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KeyMod™ vs. M-LOK™ Modular Rail System Comparison

Abstract #19427

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Background

<u>History</u>

- The MIL-STD-1913 Accessory Mounting Rail was standardized in 1995.
- MIL-STD-1913 Quad-rail Handguards currently in use.
  - MK18 Mod 1 Carbine.
  - Upper Receiver Group (URG).
- Industry developed, low profile handguards with “as needed” accessory mounting panels.
  - Rail panels can be positioned using holes machined into the handguard.

Background

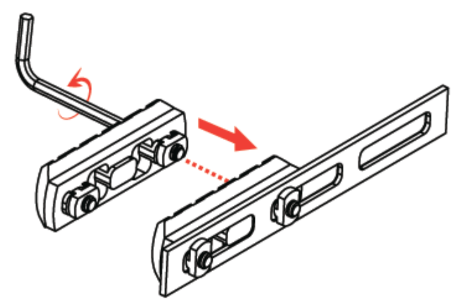
KeyMod™

- Originated by VLTOR Weapon Systems and released in 2012.
- Developed as a standardized accessory mount platform.
- Supports direct mounting of accessories and 1913 accessory rail sections.
- Current civilian market moving towards direct mounting of accessories.
- KeyMod™ accessories interface with KeyMod™ handguards by:
  - Inserting mounting nuts of accessory through the large portion of the KeyMod™ slot.
  - Sliding the accessory fully forward in smaller front portion of key shaped slot.
  - Tightening accessory bolts to secure in place.

Background

<u>M-LOK™</u>

- Originated and released by MAGPUL in early 2015.
- MAGPUL cites improved performance in polymer accessories using M-LOK™.
- Allows for mounting of accessory rails to low-profile handguard designs.
- Functions by passing mounting T-nuts on an accessory through the slots in the handguard.
- Tightening the accessory bolts rotates the T-nuts to rotate 90° and lock, allowing the bolts to be torqued.



Overview

Objectives

- Qualitative and quantitative comparisons of both the KeyMod™ and M-LOK™ accessory mounting systems.
- Recommendation of which system provides superior performance based on a comparative analysis of the two mounting options.

Scope

- Determination on whether KeyMod™ and M-LOK™ is the superior accessory mounting system in regards to repeatability, endurance, rough handling, drop testing, and failure load.
- Testing was not necessarily focused on simulating exact operational requirements; instead, the tests were designed to provide a direct comparison between the two systems in situations that may far exceed standard field conditions.

Sample Arrangement

<u>Handguards</u>

- Three manufacturers selected that fabricate the same handguard in both KeyMod™ and M-LOK™ variants.
- Three KeyMod™ and three M-LOK™ handguards per manufacturer.
- Total of eighteen handguards used for rail system evaluation.

	KeyMod™	M-LOK™
Aero Precision		
Midwest Industries		
Seekins		

Sample Arrangement

<u>Weapon Sample ID</u>

- Each handguard was installed on a 14.5-inch URG in place of the MIL-STD-1913 quad-rail.
- Each URG and respective handguard were labeled with a Weapon ID.

Weapon ID	LRG	URG
A1	M4A1	Aero Precision - KeyMod™
A2	M4A1	Aero Precision - KeyMod™
A3	M4A1	Aero Precision - KeyMod™
A4	M4A1	Aero Precision - M-LOK™
A5	M4A1	Aero Precision - M-LOK™
A6	M4A1	Aero Precision - M-LOK™
B1	M4A1	Midwest Industries - KeyMod™
B2	M4A1	Midwest Industries - KeyMod™
B3	M4A1	Midwest Industries - KeyMod™
B4	M4A1	Midwest Industries - M-LOK™
B5	M4A1	Midwest Industries - M-LOK™
B6	M4A1	Midwest Industries - M-LOK™
C1	M4A1	Seekins - KeyMod™
C2	M4A1	Seekins - KeyMod™
C3	M4A1	Seekins - KeyMod™
C4	M4A1	Seekins - M-LOK™
C5	M4A1	Seekins - M-LOK™
C6	M4A1	Seekins - M-LOK™

Repeatability

Objective

- Quantify repeatability by Point of Aim (POA) shift measurement of accessory rails from repeated installation and removal.

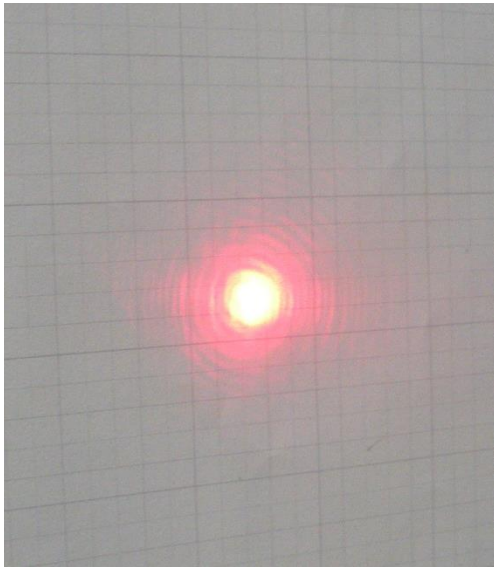
Equipment

- 18 URGs: 3 per handguard configuration
- 3 KeyMod™ 9-slot accessory rails
- 3 M-LOK™ 9-slot accessory rails
- 1 Vice with mounting blocks
- 1 Grid target: 5 graduations per inch
- 1 SL-150M laser boresighter
- 1 Laser sight

Repeatability: Procedure

<u>Procedure</u>

- URG mounted in vice and aimed at grid target.
- 9-slot accessory rail installed on handguard per respective manufacturer instructions.
- Laser sight mounted on a 9-slot accessory rail.
- SL-150M laser boresighter inserted in muzzle end of barrel.
- Laser sight zeroed to boresighter laser POA.
- Accessory rail removed and reinstalled on the handguard.
  - Without removing laser sight from accessory rail.
- Measure distance between projected boresighter laser point and laser sight point.
- Re-installation repeated for total of 5 measurements.
  - Without re-zeroing the laser sight.



Repeatability: Results

<u>Results – POA Shift</u>

- POA shift measurements were converted from Cartesian coordinates to angular measurements.
- Reported as minimum, maximum, and average POA shift of the 5 measurements per handguard in minutes of angle (MOA).

$$\theta = \tan^{-1}\frac{\sqrt{\Delta x^2 + \Delta y^2}}{R}$$

where:

