Fall arrest characteristics of a scissor lift ☆,☆☆

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ABSTRACT

Problem: Census of Fatal Occupational Injuries (CFOI) data indicate 306 aerial lift fatalities between 1992-2003. Seventy-eight of these fatalities specifically involved scissor lifts. Members of standards committees have requested that NIOSH conduct research to determine the effects of safety-control practices related to using fall-protection systems for scissor lifts. *Method:* This research examined the structural and dynamic stability of a scissor lift subjected to fall arrest forces. This was accomplished by conducting drop tests from a scissor lift. Anchorage locations evaluated included manufacturer-supplied anchorage points on the scissor lift platform as well as mid-rail and top-rail locations. *Results:* Preliminary drop tests determined that a 2400 lb maximum arrest force (MAF) could be generated by dropping 169 lb through a fall height of 36" using Nystron® rope as a lanyard. The scissor lift maintained structural and dynamic stability for all drop tests when fully extended and on an incline. *Discussion:* Anchoring a fall arrest system to either the mid-rail or top-rail is *not* a recommended practice by the scissor lift manufacturer. Anchor points are provided on the platform floor of the scissor lift for this purpose. However, our results demonstrate that the mid-rail and top-rail absorb substantial energy from an arrested fall and may have potential as appropriate anchorage points. *Impact to Industry:* Employers and workers should consider implementing fall arrest systems when using scissor lifts as part of their overall risk mitigation plan for fall injury prevention.

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1. Problem

1.1. Aerial lift/scissor lift injury statistics

Industrial reports on aerial lifts indicate increasing use in various industries, including construction (7,583,000 employment), landscape services (705,900 employment), telecommunications (705,800 employment), warehousing and storage (595,700 employment), electric power transmission and generation (162,300 employment), and other industries (Bureau of Labor Statistics, 2006). However, the use of aerial lifts introduces risk factors for fatal injury. The Census of Fatal Occupational Injuries (CFOI) identified 306 aerial lift fall-related fatalities (228 boom lifts and 78 scissor lifts) from 1992 to 2003 (Pan et al., 2007). Pan also reported an increasing trend for fall-related fatalities, from 19 in 1992 to 38 in 2003.

1.2. Fall arrest/restraint requirements for scissor lift work

Occupational Safety and Health Administration (OSHA) regulations (1926.451 (g) (1) (vii)) mandate the use of guardrails or personal fall arrest systems as primary safety controls for scissor lifts, which are designated as mobile scaffolds under OSHA regulations (OSHA, 1999). Conformance to industry-wide standard practices, the desire to safeguard workers, and the necessity to safeguard against product-liability claims has led many manufacturers and users to require the use of fall-protection systems on scissor lifts. However, there is at present no credible scientific evidence regarding the effectiveness of fall protection systems on scissor lifts (Boehler & Pan, 2006).

1.3. Scope of study

Fall arrest performance of a scissor lift is not well understood. Employers and safety professionals may lack sufficient scientific data from which to base fall arrest system design. Despite efforts by scissor lift manufacturers to protect workers by a fall restraint system of toe boards, midrails, and toprails, we know that foreseeable misuse conditions exist (e.g., standing on midrail to extend worker reach). Could a fall arrest system (FAS)[harness + energy absorbing lanyard (EAL)] protect scissor lift workers? If a FAS is utilized, where is the anchorage point? If the FAS is anchored to a free-standing scissor lift, would the lift tip over under arrest forces and risk additional injury to

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operators and bystanders? In the current research we examined the structural and dynamic stability of a scissor lift subjected to fall arrest forces.

2. Methods

This research examined the structural and dynamic stability of a scissor lift subjected to fall arrest forces. This was accomplished through two test categories: (1) drop tests from a rigid beam and (2) drop tests from a scissor lift.

2.1. Drop tests from a rigid beam

2.1.1. Materials

ANSI Z359.1-2007 limits the maximum arrest force (MAF) for a personal fall arrest system utilizing a full body harness to 1800 lb (8000 N) (ANSI/ASSE, 2007). Dropping rigid weights anchored to a rigid beam structure was necessary to identify combinations of rigid weights and free fall heights that would generate desired fall arrest forces. The following arrest force levels were chosen for this study: 500 lb (2224 N), 1000 lb (4448 N), 1500 lb (6672 N), 1800 lb (8000 N), and 2400 lb (10,675 N). The final test point (2400 lb or 10,675 N) exceeded allowable MAF, but was chosen to assess the safety factor provided by the scissor lift compared to the standard limitation of 1800 lb (8000 N).

