Cedric Smith, Mike Kuhlmeier Bios:

Cedric has been with CMC Rescue since 2003. Cedric's responsibilities at CMC include the development and testing of products, specializing in equipment used in air operations. Cedric is active with the ASTM F32 SAR committee, the NFPA Special Operations Protective Equipment committee, and the ANSI/ASSE Z359 Fall Protection committee. Cedric is an Incident Commander and training lead with the Santa Barbara County Sheriff's Office SAR Team. SBCSAR is a Mountain Rescue Association (MRA) accredited team, and routinely responds to various technical rescue incidents including vehicle over the side, downed aircraft, swift water/flood, and alpine rescue, in addition to supporting Sheriff Department operations, and fire department casualty and wildfire incidents, throughout the state of California.

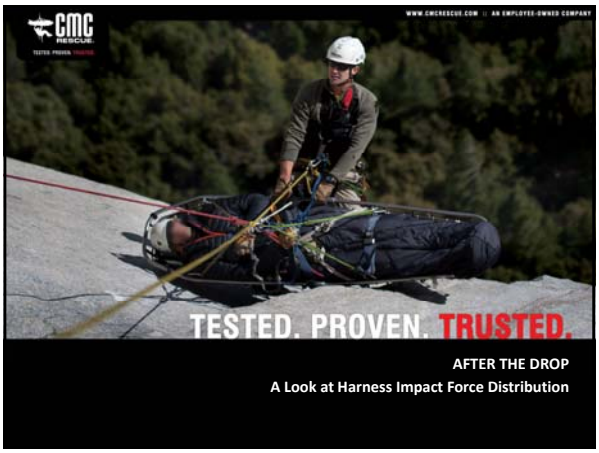
Michael Kuhlemier is a Mechanical Engineer at CMC Rescue. He graduated from Washington State University with a degree in Bioengineering. During college he worked both as a Ski Patroller at Silver Mt and as an outdoor guide. He enjoys getting outdoors, especially to ski, and designing random electro-mechanical devices.

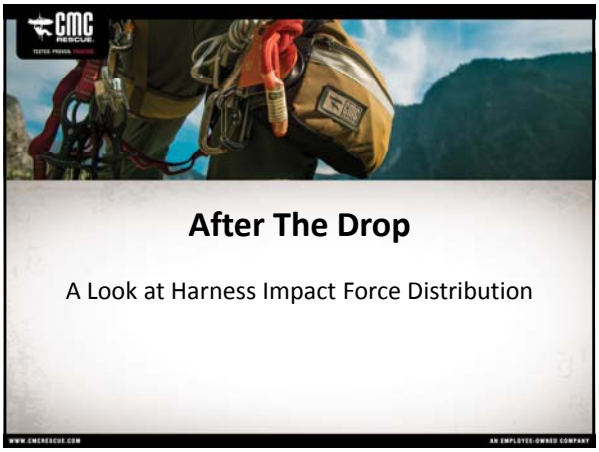
Abstract (After the Drop):

Over the decades, a considerable amount of emphasis has been placed on belay competency, rescue system rigging and other equipment consideration. The belay competency test method was originally formulated around the worst case scenario; having a mainline failure during an edge transition. The test method essentially was dropping a test mass a height of 1 meter on 3 meters of rope. The belay device's capability of arresting the load was measured and the maximum arrest force at the anchor was also recorded.

The majority, if not all of these tests, have been focused around a system, or a specific device, not the impact to a rescuer. CMC has advanced this type of testing through the instrumentation of a harness and test mass with load sensors and accelerometers during a typical belay test. The load sensors are placed at various interface points between the harness and the test mass and the impact loads imparted during the event are recorded. The accelerometer, located on the test mass, also records the g-forces imparted on the mass.

This presentation will examine the force distribution and accelerations imparted by various styles of harnesses and attachment points during a typical belay test drop. This data will be a first step in understanding the impact of harnesses and dynamic loads on a rescuer during a fall.





Dynamic Tests are Conducted to Serve Different Purposes

- Harness for structural integrity
- Belay devices for competency
- Fall protection system for proof of performance
- Various components or entire systems… what if?