Δx is the horizontal POA shift distance

Δy is the vertical POA shift distance

R is the range from weapon to target

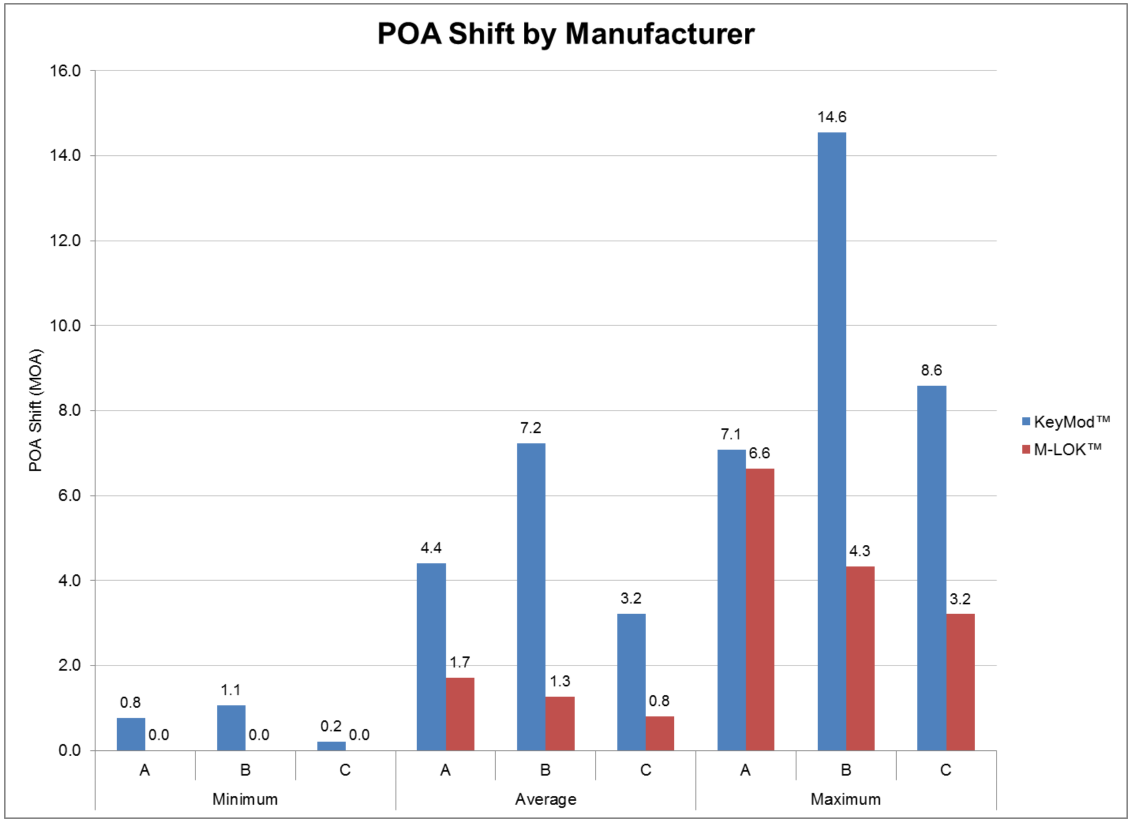
$$\theta_{MOA} = \theta_{deg} \times 60_{(MOA/\mathrm{deg})}$$

Weapon ID	System	POA Shift (MOA)		
		Avg.	Min.	Max.
A1	KeyMod™	4.3	2.3	5.4
A2	KeyMod™	4.3	0.8	7.1
A3	KeyMod™	4.6	2.1	6.4
A4	M-LOK™	2.2	0.0	6.6
A5	M-LOK™	0.7	0.5	0.8
A6	M-LOK™	2.3	0.5	3.6
B1	KeyMod™	4.2	2.2	5.4
B2	KeyMod™	5.7	1.1	9.7
B3	KeyMod™	11.8	7.5	14.6
B4	M-LOK™	0.9	0.6	1.3
B5	M-LOK™	2.1	0.5	4.3
B6	M-LOK™	0.8	0.0	2.1
C1	KeyMod™	2.6	0.2	5.4
C2	KeyMod™	6.1	2.8	8.6
C3	KeyMod™	1.0	0.5	1.8
C4	M-LOK™	0.2	0.0	0.4
C5	M-LOK™	0.1	0.0	0.3
C6	M-LOK™	2.1	1.5	3.2

Repeatability: Analysis

Analysis – POA Shift

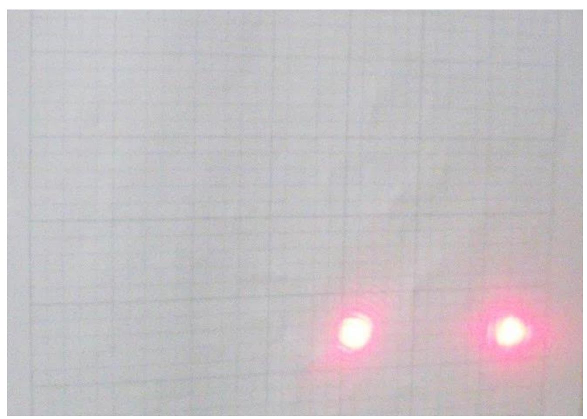
- KeyMod™ POA shift:
  - Absolute minimum: 0.2 MOA
  - Absolute maximum: 14.6 MOA
  - System average: 4.9 MOA
- M-LOK™ POA shift:
  - Absolute minimum: 0.0 MOA
  - Absolute maximum: 6.6 MOA
  - System average: 1.3 MOA



Repeatability: Analysis

Analysis – M-LOK™ Installation Sensitivity

- M-LOK™ repeatability dependent on correct installation.
- Tested worst case repeatability incurred when M-LOK™ accessory is not properly installed per manufacturer instructions.
  - Installed M-LOK™ accessory rail per manufacture instructions and zeroed laser sight.
  - Removed and reinstalled accessory rail at maximum angle allowed within the M-LOK™ slot.
  - Improperly installed average POA shift: 18.4 MOA
  - Properly installed average POA shift: 1.3 MOA



Weapon ID	POA Shift (MOA)	
	Left	Right
A4	21.4	24.4
A5	20.3	19.7
A6	27.8	21.8
B4	19.3	19.3
B5	19.3	15.8
B6	17.1	17.5
C4	14.6	15.0
C5	13.3	12.8
C6	17.1	15.0

Endurance

Objective

- Evaluate mounting systems in an environment simulating M4A1 full-auto fire in an aggressive firing schedule.
  - Cost and time savings.
  - Avoids cook-off hazards incurred above 120 rounds during live full-auto fire.

Equipment

- 1 Cyclic load machine
- 1 M4A1 lower receiver
- 6 URGs: 1 per handguard configuration
- 3 KeyMod™ 5-slot accessory rails
- 3 KeyMod™ 9-slot accessory rails
- 3 M-LOK™ 5-slot accessory rails
- 3 M-LOK™ 9-slot accessory rails
- 1 Weapon light, rail-mounted
- 1 Laser sight, unserviceable
- 1 Flash hider shim set

Endurance: Procedure

Procedure

- Barrel threaded to barrel adapter plate on the cyclic load machine.
  - ½-28 UNEF-2A M4A1 barrel thread.
  - Flash hider shims used to control weapon orientation.
- Weapon light mounted to 5-slot accessory rail at 9 o'clock position.
- Laser sight mounted to 9-slot accessory rail at 3 o'clock position.
- Accessory rail fastener inspected periodically using index marks.

