Negative Rigging Operations
Reducing Stem Stress Through the Use of Damping

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In some sense, this article is a follow up to a previous article featured in the Climbers' Corner of the February issue of Arborist News *(Follett et al. 2022), and in other ways it stands completely alone. We ask you to refer back to that article for details on some of the methods and data collection; however, the relevant content within the specific subject will be fully addressed here.*

Introduction

Tree removal situations that feature rigging operations typically conclude in what is commonly referred to as a negative rigging situation, where the load the rigging must bear "falls into the rope" from above the anchor point (such as when we work our way down a spar). This results in dynamic forces being placed on the tree and equipment that far exceed the static load of the mass of the log. Any opportunity to mitigate these forces while still working efficiently is a bonus for us—the working arborist—and our equipment. Can we use limb removal sequence to help mitigate stem stress? Can the effects of mass and aerodynamic damping be utilized to reduce the stress the stem experiences in a negative rig?

While extensive work has been done to improve our understanding of the concepts of mass and aerodynamic damping within the tree crown, the majority of this has been with a focus on tree/wind interactions. An article by Spatz et al. (2007) demonstrated the decrease in damping ratio with the removal of lateral limbs on a *Psuedosuga menzii* (Douglas fir); James et al. (2006)'s multiple mass damper model has been key to helping understand crown motion in more complex crown structures; and a recent collaborative paper by Jackson et al. (2021) has made great strides in furthering our understanding of crown motion in urban and open-grown deciduous trees. However, how this relates to tree removal situations and the changing dynamics of the tree's structure during said removals has seen far less investigation.

This project set out to examine the impact of leaving limbs below the upper anchor point in a negative rigging situation. The questions addressed are: how much remaining crown is needed to maintain reasonable damping, and does this affect actual stem strain (how much we bend the tree)?

Experimental Design

We returned to Windsor Park in Dorval, Quebec, and again with the aid of the City of Dorval tree crew, we systemically dismantled a green ash (*Fraxinus pennsylvanica*) 14 meters (46 feet) tall with a diameter at breast height (DBH) of 30 cm (12 inches)(Figure 1). The measures collected were very similar to those described in our previous article (Follett et al. 2022). We utilized strain gauges at the base of the tree, a load cell between the port-a-wrap and the tree, an accelerometer in the falling "top," as well as accelerometers attached to each limb to be removed in

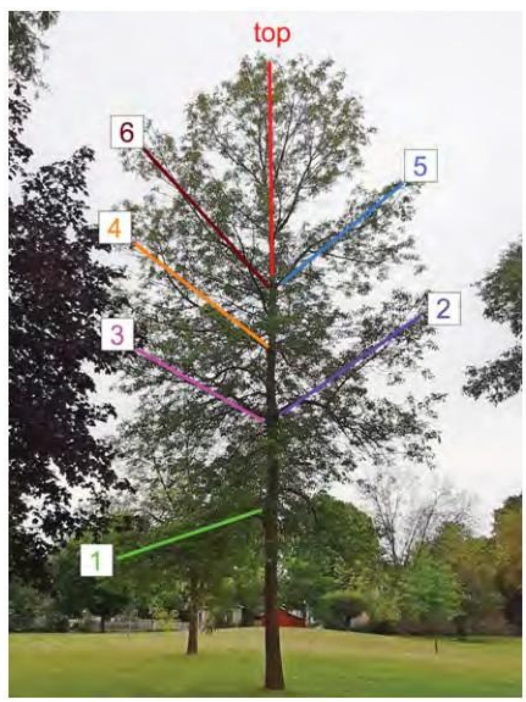

Figure 1. Subject tree and sequence of limb removal.

succession. All sensors captured data at 50 Hz. To slow the decent of a falling piece and bring it to a controlled stop, the rising rate robot groundie ramp was used once again.

To eliminate their effect, the tree was stripped of small lateral limbs on the main stem, with no pruning to any of the remaining 6 subject limbs (Figure 1). To reduce variance caused by misalignment and ease the setup up of the falling piece, a pseudo top was used consisting of just a stem log (Figure 2) and a metal alignment device to retain it during set up and direct the flight path.

Figure 2. Device to locate and retain pseudo top and direct flight path.

The pseudo top was dropped repeatedly (3 times), then the lowest limb was removed, and we dropped the top 3 times again. This continued as we worked our way up the tree until all the limbs were removed, and we conducted 3 final drops with just a standing spar.

Each limb was weighed, and several linear measurements were taken to collect allometry data; a sample of this can be seen in Table 1. It should be noted that the pseudo top had a mass approximately half that of the original top; however, if you refer to Figure 3, notice that the peak stem strain and port-a-wrap load are similar. This is attributed to the aerodynamic drag slowing the decent of the original top with its full leaf and branch arrangement.