What Happens to the Person…

- Wearing the harness
- Hanging from the system
- Having a bad day

Areas of Curiosity

- Comparing impact force imparted from various connection elements
- The effect of harness construction (sit versus full body harness)
- The damping effect of harness padding on impact force
- The effect of rope elongation (or lack therefore)

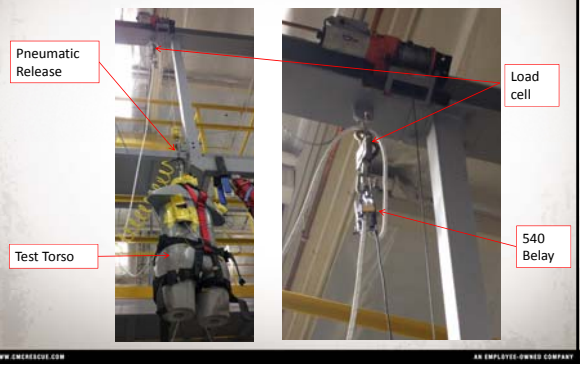
Drop Test Parameters

- Follow belay competency test model
  - 1 meter drop on 3 meters of rope
  - Rope terminated with a bowline knot
  - 540 Rescue Belay
  - 100 kg (220 lbf) ANSI Z359 test torso
- Data Collected
  - MAF measured at 540 Belay
  - Harness forces imparted on the test torso
  - G-forces of test torso

About the Belay Competency Test

- Originated from the British Columbia Council for Technical Rescue
- Intended to simulate the highest potential impact force
  - System rigged 3 meters from the edge
  - 1 meter of fall potential (height of attachment point)

Drop Tower Setup

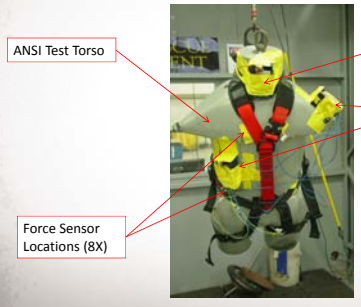


About the Equipment

- Omega LC 101-5K load cell (2.2 kHz sample rate) Located at the top of the tower to measure MAF.
- Tekscan FlexiForce A401 pressure sensors, 1 sq. in sensing area.
- Adafruit ADXL326 16g 3-axis accelerometer
- CMC custom data acquisition
  - Arduino UNO Based
  - Micro SD flash storage
  - 63Hz sampling rate




Data Acquisition on Torso



Disclaimer

- Pressure sensors placed in areas of anticipated data collection in attempt to look at trends. No claims are made that the sensors are located in areas of peak force
- In some instances, actual peak values may have been missed due to relatively low data acquisition rates on the pressure sensors.
- Pressure data was collected on a rigid test mass and values are not expected to correlate to actual pressures on a human body.

CMC /Roco Freedom Harness™

- ANSI Z359.11 Fall Protection harness
- Dorsal attachment element
- No padding
- Expected to be used with a shock-absorbing lanyard.

CMC Response Harness™

- NFPA 1983 Class III as well as ANSI Z359.11 Harness
- Waist, sternal and dorsal attachment elements
- Substantial leg (thigh) and waist (lumbar) padding

CMC Proseries® Rescue Harness

- NFPA 1983 Class II
- Waist attachment element
- Substantial leg (thigh) and waist (lumbar) padding

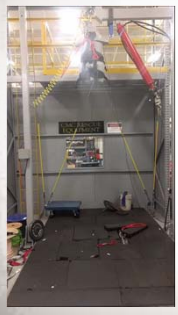
CMC Lifeline

- 13mm (1/2 inch) diameter
- 100% nylon
- NFPA 1983 – G Rated
- Elongation:
  - 2.6 % @ 1.33 kN (300 lbf)
  - 4.7 % @ 2.66 kN (600 lbf)
  - 7.5 % @ 4.44 kN (1,000 lbf)

