Lifecycle Performance of Escape Systems

A look at laboratory vs field conditioning of aramid fiber based escape systems.

By James Hunter, Cedric Smith, Ole Kils and Tyler Mayer for ITRS 2018

1.1 Introduction

At ITRS 2017, CMC™ presented "Is My Escape Line Still Safe After …?" [1] an investigation of the fatigue life of aramid fibers. This research demonstrated a significant loss of strength with increasing cycles for various aramid fiber cordage and raised questions about the service life of these cords, especially when repeatedly used in fire escape systems. However, the majority of testing was done using a simplified setup to condition the samples, enabling an accumulation of a large number of cycles as well as minimizing the number of variables. The key question remaining after this effort was: How do the test results of the simplified conditioning correlate to the actual use in an escape device?

CMC set out to answer this question by conditioning escape lines using actual descent control devices. After a series of experiments, it was determined that conducting actual rappels on the escape system was the most realistic and accurate method to condition the samples. Using this method, over 360 individual rappels were performed in a controlled environment. In addition, CMC compiled data from actual firefighter bailout training sessions during the validation phase of the new LEVR™ Escape System, comprising an additional 268 bailout rappels. These data sets allow for comparison of the lab conditioned samples to actual in-service training evolutions. The intent of this broad test effort is to build upon available data to better understand and generate further discussion within the industry regarding the fatigue properties of Technora® (an Aramid fiber) in addition to help users make more informed decisions on the serviceability of their equipment.

1.2 Purpose

To better understand the longevity of aramid escape line and web, various tests were conducted to provide empirical data useful in establishing escape system service life recommendations. In order to further investigate the theory that aramid escape lines are significantly affected by fatigue, results of the tests summarized in this document include a comparison between empirical data obtained from lab conditioned units and units that were used in fire service training sessions.

1.3 Scope

1. Evaluation of the service life vs. cycle impacts of two CMC descent control systems
    a. CMC LEVR using CMC escape web
    b. CMC Escape Artist™ using CMC 7.5mm escape line.
2. Evaluation of residual line strength with increasing number of descent evolutions.
3. Evaluation of residual system strength with increasing number of descent evolutions.
4. Comparison of results from systems subjected to lab conditioning to systems subjected to fire service training sessions.

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[1] Kils, Ole (2017) - Is My Escape Line Still Safe After …? An Investigation Into The Fatigue Strength of Aramid Fibers in Escape Applications.

1.4 Sample Size Disclaimer

The laboratory data set presented uses samples that were conditioned using a series of short, actual rappels using a live operator. Due to the manual nature of this type of conditioning as well as safety concerns and time considerations, only 1 sample (N=1) was conditioned for each cycle set series. While a larger number of samples would increase confidence in the results, the data shows clear trends and correlates well with the 2017 test effort where larger sample sets were conditioned in an automated setup.

2 Test Method

2.1 Lab Conditioning Methodology.

Procedure: Initial results from several conditioning methods (vertical pull, ground based lowering, winch pull, etc.), revealed that the most realistic method to condition the lab samples was to have an operator perform actual descents on the escape systems. The most effective method of achieving a large number of cycles was to raise the operator to the top of the CMC drop test tower with an independent rope system. The operator then transferred on to the escape system to be tested, and rappelled 20ft (6m) to the ground, constituting one cycle (Figure 1). The process was repeated 5, 25, 50, and 100 times in rapid succession, with short breaks at 25 rappel increments, resulting in a total of 4 conditioned samples for each escape system type.

Figure 1 - Test Procedure

Escape line samples: In order to eliminate variability, all samples of escape line came from the same production lot. A control sample of each escape line type was reserved for baseline comparison. Each test sample resulted in 20ft of conditioned line, which was cut into two sections. A 15ft section was used to evaluate the residual line strength and the remaining 5ft section was used to determine the residual system strength.

Operator mass: According to NIOSH[2], a 50th percentile male firefighter has a mass of 220lbs (100kg) including their turnout assembly. The operator conducting this test series was ballasted with an additional 70lb (31 kg) to achieve the target mass of 220lb / 100 kg total.

Test Systems: The CMC Escape Artist was used to condition the 7.5mm FR escape line. The CMC LEVR was used to condition the FR escape web.

[2] National Institute for Occupational Safety and Health (NIOSH) – Firefighter Dimensions for Updating Safety Specifications for Fire Apparatus and Firefighter Protective Equipment (2015)

2.2 Field Data Methodology

A series of LEVR escape systems were provided to a group of CMC School Instructors to be used in training sessions. The instructors were given operational parameters and product evaluation logs to record bailout (rappel) evolutions (Figure 2). The primary objective was to subject these systems to actual training use. These training and evaluation sessions were done using a typical population of actual fire fighters. Therefore, each data set consists of users with various physical attributes and skillsets.