Since the objective was to load the scissor lift structure with a known arrest force, an EAL was not necessary for this portion of the study. Due to its durability and strength, 5/8" (16 mm) Nystron rope (Samson Rope Technologies Inc., Ferndale, WA and Gravitec Systems Inc., Bainbridge Island, WA) with an average strength of 16,300 lb (72,502 N) was selected to support the rigid weights during initial drop testing. Nystron was supplied in a 6 ft (1.829 m) length with spliced, thimble ends. The fixture to hold rigid weights consisted of threaded rod, thimbles, and locking hardware (See Fig. 1). Weights were added to the threaded rod to reach desired weight.

The rigid beam anchorage for these drop tests consisted of two I-beam structural shapes connected and fastened at the bottom to a cast, T-slotted test bed. A plate was fastened to the I-beam to allow an offset from the I-beams for performing drops.

2.1.2. Instrumentation

Instrumentation consisted of a load cell to record the maximum arrest force (MAF), a string potentiometer for positioning of the drop test fixture, an electromagnet for securing and releasing the drop test fixture, and a laptop computer running a LabVIEW data acquisition application.

A 3,000 lb (13.4 KN) S-type load cell (Interface Inc., Scottsdale, AZ) was chosen to record the MAF. The load cell was calibrated prior to testing. One end of the load cell was connected to the anchorage location and the opposite end was connected to the lanyard. Common shackles and threaded eye bolts were used to connect the load cell to the anchor and lanyard (see Fig. 2). The load cell was electrically connected to a powered signal conditioner (Model SGA, Interface Inc., Scottsdale, AZ). The output of the signal conditioner was connected to the laptop computer via the data acquisition card.

A 250 inch (6.35 m) capacity string potentiometer (Model PT5D, Celesco Transducer Products, Inc., Chatsworth, CA) was used to measure the height to the bottom of the drop test fixture. Prior to testing, the free fall height was determined, and the string potentiometer was used to take a measurement from the floor to the bottom of the drop test fixture. This height was recorded and each test was initiated by raising the drop test fixture until the string potentiometer indicated the proper height. This ensured a consistent starting position.

An electromagnet (Model SE-35352, Magnetic Products, Inc., Highland, MI) was used to secure the drop test fixture to the hook
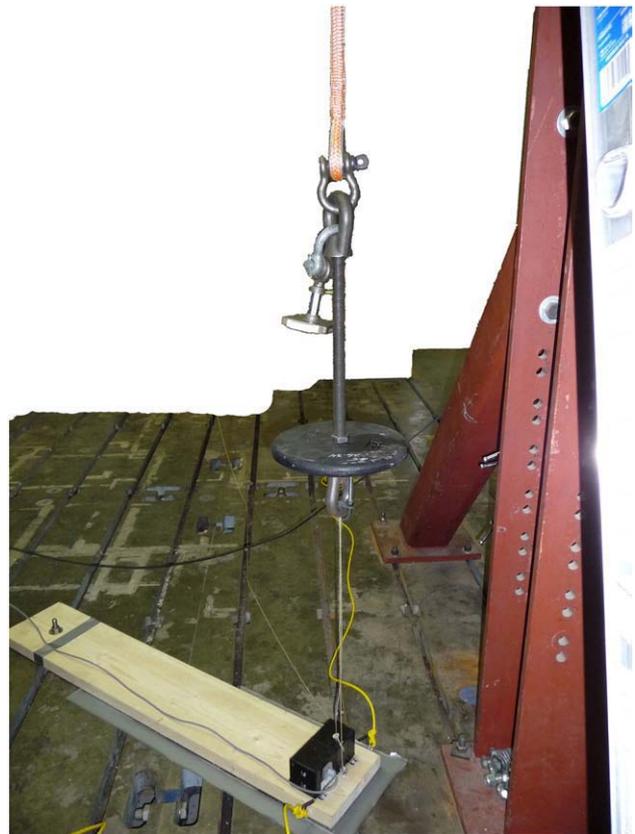

Fig. 1. Weight fixture setup for drop tests.

Fig. 2. Load cell setup.

of a 5-ton (4535 kg) overhead crane. Standard shackles and threaded eye bolts were used to connect the electromagnet to the hook of the crane. The electromagnet was rated for 700 lb (317 kg) maximum capacity. A small steel plate that matched the footprint of the electromagnet was attached to the top of the drop test fixture. To attach the electromagnet to the drop test fixture, the steel plate was held against the bottom of the electromagnet and the electromagnetic was energized. To disengage the drop test fixture, the electromagnet was de-energized, causing the drop test fixture to be released. A magnetic reed switch was also attached between the steel plate and the side of the electromagnet. The output of the switch was electrically connected to the laptop computer and was recorded in the data file as a record of the precise time that the drop test fixture was released from the electromagnet.