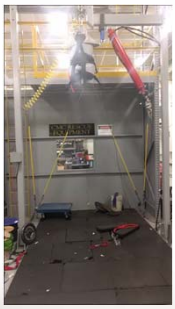
CMC Static-Pro™ Lifeline

- 13mm (1/2 inch) diameter
- 100% polyester
- NFPA 1983 – G Rated
- Elongation
  - 1.3 % @ 1.33 kN (300 lbf)
  - 1.9 % @ 2.66 kN (600 lbf)
  - 2.6 % @ 4.44 kN (1,000 lbf)

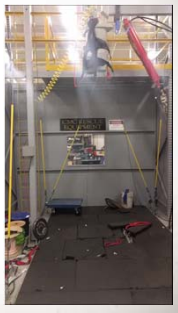
Drop Test Examples



Response - Dorsal

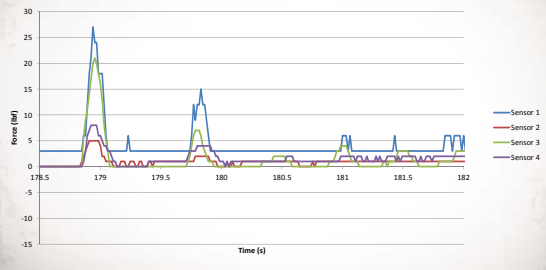


Response - Sternal



Response - Waist

Force Sensor Data Example



Response Harness, dorsal attachment, lifeline drop

Drop Test Examples

Sensor Map

PSI Readings At Rest

CMC / Roco Freedom™ Harness Static-Pro™ Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Dorsal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	80	20	17	6	52	96	8	1	2028
2	115	20	6	6	150	19	10	1	2131
3	117	22	15	6	58	46	9	3	2181
4	117	31	17	11	144	39	13	2	2218
5	126	31	20	12	150	69	7	2	2289
6	57	37	11	12	46	20	5	2	2196
7	51	44	31	14	110	55	4	1	2191
8	77	40	10	10	144	75	8	6	2122
9	4	44	10	6	46	40	4	1	2150
10	0	46	18	8	138	29	4	1	2249
AVG	74.4	33.5	15.5	9.1	103.8	48.8	7.2	2	2175.5
STD	46.33	10.22	7.01	3.07	47.34	25.06	3.01	1.56	73.05

Average PSI (10 Drops)

CMC / Roco Freedom™ Harness Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Dorsal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	100	20	87	23	180	96	79	140	1707
2	117	26	104	29	150	19	36	190	1702
3	93	28	80	31	169	46	29	160	1662
4	100	28	87	27	144	39	56	175	1711
5	91	26	78	24	150	69	52	145	1633
6	75	30	62	33	261	20	37	240	1592
7	66	28	53	29	258	55	38	210	1544
8	53	30	40	34	261	75	92	180	1589
9	73	30	60	28	283	40	23	169	1501
10	66	22	53	25	138	29	46	144	1543
AVG	83.4	26.8	70.4	28.3	199.4	48.8	48.8	175.3	1618.4
STD	19.83	3.43	19.83	3.68	58.72	25.06	21.92	31.70	76.08

Average PSI (10 Drops)

CMC Response™ Harness Sensor Map (Sternal)

Sensor Map

PSI Readings At Rest

CMC Response™ Harness (Sternal) Static-Pro™ Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Sternal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	11	13	16	10	6	13	5	8	1511
2	11	15	14	10	18	11	12	9	1793
3	11	20	19	10	18	17	12	11	1664
4	11	20	18	18	6	32	18	14	1792
5	11	17	11	10	6	21	17	18	1850
6	6	6	6	10	6	18	14	14	1795
7	11	15	7	8	15	11	14	19	1762
8	11	17	8	7	12	20	14	18	1742
9	11	20	6	5	6	18	14	13	1773
10	11	15	2	4	12	17	13	8	1680
AVG	10.5	15.6	10.7	9.2	10.5	17.8	13.3	13.2	1736.2
STD	1.58	4.43	5.79	3.82	5.15	6.09	3.50	4.18	96.54

Average PSI (10 Drops)

