How Efficient are Pulleys and Related Devices used by BWRS in Vertical Rescue.

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Introduction

It is obvious to all vertical team members that the input forces required to lift or move a load, in practice, vary significantly, when using different Pulleys or Pulley Devices.

We saw a need to have a reliable way to compare the efficiencies of pulleys and related devices (such as: - the CMC MPD; and Petzl ID, both are used as devices to combine the function of:- lowering devices, progressive capture devices, inline pulleys) in haul and belay systems. This ability to compare equipment reliably can provide these benefits: -

1. selection from available equipment to build the most efficient systems possible to reduce work load, and hence number of rescuers required;
2. used for comparison as new equipment becomes available;
3. acquisition of new equipment, or replacement of equipment.

This paper is specific to current practice of the Volunteer Rescue Association (VRA) - BWRS Squad, although it is hoped the results will be useful for other squads or other organisations involved with vertical rescue.

What influences the efficiency of a pulley:-

- quality of the bearings, many have roller bearings, while others have just bushing;
- diameter of the sheave, bigger diameter gives a larger moment to overcome bearing friction;
- the angle of the load line and haul line (in this case 180°);
- threading of the blocks to ensure the ropes don't rub: on each other, on the blocks, on other items;
- twisting of the rope in blocks such that the ropes rub, (can be lessened if the blocks have swivel connections);
- probably the load on the block bearings;
- possibly the speed of rotation of the sheaves.

What influences the efficiency of a haul system (A huge range of things including):-

- efficiency of pulleys;
- stretch of rope under load;
- number of resets of MA;
- slack and stretch in a system which needs to be overcome before effective motion can commence, after a reset, (depends on effectiveness and position the progressive capture device);
- friction from edges, obstructions, equipment, redirections;
- twists that develop in the rope system.

It will be interesting, at a later date, to measure the efficiency of systems being hauled by hand. This tends to be a jerky movement so you have repeated stretch/relaxation in the rope which will increase the work input. Low stretch ropes and/or progressive capture devices close to the edge may lessen this.

Aim

1. To develop reliable, reproducible, method to measure the achieved efficiency of pulleys, commonly used in Vertical Rescue by the VRA.
2. To be able to compare the pulley we use now and importantly to compare with any new developments.
3. To build simple mechanical advantages with the pulleys to measure and report the results.
4. To compare these results with calculations to ensure no unexpected deviations.
5. To measure and compare mechanical advantage when using mechanical Progressive Capture Devices (PCD's) as part of inline hauling systems, in current use with the VRA.
6. Use the equipment to test other aspects of vertical rescue.

Note: - this test facility was only designed to handle up to 250km maximum loads, suitable for mechanical advantage testing. <u>THIS IS NOT</u> robust enough to carry out maximum strength destructive testing. We will look at other testing set ups to do this, in the future, such as working with the Rope Test Lab in the Blue Mountains. The Rope Test Lab is already conducting testing, and reporting on equipment and methods used in vertical rescue.

Method

It was decided the simplest system to reproducibly measure the forces would be to lift a test mass vertically with only the pulley(s) being tested in the system. The force would be measured during steady state lift (5m/min) of an 80kg mass (as an "average rescue person"). The same rope and equipment is used for each test to ensure continuity. The hoist hook was connected to the rope in use by short 5mm prussic as a safety link to limit force if any malfunction. We are looking at increasing the test load up to 250kg, for future tests.

