Proposal to Study the Heating of Rappel Devices during Rappel

Dave Custer, Scott Torborg, Ben Zelnick

Summary: As a first step toward measuring and modeling the energy absorbing ability of rappel devices, we rappel and measure the temperature rise of the rappel device, rope, and rappeller's hand. This temperature data is used to determine whether different rappel devices perform differently and, further, to determine how performance varies with the velocity of the rappeller. This data is important for developing a model of rappel device performance and is of interest to the climbing community.

Introduction:

Our study of belay devices is motivated by the lack of data concerning the limitations of rappel devices (RDs). Such data, if available, would be of considerable use to climbers, guiding their purchase and use of RDs. Such data would also guide the deliberations of the UIAA Safety Committee next June when testing standards for belay and rappel devices will be considered.

The research proposed herein focuses solely on the heating of the rope and the RD during rappelling situations encountered by climbers. We want to measure the magnitude of this heating and determine whether this heating is a limitation under reasonable circumstances. Our measures of heating are the heat rise as a function of time during a single rappel and the heat rise as a function of rappel speed. If the instrumentation permits, the temperature rise of the rope will also be measured. This data is then used to better model the heating behavior of RDs and estimate the limitations of RDs in the field.

Model:

Previous Work:

No serious previous work exists on the heating behavior of RDs. Cursory analyses do show the absurdity of transferring all the energy of the rappelling climber into heating of the RD. Additionally, there are "text book" examples that model the RD as simple capstan. Thus, there is no good model showing where the energy of the rappelling climber goes. In the absence of such a model, we hypothesize that the energy of the rappelling climber is transferred to:

Heating the RD and accompanying carabiner
Heating the rope, via internal friction
Heating the rope, via conduction from the RD
Spring energy in the rope, via rope stretch
Heating the rappeller's hand
Heating the air, via radiation and convection

Kinetic energy of the rappeller

Definition of “too hot to use safely”:

Based on our model of heat flow during rappel, we define consider four limitations to RD performance: rope damage – due to both internal friction and sheath melting from contact with the heated RD – and burning of the climber’s hand – due to both friction generated during rappel and contact with the heated RD. The rope damage due to internal is difficult to assess and is thus probably beyond the scope of this experiment, although we may be able to compare the power dissipated internally to other, better documented rope tests. Detecting sheath melting should be straight forward; the melting point of nylon is well documented and such melting is visible to the naked eye. For humans, temperatures above 44ºC cause a sympathetic nervous response to withdraw from contact, and cause damage to human skin if such withdrawal does not occur. If nylon melts and/or skin burns, we consider the RD to be beyond its safety limit.

Working Assumptions:

RDs work by pumping energy into the rope. This assumption is based on the absurd result found by equating the gravitational potential energy of the climber (mass of climber * gravitational acceleration * height) with a heat energy imparted to the RD (the temperature rise * heat capacity * mass of RD). According to this calculation, the belay device should melt long before a normal rappeller gets to the bottom of a normal rappel (80 kg climber +100 meter rappel = 1000ºC temperature rise in the RD).

The rope absorbs energy due to internal friction that occurs as the rope is constrained around bends by the RD. This energy of bending $E_{(b)}$ is probably a complicated critter to figure out. If we’re clever, we’ll think of a way to measure it. In the long run, this characteristic would be a handy thing to know about a rope because this quality governs the rope’s belay and rappel characteristics. $E_{(b)}$ is probably a function of the rappeller’s mass, as well as temperature, radius of curvature, rappel speed, and a number of rope characteristics – mass, modulus, internal friction coefficient….

The limiting condition occurs when the radius of curvature is minimized. Once the rappeller is feeding rope in this configuration, the system is unstable; if the rappeller loses control, control cannot be regained. The phenomenon occurs because the friction coefficient drops precipitously as a function of both temperature and velocity. Once control is lost, the energy absorbed due to internal friction decreases; this deficit in the energy balance can only be expressed as the increased speed of the rappeller or burning of the rappeller’s hand.

A number of corollaries result from these assumptions. The most curious is the possible difference between static and dynamic rappelling, thus the differences in styles between the climbing community and the caving, sport rappelling, and rescue communities. This difference may correspond to the difference between modeling the system as a compressible/non-compressible fluid moving around a bend. And it may be that the study of RDs becomes a study of rope properties.

And there might be room for innovation:

- a RD whose bending radius decreases with temperature or speed
- a rope doped with a thixatropic material

Methods:

Our objective is to determine where the energy goes during rappelling. We compare different RD brand/models to determine the extent to which the energy dissipation differs between these different devices varieties. And, with a single RD brand/model, we determine how the energy is dissipated as a function of the speed of rappel.

Test Matrix:

The devices we have at our disposal are: Black Diamond *ATC*, Metolius *PBD*, a figure 8, the munter hitch. If we were clever, we would also get a "modern," pinch-off style device, such as a Black Diamond *ATC-advanced* or a Trango *Jaws.*

The velocities that we will be able to test are those that can be safely executed. We won't know this limitation until we've done some testing. We expect to be able to measure over about an order of magnitude, from 0.1 m/s to 2 m/s.

Temperature/time and temperature/speed data:

Our basic experiment is to rappel and measure temperature rise. Because rappelling with the measurement equipment would endanger the equipment, instead of rappelling, we'll be lowering, allowing the RD to remain stationary while a weight is lowered. We expect to have time for about 20 lowers. About 2 lowers/device type at a single speed and ten lowers on one device at different speeds. For each rappel, we will thermally image the belay device, the belayer's hand (gloved) and the rope in the vicinity of the belay device; this data will provide a time/temperature plot for each lowering. If we have the capability, we'll measure the speed and/or position of the lowering weight and use this data in conjunction with the temperature data to provide a velocity/temperature plot. We may video-tape parts of the experiment to document radius of curvature and rope thickness.

Resources Requested:

Experiment "space"
Thermal imaging camera and/or thermal probe
Data collection system(s) – laptop w/ data acquisition capability & video camera
Sonar ranger
Pulley system (webbing, carabiners, pulley – I have this DC)
Belay anchor system (DC)
Gloves (DC)

Helmets (DC)
Safety glasses (ESG)
Video camera (ESG)