CMC Response™ Harness (Sternal) Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Sternal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	35	8	11	13	118	5	38	1	1241
2	40	11	8	10	21	2	14	0	1398
3	17	13	8	10	15	3	19	0	1384
4	17	11	12	10	24	1	18	0	1362
5	22	13	17	10	18	1	18	0	1342
6	11	11	14	10	15	2	21	0	1346
7	13	13	20	10	18	1	19	0	1334
8	15	14	16	10	18	1	16	0	1382
9	14	12	18	10	18	1	17	0	1386
10	16	11	17	10	9	3	14	0	1263
AVG	20	11.3	14.1	10.3	27.4	1.8	19.4	0.1	1343.8
STD	9.74	1.57	4.20	0.95	32.08	1.32	6.90	0.32	53.05

Average PSI (10 Drops)

CMC Response™ Harness Sensor Map (Waist)

Sensor Map

PSI Readings At Rest

CMC Response™ Harness (Waist) Static-Pro™ Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Waist	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	6	20	24	2	6	3	11	7	1923
2	2	11	21	8	9	3	12	16	
3	15	31	15	8	6	2	8	6	
4	0	21	10	12	6	9	12	15	1847
5	0	15	10	16	6	11	11	17	1834
6	11	11	24	10	6	22	13	8	1799
7	40	28	20	10	6	7	10	6	1789
8	37	31	17	10	6	2	20	12	1726
9	37	28	6	17	6	13	9	11	1796
10	28	6	15	13	6	10	8	14	1764
AVG	17.6	20.2	16.2	10.6	6.3	8.2	11.4	11.2	1809.75
STD	16.37	9.15	6.18	4.30	0.95	6.30	3.47	4.24	59.33

Average PSI (10 Drops)

CMC Response™ Harness (Waist) Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Waist	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	17	26	60	64	6	1	8	0	1299
2	31	48	75	55	6	1	17	24	1579
3	15	20	86	63	6	1	7	14	1231
4	17	20	78	71	6	1	7	6	1273
5	20	8	65	59	6	1	8	6	1300
6	26	11	74	52	6	1	7	6	1321
7	22	11	71	61	6	1	7	5	1314
8	22	20	82	68	6	8	8	5	1292
9	22	17	81	56	6	1	7	5	1387
10	24	20	67	48	6	2	8	6	1416
AVG	21.6	20.1	73.9	59.7	6	1.8	8.4	7.7	1341.2
STD	4.74	11.23	8.23	7.15	0.00	2.20	3.06	6.65	98.93

Average PSI

CMC Response™ Harness Sensor Map (Dorsal)

Sensor Map

PSI Readings At Rest

CMC Response™ Harness (Dorsal) Static-Pro™ Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Dorsal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	36	34	45	31	64	4	32	8	2077
2	30	26	32	28	50	4	16	7	2080
3	51	19	36	17	55	5	27	8	2019
4	30	28	47	29	43	5	23	8	2065
5	40	27	51	24	70	5	29	8	1893
6	30	31	34	33	46	4	24	7	2017
7	34	24	30	26	49	5	27	6	2023
8	61	26	38	24	45	4	31	7	1928
9	33	17	43	24	62	5	27	7	1882
10	27	25	48	28	46	5	17	5	1730
AVG	37.4	25.7	40.4	26.2	53	4.6	25.3	7.1	1971.4
STD	10.77	5.03	7.35	4.47	9.32	0.52	5.46	0.99	112.06

Average PSI (10 Drops)

CMC Response™ Harness (Dorsal) Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Dorsal	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	27	5	21	8	22	40	21	29	1578
2	33	5	28	8	38	35	24	24	1639
3	21	4	23	4	15	38	38	19	1278
4	27	5	28	8	22	39	41	23	1566
5	33	4	38	5	14	36	37	18	1580
6	46	5	45	6	12	35	34	21	1600
7	40	5	24	5	6	33	32	27	1517
8	33	6	27	6	6	32	30	15	1445
9	46	5	37	7	9	34	35	20	1751
10	33	5	33	7	6	33	14	3	1617
AVG	33	4.7	30.4	6.2	15	35.1	29.9	19.6	1556.90
STD	7.53	0.48	7.80	1.62	6.29	3.21	8.16	6.37	125.97

