CRASTE 2018: Emerging Entry, Descent, and Recovery Systems and Technologies

Development of a Textile-Based Load Limiting Device for Mid-Air Retrieval of a 10,000-lb Payload

NASA Armstrong Flight Research Center, Edwards, CA

John W. Kelly, PMP®

Josue Cruz

Airborne Systems, Santa Ana, CA

Brian Johnson

Kurt Hempe

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Madison, Wisconsin

NASA Technology Need

- NASA 2015 Technology Roadmap
  - TA 9: Entry, Descent, and Landing Systems
    - TA 9.3: Landing
      - TA 9.3.1: Propulsion and Touchdown Systems

      Benefits of Technology

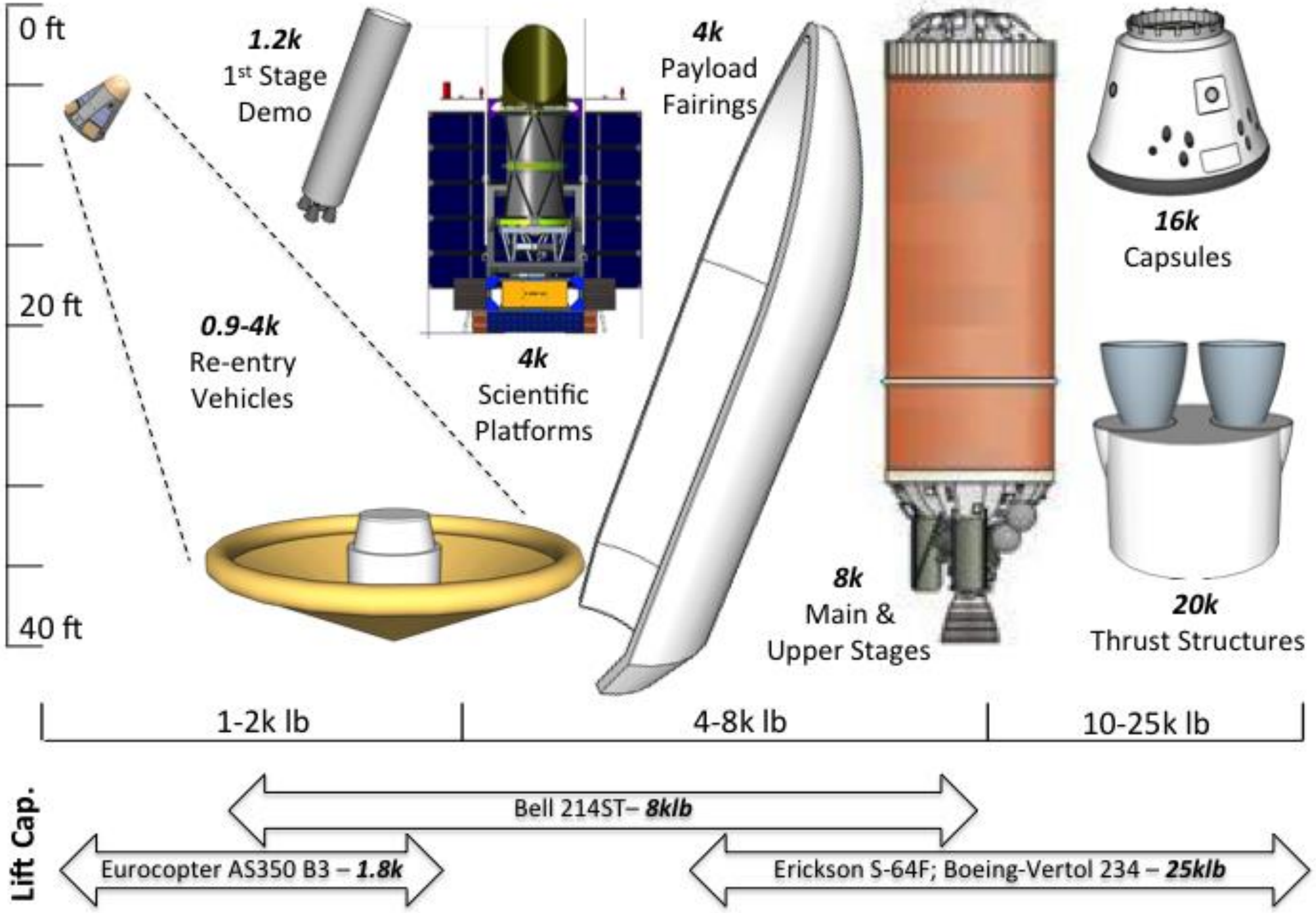
      Improved touchdown systems will increase access for NASA science missions and improve reliability for NASA human missions to the Moon, Mars, or other bodies. Alternative options such as mid-air retrieval at Earth could lower the cost and expand the reusability of the architectural elements to achieve these missions.

        - 9.3.1.3: Mid-Air Retrieval (MAR)

        Capability Description: This capability recovers objects in Earth's atmosphere, before they impact the ground. Uses include: sensitive payloads that cannot survive a shock impact; payloads that must be kept secure; items that need to be returned to a specific location more quickly than they can be located, accessed, and transported after landing; and high-value hardware that can be reused with minimal refurbishment, to save costs.