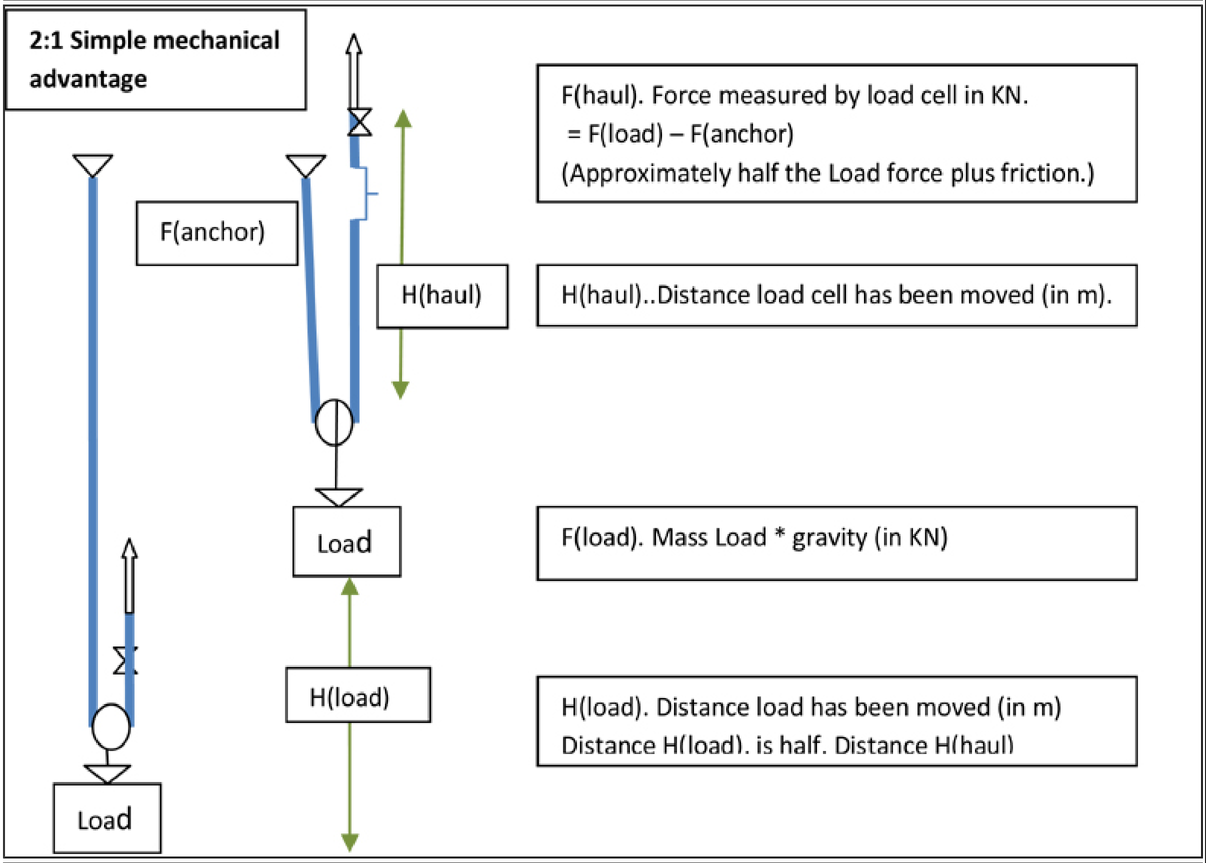
An advantage of measuring efficiency during a steady state lift is that distance moved variables cancel out in the calculation and you only need to record the force applied. In addition stretch in the rope should be comparable for any given MA set up, as the difference in loads on individual ropes are small, and the change in length as the system lifts very similar and has been ignored.

We have used the definition "efficiency of pulley/MA = work output of system / work input to system".

A 250 kg load cell was selected so that small force differences between tests could be detected. We have standardised on one, well used, Blue Water 11mm static rescue rope, for tests. Because we are seeking the "practical efficiency, seen in the field ", the mass of the Pulleys and rope have been ignored as they must be moved to move the load and small in comparison to the load, and should be comparable for comparable tests.

See the following table for explanation.

Table 1a Explanation of Calculations



Work (w) is done when a force (f) move a distance (h), w = f * h.

Work input to the test system = F(haul) (in KN) * H(haul) (in m), KJ

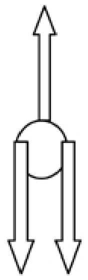
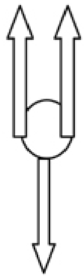
Work output from the test system = (F(load) (in KN)) * H(load) (in m), KJ

The two distances moved are related as: - H(load) = H(haul) / MA

Efficiency = work output from system / work input to system = (F(load) * H(load)) / (F(haul) * H(haul)) = (F(load) / 2) / F(haul)

Efficiency of the pulley or pulley system = (F(load) / 2) / F(haul)

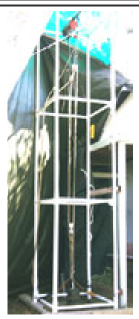
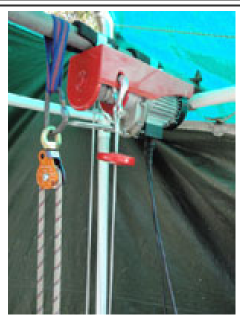
Table 1b Free Body diagram of 1:1 and 2:1 MA

Single Pulley as 1:1 Mechanical Advantage (MA)	**Single Pulley as 2:1 Mechanical Advantage (MA)**
	
Work in = F(haul) * distance moved haul Work out = F(load) * distance moved load Distance moved is same in both cases Efficiency = F(load) / F(haul)	Work in = F(haul) * distance moved haul Work out = F(load) * distance moved load Distance moved haul = distance moved load * 2 Efficiency = (F(load) / 2) / F(haul)

These diagrams show that you would expect to find different efficiencies between these two instances even though the same single pulley is used in each; see calculations below.

