Commercialization of Cost-Effective Rollover Protective Structures (CROPS)*
Research-in-Progress

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* The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Introduction

Even in the 21st century, farming remains a challenging and sometimes dangerous industry. Data from the Bureau of Labor Statistics Census of Fatal Occupational Injuries show that from 1992-2001 over 1000 U.S. workers died due to tractor overturns (U.S. Department of Labor, 2004). A rollover protective structure (ROPS) and seatbelt is an effective engineering control that is 99% effective in preventing tractor overturn-related fatalities (Hallman, 2005). As of 2001, it was estimated that 50% of all U.S. tractors were equipped with ROPS (Myers, 2003). With an average tractor age of 26 years (Myers, 2003) and a typical ROPS cost (with installation) of $1000 USD (Scharf et al., 1998), cost can be a substantial barrier to retrofitting a ROPS to a tractor.

Technical barriers also exist to retrofitting ROPS to tractors. Some of the most popular tractors used in the U.S. were manufactured before 1976 and therefore are not governed by the OSHA regulation which moved manufacturers to produce tractors designed to have ROPS (U.S. Department of Labor). The rear axle housings of these pre-1976, or pre-ROPS, tractors were not typically designed to accommodate a ROPS. However, Ayers and Liu (2001) have shown that many pre-ROPS tractors do have sufficient axle housing strength to support structural loading induced during consensus standard performance testing. Retrofit ROPS have been made available for some pre-ROPS tractors by either the tractor manufacturer or a third party. But for some tractor models, a retrofit ROPS is not available.

Harris et al. (2002) have demonstrated the technical feasibility of a "cost-effective" ROPS, or CROPS, to pass the loading requirements of a consensus performance standard. A CROPS is a weld-free construction using common structural elements and fasteners. As a secondary benefit, it can be assembled by one person. A ROPS manufacturer estimated that a prototype CROPS could be fabricated and sold for $290 USD. Shipping costs vary by destination location, but the same ROPS manufacturer estimated the highest shipping cost for the 48 contiguous states to be $193 USD (2003). In 2003, NIOSH and FEMCO, Inc., a ROPS manufacturer, entered into a collaboration to transfer CROPS techniques to industry. This paper details the collaboration and provides a progress update on CROPS commercialization.

Methods

The technical feasibility of a CROPS was first demonstrated on a Ford-4600. To impact the greatest number of tractors in the U.S. fleet, CROPS designs are needed for the most popular tractors which do not have ROPS installed. These tractors are called non-ROPS tractors. This does not mean that a retrofit ROPS is not produced for this tractor. Rather, it shows that when surveys were conducted, this tractor was found to not have ROPS installed. Comprehensive farm surveys were conducted by the United States Department of Agriculture (USDA), National Agricultural Statistical Service (NASS) with input from NIOSH in 1993 (Myers and Snyder, 1995) and 2001 (Myers, 2003). Both sets of data provide a national estimate of the number of U.S. tractors without ROPS by tractor model. The 1993 data were reported for all tractor models with an estimated total of non-ROPS tractors greater than 10,000 units. To date the 2001 data have been analyzed for the top five most popular non-ROPS tractor models only (see Table 1).

Five tractor models were chosen for CROPS commercialization potential with the collaborative partner, FEMCO, Inc. The tractor models to be investigated were selected according to the following criteria by progressing down the 1993 list of most popular non-ROPS tractors:

(1) Cost of ROPS, if available, > $862 USD [average price of "top ten" as listed by Myers and Snyder (1995)]

(2) Tractor axle housing can accept modified prototype design that was previously developed for Ford-4600 (Harris et al., 2002)

Selected tractor models for the project include Farmall-M, Ford-8N, Farmall-H, Ford-3000, and Ford-4000. The distribution of these tractor models is shown in Table 1.