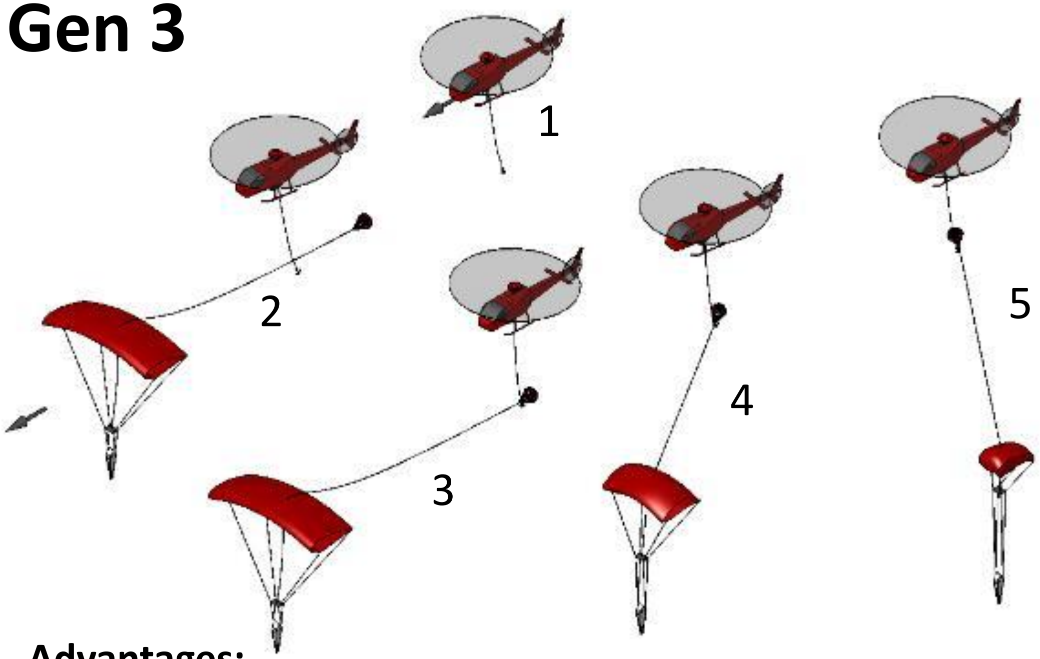
http://www.nasa.gov/offices/oct/home/roadmaps/index.html

Notional 3G MAR Opportunities



3rd Generation Mid-Air Retrieval System

Gen 3



Advantages:

- Low-speed, low-g pick-up (0.2g demonstrated)
- No aircraft modifications or “experimental” classification required; Conforms to Part 133
- Limited training required

Demonstration History:

- 2007 - ARCTUS Spacecraft demo*, 750-lb
- 2015, 2016 - scaled first-stage recovery demo, 1100-lb

* https://www.youtube.com/watch?v=3cnr3pX4tyw

Prior Study

- In FY2016, AFRC initiated a small study under NASA Space Technology Mission Directorate's Center Innovation Fund (nom. $100k, 0.5 FTE)

Study Scope:

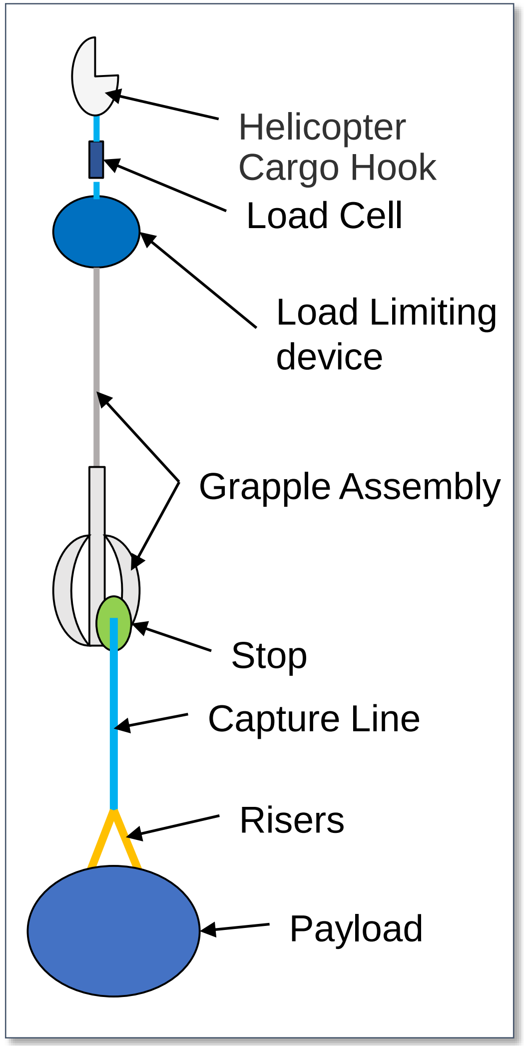
1. Aero-mechanical systems study
   - Develop a conceptual design for a system that can perform 3G MAR across the broadest range of weights up to the max. lift capacity of the largest heavy-lift helicopter
   - Perform design trade-studies, as necessary, for the load train . . .
     - Helicopter, belly hook, overload protection, aero-grapple, pick-up line, parafoil & slider system

2. Reference mission CONOPS study
   - Perform an in-depth study of 3 reference missions
   - Develop preliminary cost estimate to execute each ref. mission
   - Consideration: Commercial service delivery is highly desirable

3. GN&C and autonomy study
   - Perform a trade study on systems and techniques that enable *efficient* and *reliable* helicopter-payload rendezvous and capture

3G MAR Load-Limiting Device

- The Load Limiting Device (LLD) is a safety apparatus that prevents excessive loads on a helicopter used during Mid-Air Retrieval (MAR) operations … the "fuse" in the mechanical system
- The LLD is suspended from and progressively applies load to the helicopter's external hook during the MAR maneuver.
- The load onset rate, loading curve, and maximum load value are determined by the mass of the payload, the atmospheric conditions, pilot technique, and Parafoil retention or release during MAR.
- The LLD insures the approved rating of the external cargo hook and the helicopter can never be exceeded.
- The LLD has a variable stroke length which pays out during load transfer and if the maximum length is exceeded safely separates the payload from the helicopter.
- The LLD is an external load to the helicopter and contributes to the overall aerodynamic drag during MAR operations.