Endurance: Procedure

Procedure (cont'd)

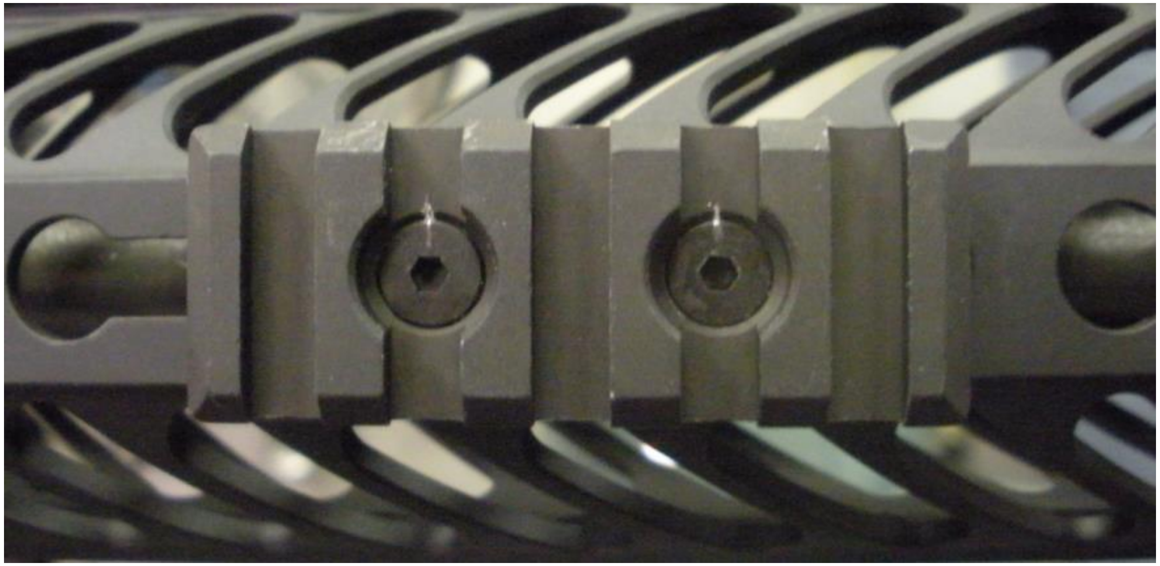
- Aggressive firing schedule at full-auto firing rate.
  - 0.15 in displacement per cycle.
    - Generate recoil inertial forces.
  - 17 Hz cycle rate.
    - Simulate 1020 rounds per minute (RPM).
  - 30 cycle bursts separated by 2 second pauses.
    - Simulate live fire of one 30-round magazine with a pause to change magazines.
  - 17 simulated magazines or 510 simulated rounds per iteration.
  - 20 Iterations for 10,200 simulated rounds per handguard.

Parameter	Setting
Waveform	Sinusoidal
Frequency	17 Hz
Amplitude	0.15 in
No. of Cycles	30 Cycles

Endurance: Results & Analysis

Results & Analysis

- No failures or fastener loosening observed for KeyMod™ or M-LOK™ systems.
- Both KeyMod™ and M-LOK™ demonstrated ability to withstand cyclic forces at the M4A1 maximum cyclic rate.
  - All handguards resisted system failure and fastener loosening.



Rough Handling

Objective

- Evaluate mounting system performance when subjected to forces in excess of typical usage and endurance test loading.

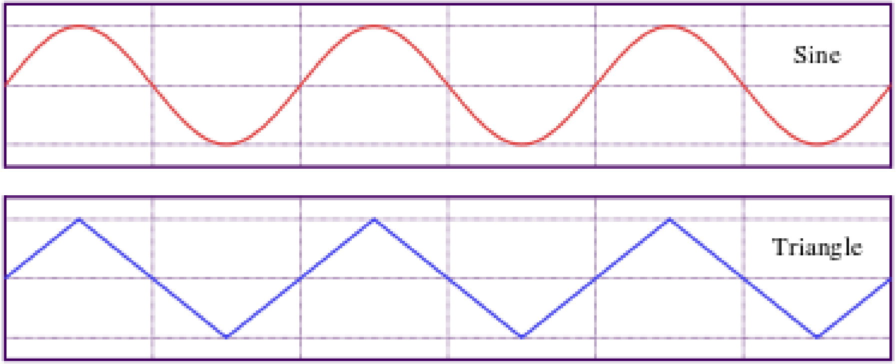
Equipment

- 1 Cyclic Load Machine
- 1 M4A1 lower receiver
- 6 URGs: 1 per handguard configuration
- 3 KeyMod™ 5-slot accessory rails
- 3 M-LOK™ 5-slot accessory rails
- 1 Weapon light, rail-mounted
- 1 Flash hider shim set

Rough Handling: Procedure

Procedure

- Weapon light mounted to 5-slot accessory rail at 9 o'clock position.
- Test parameters setup to generate a triangular waveform.
  - Triangular waveform generates larger peak loads than sinusoidal waveforms at the same frequency and amplitude.
  - Sharp peaks require higher peak acceleration of actuator to reverse direction.
- 4 iterations of increasing peak load.
  - Frequency held constant across all iterations.
  - Displacement iteratively increased to produce higher peak loads.
  - First iteration has similar peak loads to endurance testing.
  - Fourth iteration produces the maximum load produced by cyclic load machine.
    - Limited by the relatively mass of the M4A1.

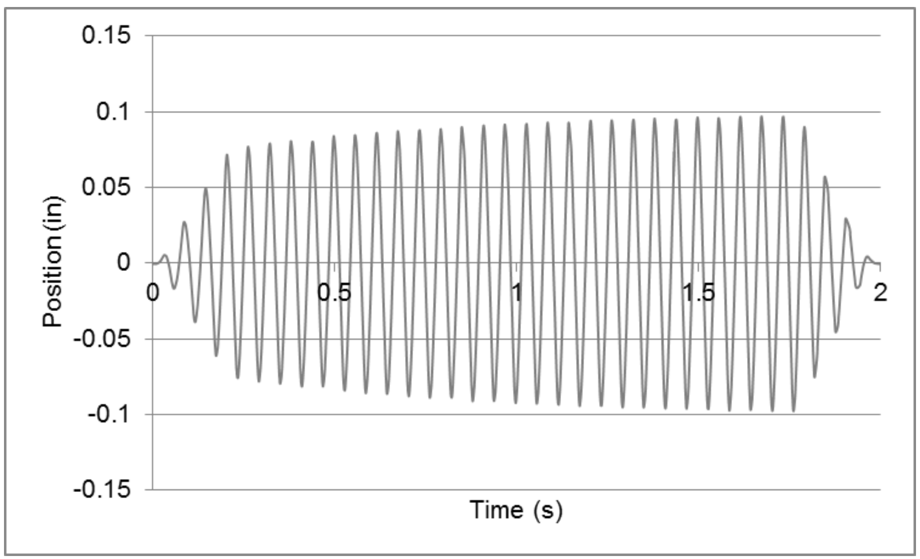


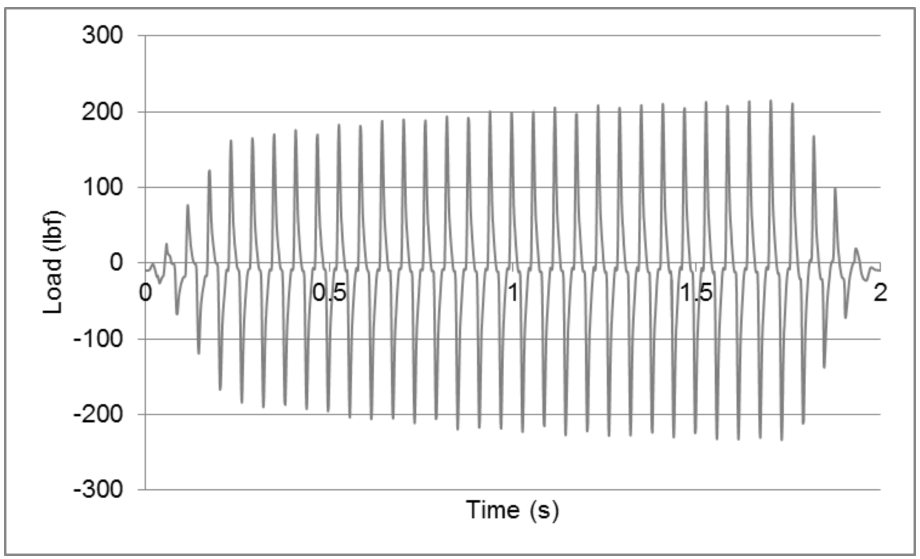
Rough Handling: Results

Results

- The position vs. time and load vs. time curves for each iteration recorded.
  - Similar results observed for each handguard tested.
- Iteration 1:
  - Input displacement: 0.1 in
  - Actual displacement: <0.1 in
  - Peak load: ~200 lbf