Table 1 - Distribution of non-ROPS tractors in the U.S. by tractor model and year

	# of non-ROPS tractors in U.S.	
Tractor model (years manufactured)	**1993**	**2001**
Farmall-M (1939-1952)	76,798	38,000
Ford-8N/9N (1947-1952 8N) (1939-1942 9N)	83,942	72,000
Farmall-H (1939-1953)	65,875	30,000
Ford-3000 (1965-1975)	43,052	Data not available
Ford-4000 (1962-1975)	39,883	Data not available

Collecting tractor dimensions

Individual tractors were identified in Morgantown and Martinsburg, West Virginia for each of the models selected to gather dimensions important in CROPS design. Information was collected on axle housing geometry to determine how the CROPS would mount to the tractor. In addition, data were collected to determine the size of the ROPS Clearance Zone (CZ) and to locate the CZ with respect to the rear axle. The ROPS CZ is defined by a consensus ROPS performance standard, SAE J2194 – "Roll-Over Protective Structures (ROPS) for Wheeled Agricultural Tractors" (SAE, 2002). This zone represents a protective envelope around the tractor operator that is to be protected by a ROPS during an overturn. The CZ from SAE J2194 is shown in Figures 1a-b.

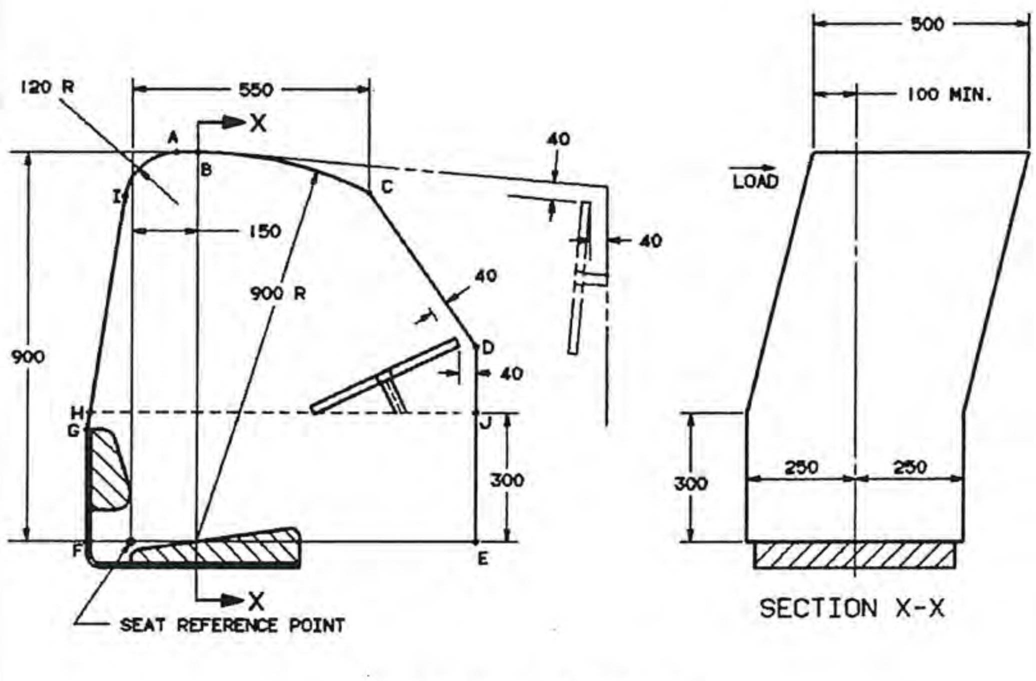

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Figure 1a - SAE J2194 Clearance Zone (CZ)

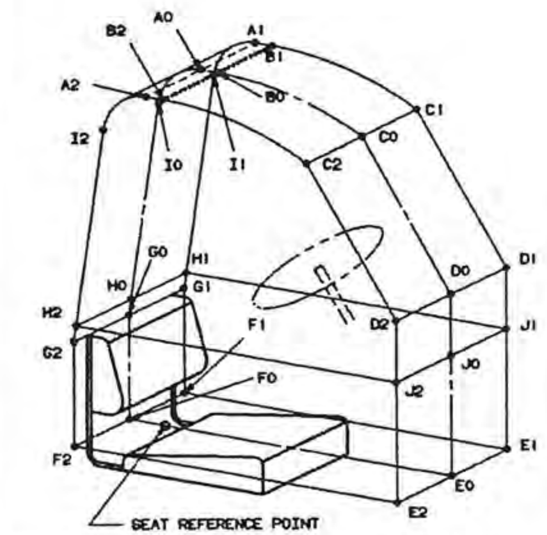

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Figure 1b - SAE J2194 Clearance Zone (CZ)