Follow-On: Load-Limiting Device Trade Study

- Performed by Airborne Systems under CIF Award FY16
- Load Limiting Device requirements
  - Cannot exceed maximum allowable loads on representative helicopters.
  - Expected acceleration ranges based on MAR experience.
  - Required safety provisions.
- Trade options
  - Identify alternative designs using adaptations of existing designs and technologies.
- Define trade criteria
  - Reliability, weight, cost, performance, complexity.
  - Select preferred design(s) for future development.
- Develop conceptual design for 10k mission
  - Size & weight, performance, safety features.

Follow-On: LLD Trade Study — Design Objectives

- Overload Protection
  - The LLD will prevent overload of the helicopter cargo hook in the event of excessive MAR capture loads.
  - In the event of continuous max capture load the LLD grapple line will payout until all stroke (~40 ft.) is used and the line will separate from the LLD prior to overload of the helicopter cargo hook.
- Reliable/Repeatable
  - Constant force payout with minimal deviation from selected setting.
  - Constant force payout throughout the length of the stroke (lighter starting force at load onset).
  - Capable of repeatable performance (multiple times preferred with little or no maintenance).
- Installation (simple attachment to helicopter cargo hook)
  - Meets FAA requirements for External Loads -CFR 29.865
- Strength (20,000 lb. peak load for 10,000 lb. payload)
  - Designed for maximum MAR payload with 2.0 Factor of Safety.

LLD Trade Study Results Summary

DESIGN ATTRIBUTE	LLD SYSTEM TYPE								
	Friction Braking System with Hydraulic Controller	Multi Disc Friction Clutch with Hydraulic Release	Multi Disc Friction Clutch with Hydraulic Release and Winch	Electric Friction Braking System with Controller	Winch with Electrically Controlled Motor/Generator Braking System	Mechanical Friction Braking System	Textile Load Limiter	Eddy Current Braking System	Capstan Braking System
Reliability	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Reusability	2.00	2.25	2.50	2.25	1.75	2.00	3.75	1.25	3.00
Repeatability	1.50	1.50	1.75	1.50	1.25	2.00	2.00	1.25	2.25
Weight	3.25	3.75	4.00	3.50	3.50	3.50	1.00	2.75	2.25
Size	2.50	3.25	4.00	3.00	2.75	2.25	1.50	2.75	1.50
Power Requirements	3.25	3.75	4.00	3.50	3.25	1.25	1.00	2.25	2.00
Complexity	3.00	3.50	4.00	3.00	3.50	2.00	1.25	2.50	1.50
Installation	3.50	3.75	4.00	3.00	3.25	2.25	1.00	2.75	1.75
Development Costs	2.50	3.00	4.00	3.00	4.00	3.25	1.25	3.00	3.75
Per Mission Costs	2.25	2.50	2.75	2.25	2.00	2.00	4.00	1.75	2.00
Total Points	24.75	28.25	32.00	26.00	26.25	21.50	17.75	21.25	21.00
Final Ranking	#5	#8	#9	#6	#7	#4	#1	#3	#2

Heavy-Lift Mid-Air Retrieval Feasibility Study: Load Limiting Device Design Trade Study Supplemental Report
Prepared for NASA Armstrong Flight Research Center by Airborne Systems under Contract: NND16AA45P Mod 003