The recorded cycles constituted actual bailout evolutions from training structures. The test section of the samples were taken from the conditioned portion of the escape line.

The system strength was determined using the conditioned line and decent device from the training sessions.

CMC LEVR PRODUCT EVALUATION

LEVR Serial Number: 26

Date	03 May 2018
Location	WFD Training Center
CMC Representative	Jim Haakenson
Descent Height [ft]	14'
Anchor Placement [window/remote/mix]	Remote

Descent Tally

X X X X X X X X X X X X X X X X

Comments: Experience of the group varied widely. The users wore a class III harness and turnout gear for all bailouts. The LEVR was attached to the d-ring at the waist.

Date	
Location	
CMC Representative	
Descent Height [ft]	
Anchor Placement [window/remote/mix]	

Descent Tally

X X X X X X

Comments:

Figure 2 - Field Test Data Evaluation Form

2.3 Residual Line Strength Test Equipment (Vertical Rope Test Machine) (Figure 3)

- Omega Engineering low-profile load cell (LCHD-20K)
- DaqView data acquisition software (200Hz)
- Rate of pull approximately 6 inches (15 cm) per minute
- Rope and web wrapped around 4-inch bollard (10 cm)

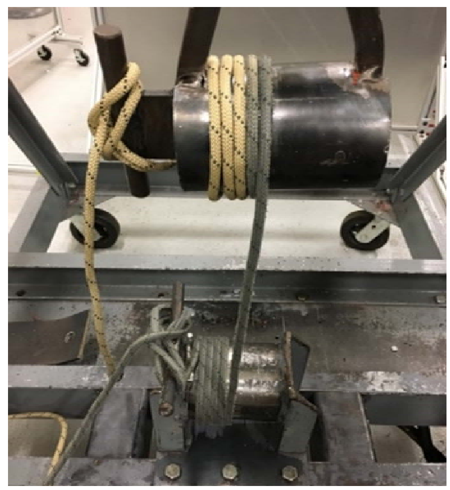

Figure 3 - CMC vertical Test Apparatus

2.4 Residual System Strength Test Equipment (Horizontal Rope Test Machine) (Figure 4)

- Omega Engineering low-profile load cell (LC101-20K)
- DaqView data acquisition software (200Hz)
- Rate of pull approximately 3 inches (7 cm) per minute
- Rope and web wrapped around 4-inch bollard (10 cm)
- Escape descent control device attached to fixed end via carabiner.

Figure 4 - CMC Horizontal Test Apparatus Testing System Strength

3 Observations

Line Condition: The conditioned samples were visually inspected prior to pull testing (Figure 5). The wear imposed by the conditioning appeared to be minor with no obvious telltale signs of structural degradation with the exception of slight fraying on the samples with the highest cycles. In most cases, the lines were darkened, likely due to material transfer from the wear surfaces of the descent control devices. All samples could conceivably pass visual inspection as acceptable for return to service. No signs of major damage such as core herniation, hour-glassing, severed sheath strands, etc. were found. The degree of darkening of the conditioned samples was progressive with the number of descents.

Post Conditioning Visual Inspection	
Escape Cord	Escape Web
 Line Control Sample	 Web Control Sample
 Cord, 5 rappels –some gray discoloration	 5 rappels –slight gray discoloration
 25 rappels –partially discolored gray	 25 rappels –discolored almost completely gray
 50 rappels –discolored (gray), and some slight fraying	 50 rappels –discolored (gray), some slight fraying
 100 rappels –discolored gray with fraying	 100 rappels –discolored gray with fraying

Figure 5 - Escape Line Appearance Post Conditioning

System condition: A single unit of each descender type was utilized for all of the lab conditioning. Both devices remained functional at the completion of the tests. With the exception of minimal wear and surface polishing, no damage or deformation was noted and both devices could be considered serviceable (Figure 6 and Figure 7). Rapid descent succession resulted in heat buildup necessitating the use of gloves in order to handle the devices. In some cases, after several consecutive descents, the operator reported a small amount of escape line creep, which can be a common occurrence with heat buildup.

Figure 6 - Escape Artist device after conditioning

Figure 7 - LEVR device after conditioning cycles

Field device observations: The web that was returned from field systems was consistent in visual appearance to the lab conditioned samples, and the LEVR units exhibited a similar amount of surface polishing in the areas of the web path (Figure 8).