There is a difference in tension between F(load) and F(haul) due to the friction in the pulley. If F(load) is 90% of F (haul) as is typical of an efficient pulley. Efficiency = F(haul)*0.9 / F(haul) = 90%.	There is a difference in tension between F(anchor) and F (haul) due to friction in the pulley. If F(load) is 90% of F (haul) as is typical of an efficient pulley. F(load) = F(anchor) + F(haul) F(anchor) = F(haul)*0.9 F(load) = F(haul) + F(haul)*0.9 = 1.9*F(haul) Efficiency = 1.9*F(haul)/2 / F(haul) = 1.9 / 2 = 95%

Table 1: Photos and Description of testing equipment.

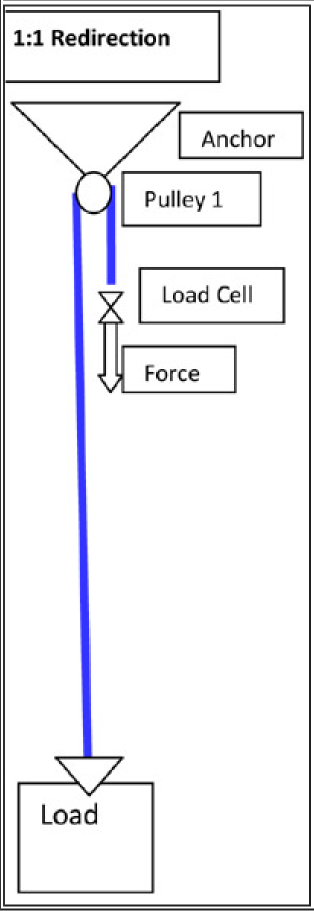
 	To help standardise testing, a tower was built from steel tubing, base 1m square, height 4.5m. A 500kg load, electric cable hoist was mounted at the top in such a way that the lift point can be moved from side to side, to facilitate different setups.
  	A Millennium Mechatronics MT 501 Load Cell with a capacity of 250kg, combined with a MI 102 indicator was used to measure the forces. This meter was picked on the basis it should be able to be read from a distance, and it has a 0-10V analogue output which we integrate with a computer system, using a LabJack U3 HV interface, sampling 20 times a second. An IBM R51 laptop was used for the computing side. The load cell calibration did not zero exactly, so a 4.1kg zero calibration weight was added to the load cell, to enable the log to be read to zero, when required. This combination gives the precision to detect small differences between tests, especially with the higher Mechanical Advantages, where the force measured can be down to less than 20kn. The test load comprises of a stack of gym weights that have been calibrated against two sets of scales. These weights were used to check the calibration of the instrumentation. (*See photos opposite: click to see enlargement)*

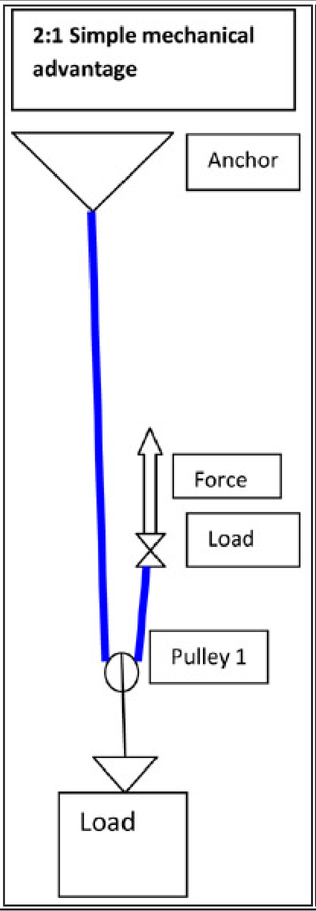
		

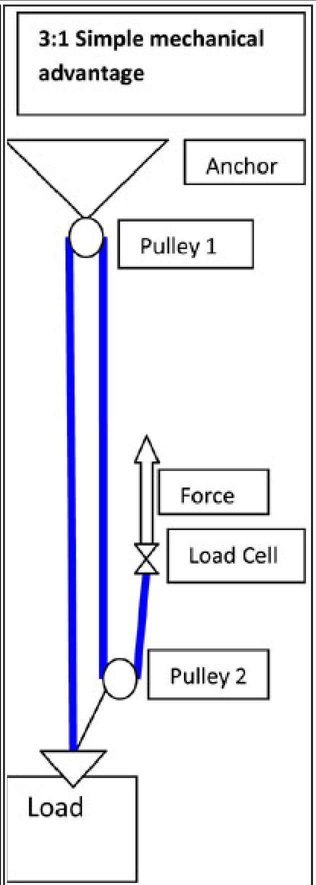
All testing was done by a single operator. A typical sequence was:-

- Set up system within the test tower, with the same rope and equipment each time;
- Lift load stack with hoist to confirm instrumentation and starting mass;
- Set up pulley system to be tested and lightly tension (check meter before each lift);
- Start computer logging, lift working rope with hoist to just below auto cut-out switch, stop logging, (about 25 - 36 seconds of travel);
- Repeat with next test system;
- At end of all tests check full load stack to confirm no drift in meter reading.
- Each recorded log files loaded into Microsoft Excel and a spread sheet created showing average, maximum, minimum, and a graph for analysis (*see below)*.