Follow-On: Dev. of Modular Textile-Based LLD

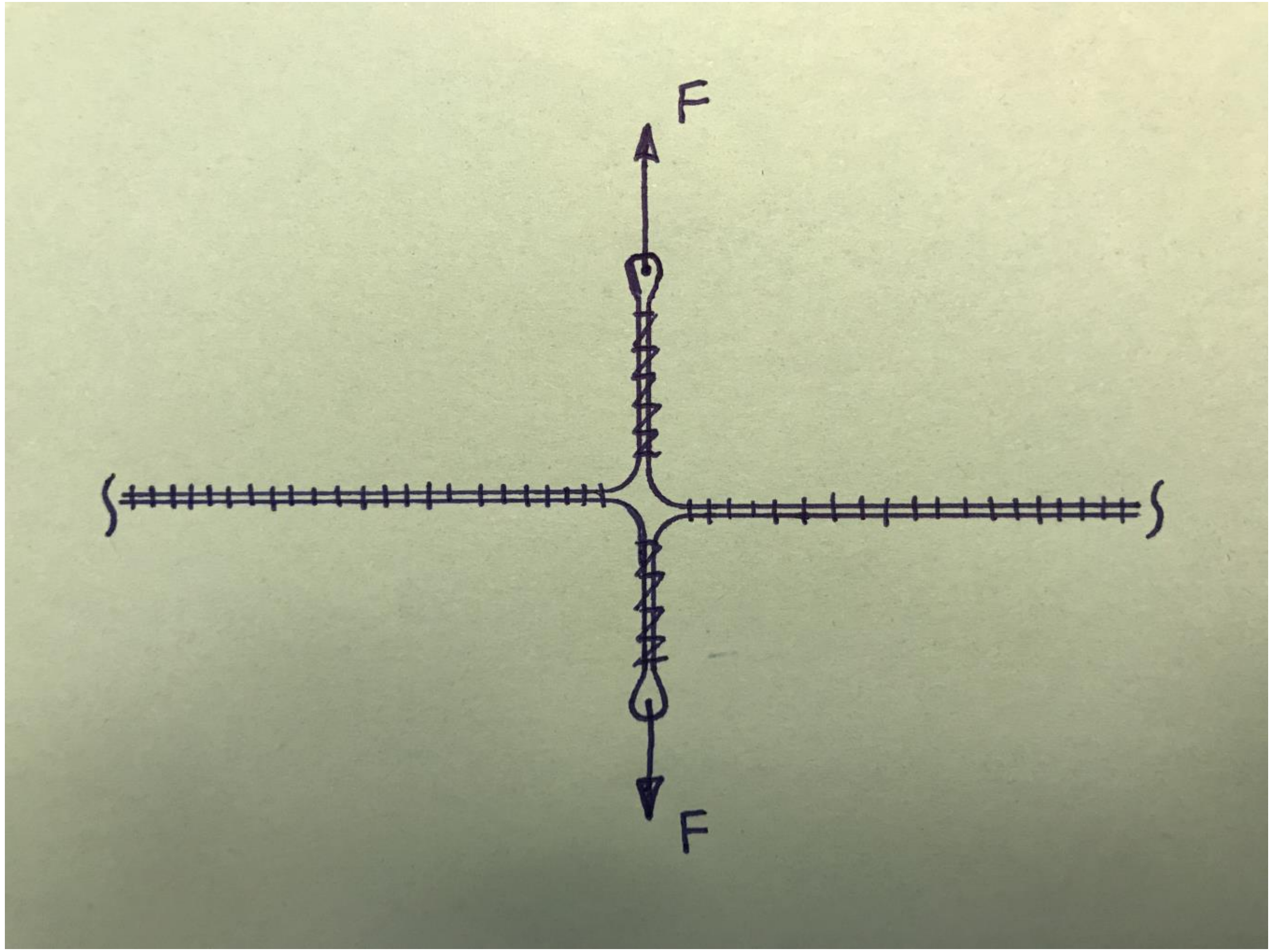
- Performed by Airborne Systems under CIF Award FY18
- Capture Load
  - 10K lbm Payload Recovery Weight
  - Max Capture Acceleration .7g
  - Capture acceleration for 3-G Cut-Away MAR has not been determined
- LLD Strength
  - Target Dual Leg LLD Force: Mean 17,000 lbf; Max: 23,000 lbf; Min: 11,000 lbf
  - Target dual leg bridle average activation force 2125 lbf (17,000 lbf/8 bridles = 2125 lbf each dual leg bridle)
- Sample Design
  - Use existing dual leg bridle design adjusted to 10 ft length total stroke
  - Light lead in bar tacks to eliminate initial spike
  - New bartacks programmed to adjust force to desired range
  - Materials for samples have been identified and ordered