Iteration 1: 200 lbf	
Parameter	**Setting**
Waveform	Triangle
Frequency	17 Hz
Amplitude	0.1 in
No. of Cycles	30 Cycles





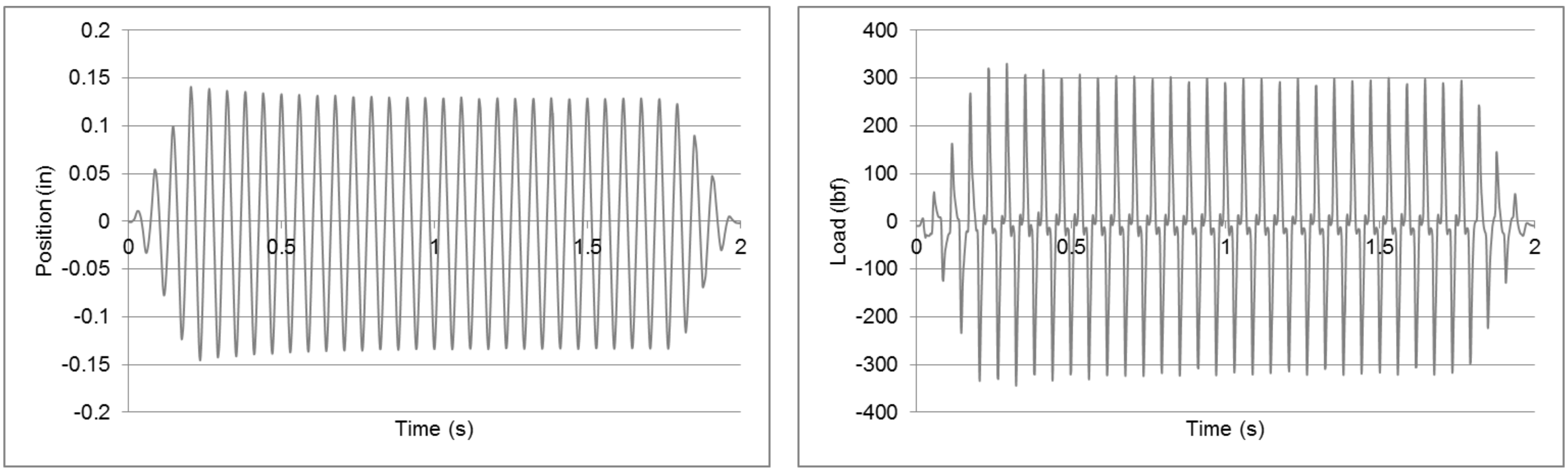
Endurance Test – Handguard A2 – Iteration 1 – Position vs. Time & Load vs Time – First 30 Rounds

Rough Handling: Results

Results (cont’d)

- Iteration 2:
  - Input displacement: 0.2 in
  - Actual displacement: 0.13 – 0.14 in
  - Peak load: ~300 lbf

Iteration 2: 300 lbf	
Parameter	**Setting**
Waveform	Triangle
Frequency	17 Hz
Amplitude	0.2 in
No. of Cycles	30 Cycles



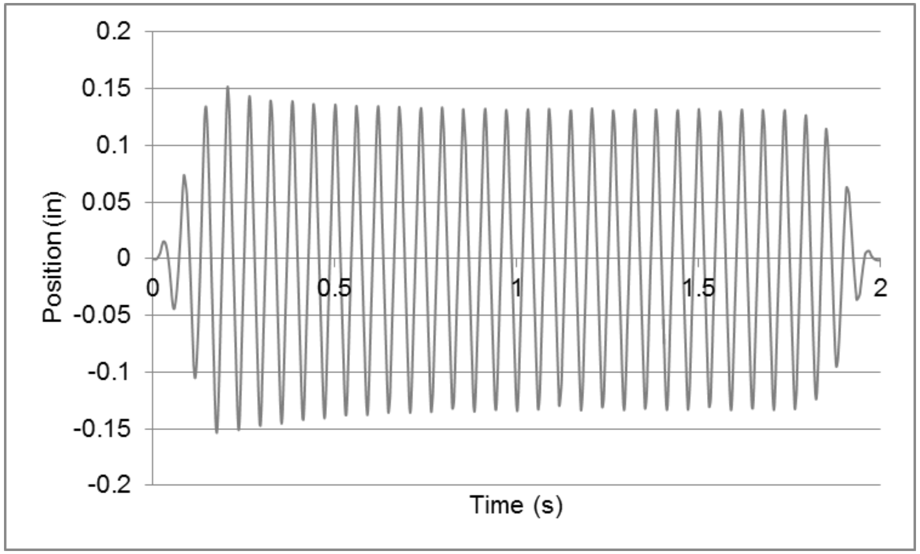
Endurance Test – Handguard A2 – Iteration 2 – Position vs. Time & Load vs Time – First 30 Rounds

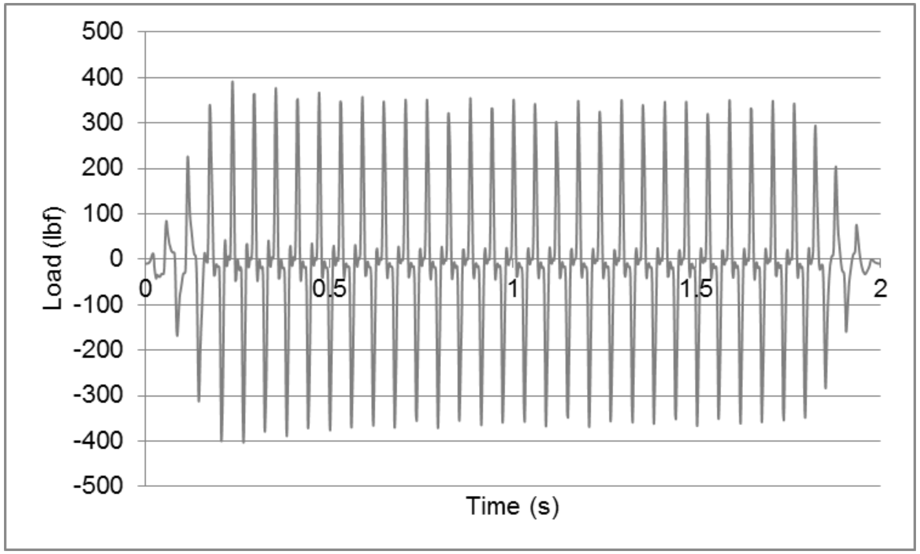
Rough Handling: Results

Results (cont'd)

- Iteration 3:
  - Input displacement: 0.27 in
  - Actual displacement: 0.13 – 0.15 in
  - Peak load: ~350 lbf
  - Peak load less consistent, small deviations.

