn situation is sensed.

Occupational Safety and Health (NIOSH), developed a prototype for an automatically deploying, telescoping ROPS (AutoROPS). Technology innovations of this type have recently been developed for protecting drivers and passengers from the overturn hazard in convertible automobiles.<sup>2–4</sup> The NIOSH AutoROPS is a passive device consisting of (1) a retractable ROPS that is normally latched in its lowered position for day-to-day use, and (2) a sensor that monitors the operating angle of the tractor. If an overturn condition is detected by the sensor, 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 NIOSH AutoROPS have been conducted in accordance with SAE J2194.<sup>5</sup> Additionally, timed trials of the AutoROPS deployment mechanism were completed. This paper discusses the basic design of the NIOSH AutoROPS as well as the results of the different testing phases.

In tribute to Dr Karl Snyder, who died suddenly the week before the National Occupational Research Symposium, where this research was presented. Dr Snyder was well known for his work in agricultural safety engineering, and in particular for his work in developing the auto deploying ROPS described in this article. He was a highly skilled, creative, and generous friend and colleague, and it is with deep sadness that we remember and honor him.

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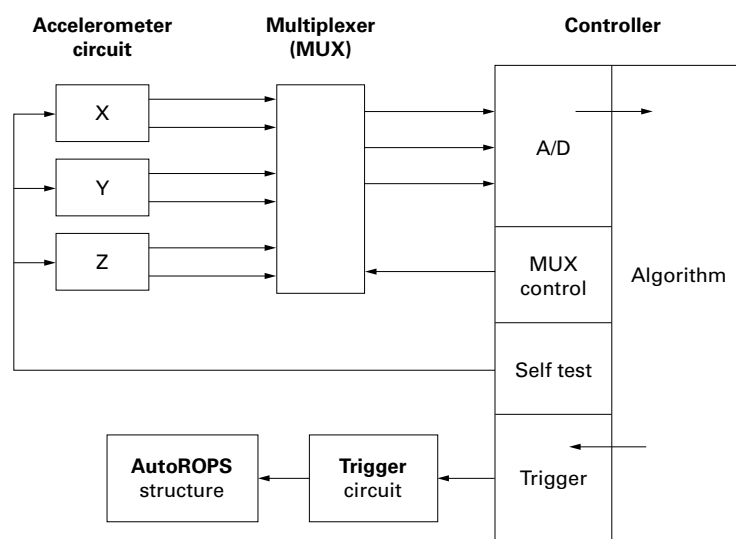


Figure 2 Diagram of sensor mechanism used to monitor the roll and pitch of the tractor and deploy AutoROPS when rollover is likely (A/D = analog to digital converter).

## Methods

### ROPS SUBSYSTEM

The AutoROPS structure subsystem consists of two telescoping tubes which are extended by a spring (fig 1). The retracted height for the tubes is based upon the sitting mid-shoulder height for a fifth percentile female.<sup>6</sup> This ensures the AutoROPS is below head height and that nearly all operators can see over the crossbar. The deployment distance required to engage the AutoROPS is 59.05 cm (23.25 in), and was determined by keeping the deployed height of the AutoROPS crossbar approximately equal to the height of a commercial ROPS. A key design parameter was for deployment to occur in less than 0.3 seconds, the same criterion used to protect convertible automobile occupants from an overturn hazard.<sup>7</sup> This is well below the 0.75 seconds that Hathaway and Kuhar indicate it takes for a tractor in a rear overturn to go from a point-of-no-return to ground contact.<sup>8</sup> Design and component sizing of the telescoping tubes was facilitated by use of finite element analysis and computer aided design software.<sup>9-11</sup>

Pyrotechnic squibs provide the force needed to simultaneously disengage two pins that hold the structure in the retracted configuration (fig 1B). Each pin is forced outward by the gas pressure acting in an expansion chamber.

Two pins on each lower tube snap into place underneath the upper tube and piston to lock the ROPS into the deployed position (fig 1A, pins not shown since they are oriented normal to the page). These pins provide critical vertical support for the structure.

The AutoROPS is retracted by a hydraulic cylinder inside of the spring. The cylinder is mounted to a block which directs hydraulic fluid to the retract cylinder. A two position, manually levered valve currently controls the hydraulic flow for raising and lowering the upper structure.