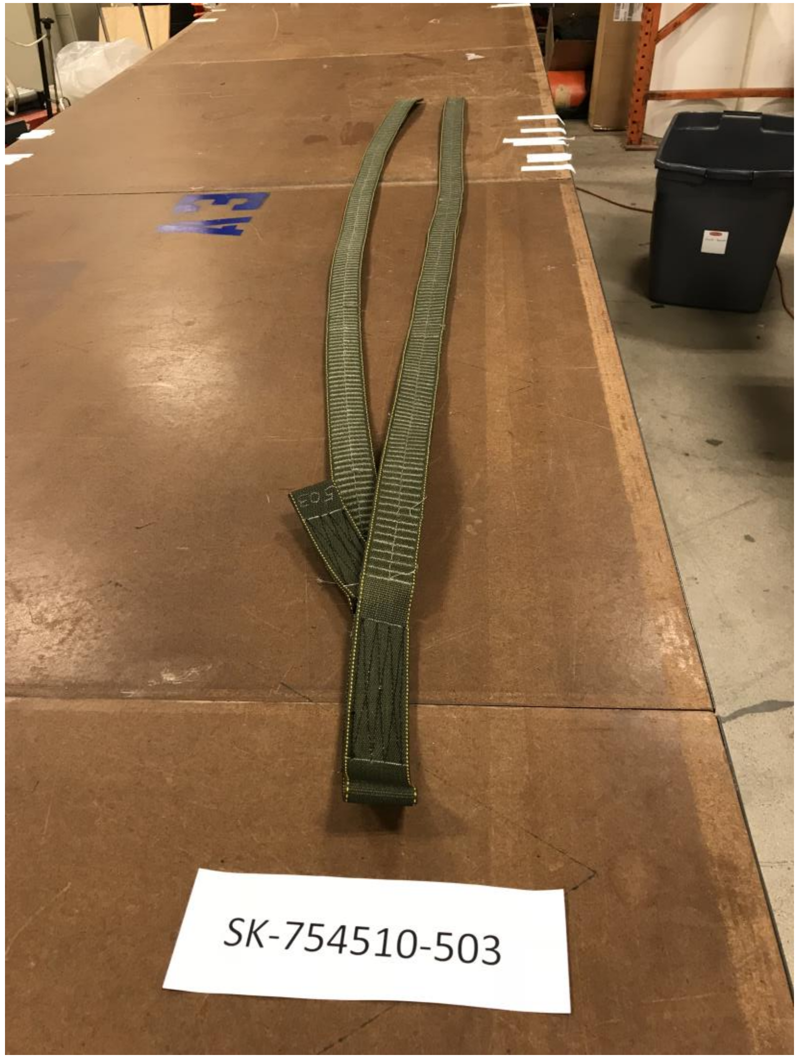
Bridle Test Configurations

Dash #	Webbing	Thread	Stitch Type	Stitch No.	Spacing	Stitch L x W	S.P.I	No. Rows	Sewing Machine	Program # & Stitches	Stock Code Web/Thd	Lot # Web/Thd
-1	PIA-W-27265 T/7	A-A-59826 Size FF	Bar Tack	136	3/8	1 7/16 x 1/8	N/A	N/A	Brother BAS311E-31	#1-66 stitch (8 ea) #4-136 stitch	162239 139550	379286 373129
-501	PIA-W-27265 T/7	A-A-59826 Size FF	Bar Tack	128	3/8	1 7/16 x 1/8	N/A	N/A	Brother BAS311E-31	#1-66 stitch(8 ea) #3-128 stitch	162239 139550	379286 373129
-503	PIA-W-27265 T/7	A-A-59826 Size FF	Bar Tack	120	3/8	1 7/16 x 1/8	N/A	N/A	Brother BAS311E-31	#1-66 stitch (8 ea) #2-120 stitch	162239 139550	379286 373129
-505	PIA-W-27265 T/13	A-A-55220 Size FF	Bar Tack	128	3/8	1 7/16 x 1/8	N/A	N/A	Brother BAS311E-31	#1-66 stitch (8 ea) #3-128 stitch	162240	379287 130123-1
-507	PIA-W-27265 T/13	A-A-59826 Size FF	Bar Tack	128	3/8	1 7/16 x 1/8	N/A	N/A	Brother BAS311E-31	#1-66 stitch (8 ea) #3-128 stitch	139550	373129
-509	PIA-W-27265 T/13	A-A-59826 Size FF	308 Dbl zig-zag	N/A	N/A	3/16 Width	7	6	SEIKO SKZ-2B-2/3	N/A	162240 139550	?????? 373129
-511	PIA-W-27265 T/13	A-A-59826 3 Cord	308 Dbl zig-zag	N/A	N/A	1/4 Width	4	5	SEIKO SKZ-2B-2/3	N/A	??????? 139538	?????? 364469
-513	PIA-W-27265 T/13	A-A-59826 5 Cord	308 Dbl zig-zag	N/A	N/A	5/16 Width	6	4	SEIKO SKZ-2B-2/3	N/A	162240 126245	?????? 379386
-515	PIA-T-87130 T/10, C/9	A-A-55220 Size FF	308 Dbl zig-zag	N/A	N/A	3/16 Width	8	6	SEIKO SKZ-2B-2/3	N/A	119469 Saunders	378447 26940
-517	PIA-T-87130 T/10, C/9	A-A-55220 Size 210	308 Dbl zig-zag	N/A	N/A	1/4 Width	7	5	SEIKO SKZ-2B-2/3	N/A	119469 125781	378447 369992
-519	PIA-T-87130 T/10, C/9	A-A-55220 Size 450	308 Dbl zig-zag	N/A	N/A	5/16 Width	4.5	4	SEIKO SKZ-2B-2/3	N/A	119467 162241	378447 378572
-521	PIA-W-27265 T/10	A-A-59826 Size FF	Bar Tack	120	3/8	1 1/2 x 1/8	N/A	N/A	Brother BAS-3260-01A	#156-66 stitch (8 ea) #157-120 stitch	162240 139550	379287 373129
-523	PIA-W-27265 T/10	A-A-59826 Size FF	Bar Tack	128	3/8	1 1/2 x 1/8	N/A	N/A	Brother BAS-3260-01A	#156-66 stitch (8 ea) #158-128 stitch	162240 139550	379287 373129

[chart will be updated]

