Vertical Rescue Friction Testing

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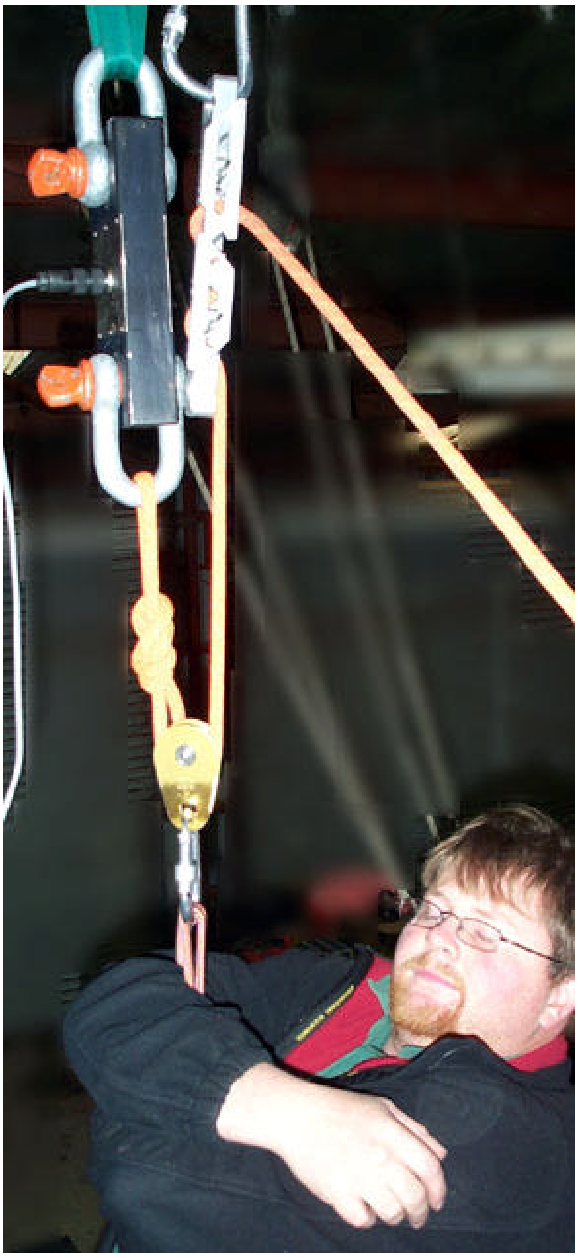
The following tests were carried out one rainy Saturday afternoon in the Oberon State Emergency Service (SES) headquarters. The load cell is a Straightpoint NIP/5T 5 tonne capacity load cell with remote handheld display. Whilst the display error for the load cell is +/- 0.5 kg, calibration data for the unit shows the true measurement error is +/- 2 kgs over the full range from 0 to 5000 kgs.



Aim

The aim was to measure the amount of friction developed in vertical rescue pulleys and similar equipment.

Test Method

The method chosen was to anchor a rope to the load cell in the roof of the building, run the rope through a pulley to create a 180 degree wrap on the pulley (i.e. a 2:1 mechanical advantage) and then control the motion of the rope with a rescue descender (Spelean Rescue Whaletail) also anchored in the roof. To simplify movement and resetting of the load for each test we chose to use a rescuer, Peter Howard in this case. Working beside the mezzanine floor gave good access to simplify loading and resetting of the test rig.

Figure 1 (left) shows Pete having a hard day at the office and may better illustrate the test rig than words alone.

In the test procedure we found it was important to achieve a free hanging pitch. The very act of pushing off from the mezzanine floor was able to affect the load measurements.

Appendix 1 shows the test results and calculations. Most tests were repeated twice. The exception to this is test 1 on the SRT P1a Pulley which we actually did three times but rejected the first two results based on measurement errors due to pushing off the mezzanine floor. After minor adjustment to the position of the test rig we were able to achieve a properly free hanging pitch for the remainder of the tests.

Discussion

Some tests show 3 or 4 measurements despite the test only being repeated twice. These measurements were recorded where the measurement was stable for the first half of the lowering run than changed and was again stable for the second half of the lowering run. In all cases the change was indicated at 1 kilogram force change, and the change was always upwards. His suggested a repeatable mechanism was at work, and worthy of recording. It is possible the load was near the high end of the measurement error band for the load cell, and that heat created by friction in the pulley caused a minor change in load that bumped the measurement out of the error band for the lower measurement into its higher neighbour. Whatever the mechanism, the split recording and averaging of the load readings was felt to be justified. The repeatability of results was felt to be good.