A laptop computer (Dell, Round Rock, TX) was equipped with a data acquisition card (Model DAQCard-6036E, National Instruments Corporation, Austin, TX) and was running a LabVIEW (National Instruments Corporation, Austin, TX) data acquisition program. The LabVIEW program was designed to record the output of the string potentiometer, the output of the load cell, the output of the reed switch, and the total test duration. Data were collected at a rate of 1000 Hz. The program also provided selections to identify the tilt axis, the anchorage location, and the drop type that was being conducted. Upon initiation of the program, the user was prompted to ensure the test was set up properly and the string potentiometer was set to zero. The program would then monitor the output of the string potentiometer while the drop test fixture was raised. Once the proper height was achieved, the user was prompted to continue the test by disengaging the electromagnet. The program would record data and monitor the reed switch output. Once the reed switch was disconnected, the program would continue data collection for an additional 10 seconds and would automatically save the file and terminate.

2.1.3. Procedure

An empirically determined fall arrest equation (Eq. (1); Sulowski, 1981) was used to estimate weight and free fall height requirements to generate the desired arrest forces of 500 lb (2224 N), 1000 lb (4448 N), 1500 lb (6672 N), 1800 lb (8000 N), and 2400 lb (10,675 N).

$$F = \left(W + 1.45\sqrt{kfW}\right)\frac{abs}{c} \, for \, 0.1 \leq f \geq 2 \qquad (1)$$

Where,

F	maximum arrest force acting on falling body [lb]
W	weight of the falling body [lb]
k	rope modulus [lb]
$f = h/L$	fall factor
h	free fall distance
L	active length of lifeline or a lanyard
a	fall arrestor reduction factor
b	body gripping device reduction factor
s	shock absorber reduction factor
c	rigid weight/manikin conversion factor

Rope modulus was estimated from previously reported results and preliminary drop test data (Sulowski, 1981).

Based upon estimates from Eq. (1), an initial series of drop tests were performed using the rigid beam anchorage. Four different weights were dropped using two different free fall heights. These tests allowed for a better estimate of Nystron rope modulus and removed any Nystron "construction stretch." Construction stretch refers to the state of new Nystron rope when it is less stiff until initially loaded. To verify that construction stretch was removed from the Nystron, a second series of drop tests were performed while anchored to the rigid beam. Removing the construction stretch modified the Nystron

rope to a stiffer configuration. For a set weight and drop height, a stiffer Nystron rope presented a worst-case scenario.

2.2. Drop tests from scissor lift

2.2.1. Materials

Many of the same materials from drop tests with a rigid beam were used for drop tests from the scissor lift. For these tests, however, Nystron rope was anchored to various points on the scissor lift platform during drops. The scissor lift utilized in these tests was a SJIII3219 (Skyjack Inc., Guelph, Ontario, Canada). This model is 32" (0.813 m) wide and the platform floor can be raised to a maximum lift of 19 ft (5.791 m) above the ground. The listed weight for this model is 2579 lb (1170 kg). Ronaghi et al. (2009) details the scissor lift center of gravity for various platform heights.

2.2.2. Procedure

Known arrest forces were applied to the rope and the scissor lift to evaluate structural and dynamic stability. Stability was evaluated for the two orthogonal and major tilt axes in the horizontal plane of the scissor lift: (1) tilt about the longitudinal axis [LA tilt] and (2) tilt about the short axis [SA tilt] as shown in Fig. 3.

LA tilt stability tests were performed with the scissor lift tilted 1.5° above the horizontal/ground reference plane. SA tilt stability tests were performed with the scissor lift tilted 3.5° above the horizontal/ground reference plane. The scissor lift has a tilt angle interlock that prevents driving or lifting when tilt exceeds these angles. Fig. 4 illustrates the naming convention for the various platform locations where the rope was anchored. Note that the "left" and "right" naming conventions are with respect to an operator facing front in the scissor lift platform.

Similar to other drop tests described in 2.1, fall height was precisely controlled using a string potentiometer.

Stability for SA tilt was evaluated in a similar manner. Fig. 5 illustrates the naming convention for the various platform locations where the rope was anchored.