Average PSI (10 Drops)

ProSeries® Rescue Harness Sensor Map

Sensor Map

PSI Readings At Rest

ProSeries® Rescue Harness Static-Pro™ Lifeline

Attachment	Lower Set				Upper Set				Load Cell
Waist	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	20	16	18	32	41	10	10	19	1706
2	11	14	17	2	38	14	31	17	1739
3	22	19	19	8	35	13	20	17	1580
4	14	18	25	13	40	11	22	27	1573
5	18	17	4	8	31	15	2	18	1466
6	11	16	22	9	20	13	20	22	1803
7	20	14	37	11	28	15	20	13	1762
8	17	15	17	6	34	17	6	6	1759
9	13	18	12	7	24	15	2	13	1638
10	18	19	18	8	20	17	2	16	1585
AVG	16.4	16.6	18.9	10.4	31.1	14	13.5	16.8	1661.5
STD	3.92	1.90	8.52	8.13	7.85	2.31	10.38	5.61	108.59

Average PSI (10 Drops)

ProSeries® Rescue Harness Lifeline

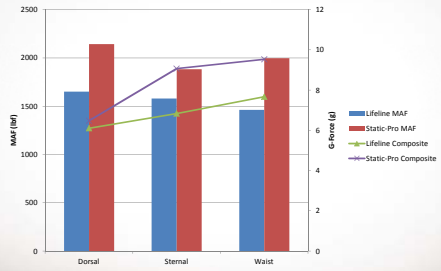
Attachment	Lower Set				Upper Set				Load Cell
Waist	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	Sensor 1 (PSI)	Sensor 2 (PSI)	Sensor 3 (PSI)	Sensor 4 (PSI)	MAF (lbf)
1	20	4	0	32	6	10	10	19	1318
2	11	4	0	2	6	22	31	8	1168
3	6	7	19	8	35	13	0	17	1290
4	6	6	25	13	40	11	0	27	1271
5	6	6	4	8	31	15	2	13	1410
6	6	8	22	9	20	13	20	8	1089
7	6	6	37	11	20	15	20	13	1182
8	6	6	17	6	0	17	16	6	1290
9	6	4	12	7	24	15	17	2	1436
10	6	2	8	8	20	17	18	16	1257
AVG	7.9	5.3	14.4	10.4	20.2	14.8	13.4	12.9	1271.1
STD	4.53	1.77	11.92	8.13	13.14	3.43	10.21	7.28	106.11

Average PSI (10 Drops)

G-Force Comparison

Maximum values averaged over 5 drops

G-Force/ MAF Comparison



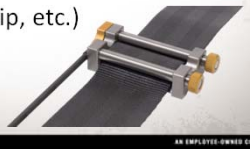
Maximum values averaged over 5 drops

Observations

- BCCTR Belay Tests generate substantial impact forces.
- Lower peak accelerations and MAF recorded for dynamic vs. static ropes.
  - Likely due to additional system extension.
- G-Force and MAF not directly correlated.
  - Likely due to high rotational acceleration.
- Padded harnesses show reduced impact pressures.
  - Force distributed across larger area.
- Pressure Data is interesting but inconclusive.
  - Extremely difficult to capture peak forces.

Next Steps

- Further Testing
- Increased sample rate of DA
- Pressure Sensor Resolution
- Belt tension sensor
- Anatomically correct mannequin
- Fall axis (Head Down, Trip, etc.)



Questions?

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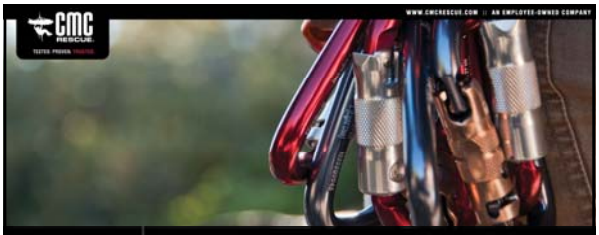

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