All the pulleys tested were plain bearing, or bushed, pulleys. None were believed to have rolling or ball bearings fitted. Three pulleys were chosen to be tested a second time after lubrication with WD 40. The lubricant was applied to the axles of the pulleys with excess lubricant wiped off the pulleys before use to prevent contamination of the rope. The effects of lubrication appear to be minimal, suggesting either the lubricant was not particularly effective or that the pulleys were reasonably lubricated to start with. The plastic sheaved CMI Rescue Pulley showed an average 3% reduction in friction after lubrication, while for the SRT P1a and P3a Pulleys, the improvement was 4% and 1.5% respectively. The lubricated test for the P1a was interesting in that at the start of the first lubricated lower the friction was 2 kgs less than unlubricated, but by the bottom of the run it had gained 1 kg in tight side tension, and during the second run the friction was exactly as if it had not been lubricated. It appears that the lubricant was squeezed out of the bearing on the first run, suggesting that perhaps WD 40 is not the most appropriate lubricant to use.

Both the stainless steel and plastic sheaved CMI Rescue Pulleys demonstrated exactly the same friction characteristics suggesting that both pulleys use the same bearing bush and axle material combinations.

Perhaps the most important point that the test reinforced is that there is no substitute for sheave diameter in reducing friction. There is a good correlation between increasing sheave diameter and reducing friction. In short, ***the bigger the pulley wheel, the less friction developed***. For those who haven't though about this too much, this is because the pulley sheave acts like a lever. The friction force acts circumferentially between the axle and the bearing (or bush). A larger diameter wheel is like having a longer lever on that friction force so the force at the outer diameter of the wheel, where the rope acts, is less.

Apart from pulleys, comparative tests were completed on alloy and steel karabiners and also on a figure eight descender and an Italian or Munter Hitch. These were done to give an indication of their effect on friction if they are substituted into a pulley system through necessity (usually some sort of improvisation) or simply a lack of gear.

The Friction results are calculated and presented in three different ways.

The Effort Friction is the percentage of effort applied by a hauler on a 2:1 MA hauls system that is lost as heat in the pulley. This is the best figure to use to calculate and compare the friction and true mechanical advantage of various haul systems.

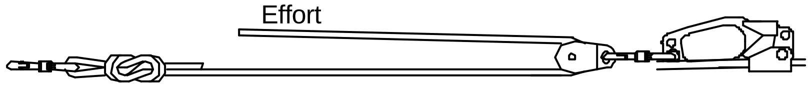
The Load Friction is the percentage increase in rope tension when a load line runs over a 180 degree redirection such as the head pulley on a Larkin Rescue Frame, or the top pulley in a counterweight system.

The Redirection Friction is the change in load in the rope expressed as the load on the redirection. So this is the figure that can be used to estimate the effects of a slight redirection on the tension in the load line. Note that this is accurate considering first order effects only, but this is well outside the expectations of rescue operators to be concerned with in the field.

Real Mechanical Advantages

Probably the most obvious thing we can do with this friction data is use it to calculate the real mechanical advantages of some common rescue haul systems. All rescuers are used to working with Theoretical Mechanical Advantages (TMAs) but how do different haul systems compare in reality?

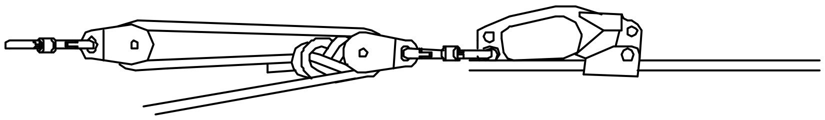
2:1 Mechanical Advantage (shown as Bolt On)



Effort Friction:	0%	5%	10%	20%	30%	40%	50%
Effort:	50%	51%	53%	56%	59%	63%	67%
Anchor:	50%	49%	47%	44%	41%	38%	33%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**2**	**1.95**	**1.9**	**1.8**	**1.7**	**1.6**	**1.5**

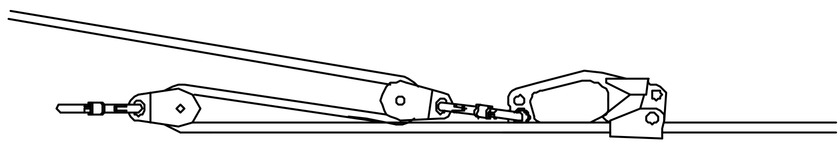
The above table and diagram represents a bolt on 2:1 MA. I.e. the Theoretical Mechanical Advantage is 2:1. Lets say we rig this hauls system with an SRT P2a Pulley which we can see from Appendix 1 has an effort friction factor of 20.2% - from this table we can see the real MA is 1.8:1.