Dual-Leg Bridle Test Unit

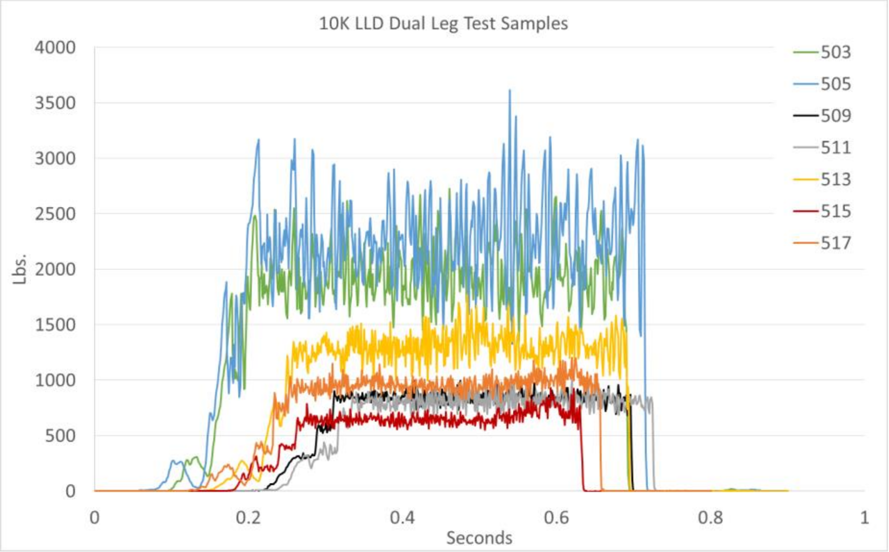


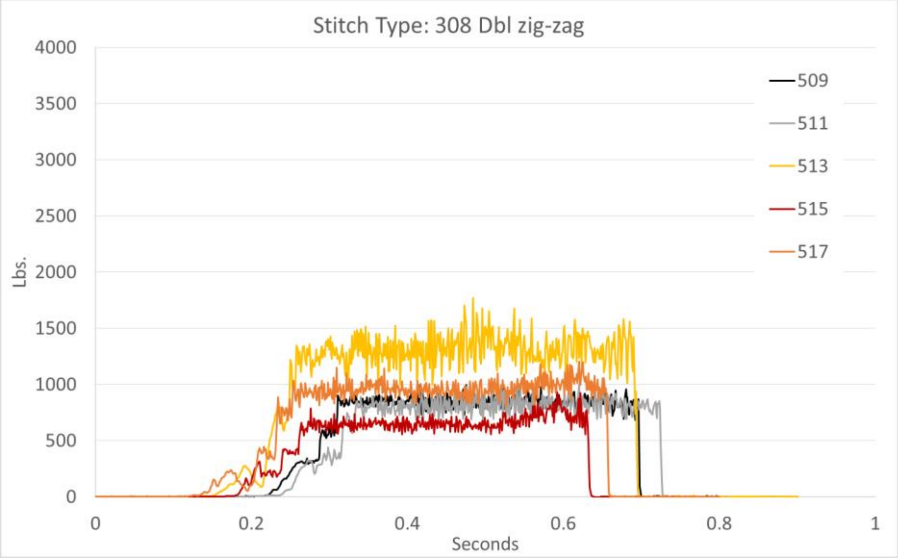


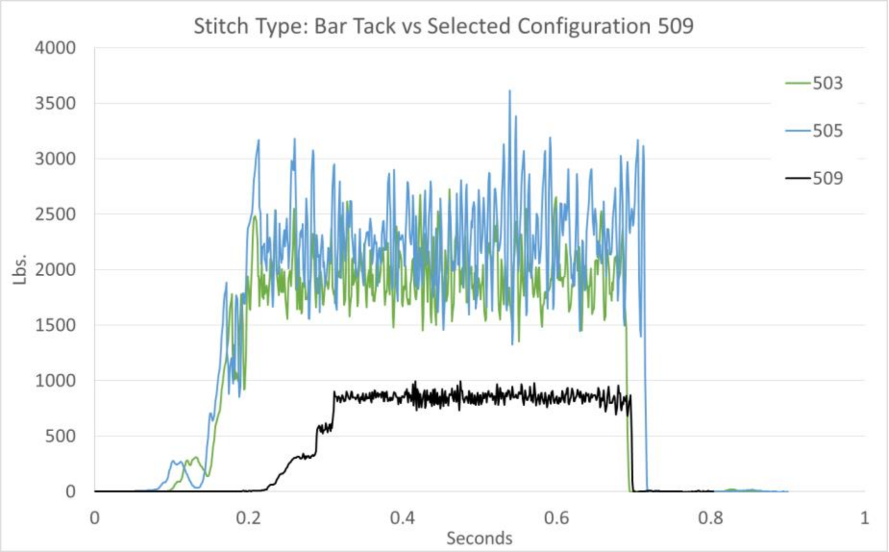
Dual-Leg Bridle Unit Testing

Unit Test Results: Non-Failure Cases

Series	Specs	Avg Force, lbs.	Peak Force, lbs.	Peak/Avg
503	PIA-W-27265 T/7, A-A-59826 Size FF, 120 Stitch Bartack, 3/8 Spacing, 1 7/16 Length, 1/8 Width	1956	2724	39%
505	PIA-W-27265 T/13, A-A-55220 Size FF, 128 Stitch Bartack, 3/8 Spacing, 1 7/16 Length, 1/8 Width	2297	3615	57%
509	PIA-W-27265 T/13, A-A-59826 Size FF, Type 308 Stitch, 3/16 Width, 7 SPI, 6 Rows	849	997	17%
511	PIA-W-27265 T/13, A-A-59826 Size 3 Cord, Type 308 Stitch, 1/4 Width, 4 SPI, 5 Rows	817	1012	24%
513	PIA-W-27265 T/13, A-A-59826 Size 5 Cord, Type 308 Stitch, 5/16 Width, 6 SPI, 4 Rows	1308	1769	35%
515	PIA-T-87130 T/10 C/9, A-A-55220 Size FF, Type 308 Stitch, 3/16 Width, 8 SPI, 6 Rows	664	932	40%
517	PIA-T-87130 T/10 C/9, A-A-55220 Size 210, Type 308 Stitch, 1/4 Width, 7 SPI, 5 Rows	965	1205	25%