Developing tractor model specific CROPS

After collecting tractor dimensions, a two-dimensional (2D) side view of the CZ could be developed for each tractor model with respect to the seat reference point (SRP) and rear axle. Utilizing previous prototype test results for SAE J2194 loadings with similar CROPS structural shapes and materials, CROPS deflection during static testing was estimated by scaling experimental results through application of basic beam deflection equations. Deflection of a fixed-free beam under application of a point load (cantilever) is dependent upon L^3, where L is the beam length. Consequently, with the same flexural rigidity between tested CROPS and new CROPS design, the following relationship was utilized for a given load: $y_{design}/y_{test}=(L_{design}/L_{test})^3$, where y represents beam deflection at point of load application. These deflection estimates were used to determine the CROPS design "layback" angle so that the CROPS design would not enter the CZ during testing. The layback angle is the angle between the CROPS upright and a vertical plane. Additionally, the CROPS design could not allow exposure of the CZ to the ground plane. This means that the CZ could not touch the ground if an overturn occurred in the direction of static loading.

Once the CROPS conceptual design was developed in 2D, a three-dimensional (3D) assembly drawing was completed. From this assembly drawing, necessary engineering drawings were generated to guide fabrication.

Testing CROPS prototypes

Prototypes were fabricated for static testing according to SAE J2194. Static testing by this standard included a sequence of four loads applied to the same ROPS: (1) longitudinal (rear), (2) vertical crush, (3) transverse (side), and (4) vertical crush. Figures 2a-b from SAE J2194 show the typical test setup.