Three groups of drop tests were performed that involved being anchored to the scissor lift. First, drop tests that generated known
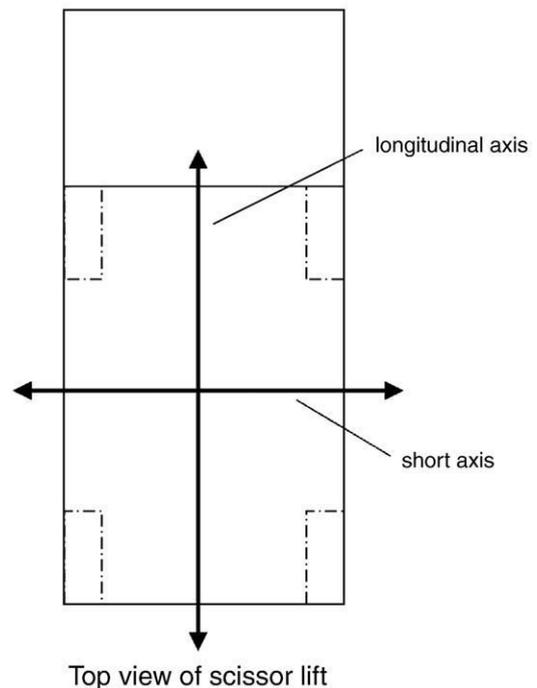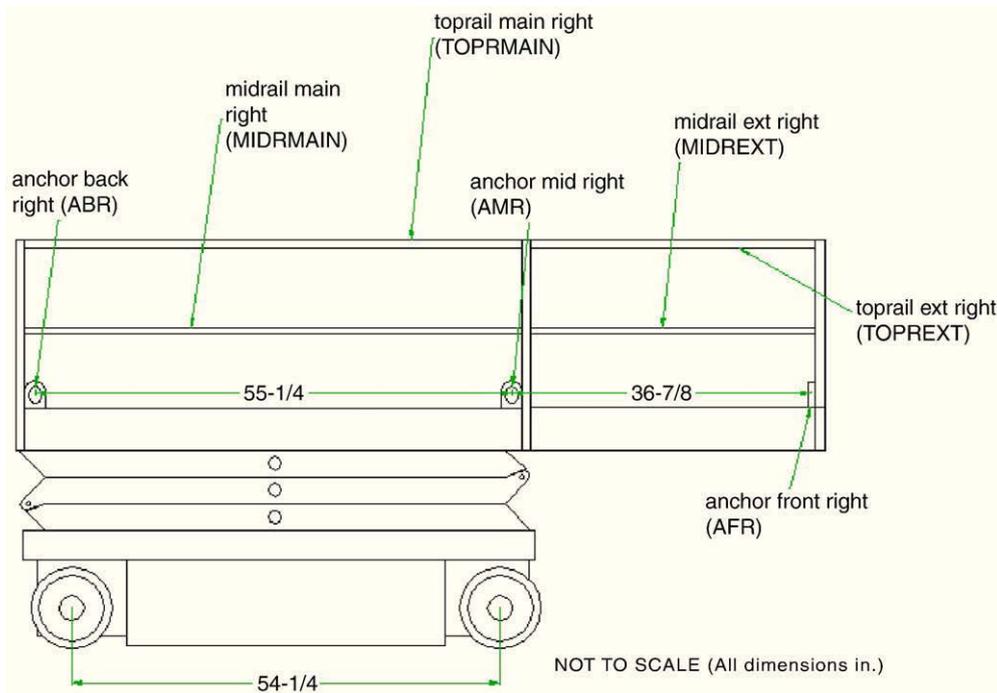

Fig. 3. Scissor lift axes.

Fig. 4. Scissor lift anchorage point labels – side view.

MAF values were performed by varying weight and fall height. Second, drop tests were performed that mirrored requirements in CSA B354.4-02, "Self-Propelled Boom-Supported Elevating Work Platforms" (CSA B354.4-02, 2002). This standard requires that the scissor lift maintain dynamic and structural stability when arresting the force from 300 lb (136 kg) falling 47.2" (1.2 m). The fall arrest system is not to use an EAL and the weight must be 18" (450 mm) horizontally from the platform anchorage location. Testing was conducted with the scissor lift in the least favorable stability orientation, a tilt of 1.5° about

Fig. 5. Scissor lift anchorage point labels – front view.

the long axis of the lift. Nystron rope was used and in the three tests, the rope was anchored to one of the three platform anchors: (1) anchor front right (AFR), (2) anchor mid right (AMR), and (3) anchor back right (ABR). A third series of drop tests using the scissor lift considered foreseeable misuse concerns. These tests evaluated the effect of a 95th percentile person (by height) standing on the midrail, anchored to either the midrail or the toprail and then falling from the scissor lift platform. To determine the free fall height for these tests, the lanyard attachment point to a fall arrest harness was assumed at approximately chest height. For a 95th percentile worker, nipple height is 53.7" (1.364 m) (MIL-STD-1472D, 1989). Total fall height (before EAL tear out) was 139" (3.53 m) when anchored to the midrail and 122" (3.10 m) when anchored to the toprail.