3:1 Bolt On Mechanical Advantage



Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	33%	35%	37%	41%	46%	51%	57%
Anchor:	67%	65%	63%	59%	54%	49%	43%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**3**	**2.8525**	**2.71**	**2.44**	**2.19**	**1.96**	**1.75**

3:1 Inline Z Rig Mechanical Advantage

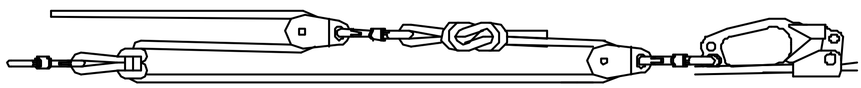


Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	33%	35%	37%	41%	46%	51%	57%
Anchor:	67%	65%	63%	59%	54%	49%	43%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**3**	**2.8525**	**2.71**	**2.44**	**2.19**	**1.96**	**1.75**

3:1 Mechanical Advantage Haul Systems, regardless of whether they are an inline Z rig or a bolt on, are essentially the same from a friction point of view. Again working our example of using SRT P2a pulleys, the real MA of this system would be 2.44:1 not 3:1.

If we were short of gear and decided to make this system using karabiners only because we had no pulleys, from Appendix 1 we see that the Effort friction of karabiners is about 50%, so the real MA of a 3:1 with krabs only would be just 1.75:1.

4:1 Multiplying Bolt On Mechanical Advantage (2:1 x 2:1)



Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	25%	26%	28%	31%	35%	39%	44%
Anchor:	75%	74%	72%	69%	65%	61%	56%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**4**	**3.8025**	**3.61**	**3.24**	**2.89**	**2.56**	**2.25**

4:1 Block and Tackle, Double Sheaved Running Block, Single Sheave Fixed Block

Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	25%	27%	29%	34%	39%	46%	53%
Anchor:	75%	73%	71%	66%	61%	54%	47%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**4**	**3.709875**	**3.439**	**2.952**	**2.533**	**2.176**	**1.875**

4:1 Block and Tackle, Double Sheaved Blocks Both Ends

Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	25%	28%	32%	42%	56%	77%	107%
Anchor:	125%	128%	132%	142%	156%	177%	207%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**4**	**3.524381**	**3.0951**	**2.3616**	**1.7731**	**1.3056**	**0.9375**

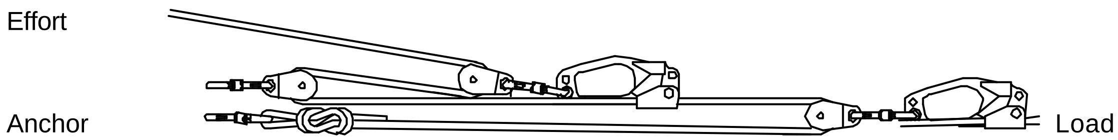
Once we start considering 4:1 TMA Haul Systems, and this is in the realm of bread and butter for vertical rescue operators, the above table shows that friction becomes significant not only in terms of choice of pulley for the task but also in terms of the type of haul system that is chosen to be rigged. From the above table it is easy to compare a 4:1 Multiplying Bolt On with either of the traditional block and tackle rigs.

Of special note here, if a 4:1 lifting block and tackle (i.e. double sheave blocks both ends) was improvised using karabiners only, the friction would be so great that it would be easier to haul the load directly with no MA! I.e. the real MA is 0.9375:1.

5:1 Block and Tackle, Double Sheaved Blocks Both Ends

Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	20%	22%	24%	30%	36%	43%	52%
Anchor:	80%	78%	76%	70%	64%	57%	48%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**5**	**4.524381**	**4.0951**	**3.3616**	**2.7731**	**2.3056**	**1.9375**

6:1 Multiplying Mechanical Advantage (3:1 x 2:1 - shown as Bolt On)



Friction*:	0%	5%	10%	20%	30%	40%	50%
Effort:	17%	18%	19%	23%	27%	32%	38%
Anchor:	83%	82%	81%	77%	73%	68%	62%
Load:	100%	100%	100%	100%	100%	100%	100%
MA:	**6**	**5.562375**	**5.149**	**4.392**	**3.723**	**3.136**	**2.625**

To complete our comparison of haul systems consider the 6:1 multiplying MA and the 5:1 block and tackle. If we used SRT P2a Pulleys to rig the 6:1 Multiplying rig, the real MA is about 4.1:1, not 6:1. Compare this with a 4:1 multiplying MA at 3.24:1.

Conclusion

This paper is not about getting rescuers to do accurate load calculations in the field. It's about making rescuers aware of the effects of friction and some of the decisions that rescuers can make to make their systems simpler, safer and easier to operate. Keep the friction in your system low, and you will have lower loads and stresses on gear, easier work for the haul team and a better feel for what is happening in you system, especially if something jams!

So what does all this mean in a nut shell?