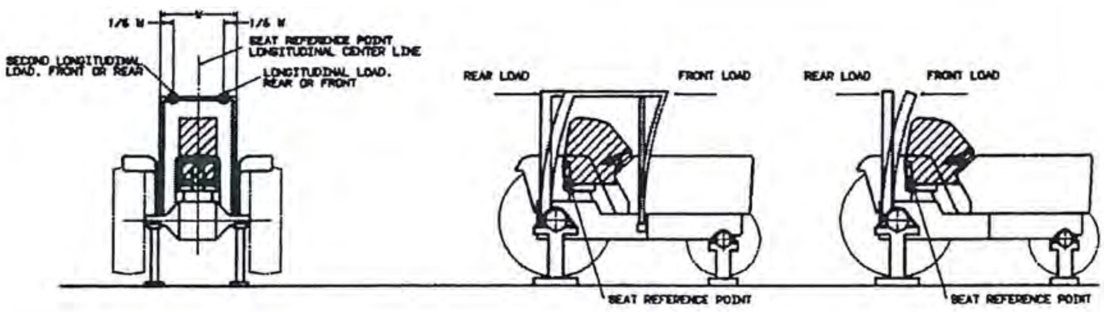

FIGURE 5A—TYPICAL REAR (FRONT) LOAD APPLICATION

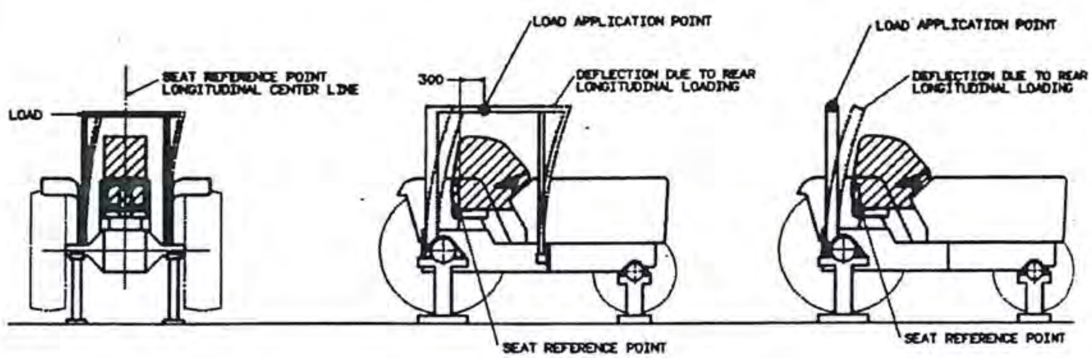

FIGURE 5B—TYPICAL SIDE LOAD APPLICATION

Figure 2a - SAE J2194 longitudinal and transverse loading setup

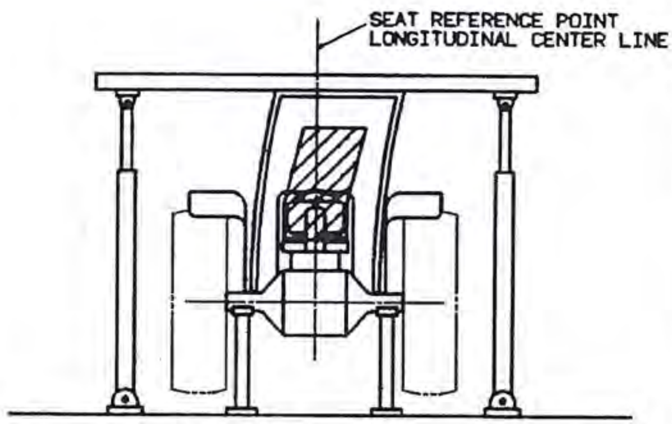

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Figure 2b - SAE J2194 vertical crush test setup

The laboratory setup used for testing has been described previously (Powers et al., 2001).

Designs have been completed for all five tractor models of this study. SAE J2194 static testing is complete for CROPS prototypes on the Ford-3000 and Ford-4000 tractor models. At this point, static testing has not been conducted on designs for the Farmall-M, Ford-8N, and Farmall-H.

Results

Critical design parameters

Table 2 shows the distance variation among the five tractors studied for seat reference point (SRP) to rear axle centerline (vertical and horizontal projection). These dimensions influence how tall the CROPS must be to protect the clearance zone displayed in Figures 1a-b. As the required CROPS height increases, CROPS deflection under load also increases. This must be accounted for by adjusting the CROPS layback angle to ensure that the CROPS does not encroach on the CZ.

Table 2 - SRP to rear axle centerline distance variation

SRP to axle center (vertical)	Farmall-M	Farmall-H	Ford-8N	Ford-3000	Ford-4000
	762 mm (30")	641 mm (25-1/4")	397 mm (15-5/8")	463 mm (18.21")	416 mm (16-3/8")
SRP to axle center (horizontal)	-468 mm* (-18-3/4")	-432 mm* (-17")	41 mm (1-5/8")	200 mm (7-7/8")	203 mm (8")

* - SRP is to the rear of tractor behind the rear axle centerline

Prototype components (Appendix A provides more details)

Results from previous prototype testing using stock structural components led to selection of 2"x3"x1/4" (50.8 mm x 76.2 mm x 6.35 mm) steel tubing for both uprights and the crossbar for the Ford-3000 and Ford-4000 prototypes. This material met specifications for grade B/C of ASTM A500 (ASTM, 2001). In addition, Charpy V-notch impact testing was conducted on samples of similar material by a certified laboratory. All samples exceeded requirements of SAE J2194 at the required temperature of -30° C (-22° F). Material properties for the actual tubing utilized to fabricate the Ford-3000 prototype as reported in the certification sheet from the steel mill were: yield strength = 396.45 MPa (57,500 psi) and ultimate strength = 470.22 MPa (68,200 psi). For the steel tubing used in the Ford-4000 prototype, the mechanical test results as reported by the steel mill were: yield strength = 375.76 MPa (54,500 psi) and ultimate strength = 441.26 MPa (64,000 psi).

Standard SAE grade 5 bolts with a minimum proof strength of 586 MPa (85,000 psi) were utilized for both the Ford-3000 and Ford-4000 prototypes. All plate components were 3/8" (9.53 mm) thick and supplied by a ROPS manufacturer per their material specifications.

SAE J2194 static test results

Static testing is complete for the Ford-3000 and Ford-4000 CROPS prototypes. Figures 3 and 4 show results from Ford-3000 horizontal load (longitudinal and transverse) testing. Note that the reference mass for this test is 1995 kg (~4400 lb). SAE J2194 states that the reference mass can be selected, but cannot be less than the tractor mass. Tractor mass is defined in SAE J2194 as "The mass of the unladen tractor in operating order with tanks and radiators full, protective structure with cladding and any wheel equipment or additional front wheel drive components required to support the tractor static weight. The operator, optional hitch equipment, optional ballast weights, additional wheel equipment, and other special equipment are not included." The Nebraska Tractor Test #883 lists Ford-3000 without ballast weight of 1900 kg (4190 lb, including the operator) (Nebraska Tractor Test Laboratory, 1965). The reference mass selected in consultation with FEMCO, Inc. exceeds this value.