Table 2: Schematics of 1:1, 2:1, 3:1, 4:1 Blocks Used







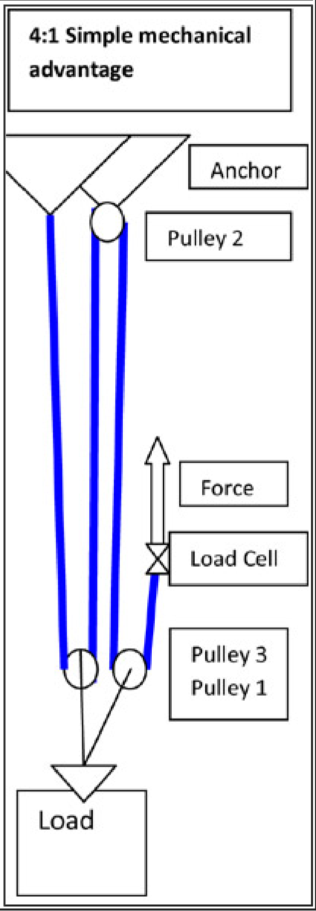
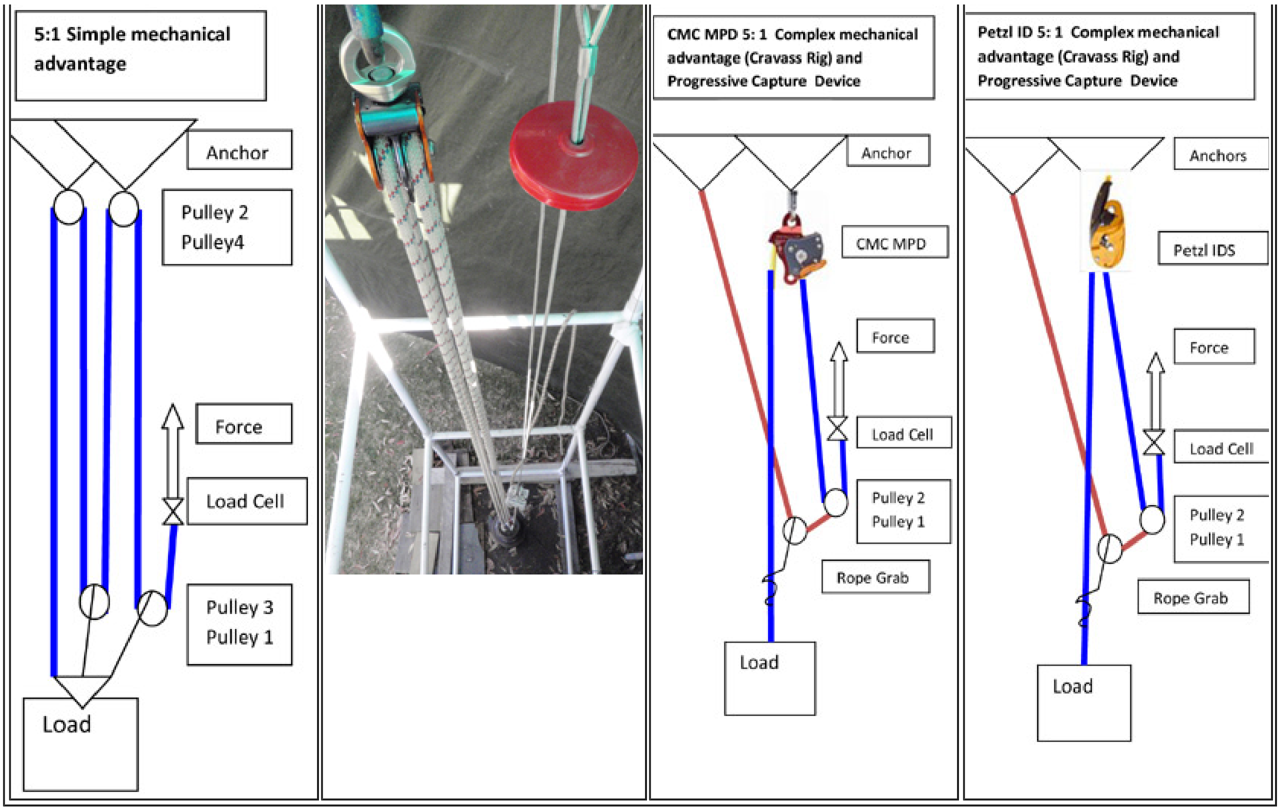


Table 3: Schematic of 5:1 Block with photo of the rig in tower; and of complex 5:1 used with Petzl ID and CMC MPD.			
	5:1 simple in test tower.		