### SENSOR SUBSYSTEM

The primary goal of the AutoROPS sensor was a device that did not rely on the tractor's center

of gravity, because the center of gravity can change when implements are attached to the tractor. Figure 2 shows the block diagram of the AutoROPS sensor. As can be seen from this diagram, the sensor consists of three accelerometer circuits, a multiplexer, a microcontroller, and a triggering circuit. The accelerometer circuits are configured to monitor the roll and pitch of the tractor. The accelerometer signals are passed to the microcontroller via the multiplexer. The microcontroller contains an algorithm that monitors the received signals and makes a determination as to whether or not the tractor is operating in a safe condition. If an overturn condition is sensed, the microcontroller will send a signal to the triggering circuit to deploy the telescoping ROPS.

### RELEASE MECHANISM TESTS

The release mechanism tests were completed in the laboratory (early December 1998) by securing the AutoROPS structure to a test bed and using one pyrotechnic squib. An OptoTrak 3020 optical motion measurement system, sampling at 200 Hz, was used to record the position of the structure as it deployed. A timing circuit connected to a switch was used to activate the squib. Video cameras were used to capture the event. The OptoTrak data were used to calculate deployment time. The AutoROPS was also latched in its lowered position for approximately 2.5 months to determine if keeping the spring in a compressed state would degrade deployment time.

### STATIC LOAD TESTS

The AutoROPS structure was tested to the SAE J2194 static load test sequence during July 1999. All static loading tests, with the exception of the vertical crush test, were run via a QuickBASIC program and PC link to an MTS MicroProfiler under displacement control. As required in the standard, the energy of the force versus deflection curve was continually monitored by the program. Loading was provided by 20 kip hydraulic actuators. The vertical crush test was performed under manual displacement control to the required load level. These tests were performed in the laboratory with the AutoROPS mounted to the axle housing of the tractor.

### FIELD UPSET TESTS

To meet the field test requirements of SAE J2194, engineers and technicians at the NIOSH Pittsburgh Research Laboratory modified a Ford 4600 tractor with remote control capability. Rear and side overturn test ramps were constructed to the specifications set forth in SAE J2194.

The AutoROPS was mounted on the axle housing of the tractor. The sensor was mounted near the center of the tractor and aligned so that the X-axis was front-to-back, the Y-axis was side-to-side, and the Z-axis up-and-down.

The tractor was equipped with a Fieldworks F7500 ruggedized laptop which contained a