The weight fixture described previously was used for this portion of the study. Previous research has shown that there is a 1.1 conversion ratio to equate rigid weight fall arrest performance and human fall arrest performance (Gravitec Systems Inc, 2006). ANSI Z359.1-2007 establishes the upper limit for lanyard performance at 310 lb (140 kg). Using the 1.1 conversion ratio that compensates for energy absorption through the human body equates to ~282 lb (128 kg) when using weights. A typical 6 ft (1.8 m) EAL (Manyard II, Miller Fall Protection, Franklin, PA) was used during this phase of testing. A typical test setup is shown in Fig. 6.

3. Results

3.1. Drop tests from rigid beam

Table 1 summarizes the initial series of drop tests. For these tests, the weight fixture was connected to a Nystron rope and anchored to a rigid beam structure. For all results, weight indicates the total weight supported by the rope (weights + test fixture).

Fig. 7 shows a typical force versus time graph for 1st series drop tests with rigid beam anchorage.

Table 2 summarizes the 2nd series of drop tests. For these tests, as with the initial series of tests, the weight fixture was connected to a Nystron rope and anchored to a rigid beam structure. Different
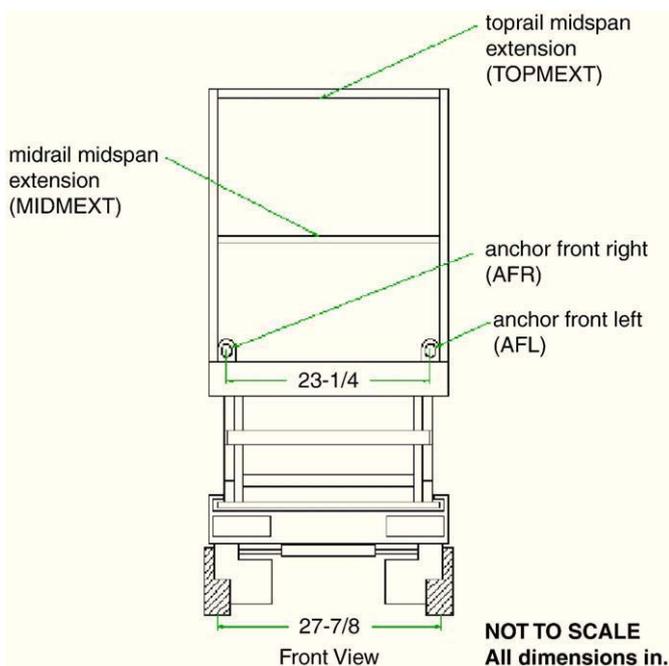
Fig. 6. Example foreseeable misuse setup.

combinations of weights were used in the 1st and 2nd series of tests leading to slightly different weight totals.

3.2. Drop tests from scissor lift

Table 3 summarizes a series of drop tests performed with weights anchored to one of six scissor lift platform anchor points (Figs. 4 and 5 define anchor point location nomenclature). For all tests using the scissor lift, "max anchorage force" was the load cell force recorded at the anchorage point.

The scissor lift remained structurally and dynamically stable (i.e., no catastrophic structural failure or lift tip over) through all tests summarized in Table 3.

Based on these results, the next series of drop tests were all designed to generate the maximum test level of 2400 lb (10,675 N)

MAF to the remaining five scissor lift platform anchorage points: (1) anchor mid left (AML), (2) anchor back right (ABR), (3) anchor back left (ABL), (4) anchor front right (AFR), and (5) anchor front left (AFL). Table 4 summarizes these results.

We then used likely worst-case anchorage points. These anchorage points included the midrail and toprail on the main platform as well as the midrail and toprail of the extension platform. As a worst-case condition, anchorage points were at rail midspan. The evaluated anchorage points included: (1) right midrail of the main platform (MIDRMAIN), (2) left midrail of the main platform (MIDLMAIN), (3) right toprail of the main platform (TOPRMAIN), (4) left toprail of the main platform (TOPLMAIN), (5) right midrail of the extension platform (MIDREXT), (6) left midrail of the extension platform (MIDLEXT), (7) right toprail of the extension platform (TOPREXT), and (8) left toprail of the extension platform (TOPLEXT). Table 5 summarizes the results of these tests. Fig. 8 illustrates deformation from the drop test for anchor point TOPLEXT.

Table 6 summarizes the results of the CSA 354.4 style testing.

Table 7 lists results for the foreseeable misuse scenarios. Four anchorage locations were used: (1) right midrail of the main platform (MIDRMAIN), (2) right toprail of the main platform (TOPRMAIN), (3) right midrail of the extension platform (MIDREXT), and (4) right toprail of the extension platform (TOPREXT).