Iteration 3: 350 lbf	
Parameter	**Setting**
Waveform	Triangle
Frequency	17 Hz
Amplitude	0.27 in
No. of Cycles	30 Cycles





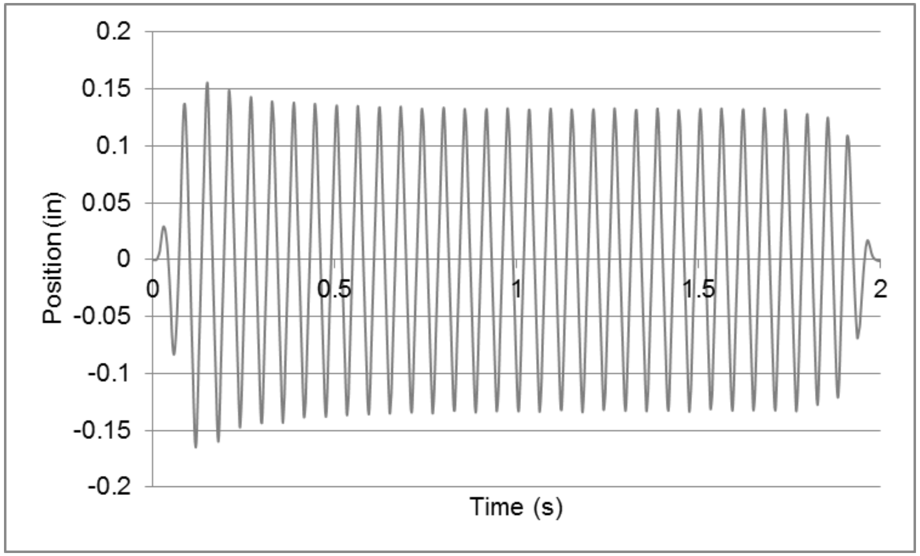
Endurance Test – Handguard A2 – Iteration 3 – Position vs. Time & Load vs Time – First 30 Rounds

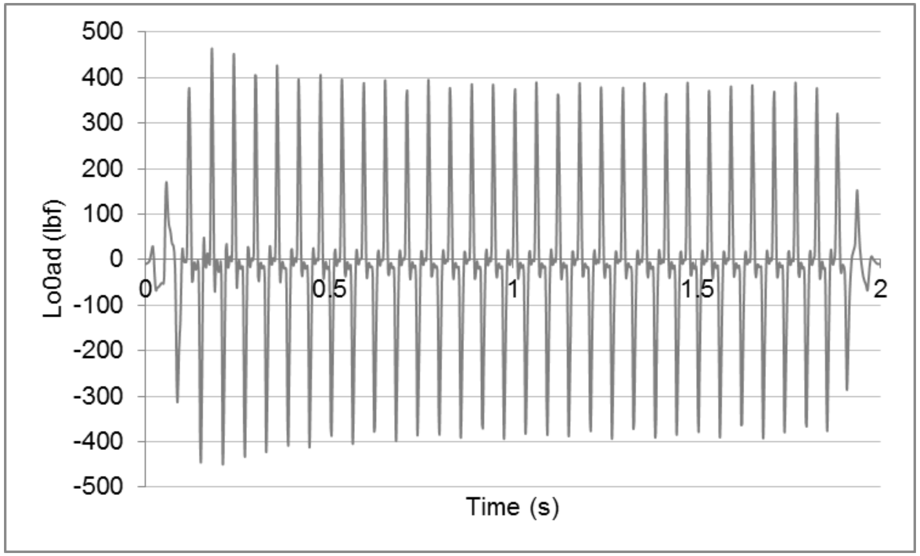
Rough Handling: Results

Results (cont’d)

- Iteration 4:
  - Input displacement: 0.5 in
  - Actual displacement: 0.13 – 0.15 in
  - Peak load: ~400 lbf
  - Peak load varied significantly.

Iteration 4: 400 lbf	
Parameter	**Setting**
Waveform	Triangle
Frequency	17 Hz
Amplitude	0.5 in
No. of Cycles	30 Cycles





Endurance Test – Handguard A2 – Iteration 4 – Position vs. Time & Load vs Time – First 30 Rounds

Rough Handling: Analysis

Analysis

- No failures or fastener loosening observed for KeyMod™ or M-LOK™ systems.
- Both KeyMod™ and M-LOK™ systems found to be adequate for securing accessories when subjected to high frequency, high acceleration vibrational loads.
  - No damage observed to the handguards or accessory rails.
  - No fastener loosening observed.

Drop Test

Objective

- Evaluate mounting system performance from dynamic, impact loads including impacts directly on the accessory.

Equipment

- 1 M4A1 lower receiver
- 6 URGs: 1 per handguard configuration
- 3 KeyMod™ 5-slot accessory rails
- 3 M-LOK™ 5-slot accessory rails
- 6 Weapon light mounts
- 1 Simulated weapon light

Drop Test: Procedure

Procedure

- Simulated weapon light installed on 5-slot accessory rail.
- Accessory rail installed at 9 o’clock on handguard in forward most position.
- 6 drops per handguard of the 6 specified orientations.
- All samples were dropped from a height of 5ft onto steel plate.
- Handguard and accessory examined after each drop.

Drop Number	Orientation
Drop 1	Major axis horizontal - normal firing orientation
Drop 2	Major axis vertical - buttstock down
Drop 3	Major axis vertical - muzzle down
Drop 4	Major axis 45° from vertical - buttstock down
Drop 5	Major axis 45° from vertical - muzzle down
Drop 6	Major axis vertical - muzzle down – weapon light impact

Drop Test: Results

<u>Results – KeyMod™ – Handguard A1</u>

- Drop 1 – no damage.
- Drop 2 **– accessory rail loose, but in position.**
- Drop 3 – no damage.
- Drop 4 **– rear mounting nut to pulled through handguard.**
  – handguard fractured between KeyMod™ slots.
- Drop 5 **– accessory rail detached from handguard.**
- Drop 6 – not conducted.

Drop 4

Drop 5

Drop Test: Results

<u>Results – KeyMod™ – Handguard B1</u>

- Drop 1 – fractures on the 12 o'clock rail.
- Drop 2 – no new damage.
- Drop 3 – handguard slid forwards off the barrel nut approximately 0.5 in.
  – accessory rail loose.
- Drop 4 – handguard rotated on the barrel nut ~30° CW.
  – fracture between the KeyMod™ slots.
- Drop 5 – handguard slid further off barrel nut.
  – barrel was no longer parallel handguard.

Drop 4

Drop Test: Results

Results – KeyMod™ – Handguard B1 (cont'd)

- Drop 6A – failed drop, simulated weapon light missed raised block.
  – handguard completely separated from barrel nut.
  – simulated flashlight missed the raised block.
- Drop 6B – handguard was reattached to the weapon.
  – accessory rail detached from handguard on impact.
  – final position 8ft-4in (2.5 m) from handguard.