The log files were loaded into Excel and spread sheets created. The functionality of Excel was used to graph the log of force against time to ensure that the reading was reasonably steady. An average force was created for 2 or 3 parts of the trace for the steady portion of the log, to ensure reliability. In all cases the overall average with maximum value and minimum value were recorded. Typical log graph and values reproduced below. This graph demonstrates the rise in force as the system "takes up". From here the graph is steady from approximately 2.4 seconds, to when the hoist was stopped at 27 seconds. After stopping the graph shows the typical decline in force as it equalizes about the pulley anchor. The two glitches at about 15 seconds and 22 seconds occur when the cable over rides another strand and then slips back on the take up drum. With two operators it is possible to reduce these occurrences greatly. However because the averages are derived from so many readings (600 -800) the results are for practical purposes identical.

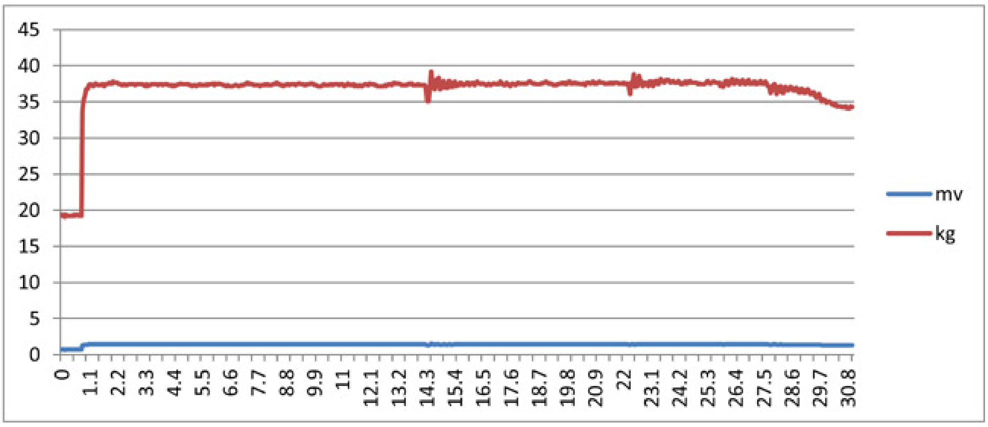
Example of Microsoft Excel Spread Sheet. Showing a Typical Graph of Force with Time during the lift. The lift was stopped at about 27.2 seconds in this example, the decay in force is typical as the "load settles" around the pulleys.

30/08/2012 3:1 Riley 3, bottom, CMI 1 top.

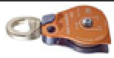
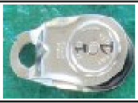
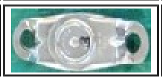
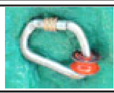
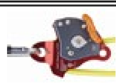
4:14 PM

0, CH+=0, CH-=199, Range=+/-10, y=24.778*a+1.8848

			Count	621	Av overall 37.50	
			Seconds	2.4 -> 14.3	15.8 -> 22	23 -> 27
Time			Av	37.39	37.53	37.73
	mv	kg	min	37.09	37.22	37.09
0	0.7	19.339	max	37.71	37.83	38.20
0.05	0.7	19.215				
0.1	0.7	19.339				
0.15	0.69	19.092				
0.2	0.7	19.339				
0.25	0.7	19.215				
0.3	0.7	19.215				
0.35	0.7	19.215				
0.4	0.7	19.215				
0.45	0.7	19.215				
0.5	0.7	19.339				
0.55	0.7	19.215				
0.6	0.7	19.339				
0.65	0.7	19.339				
0.7	0.7	19.215				
0.75	0.7	19.339				



The following pulleys were tested: -

Pulley	Weight	Sheave	Sheave	Height	Width		Rated Strength
	kg	inner mm	outer mm	mm	mm		kn
Rock Exotica Omni Block 1.5 double	0.517	36	48	135	63		36kn
http://www.rockexotica.com/products/pulleys/omni_blocks.html							
Rock Exotica Omni Block 1.5 single	0.26	36	48	135	63		36kn
http://www.rockexotica.com/products/pulleys/omni_blocks.html							
Rock Exotica Omni Block 1.1 single	0.14	28	36	109	51		23kn
http://www.rockexotica.com/products/pulleys/omni_blocks.html							
CMI RP102 single end	0.29	60	-	108	83		27kn
http://www.cmi-gear.com/catalog/pulleys/original2.asp							
CMI RP112 Double end	0.32	60	-	146	76		27kn
http://www.cmi-gear.com/catalog/pulleys/doubleend.asp							
Riley RM 15 AR single end	0.132	40	48	94	52		15kn
http://www.rileyfittings.com/Page-Home/PDF/Blocks.pdf							
Riley RM 15 A DE double end	0.214	40	48	130	52		15kn
Rescue Systems (bushed bearing)	0.085	23	35	80	46		31kn
CMI Micro RP110D double sheave	0.11	18	32	89	45		31kn
http://www.cmi-gear.com/catalog/pulleys/micro.asp							
CMI Double Micro Hauler	0.25	18	32	159	57		30kn
http://www.cmi-gear.com/catalog/pulleys/uplift.asp							
Petzl red sheave (ULTRALEGERE)	0.001	24	40	40	40		1kn work load
http://www.petzl.com/en/outdoor/single-pulleys/ultralegere							
Steel Carabiner	0.21	12	-	110	68		33kn
Petzl ID S	0.533						2.25kn work load
http://www.petzl.com/en/pro/self-braking-descenders-0/id-s							
CMC MPD	1.2						44kn
http://www.cmcrescue.com/mpd							