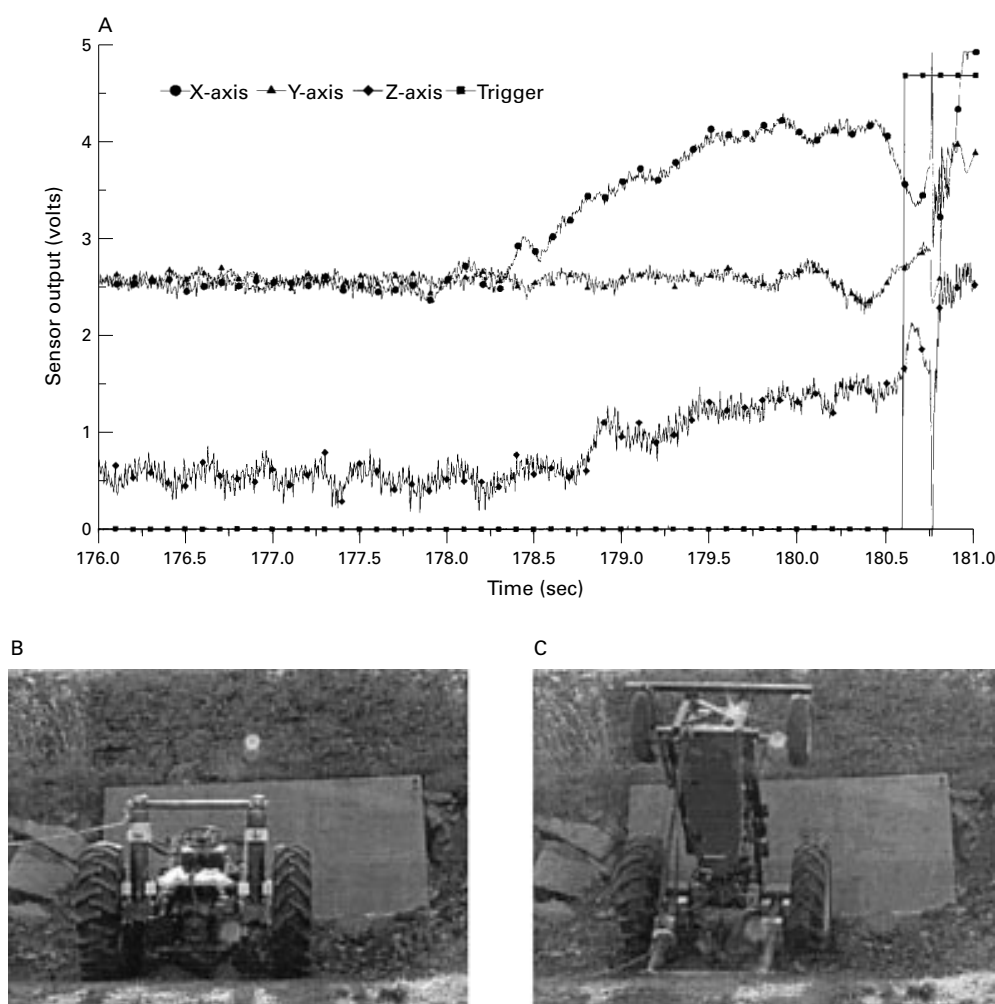


Figure 3 Field test of tractor rollover protective system showing rear roll accelerometer outputs that trigger discharge of AutoROPS (A) and the tractors approach to the ramp just before (B) and after (C) the rear roll when AutoROPS activated.

National Instruments DAQCard-700 and LabVIEW software. The DAQCard-700 was configured to accept five differential analog inputs: X-axis, Y-axis, Z-axis, sensor voltage (Vcc), and trigger signal. The data were recorded at a sampling rate of 250 Hz. In addition, video cameras were set up to record the overturn tests from different angles.

The rear and side upset tests were conducted after taking cone penetrometer readings in the impact area, in accordance with ASAE S313,<sup>12</sup> to ensure that the soil met or exceeded the soil firmness requirements of the SAE J2194 standard ( $\geq 1030$  kPa). The tractor was aligned with the ramp, placed in the appropriate gear, and shut off. Following installation of the pyrotechnic squibs, the LabVIEW data collection program was started and the tractor engine restarted. For the rest of the test, the remote tractor operator released the brakes, engaged the clutch, adjusted the engine speed to achieve the required tractor speed, and performed steering necessary to maintain alignment with the overturn ramp. Once the overturn was completed, the tractor engine was shut off and the tractor was returned to its wheels with a crane. When the test area was safe to enter, the

LabVIEW program was stopped and the data were secured.

## Results and discussion

### RELEASE MECHANISM TESTS

Four release tests were conducted. In these laboratory tests, the two post structure consistently deployed in less than 0.3 seconds and latched-up securely. The results of the 2.5 month latch test also produced a deployment time of less than 0.3 seconds.

### STATIC LOAD TESTS

The first longitudinal and transverse tests were terminated (test load successfully sustained) when they reached load levels equal to those recorded by NIOSH (J R Etherton, J R Harris, NIOSH, unpublished data, 1995) for standard ROPS for the same tractor. These load levels were achieved before the energy criterion of the standard was met. The second longitudinal load was terminated when it met the energy criterion of the standard and before it reached a load level found for standard ROPS in earlier testing. No permanent (plastic) deformation was observed as a result of any of the four tests.

## FIELD UPSET TESTS

Figure 3A shows the data collected during a rear upset test. For this test the tractor was put into third gear with an engine speed of 2200 rpm producing a tractor speed of approximately 5.6 km/h (3.5 mph). Cone penetrometer readings were taken at six locations in the impact area. The average cone index of these six locations was 2814 kPa. Figures 3B and C show the position of the tractor just before climbing the ramp and at the completion of the roll, respectively. It can be seen from fig 3A that as the tractor climbed the ramp the X-axis and Z-axis signals increased. The AutoROPS deployed when the tractor reached an angle of approximately 65°. The time from AutoROPS deployment until ground contact was approximately 2 seconds.

Figure 4A shows the data collected during a side upset test. For this test the tractor was put into sixth gear with an engine speed of 2000 rpm producing a tractor speed of approximately 10.5 km/h (6.5 mph). Cone penetrometer readings were recorded in nine different locations in the impact area. The average cone index for these nine locations was 2699 kPa. Figures 4B and C show the position of the tractor just before entering the side overturn

pit and at the completion of the roll, respectively. It can be seen from fig 4A that as the tractor entered the overturn pit the Y-axis signal decreased while the Z-axis signal increased. The AutoROPS deployed when the tractor reached an angle of approximately 66°. The time from AutoROPS deployment until ground contact was approximately 1.5 seconds. A change in the X-axis signal can also be seen. This was caused by the impact of the right tractor wheel with the ramp.

The sensor was also evaluated by operating the tractor over rough terrain at a variety of forward speeds. No false deployments of the AutoROPS occurred during these tests.