As mentioned in Section 2.2 we also evaluated scissor lift performance for fall arrest loads that would tip the scissor lift about the short axis. For these tests, the lift was initially tilted 3.5°. Three general types of testing were conducted: (1) 2400 lb (10,675 N) MAF testing, (2) CSA B354.4-02 testing, and (3) 95th percentile person (by height) standing on the midrail.

3.2.1. Tilt about short axis – 2400 lb (10,675 N) MAF testing

This testing utilized three anchorage locations on the extension platform: (1) anchor front right (AFR), (2) midspan of the midrail (MIDMEXT), and (3) midspan of the toprail (TOPMEXT). Table 8 summarizes the results.

Table 1
1st series drop tests, rigid beam anchorage.

Weight [lb] (kg)	Fall height [in] (m)	# of repeats	MAF max.[lb] (N)	MAF avg. [lb] (N)	SD [lb] (N)	Rope modulus* [lb] (N)
44 (20 kg)	18 (0.457 m)	6	642 (2856 N)	611 (2718 N)	30.5 (136 N)	14,000 (62,300 N)
94 (43 kg)	36 (0.914 m)	6	1600 (7117 N)	1531 (6810 N)	42.2 (188 N)	21,000 (93,450 N)
119 (54 kg)	36 (0.914 m)	6	1871 (8322 N)	1847 (8215 N)	22.1 (98.3 N)	24,000 (106,800 N)
169 (77 kg)	36 (0.914 m)	6	2447 (10,884 N)	2394 (10,649 N)	37.1 (165 N)	28,000 (124,600 N)

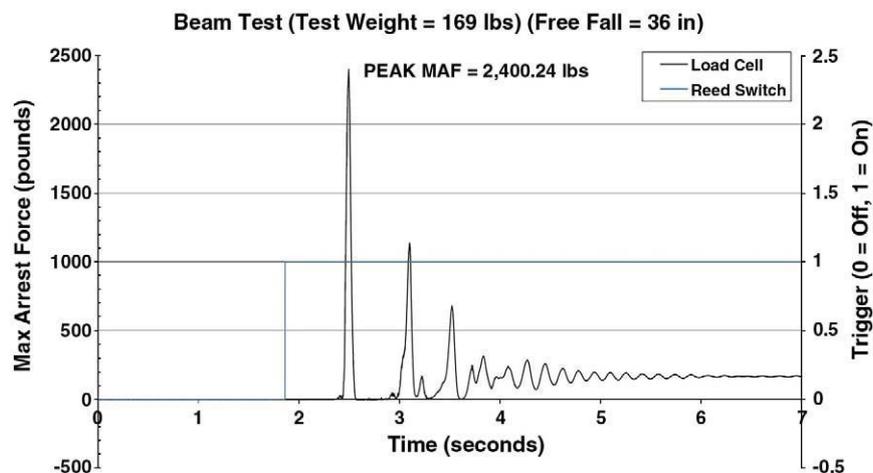*Rope modulus (k) calculated from Eq. (1).

Fig. 7. Example force vs. time graph for drop test.

Table 2
2nd series drop tests, rigid beam anchorage (construction stretch removed).

Weight [lb] (kg)	Fall height [in] (m)	# of repeats	MAF max.[lb] (N)	MAF avg. [lb] (N)	SD [lb] (N)	Rope modulus* [lb] (N)
43 (20 kg)	12 (0.305 m)	6	572 (2544 N)	549 (2442 N)	11.8 (52.5 N)	17,000 (75,650 N)
43 (20 kg)	36 (0.914 m)	6	1141 (5075 N)	1017 (4524 N)	64.9 (289 N)	21,000 (93,450 N)
93 (42 kg)	36 (0.914 m)	6	1667 (7415 N)	1614 (7179 N)	32.5 (145 N)	24,000 (106,800 N)
118 (54 kg)	36 (0.914 m)	6	1982 (8816 N)	1941 (8634 N)	31.4 (140 N)	27,000 (120,150 N)
167** (76 kg)	36 (0.914 m)	6	2430 (10,809 N)	2395 (10,653 N)	40.1 (178 N)	28,000 (124,600 N)

*Rope modulus (k) calculated from Eq. (1).
**A difference in required test setup (shackles, fastening hardware) caused this weight measurement to differ slightly from 169 lb.