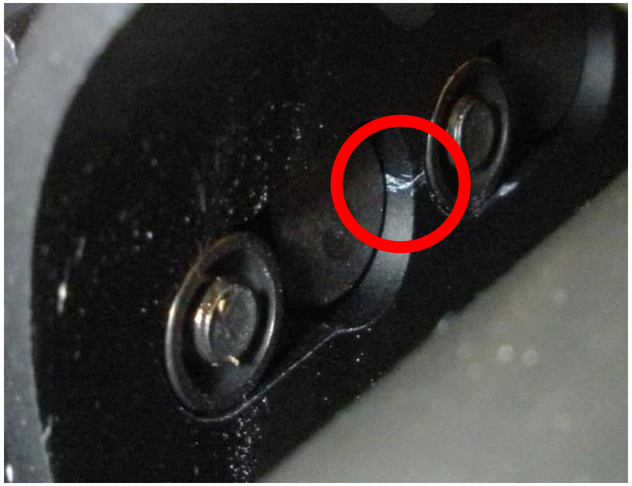
Drop 6A

Drop 6B

Drop Test: Results

Results – KeyMod™ - Handguard C1

- Drop 1 – no damage.
- Drop 2 – scrape at 3 o'clock position on the handguard.
- Drop 3 – slight gap was between the handguard and receiver.
  – weapon light slid forward ~2 mm (~0.08 in) within the flashlight mount.
- Drop 4 – scraping on handguard.
- Drop 5 **– fracture between the KeyMod™ slots.**
- Drop 6 – major handguard damage around accessory rail.
  – accessory rail loosened but remained attached to the deformed handguard.



Drop 5

Drop 6

Drop Test: Results

Results – M-LOK™ - Handguard A4

- Drop 1 – no damage.
- Drop 2 **– slight deformation of accessory rail.**
- Drop 3 – weapon light slid forward in weapon light mount.
- Drop 4 – fracturing of handguard, not near accessory rail.
- Drop 5 – no new damage.
- Drop 6 – **significant rearward displacement of accessory rail in M-LOK™ slot.**

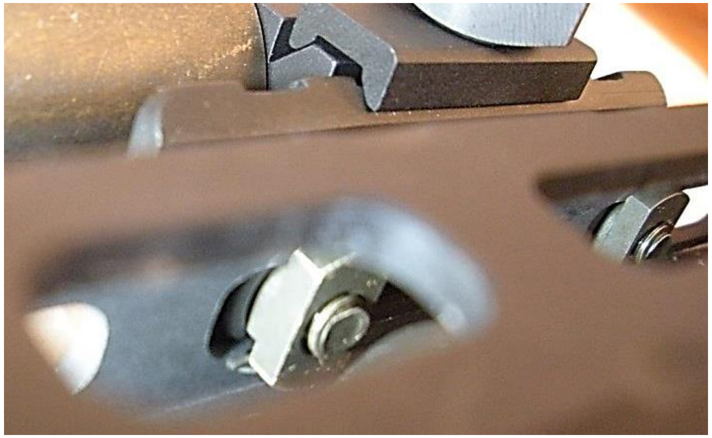
Drop 2

Drop 6

Drop Test: Results

Results – M-LOK™ - Handguard B4

- Drop 1 – significant damage to 12 o'clock rail.
- Drop 2 – no new damage.
- Drop 3 – handguard displacement on barrel nut.
  – slight handguard rotation on barrel nut.
- Drop 4 – increased handguard displacement on barrel nut.
- Drop 5 – handguard rotation ~45° on barrel nut.
  – increased handguard displacement on barrel nut.
- Drop 6 – handguard pushed rearward onto barrel nut, damaging torque plate.
  – accessory rail remained in place with minimal movement.



Drop 6

Drop Test: Results

Results – M-LOK™ - Handguard C4

- Drop 1 – slight rotation of simulated weapon light in mount.
- Drop 2 – no new damage.
- Drop 3 **– slight rearward displacement of accessory rail in M-LOK™ slot**
  – simulated weapon light slight displacement in mount.
- Drop 4 **– slight rearward displacement of accessory rail in M-LOK™ slot.**
- Drop 5 – no new damage.
- Drop 6 **– significant rearward displacement of accessory rail in M-LOK™ slot**.
  – minor deformation of handguard behind the accessory rail.

Drop 3

Drop 4

Drop 6

Drop Test: Analysis

Analysis

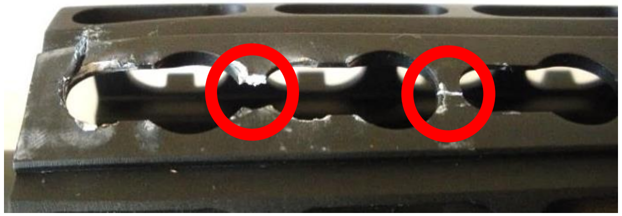
- 1 M-LOK™ system: secured and in initial position.
  - Handguard B4
- 1 KeyMod™ system: loosely secured in initial position with major handguard damage.
  - Handguards C1
- 2 M-LOK™ systems: secured but displaced rearwards in mounting slots.
  - Handguards A4 & C4
- 2 KeyMod™ systems: accessory detached.
  - Handguards A1 & B1

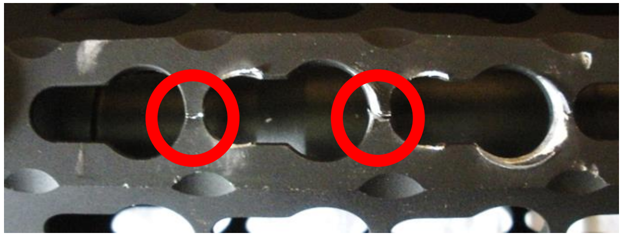
Weapon ID	System	Status	Final Condition
A1	KeyMod™	Detached	Fractured KeyMod™ Slots
B1	KeyMod™	Detached	Fractured KeyMod™ Slots
C1	KeyMod™	Attached	Loosened Bolts
A4	M-LOK™	Attached	Pushed Rearward
B4	M-LOK™	Attached	Intact & Initial Location
C4	M-LOK™	Attached	Pushed Rearward

Drop Test: Analysis

Analysis (cont'd)

- KeyMod™ Damage:
  - Complete separation of accessory rail from handguard.
  - Fracture between the two KeyMod™ slots utilized.
  - Fracture between utilized KeyMod™ slot and an adjacent slot.
  - No major damage to KeyMod™ fasteners.
  - Front of KeyMod™ slots damaged where fasteners were mounted.
  - No removed material captured between accessory rail and mounting nut.





A1

B1

Drop Test: Analysis

Analysis (cont'd)

- M-LOK™ Damage:
  - Accessory rail remained intact and securely attached to the handguard.
  - Accessory rail pushed rearwards from initial index location.
  - Scraping marks on the handguards from the rearward displacement of accessory rail.
- M-LOK™ impact damage initiates with rearward displacement of accessory rail.
- KeyMod™ impact damage initiates with fracturing between slots contributing to detachment of accessories.