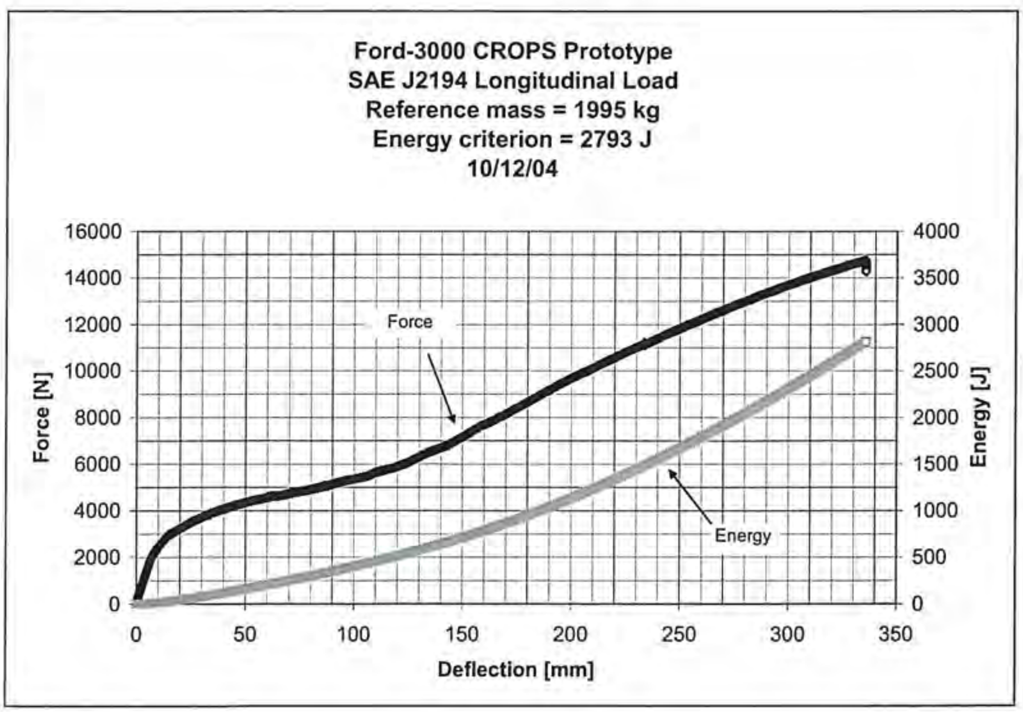

Figure 3a - Ford-3000 longitudinal load data

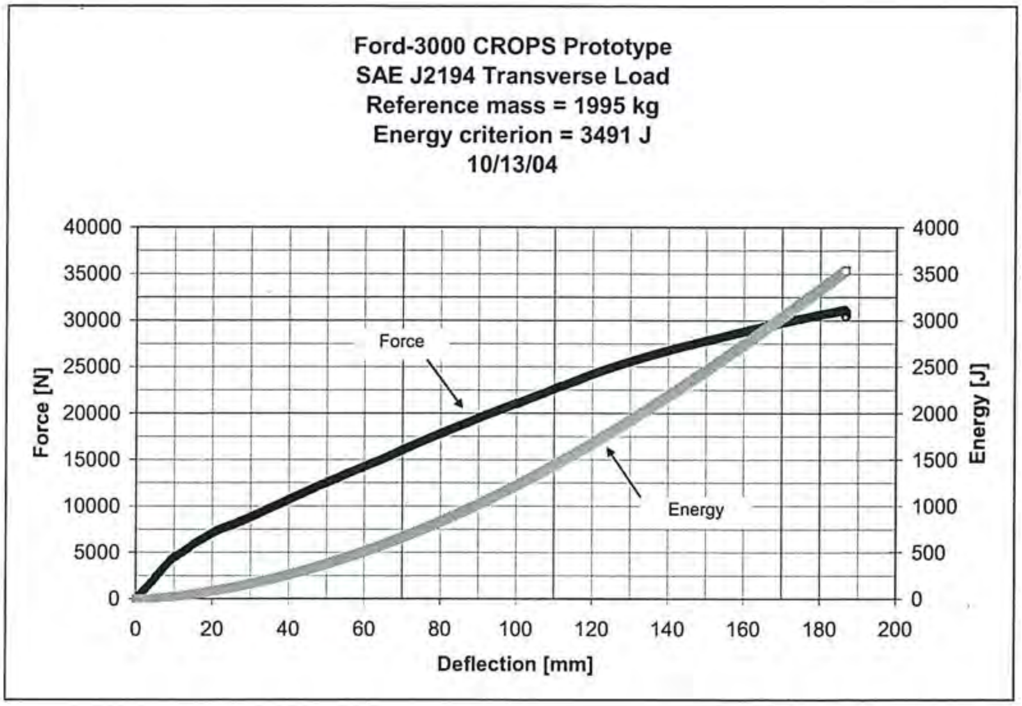

Figure 3b - Ford-3000 transverse load results

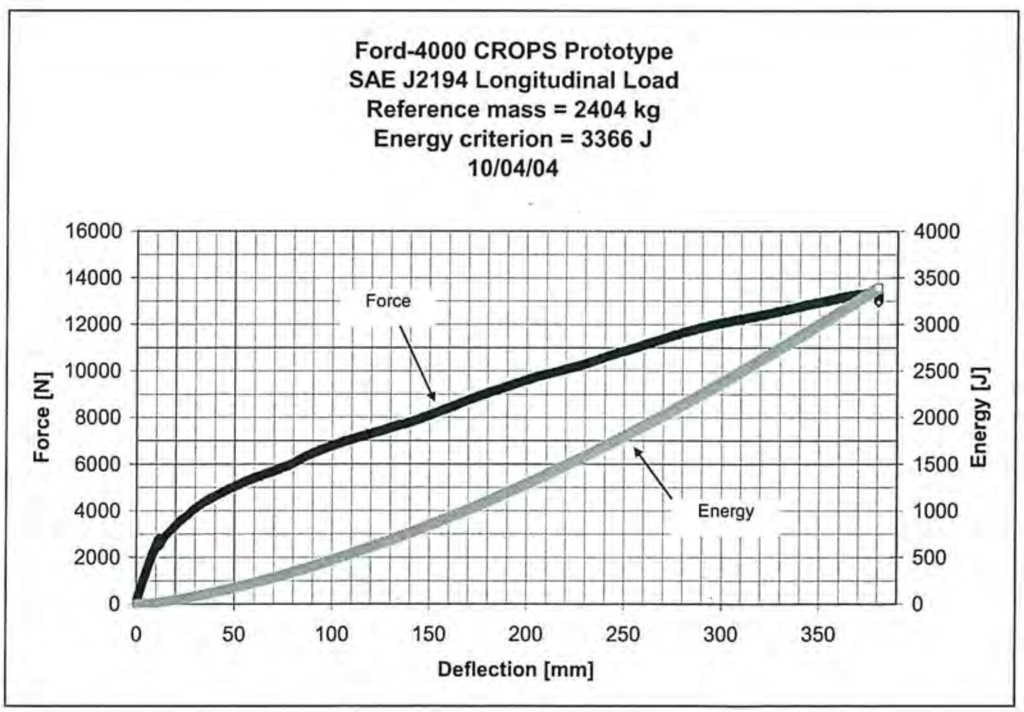

Figure 4a - Ford-4000 longitudinal load results

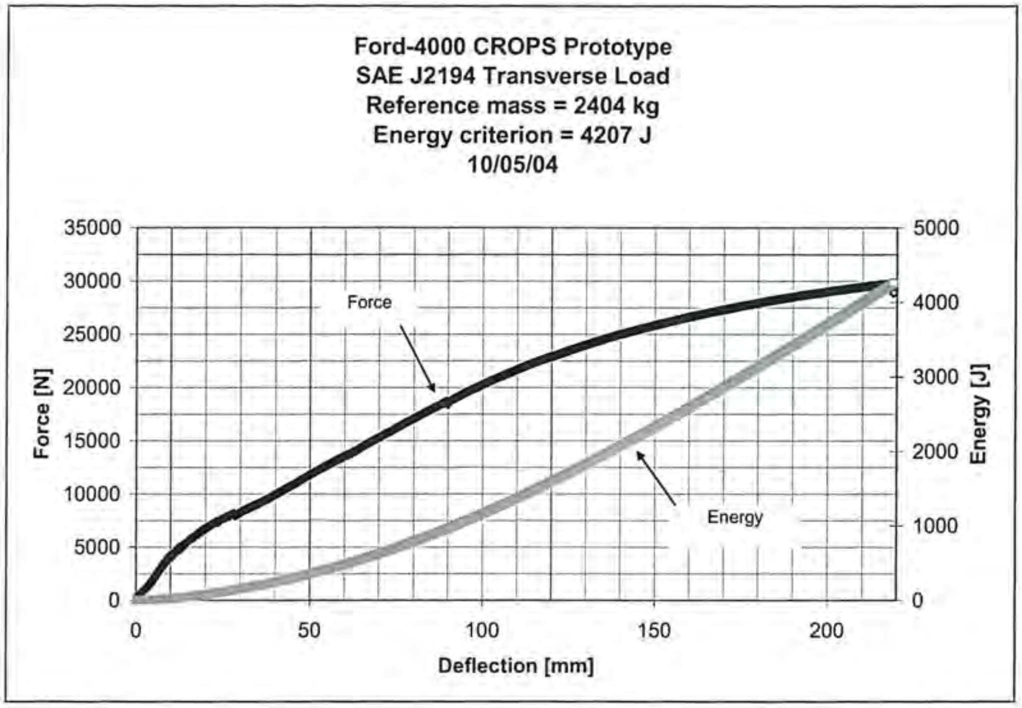

Figure 4b - Ford-4000 transverse load results

For the Ford-3000 with a reference mass of 1995 kg (~4400 lb), the required vertical crush load was 39,900 N (8970 lb). For the Ford-4000 with a reference mass of 2404 kg (~5300 lb), the required vertical crush load was 48,080 N (10,809 lb). Both the Ford-3000 and Ford-4000 satisfactorily supported the vertical crush loadings.

Discussion

Locating nearby tractors for this study and talking with different tractor owners reinforced the importance of involving stakeholders when developing or modifying safety control designs. The tractor owners involved with this work provided valuable information that influenced prototype design. For example, while collecting measurements for the Ford-8N, one owner showed the design team