Table 3
Drop tests from scissor lift while anchored to platform anchor points. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in] (m)	MAF* [lb] (N)	Rope modulus [lb] (N)	Final deformation	Max anchorage force [lb] (N)
AMR	44 (20 kg)	12 (0.305 m)	500 (2224 N)	17,000 (75,650 N)	negligible	136 (605 N)
AMR	44 (20 kg)	36 (0.914 m)	1000 (4448 N)	21,000 (93,450 N)	negligible	285 (1268 N)
AMR	94 (43 kg)	36 (0.914 m)	1600 (7117 N)	24,000 (106,800 N)	negligible	637 (2833 N)
AMR	118 (54 kg)	36 (0.914 m)	1900 (8451 N)	27,000 (120,150 N)	negligible	732 (3256 N)
AMR	167** (76 kg)	36 (0.914 m)	2400 (10,675 N)	28,000 (124,600 N)	negligible	827 (3678 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1) and rope modulus.
**A difference in required test setup (shackles, fastening hardware) caused this weight measurement to differ slightly from 169 lb.

3.2.2. Tilt about short axis - CSA B354.4-02 testing

This test evaluated scissor lift performance under fall arrest forces generated by 300 lb (136 kg) falling 47.2" (1.2 m). Only the front right anchor (AFR) needed to be tested since it represented the least favorable stability condition for this axis. Table 9 shows the results from this test.

3.2.3. Tilt about short axis – 95th percentile person (by height) standing on the midrail

Table 10 lists results for the foreseeable misuse scenarios. Two anchorage locations were used: (1) midspan of the midrail (MID-MEXT), and (2) midspan of the toprail (TOPMEXT).

4. Discussion

This study has demonstrated that the specific scissor lift examined in this study, and perhaps others, can withstand many different levels of fall arrest forces when fully elevated and on an incline. While OSHA regulations prescribe the use of a guardrail system (i.e., midrail, toprail, and toeboard) or personal fall arrest system for a scissor lift (OSHA, 1998), employers may want to consider adding personal fall arrest systems for increased safety of employees working in scissor lifts. It may have been a concern in the past that a scissor lift worker with a fall arrest system may tip the entire lift in a fall event, and thereby risk injury to operators and

Table 4
Drop tests from scissor lift while anchored to platform anchor points. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
AML	167** (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	861 (3830 N)
ABR	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	984 (4377 N)
ABL	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	932 (4146 N)
AFR	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	704 (3131 N)
AFL	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	839 (3732 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).
**A difference in required test setup (shackles, fastening hardware) caused this weight measurement to differ slightly from 169 lb.

Table 5
Drop tests from scissor lift while anchored to midrail or toprail. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in]	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
MIDRMAIN	167** (76 kg)	36 (0.914 m)	2400 (10,675 N)	1-3/4" (44 mm) vert. in toprail	361 (1606 N)
MIDLMAIN	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	1-1/4" (32 mm) vert. in toprail, 11/16" (17 mm) horiz. in toprail	583 (2593 N)
TOPRMAIN	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	1-3/16" (30 mm) vert. in toprail, 5/16" (8 mm) horiz. in toprail	1414 (6289 N)
TOPLMAIN	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	5/8" (16 mm) vert. in toprail, ½" (13 mm) horiz. in toprail	714 (3176 N)
MIDREXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	5-3/8" (137 mm) vert. in ext. toprail	277 (1232 N)
MIDLEXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	6-3/8" (162 mm) vert. in ext. toprail	465 (2068 N)
TOPREXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	7-1/2" (191 mm) vert. in ext. toprail	1136 (5053 N)
TOPLEXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	5-3/8" (137 mm) vert. in ext. toprail, 2-7/8" (73 mm) horiz. in ext. toprail	520 (2313 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).
**A difference in required test setup (shackles, fastening hardware) caused this weight measurement to differ slightly from 169 lb.

Fig. 8. Sample scissor lift component deformation for anchor point TOPLEXT.

bystanders. Scissor lift tip over did not occur for any of the fall arrest forces generated in our study.

Anchoring a fall arrest system to either the midrail or toprail, as we did in this study to investigate foreseeable misuse, is *not* a recommended practice by the scissor lift manufacturer. Established anchorage points are provided in the platform floor of the scissor lift for this purpose in the scissor lift we used. However, our results demonstrate that the midrail and toprail absorb substantial energy of the fall arrest and may have potential in the future as appropriate anchorage points. Fall arrest system connecting hardware can slide along midrails and toprails, which may present an attractive option to fixed anchor points. Before using midrails or toprails as anchorage points, performance standards concerning toprail and midrail structural response under fall arrest loads would need to be developed to guide designers and manufacturers. Currently, consensus standards require that a scissor lift anchorage "…be capable of withstanding a static force of 3,600 lb. (16,000 N) for each person allowed by the manufacturer without reaching the ultimate strength" (ANSI/SIA, 2006). The authors are aware of misuse conditions where workers remove midrails and toprails or stand on midrails. In this case, a fall arrest system may prevent serious injury.