A4

B4

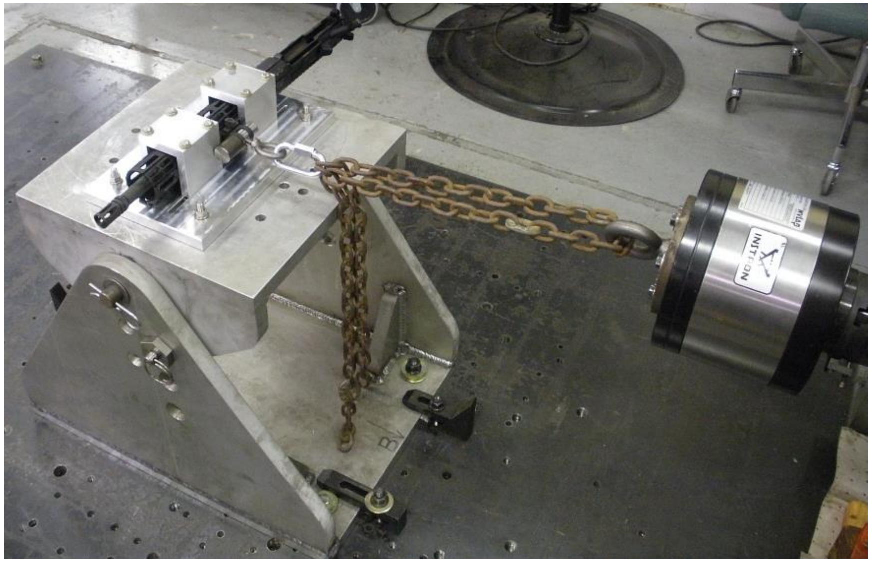
Failure Load

Objective

- Evaluate failure mode and quantify the failure load of mounting systems when subjected to a tensile normal to the primary axis of the handguard.

Equipment

- 1 Cyclic load machine
- 1 Test stand
- 12 URGs: 1 per handguard configuration
- 6 KeyMod™ 5-slot accessory rails
- 6 M-LOK™ 5-slot accessory rails
- 6 Weapon light mounts
- 1 Handguard test fixture
- 1 Simulated weapon light
- 1 3/4-16” eyebolt
- 1 3/4-24” eyebolt
- 1 Steel chain
- 1 Steel quick-link

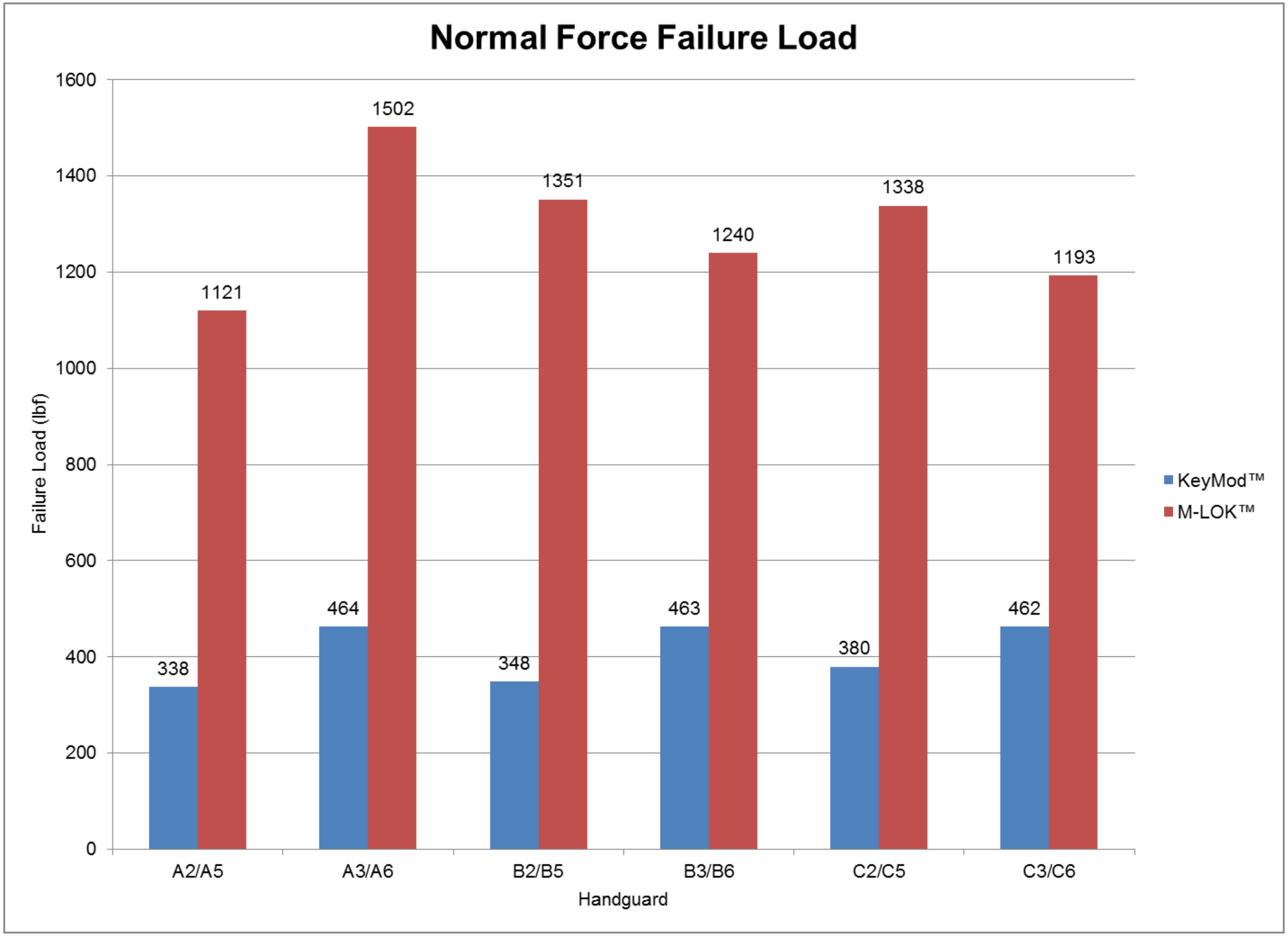


Failure Load: Procedure

Procedure

- Test parameters:
  - Linear displacement ramp
  - Single direction: tensile load
  - Constant rate: 0.1 in/s
- Force applied to the accessory rail through the simulated weapon light.
  - Steel chain, eyebolts, and quick links used to connect the simulated flash light to the actuator.
- Purpose-built handguard fixture secured samples to the test stand.
  - U-blocks with adjustable position along the handguard.
- Each accessory rail was pulled by the simulated weapon light until failure occurred.