Results

Figure 4 provides a sample of the changes in the raw data as we progressed through the experiment. Note the progressively increasing stem strain and the increase in the decay time

Table 1. Sample of allometry data collected.

Part	Mass (kg)	Length (m)	% Total mass	Stem area
Top	108	5.5	13	1.0
Limb 1	71	6.7	8	0.87
Limb 2	62	5.8	7	0.36
Limb 3	24	4.6	3	0.59
Limb 4	38	5.8	4	0.32
Limb 5	16	4.8	2	0.22
Limb 6	18	4.5	2	0.22
Repeat piece	50	2.0		1.0

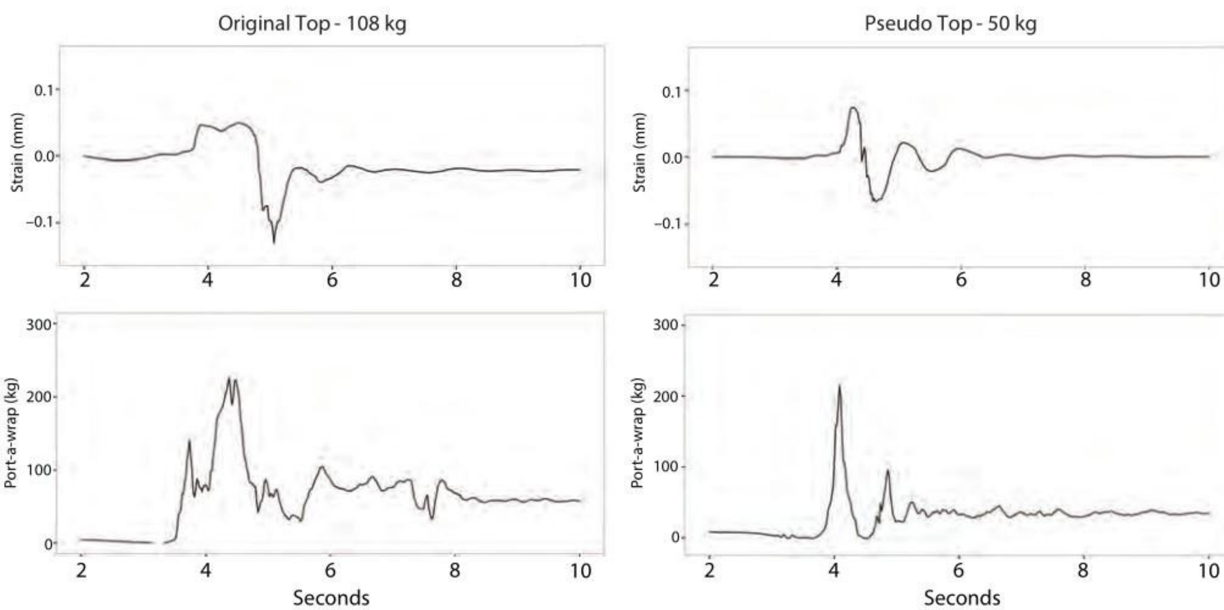

Figure 3. Sample data set showing original top with leaves as compared to pseudo top used for all subsequent tests.

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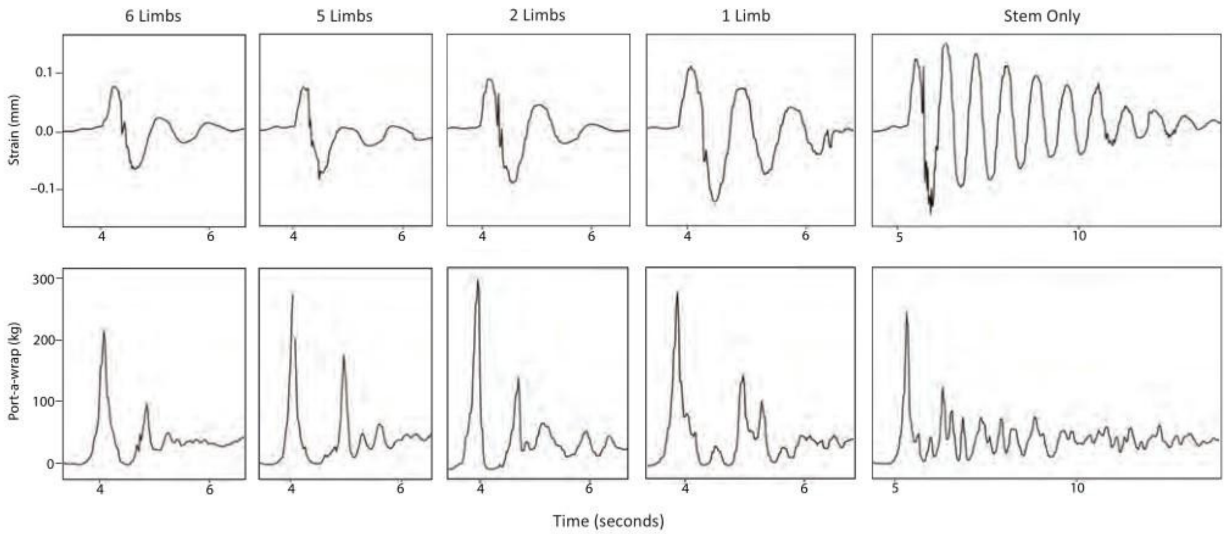