All systems were returned in serviceable condition with varying degrees of cosmetic damage. No functional abnormalities were reported from those administering the evaluation.

Figure 8 - Field Returned LEVR

4 Residual Strength Results

4.1 Lab Conditioned CMC ProSeries® Escape Line and Escape Web- 100% Technora® Fiber

Results from the lab conditioned escape line samples are shown below in Figure 9. Each sample was pulled to failure in the vertical test fixture as shown in Sec 2.3. The strength loss is calculated by comparing the conditioned test specimen to the control sample of each type. A negative percent loss reflects a breaking strength greater than the control specimen, likely due to the combination of test variability and low number of samples, N=1.

The chart in Figure 9 shows increasing strength loss with increasing cycles and good correlation between both types of lines. The data suggest that both lines retain approximately 50% strength after 100 cycles. The magnitude of residual strength after **100 cycles** is still above the NFPA escape line minimum of 3,034 lbf (13.5kN)[3] for new web or cord.

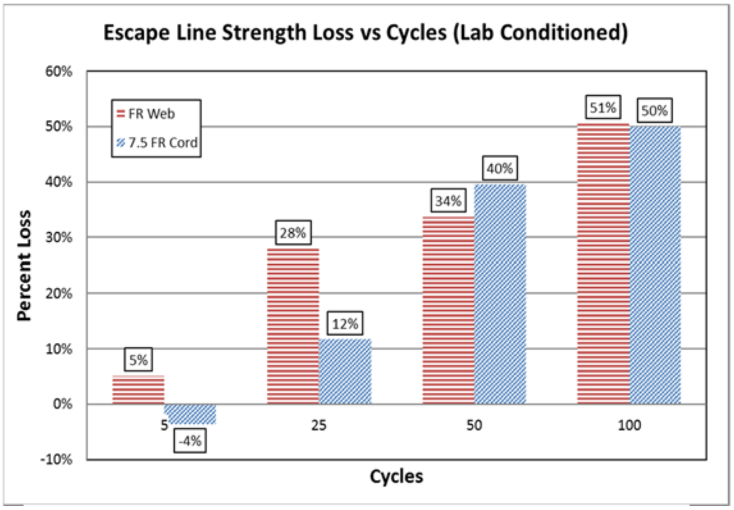

Figure 9 – Escape Line Strength Loss vs Cycles

[3] National Fire Protection Association (NFPA) 1983 – Standard on Life Safety Rope and Equipment for Emergency Services, (Editions 1995 – 2017)

4.2 Lab Conditioned Escape Artist System and LEVR System

Results from the residual strength tests of the lab conditioned systems are shown below in Figure 10. Each sample was tested in the horizontal test fixture per Sec 2.4. Strength loss is calculated by comparing the conditioned test specimen to the control sample. A negative percent loss reflects a breaking strength greater than the control specimen, again likely due to the combination of variability and low number of samples, N=1. All conditioned samples experienced failure in the area where the escape line enters the device.

As before, the chart shows increasing strength loss with increasing cycles and good correlation between both types of lines/systems. The data suggest that both systems retain approximately 70% strength after 100 cycles. The magnitude of residual strength after **50 cycles** is still above the NFPA Escape System minimum of 3,034 lbf (13.5kN).The additional variability in this dataset is likely due to the increased complexity of system strength testing.

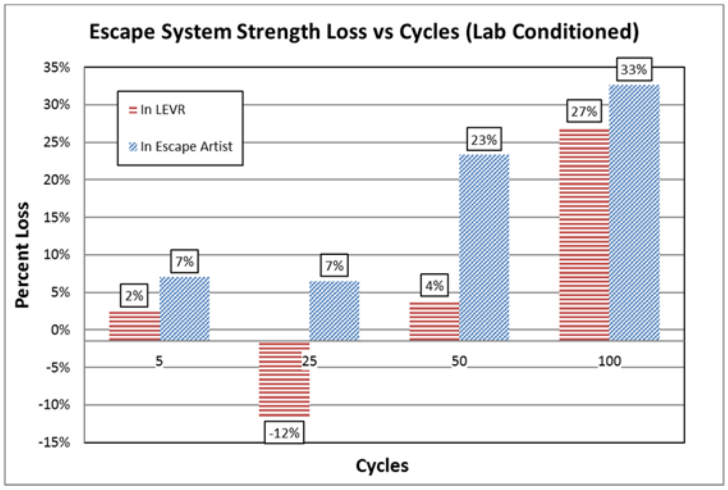

Figure 10 - System Strength Loss vs Cycles

4.3 Field Conditioned Web and System Strength Loss

Results from field conditioned LEVR systems (Figure 11) show a measurable strength loss in the escape web for units that experienced more than 25 cycles. There is no strong correlation of further loss of strength in the web with increasing cycles up to the maximum reported system of 110 cycles.