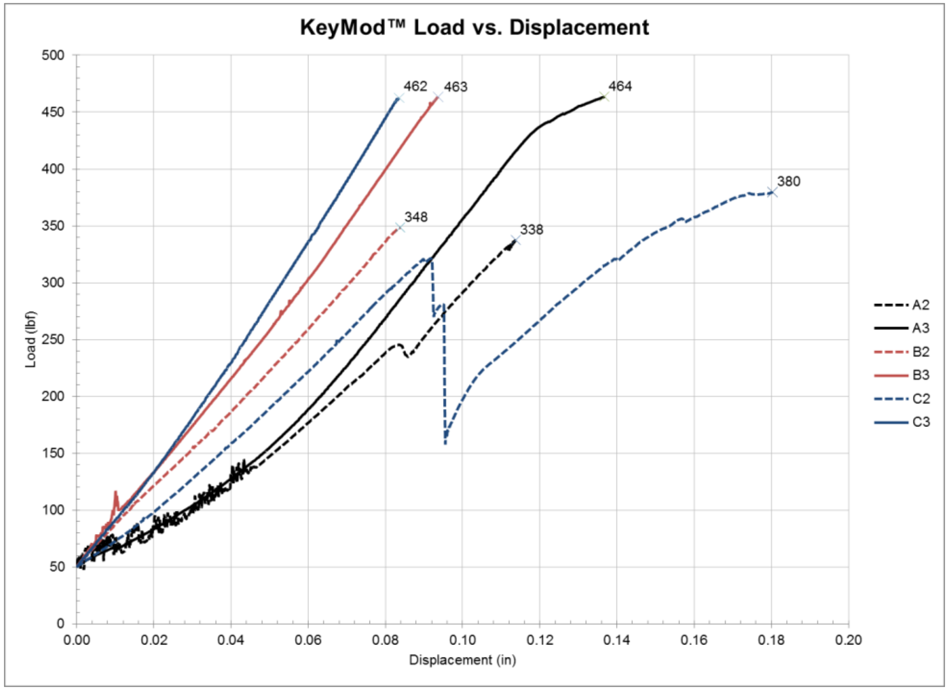
Failure Load: Results

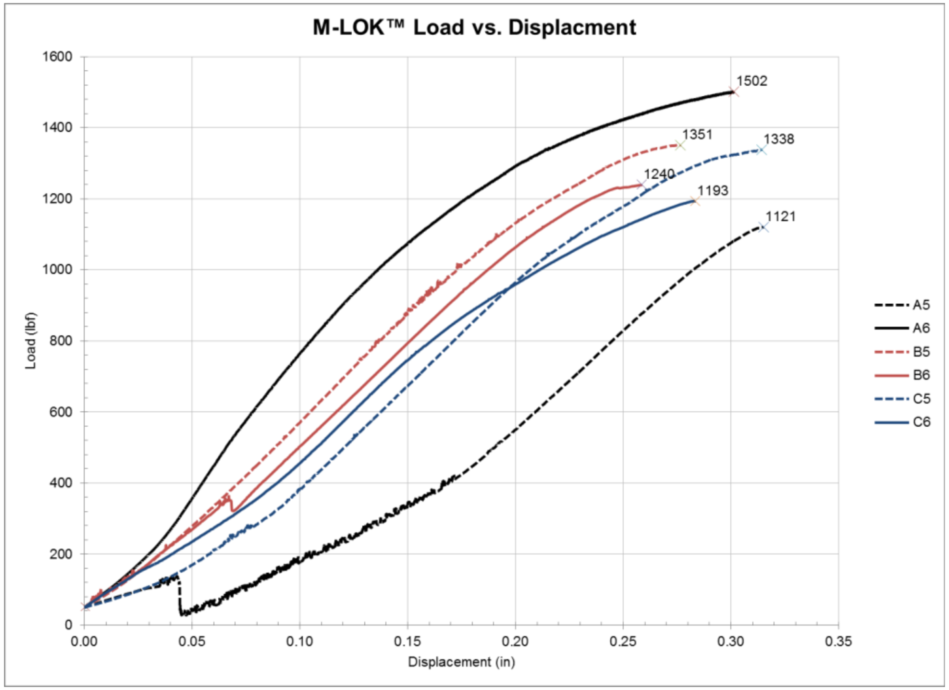


Failure Load: Analysis

Analysis

- KeyMod™ system loading shows mostly linear, elastic properties.
- M-LOK™ system loading shows non-linear properties, especially at high loads.
- Some momentary load drops from fixture slipping.

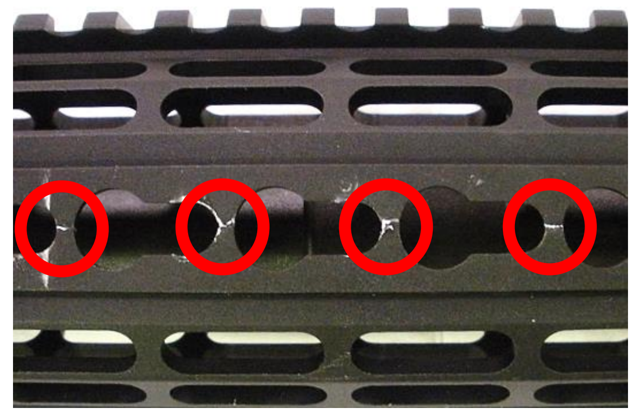




Failure Load: Analysis

<u>Analysis (cont'd)</u>

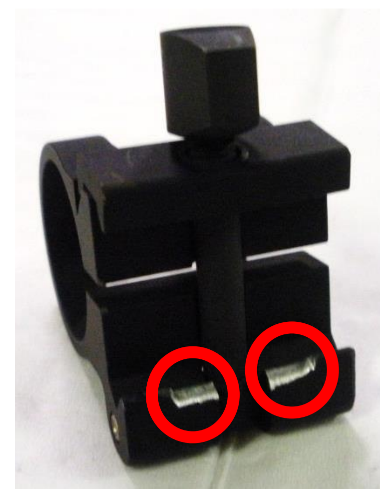
- KeyMod™ systems showed nearly identical failure mode to that observed in drop testing.
  - Complete separation of accessory rail from handguard.
  - Fracture between the two KeyMod™ slots utilized.
  - Fracture between utilized KeyMod™ slot and an adjacent slot.
  - No major damage to KeyMod™ fasteners.
  - Front of KeyMod™ slots damaged where fasteners were mounted.
  - No removed material captured between accessory rail and mounting nut.



Failure Load: Analysis

Analysis (cont'd)

- All M-LOK™ tests featured failure modes at the weapon light mount.
  - 1/6 samples: mount fractured near clamping end.
  - 5/6 samples: mount pulled off of the deformed accessory rail.
- Increase of 215% in average sustained load of M-LOK™ over KeyMod™.
- M-LOK™ system tests showed 140-220% increase in sustained load over the maximum KeyMod™ load observed.



Conclusions

- Repeatability
  - M-LOK™ achieved a 73% improvement in average POA shift over KeyMod™.
- Endurance
  - KeyMod™ and M-LOK™ system performance exceeded cyclic load test conditions.
- Rough Handling
  - KeyMod™ and M-LOK™ system performance exceeded cyclic load test conditions.
- Drop test
  - 100% of M-LOK™ accessories remained attached.
    - 1/3 M-LOK™ accessories remained in-place.
    - 2/3 M-LOK™ accessories slid rearwards but remained secure.
  - 33% of KeyMod™ accessories remained attached.
    - 1/3 KeyMod™ accessories remained attached, but severely damaged handguard.
    - 2/3 KeyMod™ accessories completely detached.
- Failure Load
  - Average M-LOK™ test failure load over 3 times greater than average KeyMod™ system failure load.
  - All KeyMod™ failures occurred at the interface between the handguard and accessory rail.
  - All M-LOK™ system tests failed at weapon light mount or mount to accessory rail interface.

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