Results

2:1 Mechanical Advantage Tests

Summary of Trials testing one pulley as 2:1							
Gravity	0.00981		Mechanical Advantage = MA				
Mass lifted	79.90	-	0.78				
Mass ÷ MA	39.95		0.39		MA ideal =		2
	Kg	Kg	KN	KN			
Pulley	Measured	Extra Force	Force KN	Extra Force	Efficiency		Measured MA
CMI RP 102	42.87	2.92	0.42	0.03	93.2%		1.86
Omni 1.5	42.89	2.94	0.42	0.03	93.2%		1.86
CMI RP 112	42.94	2.99	0.42	0.03	93.0%		1.86
Omni 1.1	43.86	3.91	0.43	0.04	91.1%		1.82
Riley RM 15A single	44.33	4.38	0.43	0.04	90.1%		1.80
Riley RM 15A double	45.17	5.22	0.44	0.05	88.4%		1.77
Petzl red sheave (ULTRALEGERE)	47.60	7.65	0.47	0.08	83.9%		1.68
Rescue System	49.04	9.09	0.48	0.09	81.5%		1.63
Carabiner	53.03	13.08	0.52	0.13	75.3%		1.51

The CMI RP 102 and Omni 1.5 pulleys are both high efficiency but still result in approximately 3kg extra weight to be lifted, compared with ideal. This increases to 4kg for the Omni 1.1 and Riley RM15A. A carabiner used as a pulley requires and extra 13kg to be lifted compared with ideal, but still gives some mechanical advantage.

The results for the Riley pulleys and the Petzl red sheave (ULTRALEGERE) are surprisingly good. The bush bearing in the Rescue System Pulley gave a lower efficiency that didn't improve with cleaning or with lubrication (oil, or graphite grease, or WD40)

3:1 Mechanical Advantage Test

Summary of Trials testing two pulley as 3:1								
	Gravity	0.00981	Mechanical Advantage = MA					
	Mass lifted	79.90	-	0.78	-	-		
	Mass ÷ MA	26.63		0.26		MA ideal =		3
Pulleys		Kg	Kg	KN	KN			
Bottom	Top	Measured	Extra Force	Force KN	Extra Force	Efficiency		Measured MA
CMI RP 112	CMI RP 102	30.95	4.32	0.30	0.04	86.0%		2.58
Omni 1.5	Omni 1.5	31.16	4.52	0.31	0.04	85.5%		2.56
Omni 1.1	Omni 1.1	32.84	6.20	0.32	0.06	81.1%		2.43
Riley RM 15A single end	Riley RM 15A single end	33.60	6.96	0.33	0.07	79.3%		2.38
Riley RM 15A double end	Riley RM 15A double end	34.13	7.50	0.33	0.07	78.0%		2.34
Compare other devices in top pulley position, CMC MPD, Carabiner, Petzle ID.								
CMI RP 102	CMC MPD	29.93	3.29	0.29	0.03	89.0%		2.67
CMI RP 102	Carabiner Steel	35.23	8.60	0.35	0.08	75.6%		2.27
CMI RP 102	Petzl ID	39.05	12.41	0.38	0.12	68.2%		2.05
Carabiner Steel	CMI RP 102	42.02	15.39	0.41	0.15	63.4%		1.90

This test demonstrates, as expected the more efficient pulleys require less force to raise the load. One interesting result is: if you have an efficient pulley and a less inefficient pulley where you use the pulley in the system is very important. Note the tests with a carabiner used as a pulley paired with a high efficiency CMI RP102. When the carabiner is used as the moving (bottom) pulley, an extra 15,39 kg force is required to lift the load; compared with the case where the carabiner is the second (top) pulley (redirectional) requires an extra 8.60. An difference off 6.79 kg force.

Also interesting in this case the Petzl ID as a PCD/pulley is less efficient than the carabiner in the same place. The CMC MPD is an even high efficiency pulley compared with the CMI or Omni pulleys (It is a joy to work with).