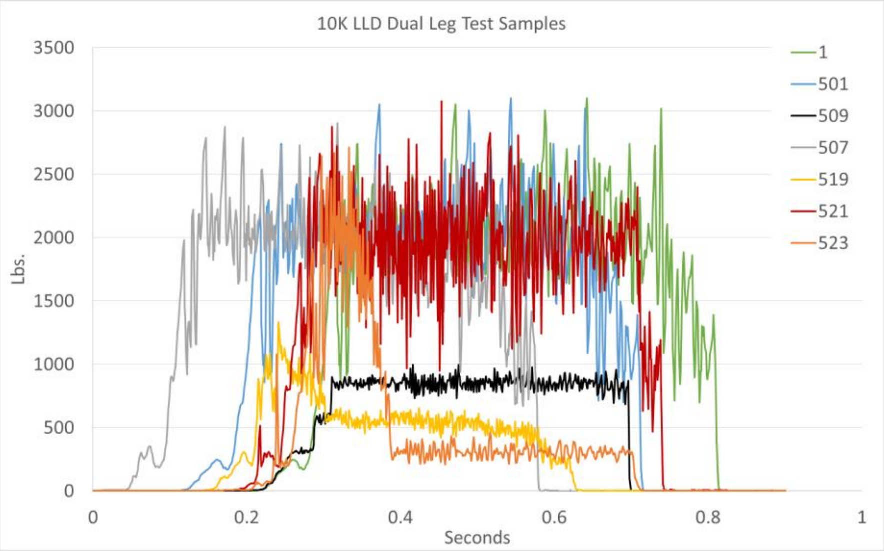


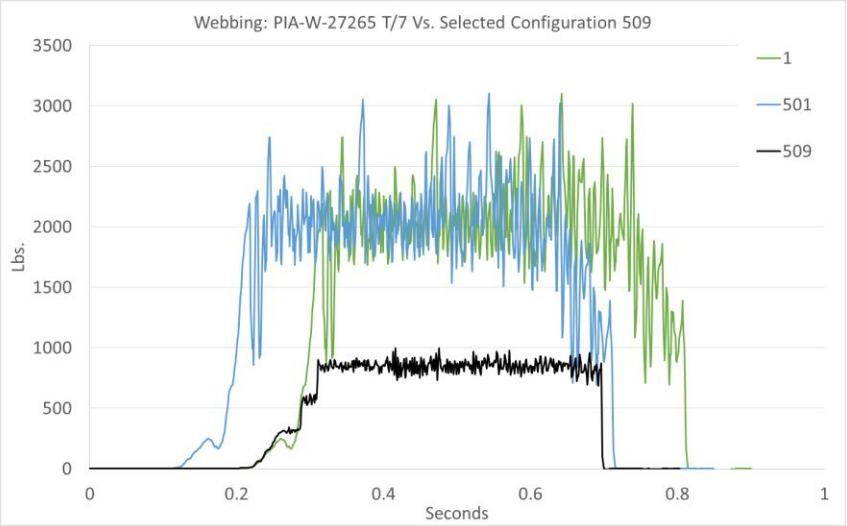


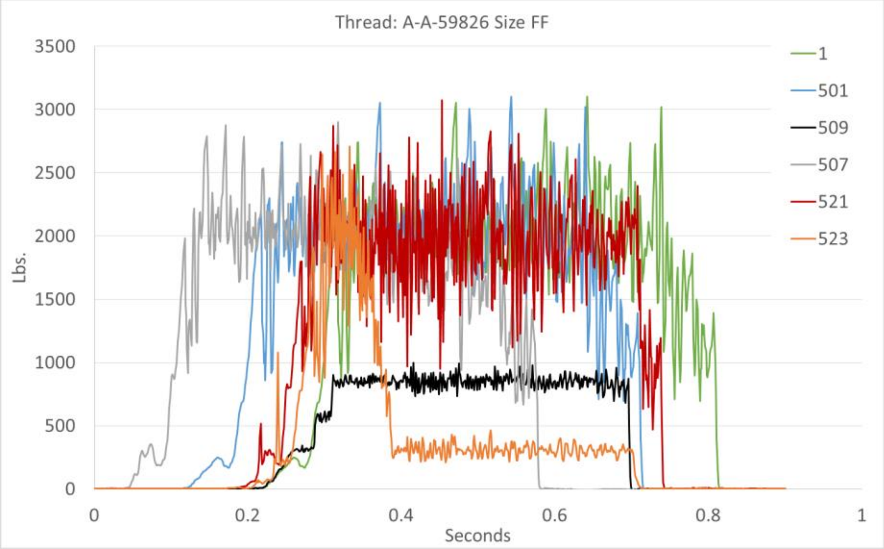


Unit Test Results (cont'd): Failure Cases

Series	Specs	Avg Force, lbs.	Peak Force, lbs.	Peak/Avg
1	PIA-W-27265 T/7, A-A-59826 Size FF, 136 Stitch Bartack, 3/8 Spacing, 1 7/16 Length, 1/8 Width	2118	3102	46%
501	PIA-W-27265 T/7, A-A-59826, 128 Stitch Bartack, 3/8 Spacing, 1 7/16 Length, 1/8 Width	2013	3102	54%
507	PIA-W-27265 T/13, A-A-59826 Size FF, 128 Stitch Bartack, 3/8 Spacing, 1 7/16 Length, 1/8 Width	2125	2902	37%
509	PIA-W-27265 T/13, A-A-59826 Size FF, Type 308 Stitch, 3/16 Width, 7 SPI, 6 Rows	849	997	17%
519	PIA-T-87130 T/10 C/9, A-A-55220 Size 450, Type 308 Stitch, 5/16 Width, 4.5 SPI, 4 Rows	617	1335	116%
521	PIA-W-27265 T/10, A-A-59826 Size FF, 120 Stitch Bar Tack, 3/8 Spacing 1 1/2 Length, 1/8 Width	1992	3076	54%
523	PIA-W-27265 T/10, A-A-59826 Size FF, 128 Stitch Bar Tack, 3/8 Spacing 1 1/2 Length, 1/8 Width	2247	2710	21%