a typical side attach mower. The routing of cables to control this attachment and the mounting locations to support this structure influenced the conceptual design of the Ford-8N

CROPS. It was important to ensure that this attachment would still function as intended with a CROPS installed.

In addition to cost considerations that should make a commercial CROPS an attractive retrofit option, the basic layout of the CROPS design allows for installation by one person. The mounting plates can be fastened to the axle housing. The uprights, reinforcement plates, and crossbar can be assembled on the ground and then rotated about a secure hole on each mounting plate. Once in an upright position, the assembly can be locked in place using the remaining holes on the mounting plates. Since the uprights are not welded to the mounting plates, a feature has been designed into each prototype to allow the entire upper structure of the CROPS (i.e. uprights, reinforcements plates, and crossbar) to rotate back to allow the tractor and CROPS to be driven through a standard height garage door opening (7 ft. or 2134 mm – see Appendix B). Tilting the upper portion of the CROPS prototype back is accomplished by extending a small length of chain between the upright and the upper mounting plate. Normally this chain would be slack, but the upper bolt connecting the upright to the upper mounting plate can be removed. When this occurs, the chain tightens and the upper portion of the CROPS rotates back.

Conclusions

Collaborating with a ROPS manufacturer, NIOSH has developed CROPS designs for five popular non-ROPS tractor models: Farmall-M, Ford-8N, Farmall-H, Ford-3000, and Ford-4000. To date, prototypes for the Ford-3000 and Ford-4000 have been fabricated and successfully tested according to the static testing procedures of the ROPS consensus performance standard, SAE J2194. The estimated cost of an early CROPS prototype was $290 (shipping and installation not included) in 2003. This is substantially less than the advertised price for many ROPS retrofits. The goal is for less costly ROPS alternatives to increase the adoption rate for ROPS in the United States.