4:1 Mechanical Advantage Test

Summary of Trials testing three pulley as 4:1									
		Gravity	0.00981	Mechanical Advantage = MA					
		Mass lifted	79.90		0.78				
		Mass ÷ MA	19.98		0.20		MA ideal =		4
Pulleys			Kg	Kg	KN	KN			
Bottom Inner	Bottom Outer	Top	Measured	Extra Force	Force KN	Extra Force	Efficiency		Measured MA
CMI RP 102	CMI RP 102	CMI RP 112 double end	23.93	3.96	0.23	0.04	83.5%		3.34
Omni 1.5 Double	<-	Omni 1.5	25.04	5.07	0.25	0.05	79.8%		3.19
Omni 1.5 Double	<-	Omni 1.1	25.93	5.96	0.25	0.06	77.0%		3.08
Riley RM 15A single end	Riley RM 15A single end	Riley RM 15A double end	28.05	8.08	0.28	0.08	71.2%		2.85
CMI Micro Double	<-	CMI Double Micro Hauler	47.88	27.90	0.47	0.27	41.7%		1.67

These tests reinforce the fact that the more pulleys in a system will give lower efficiencies, compared with ideal. The less efficient the pulley the more force required as the number of pulleys increase. e.g. the CMI pulleys give a measured MA of 3.34 instead of 4, while the Riley pulleys give a measured MA of only 2.8 rather than 4 and CMI Micro Doubles only 1.67 instead of 4.

5:1 Mechanical Advantage Test

Summary of Trials testing Four pulley as 5:1										
			Gravity	0.00981	Mechanical Advantage = MA					
			Mass lifted	79.90	0.78					
			Mass ÷ MA	15.98	0.16			MA ideal =		5
Pulleys				Kg	Kg	KN	KN			
Bottom Inner	Bottom Outer	Top Inner	Top outer	Measured	Extra Force	Force KN	Extra Force	Efficiency		Measured MA
CMI RP 102 single end	CMI RP 112 double end	CMI RP 102 single end	CMI RP 112 double end	21.71	5.73	0.21	0.06	73.6%		3.68
Omni 1.5 Double	<-	Omni 1.5	Omni 1.5	21.84	5.86	0.21	0.06	73.2%		3.66
Omni 1.5	Omni 1.5	Omni 1.5 double	<-	22.17	6.19	0.22	0.06	72.1%		3.60
Omni 1.5 Double	<-	Omni 1.1	Omni 1.1	23.10	7.12	0.23	0.07	69.2%		3.46
Omni 1.5	Omni 1.5	Omni 1.1	Omni 1.1	23.38	7.40	0.23	0.07	68.3%		3.42
Riley RM 15A single end	Riley RM 15A single end	Riley RM 15A double end	Riley RM 15A double end	26.06	10.08	0.26	0.10	61.3%		3.07
CMI Double Micro Hauler	<-	CMI Micro RP110D double	<-	31.19	15.21	0.31	0.15	51.2%		2.56
Compare Simple 5:1 with complex Crevasse 5:1 using CMC MPD or Petzl ID as the										
Omni 1.5	Omni 1.5	CMC MPD	Complex 5:1 (Crevasse)	18.84	2.86	0.18	0.03	84.8%		4.24
Omni 1.5 Double	<-	CMC MPD	Simple 5:1 Omni 1.5 single	21.07	5.09	0.21	0.05	75.8%		3.79

Omni 1.5	Omni 1.5	Petzl ID	Complex 5:1 (Crevasse)	21.64	5.66	0.21	0.06	73.8%		3.69
Omni 1.5 Double	<-	Petzl ID	Simple 5:1 Omni 1.5 single	23.8	7.82	0.23	0.08	67.1%		3.36

This test continues to demonstrate the diminishing returns as more pulleys are added to the system. However at 5:1 there is still significant benefit from the extra MA.

The effect of having less pulleys in a system is clearly shown by the results for complex 5:1 systems using only 3 pulleys (see schematic of system above, "CMC MPD 5:1" and "Petzl ID 5:1"). The MPD in this configuration returns 4.24 measured MA for the ideal 5:1 compared with the simple 5:1, at 3.79 measured MA.

A surprising result is the performance of the ID in the complex system with a 3.69 measured MA. Observation of the action of the rope passing through the ID, suggests the rope slides through the ID more smoothly than it did in the 3:1 test. One reason for this is that, the load on the rope running through the ID has decreased in comparison to the total load of the system, so there is less force to generate losses on. The device still acts as a PCD though).