This study primarily focused on performance of the scissor lift under various fall arrest loading scenarios. Accordingly, we did not evaluate a wide range of EAL systems. It is anticipated that the EAL system used in our study yielded typical results. However, variation from the results presented would be expected for different EAL systems. In addition, fall arrest system fastening hardware was not specifically investigated during this study. A follow-up study will investigate the safety and health impact to workers during fall arrest using various EAL systems.

5. Summary

This study evaluated the structural and dynamic stability of a scissor lift when subjected to fall arrest loading. Fall arrest loads of approximately 2,400 lb (10,675 N) were applied to anchorage point locations in the platform. Additionally, the same loads were applied at the midspan location for the midrail and toprail. In a second series of tests, CSA B354.4 loads of 300 lb (136 kg) falling 47.2" (1.2 m) were applied to platform anchorage locations. The final series of tests evaluated scissor lift performance under foreseeable misuse fall arrest conditions. These tests evaluated the effect of a 95th percentile worker (by height) falling from the platform when standing on the midrail and anchored to either the midrail or toprail. While there was substantial component deformation at the anchorage site for several tests, the scissor lift remained dynamically and structurally stable under all fall arrest scenarios evaluated. A rigid weight fixture was used to represent a worker during all tests. Consequently, these tests

Table 6
Drop tests from scissor lift while anchored to platform anchor points. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
AFR	300 (136 kg)	47.2 (1.2 m)	3700 (16,458 N)	negligible	990 (4404 N)
AMR	300 (136 kg)	47.2 (1.2 m)	3700 (16,458 N)	negligible	1116 (4964 N)
ABR	300 (136 kg)	47.2 (1.2 m)	3700 (16,458 N)	negligible	1283 (5707 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).

Table 7
Drop tests from scissor lift while anchored to midrail or toprail. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height[1] [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
MIDRMAIN	282 (128 kg)	>139 (3.53 m)	N/A EAL used	3-7/8" (98 mm) vert. in toprail	522 (2321 N)
TOPRMAIN	282 (128 kg)	>122 (3.10 m)	N/A EAL used	10-1/2" (267 mm) vert. in toprail	1491 (6632 N)
MIDREXT	282 (128 kg)	>139 (3.53 m)	N/A EAL used	11" (279 mm) vert. in toprail	408 (1815 N)
TOPREXT	282 (128 kg)	>122 (3.10 m)	N/A EAL used	11" (279 mm) vert. in toprail	1678 (7464 N)

1 – fall height does not include EAL tear out length.
* - MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).

Table 8
Tilt about short axis drop tests while anchored to scissor lift. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
AFR	167** (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	519 (2309 N)
MIDMEXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	497 (2211 N)
TOPMEXT	167 (76 kg)	36 (0.914 m)	2400 (10,675 N)	negligible	1358 (6040 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).
**A difference in required test setup (shackles, fastening hardware) caused this weight measurement to differ slightly from 169 lb.

Table 9
Tilt about short axis drop tests while anchored to scissor lift. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
AFR	300 (136 kg)	47.2 (1.2 m)	3700 (16,458 N)	negligible	958 (4261 N)

* Note: MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).

Table 10
Tilt about short axis drop tests while anchored to scissor lift. (NOTE: Scissor lift stability was maintained throughout testing with no catastrophic failures.)

Anchor point	Weight [lb] (kg)	Fall height[1] [in] (m)	MAF* [lb] (N)	Final deformation	Max anchorage force [lb] (N)
MIDMEXT	283 (128 kg)	>139 (3.53 m)	N/A EAL used	negligible	848 (3772 N)
TOPMEXT	283 (128 kg)	>122 (3.10 m)	N/A EAL used	negligible	1997 (8883 N)

1 – fall height does not include EAL tear out length.
* - MAF* is the estimated MAF at the lanyard/weight connection using Eq. (1).

could not predict potential worker injury during a fall arrest event from impact or acceleration. Future work could measure fall arrest loads applied to workers and evaluate worker injury potential during fall arrest.

6. Impact to Industry

This research should open discussion among safety professionals for consideration of new techniques in designing fall arrest systems for workers in scissor lifts. Fall arrest system use in the scissor lift evaluated did not result in lift tip over. With careful design and testing, fall arrest systems may be possible that utilize toprail or midrail anchorage points. Such fall arrest systems may provide the added benefit of allowing increased worker mobility within the scissor lift platform.

Acknowledgements

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