Acknowledgments

The authors appreciate the collaboration and assistance of FEMCO, Inc. that has been an important part of this research. Additionally, the authors are thankful for the time and effort of several farmers who provided critical "real world" guidance and advice on tractor operations in the field. The data acquisition assistance of John Powers from NIOSH is greatly appreciated. John Myers and Paul Moore of NIOSH and Paul Ayers of the University of Tennessee are acknowledged for their reviews of draft versions of this paper.

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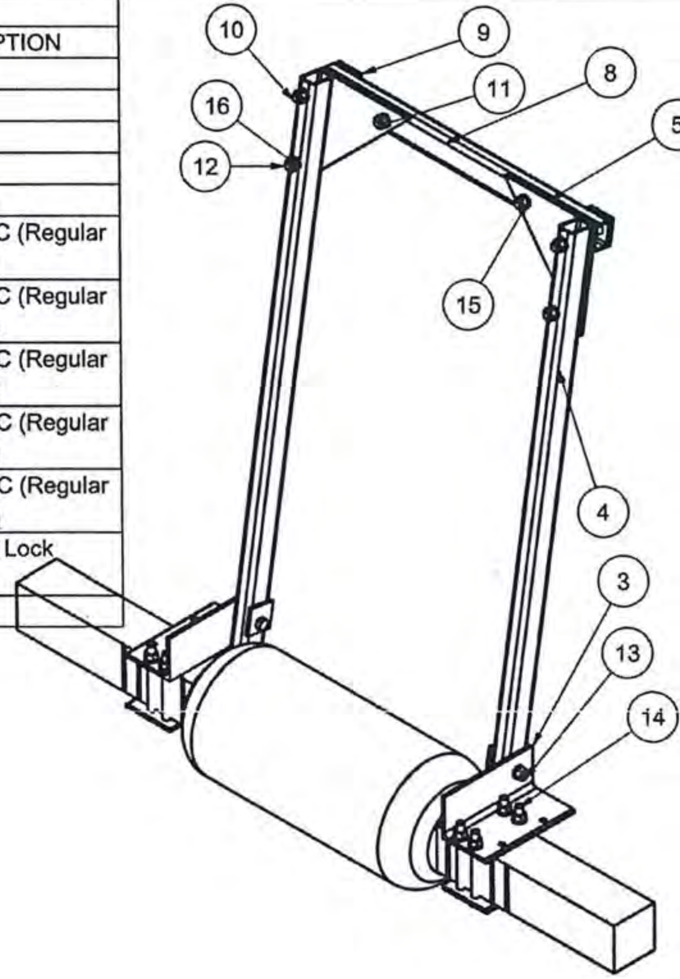
Appendix A

Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
3	1	AISC - L 6 x 6 x 3/8 - 12	Angle Steel
4	2	AISC - 3x2x 1/4 - 66.5	Tube
5	2	CORNERBRACE	
8	1	AISC - 3x2x 1/4 - 37	Tube
9	6	AISC - 2 x 3/8 - 3	Flat Bar Steel
10	2	ANSI/ASME B18.2.1 - 3/4-10 UNC - 7	Hex Bolt - UNC (Regular Thread - Inch)
11	2	ANSI/ASME B18.2.1 - 3/4-10 UNC - 3.5	Hex Bolt - UNC (Regular Thread - Inch)
12	2	ANSI/ASME B18.2.1 - 3/4-10 UNC - 4.5	Hex Bolt - UNC (Regular Thread - Inch)
13	4	ANSI/ASME B18.2.1 - 3/4-10 UNC - 3.75	Hex Bolt - UNC (Regular Thread - Inch)
14	8	ANSI/ASME B18.2.1 - 3/4-10 UNC - 8	Hex Bolt - UNC (Regular Thread - Inch)
15	18	ASME B18.21.1 - 13/16 Regular. Carbon Steel	Helical Spring Lock Washer
16	18	ANSI B18.2.2 - 3/4 - 10	Hex Nut



Notes:

'Item #3 has quantity of 4

'Fender and fasteners not shown

NIOSH CROPS design for Ford-4000
SAE J2194 test completion date: 10/05/04

Appendix B

Figure 5 - Ford-8N CROPS in normal position

Figure 6 - Ford-8N CROPS tilted to enter standard garage opening