The two systems with the highest number of cycles were also pulled to failure as complete systems (per section 2.4) and no conclusive evidence of system strength loss was observed.

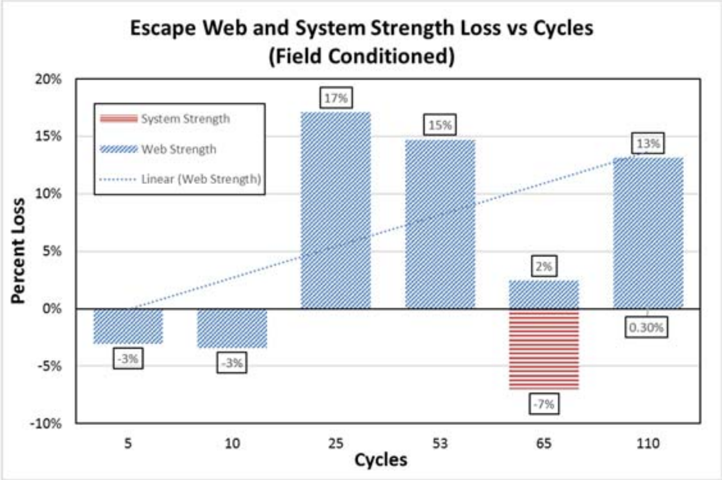

Figure 11 - Field Conditioned Strength Loss of Escape Web and LEVR Systems

4.4 Comparison of field training and lab conditioned lines

The field data shows a lower slope and no clear linear correlation of strength loss to cycle count when compared to the lab conditioned data (Figure 12). Plausible explanations for these differences are the additional variables inherent with field evaluations, such as weight, operator experience, setup and environment.

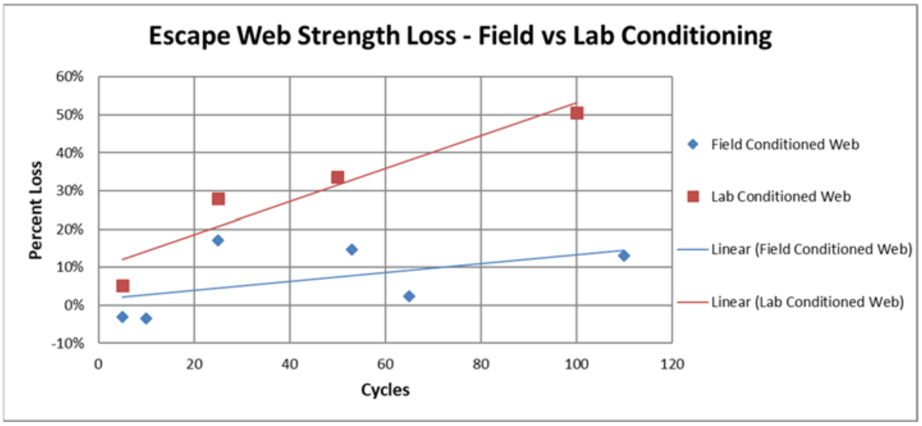

Figure 12 - Comparison of Field and Lab Conditioned Strength Loss in Escape Web

4.5 Comparison to O-Ring Conditioning per ITRS 2017

In 2017, CMC reported on strength loss in escape web and line resulting from cyclic fatigue conditioning through a steel O-ring under tension (300lb). The results showed that in this simplified test, the escape cord suffered greater damage compared to the escape web. The results were believed to be indicative of the more complex conditioning experienced in actual descent control devices and it was hypothesized that a factor could be used to scale O-ring induced fatigue damage to damage incurred in descent control devices.

The chart below in Figure 13 shows cycles vs. strength loss of escape cord and web conditioned in the O-ring test as well as the lab conditioning program. The data from the O-ring testing is plotted on the secondary Y-axis which has been scaled 5x to achieve a general overlay of the curves. The following observations can be taken from this graph:

- Both types of escape line suffered approximately 50% strength degradation at 100 cycles of in-device testing.
- The general trend of increasing fatigue damage with increasing cycles appears to correlate well.
- A 5x factor applied to the O-ring conditioned strength loss values under-predicts damage for the escape web device and over-predicts damage for the escape cord device.