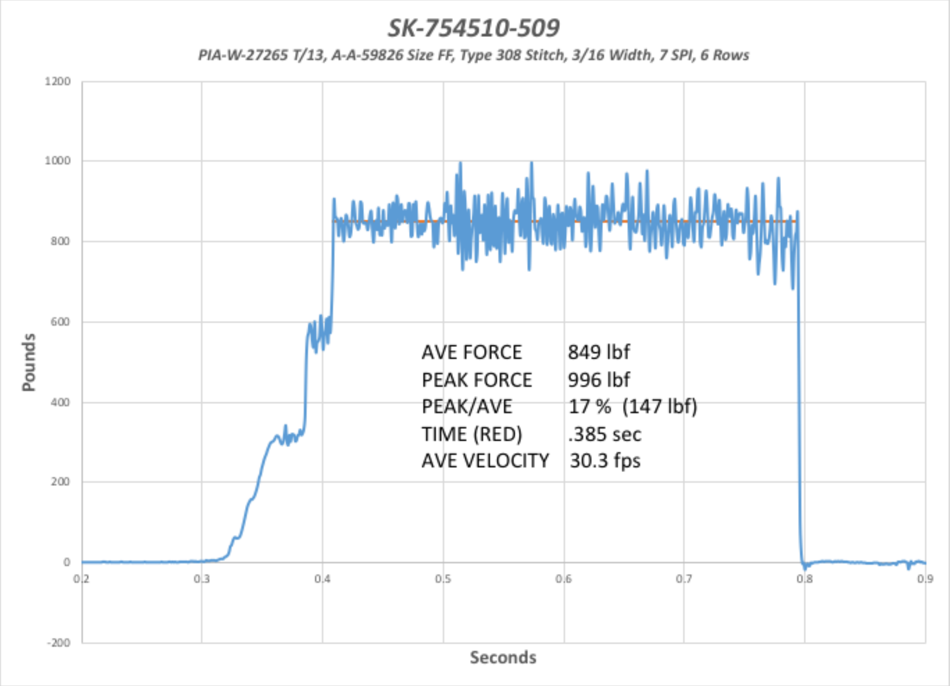


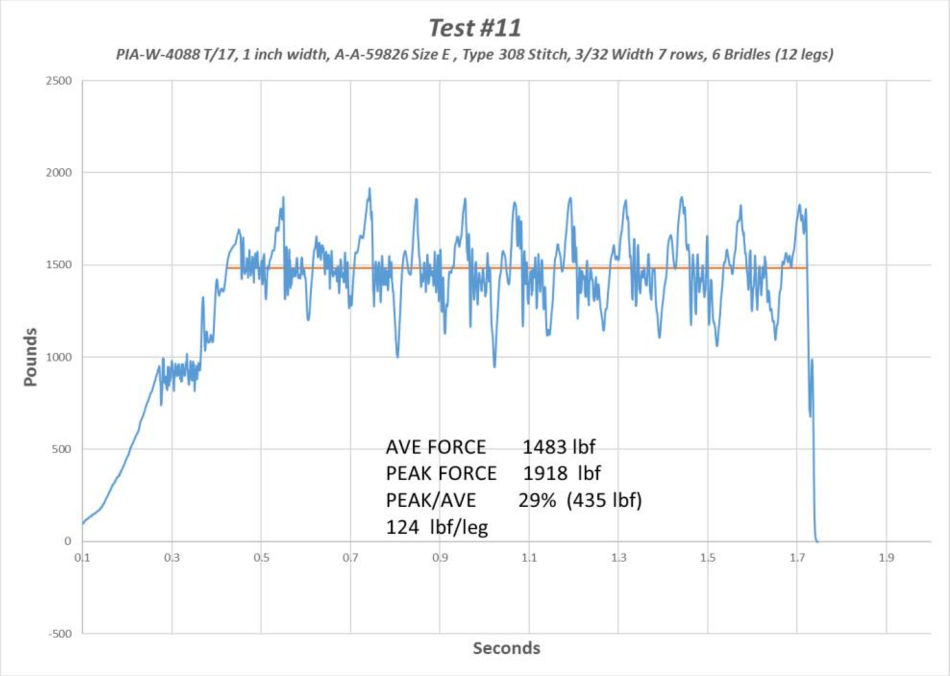




Test Conclusions

- 13 samples of varying configuration were successfully tested
- 6 of 13 samples experienced webbing failure or damage on one or both legs of the bridle and did not function properly the entire stroke
  - The failures occurred on bridles using high strength thread and/or high density stitching (128 and 136 stitch bar tacks)
  - The failure of the fill fibers allowed the webbing to ravel and lose structure
  - The combination of the superimposed seam and peel loading condition creates higher stress on the fill fibers causing failures at significantly lower than rated loads
- Of the non-failed units, -509 had the best peak/avg load at 17%
  - The low peak force will allow the LLD Assembly to accomplish the most work without overloading the helicopter cargo hook increasing mission reliability
  - The 17% measured on the -509 single bridle may be lower than when multiple legs are added.
  - The chart (bottom, right) shows a similar design from a prior test with multiple bridles with a 29% peak/avg
  - The difference may be due to the test methodology with significantly lower force to exercise the bridle.
- The -517 bridle had the second lowest peak/ave at 25%
  - The 965 pound average force using 64 pound Kelvar thread is only a little greater than the 849 pound average force using 17.5 pound nylon thread. This indicates a low stitch efficiency that could possibly result in higher peak/avg forces if more tests were conducted.





Final Design Selection

- The -509 requires 20 each bridles (40 legs) to achieve the desired 17K average force with and estimated mass of 38.4 lbm for 20 bridles
- Changing the webbing from PIA-W-27265 T/13 (7000lb) to PIA-W-27265 T/7 webbing would reduce the mass by 8 pounds with a very low risk of affecting the performance of the bridle
- The risk of webbing damage to the -509 configuration is extremely low due to the low stitch density and force required to exercise the bridle.