- Buy and use the largest diameter pulleys you can afford to buy and/or carry. Remote area teams who must carry all their gear, and survival gear as well, will be well aware of the trade off to be made and may well choose to continue with small light pulleys.
- Rig the simplest and most efficient haul systems you can. The greater the MA you can build with the least number of pulleys, the more efficient the system will be. This usually means using multiplying MAs, or piggy back systems as some people know them. Typically the 4:1 and 6:1 multiplying MA's are the most practical and efficient. If you aren't proficient at rigging multiplying MA's, here is you incentive to learn them: they require less gear, produce less friction (i.e. more real MA!), provide better feel and are easier for the haul team to operate.

Appendix 1: Test Measurements and Calculations

Friction Testing

24/07/2004

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		Sheave Diameter, mm	**Measured Tight Side Load, kg**				**Average Measured Tight side load, kg**	**Tight Side Load Error, kg +/-**	**% Load Tight Side**	**% Load Slack Side**	**Effort Friction**	**Redirection Friction**	**Load Friction**	**% Load Error, +/-**	**2:1 Actual MA**
Load Calibration Tests			118	114	115		116	2	**100.0%**						
Test 1	SRT P1a Pulley	28.5	65				65	2	**56.0%**	44.0%	**21.5%**	**12.1%**	**27.5%**	4.8%	1.78
Test 2	SRT P2a Pulley	38	64	65			64.5	2	**55.6%**	44.4%	**20.2%**	**11.2%**	**25.2%**	4.8%	1.80
Test 3	RSI Rescue Pulley	31	65	66	66		65.5	2	**56.5%**	43.5%	**22.9%**	**12.9%**	**29.7%**	4.8%	1.77
Test 4	SRT P3Ta Pulley (red 16mm)	46	64	64			64	2	**55.2%**	44.8%	**18.8%**	**10.3%**	**23.1%**	4.8%	1.81
Test 5	SRT P3a Pulley	49	63	63			63	2	**54.3%**	45.7%	**15.9%**	**8.6%**	**18.9%**	4.9%	1.84
Test 6	Petzl P00 Pulley wheel	25.5	70	71	70	71	70.5	2	**60.8%**	39.2%	**35.5%**	**21.6%**	**54.9%**	4.6%	1.65
Test 7	CMI Plastic Sheave Rescue Pulley	53	62	61	62		61.5	2	**53.0%**	47.0%	**11.4%**	**6.0%**	**12.8%**	5.0%	1.89

Test 8	SRT P2Pa Prusik Minding Pulley	38	63	64	64		63.5	2	**54.7%**	45.3%	**17.3%**	**9.5%**	**21.0%**	4.9%	1.83
Test 9	CMI Stainless Steel Sheave Rescue Pulley	53	61	62	62		61.5	2	**53.0%**	47.0%	**11.4%**	**6.0%**	**12.8%**	5.0%	1.89
Test 10	Alloy Karabiner		78	79	79	80	78.5	2	**67.7%**	32.3%	**52.2%**	**35.3%**	**109.3%**	4.3%	1.48
Test 11	Steel Karabiner		76	77	76	77	76.5	2	**65.9%**	34.1%	**48.4%**	**31.9%**	**93.7%**	4.3%	1.52
Test 12	CMI Plastic Sheave Rescue Pulley - lubricated	53	60	61	59	60	60.5	2	**52.2%**	47.8%	**8.3%**	**4.3%**	**9.0%**	5.0%	1.92
Test 13	SRT P1a Pulley - lubricated	28.5	63	64	65	65	63.5	2	**54.7%**	45.3%	**17.3%**	**9.5%**	**21.0%**	4.9%	1.83
Test 14	SRT P3a Pulley - lubricated	49	62	63	62	63	62.5	2	**53.9%**	46.1%	**14.4%**	**7.8%**	**16.8%**	4.9%	1.86
Test 15	Figure 8 Descender		99	100	100		99.5	2	**85.8%**	14.2%	**83.4%**	**71.6%**	**503.0%**	3.7%	1.17
Test 16	Italian / Munter Hitch on Alloy Krab		108	108			108	2	**93.1%**	6.9%	**92.6%**	**86.2%**	**1250.0%**	3.6%	1.07

Notes:

All tests completed on 11mm static kernmantel rope.
Figure 8 descender tested with brake rope parallel to standing part, so indicated friction is less than normal abseiling position.
All tests completed with rope forming 180 degree bend around pulley (i.e.M.A. = 2)
Lubricated pulley tests were completed after lubricating the same pulleys as previously tested with WD 40 and wiping away excess lubricant.
Effort Friction measures friction as a % of hauling effort.
Redirection Friction measures friction as a % of load on the redirection.
Load Friction measures friction as a % of the load being lifted.

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