1:1 Mechanical Advantage tests

Results testing one pulley at a time as 1:1 redirection							
Gravity	0.00981		Mechanical Advantage = MA				
Mass lifted	79.90	-	0.78				
Mass ÷ MA	79.90		0.78		MA ideal =		1
	Kg	Kg	KN	KN			
Pulley	Measured	Extra Force	Force KN	Extra Force	Efficiency		Measured MA
CMI RP 102	86.04	6.14	0.84	0.06	92.9%		0.93
Omni 1.5	86.69	6.79	0.85	0.07	92.2%		0.92
Omni 1.1	91.69	11.79	0.90	0.12	87.1%		0.87
Riley RM 15A single	92.40	12.50	0.91	0.12	86.5%		0.86
Riley RM 15A double	95.61	15.71	0.94	0.15	83.6%		0.84
Petzl red sheave (ULTRALEGERE)	109.20	29.30	1.07	0.29	73.2%		0.73
Alloy carabiner	149.34	69.44	1.47	0.68	53.5%		0.54

When you compare this 1:1 test with the 2:1 test, the results for efficiency are always less in the 1:1 instance. The reasons for this were explained by the Free Body Diagram, earlier in this report.

Conclusion

These tests set a benchmark against which other pulleys and equipment can be tested, as it becomes available.

The old adage “buy the best pulleys you can afford” defiantly applies as each pulley you use in a system increases the force you must apply to lift your load. In the 3:1 tests the Riley double ended pulleys required an extra 7.5 kg to lift the load compared with the CMI pulleys 3.2kg extra. Theses extra forces could quickly add up to requiring more people on the haul team and add extra stress to the system.

The CMC MPD has been designed as a multi purpose device for rope rescue, it acts as a high efficiency pulley for mechanical advantage, as a lowering device as well as a Progressive Capture Device (PCD). It is an expensive piece of equipment but in this case you do get value for money, compared with anything else available at the moment.

The Petzl ID was designed as an autostop abseil device a job it does very well. It has been adapted as a multi purpose device for rope rescue. It does the lowering and PCD roles very well, but the low efficiency in the pulley roll for MA, means this must be managed carefully. It is vital to ensure any MA is connected to the rope entering the device as this gives acceptable friction. If the MA is connected to the rope coming out of the device the friction multiplies to the extent that the system is unworkable.

The effect the diameter of the sheave has is clearly shown between the Omni 1.5 with 36mm diameter sheave and Omni 1.1 with 28mm diameter sheave, with the 1.5 significantly more efficient than the 1.1cm. At 3:1 MA this equates to an extra 1.7 kg for the Omni 1.1.

The effect of pulley bearings is shown to some extent, between the CMI pulley with a 60mm sheave being slightly more efficient, compared with the Omni 1.5 which has a supper high efficiency bearing but only 28mm sheave. At 3:1 MA this equates to only 0.2kg extra force for the Omni 1.5.

Based on these tests the CMI RP pulleys and Rock Exotica Omni pulleys are the most efficient and provide value for money. The CMC MPD performed exceptionally well. The complex 5:1 "crevasse" mechanical advantage showed clear advantages (compared with a simple 5:1) from the point of view of lower force to lift a given load. The down side of using complex mechanical advantage systems is that the re-set needs to thought out in advance to give the best possible operations.

A comment on pulleys with built in swivels:-

We were very careful to ensure the ropes did not twist during these tests so that rope rubbing on rope should not be a factor in the results.

In the field twisted ropes can add significantly to the haul team load. We will carry out tests to measure this in the future but it is thought unlikely that such tests would be repeatable due to the large number of variables.

In real situations any twist in the haul system can be effectively removed if there is a built in pulley such as the Rock Exotica Omni range. The Omni range also features a patented side-plates that facilitate installing and uninstalling the rope while the pulley is still anchored.

Comparison with the calculations from theoretical

Appendix 1 [link here] is a spread sheet prepared by G. Horrocks designed to calculate the efficiencies and Measured MA for a 3:1 mechanical advantage system as used in these tests. This has been seeded with the Pulley efficiencies measured in the 2:1 tests. As you can see the results are reasonably close, suggesting that we are on the right path.

Executive Summary

From our practical work with rescue rope lowering and lifting systems it is obvious that the effort (forces) required depends to a significant extent on the pieces of equipment being used. We are developing a testing rig that can reliably measure forces involved in those operations. This enables us to compare forces between different equipment and to calculate and compare efficiencies.

We have conducted initial testing which demonstrates that the results are reproducible and reliable measurements made of the efficiencies of a few pulleys and other equipment available for these tests.

Of the equipment tested: -

- Pulleys made by CMI, the RP 102 and RP 112, performed very well giving 93% efficiency.
- Pulleys made by Rock Exotica, the Omni 1.5, performed very well giving 93% efficiency.
- Pulleys made by Rock Exotica, the Omni 1.1, performed well giving 91% efficiency.
- Pulley made by Riley and used for many years in Australia the RM15A, performed well with 89% efficiency, however the strength is marginal for rescue work.
- The Multi Purpose Device manufactured by CMC, the MPD, performed exceptionally as a pulley for inline haul systems, giving 94% efficiency. (A device used for lowering, as a belay and as a progressive capture).
- The Petzl ID performed well as a lowering device and for progressive capture, however it was only just adequate as part of a haul system.