## Conclusions

NIOSH has developed an automatically deploying, telescoping ROPS. The device is normally in a compact form, allowing for use in low clearance situations, but extends automatically to its full height to protect the operator in an overturn event. A sensor has also been developed that monitors the operating angle of the tractor and determines if an overturn is imminent. Results from actual field upset tests conducted in accordance with SAE J2194

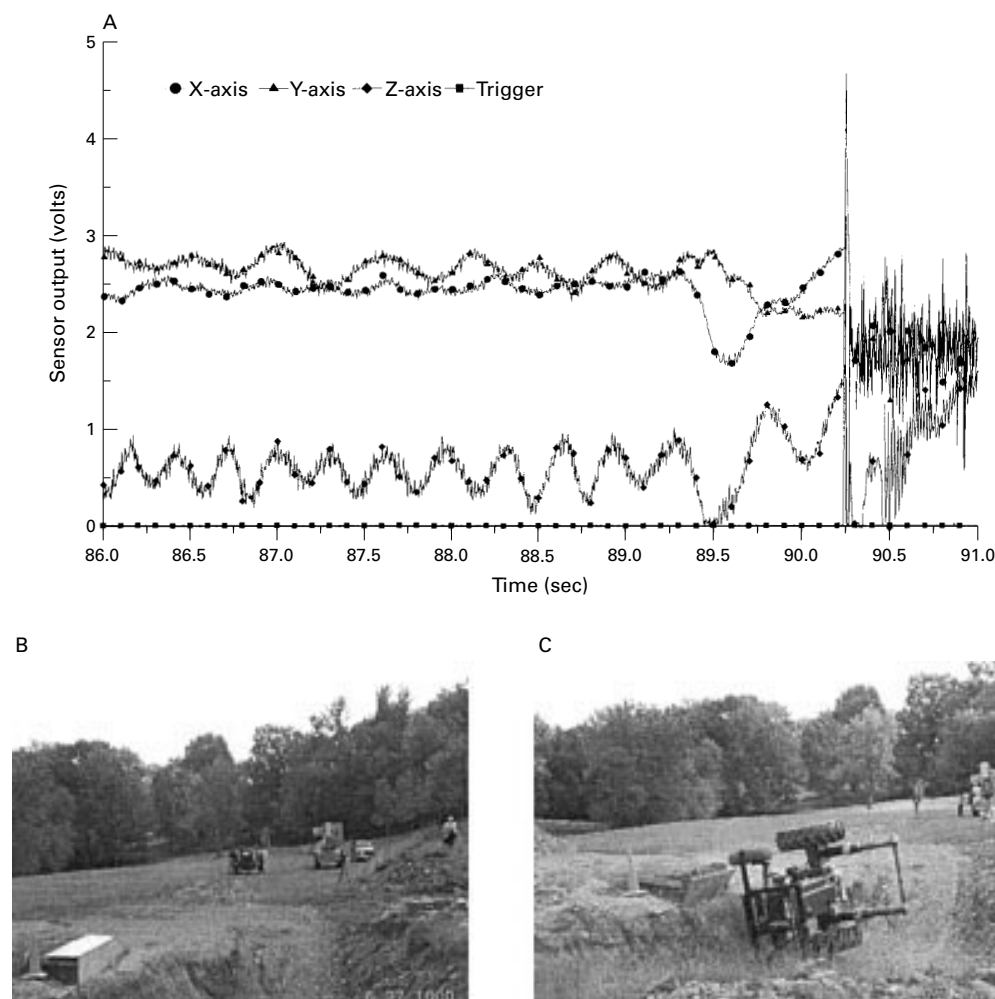


Figure 4 Field test of tractor rollover system showing side roll accelerometer outputs that trigger discharge of AutoROPS (A) and view of tractor before (B) and after (C) side roll when AutoROPS activated.



show that the AutoROPS structure absorbed the impact with no measurable permanent deflections in the structure. The sensor was able to predict the overturn in a timely manner so that the AutoROPS was fully deployed and locked before ground impact occurred.

The primary goal of this phase of the research was to build a structure that would prove the concept that a ROPS can be built that will reliably deploy on signal, rise in a sufficiently short time, firmly latch in its deployed position, and satisfy the SAE J2194 testing requirements. Further improvements to the AutoROPS system are currently being developed by NIOSH staff. As noted by a recent systematic review of the effectiveness of ROPS, Northern European countries have virtually eliminated tractor rollover fatalities through the use of ROPS (or equivalent crushproof cabs) and seat belts which ensure that the operator remains within the areas protected by the ROPS.<sup>13</sup> The use of automatically deploying ROPS can overcome some of the barriers to ensuring universal use of ROPS on farm tractors

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#### Disclaimer

Mention of the name of any company or product, or inclusion of

any reference, does not constitute endorsement by the National Institute for Occupational Safety and Health.

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