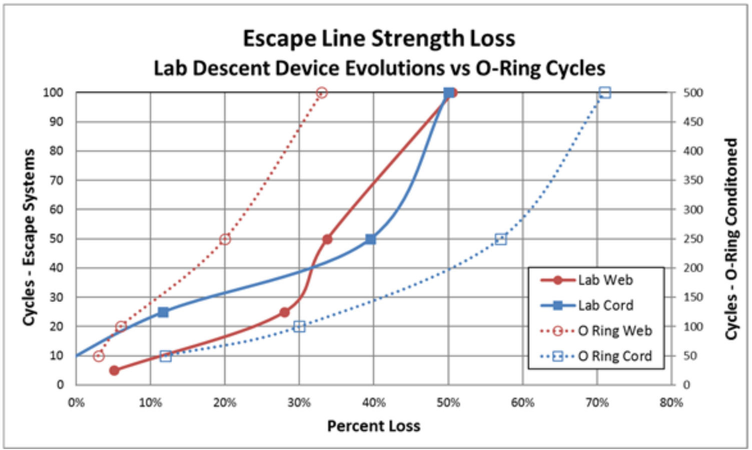

Figure 13 - Comparison to O-Ring Conditioning (ITRS 2017)

Several factors could be important contributors to the trends in the above chart. Since the escape web is able to significantly flatten out around bends, less internal shear can be expected in the O-Ring test (ratio of bend radius to effective escape line diameter). This may explain the improved performance of the escape web in the simplified test. The descent control devices used in this study also rely on a combination of pinch-and wrap-induced friction which are not completely captured by the simplified O-ring test.

5 Conclusions

The key results of this test effort support the trend that lines made of aramid fibers are subject to fatigue and lose strength with use, and therefore have a finite service life. The escape lines tested lost ~50% strength after 100 rappel cycles but still remained above the NFPA 1983 strength requirement. The escape systems that were tested lost ~30% strength after 100 rappel cycles and remained above the NFPA 1983 strength requirement for ~50 cycles. It is important to consider that the NFPA 1983 strength requirement is a breaking strength for new equipment and is not a system replacement threshold.

The test results also indicate that lab conditioned samples accumulated damage faster than field conditioned samples. The reasons for this difference are unclear but may be due to the varying weights or skill sets of users in the field trials, as well as other environmental factors or the configuration of the bailout props used.

Finally, comparison of the simplified O-Ring testing from ITRS 2017 shows similar trends in cyclic damage accumulation, but is not directly scalable to the damage accumulated from rappels using an escape device.

The question that still needs to be answered is the recommended service life of a firefighter emergency escape system, especially when used in a training capacity. While there are too many variables to provide a guarantee of a maximum number of descents for an escape system, the data from these extensive field and lab tests show that systems with 100 descents and/or training bailouts saw no noticeable change in performance and a modest loss (30%) of system strength.

In addition, some escape devices, such as the CMC LEVR, are designed to include shock mitigation features that can reduce the risk of subjecting an escape system to a high force. These devices allow a limited amount of slip during high energy events, thereby reducing the maximum impact force on the system. The chart in Figure 14 illustrates this effect where impact force resulting from an 18” drop on 5’ of escape web is compared between a LEVR system and a non-force limiting connection using only escape web. The peak force during this very dynamic event is limited to approximately 1000lbf, a 50% reduction over the non-force limiting peak. Shock and force limiting can further reduce the risks of system failure associated with a worn escape line.

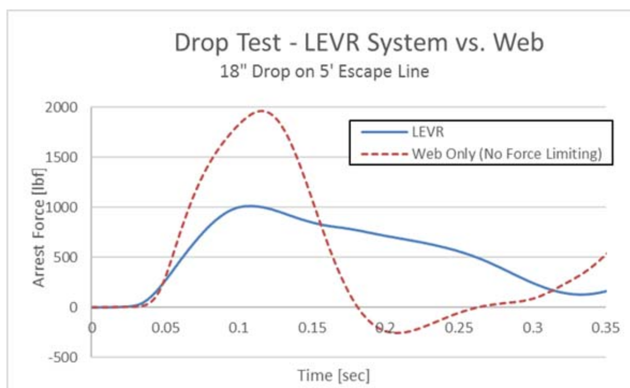

Figure 14 - Anchor Impact Force Comparison

The results obtained in this effort are unique to the escape line and escape device combinations and do not directly correlate to other escape line / device combinations. While this data is meant to give a realistic look at the fatigue life of escape systems, it does not consider all the variables that can impact the service life of aramid fiber products. As always additional data is required…. In other words… more testing!