Figure 4. Selection of data to demonstrate changing peak strain and increased decay time.

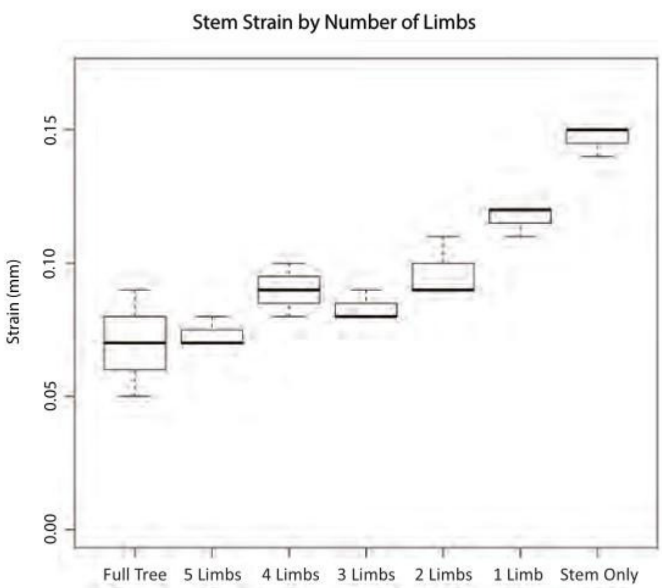

Figure 5. Results showing increasing stem strain with removal of limbs.

(the period of time and number of oscillations in the stem since the trigger event). To analyze these data, we selected peak strain and used one-way analysis of variance (ANOVA). This is represented in Figure 5, where we see a significant increase in measured stem strain with the removal of the last two limbs. This suggests that leaving even one small limb (less than 1/3 stem diameter) near the upper anchor reduces the peak stem strain (in this case by approximately 20%); furthermore, in this specific instance, leaving two limbs in close proximity reduced the strain by approximately 35%!

Discussion Points

Obviously, it would be difficult if not impossible to retain limbs all the way to the bottom of the tree for a rigging operation (particularly in tight drop zones where we routinely utilize the upper anchors to manipulate large limbs into tight quarters on the ground). However, these results have potential to adjust our habits when sequencing removal operations. While having a clear spar below makes the removal easy, in the case of tall slender stems, perhaps consider leaving a few limbs below at least the "big ugly top" you want to throw. Go even further and leave some manageable limbs further down the spar to remove once you get close. There's also a little trick to reduce the negative rig scenario if the sequence follows something like that shown in Figure 6, where the anchor point can be above the limb that was used as the damping member. This is particularly useful in those cases where you are blocking down firewood sized pieces of a tall slender stem, but the limbs themselves are too large or too unwieldy to fit/land in the drop zone.

One More Discussion Point

It is important to note that this concept of damping works on the stem in what can be considered lateral

Bending Moment

$M = FL$, where M is the moment, F is the Force, and L is the length of the beam.

Potential Energy

$E_p = MGH$, where E_p is potential energy, M is the mass of the object, G is the force of gravity, and H is the height, or our distance of fall.

Figure 6a. Suggested sequence of limb removal with numbered locations indicating approximate center of mass (COM) relative to the rigging point: height of COM above rigging point × 2 = DOF. Note that limb #2 has a shorter DOF then #1, while limb #3 is not a negative rig; the COM is below the rigging point. Photograph courtesy of Jimmy Beaupre-Cauchon.

Figure 6b. Keeping the rigging point above the union of limbs #1 and #2 allows limb #2 to have a shorter DOF then if the rigging point for the initial top (#1) had been at or below the union. Photograph courtesy of Jimmy Beaupre-Cauchon.

(sideways) forces; the forces that produce what we know as a bending moment within the stem. Similarly, a negative rigging scenario initially creates a lateral force in the stem, as the piece is caught by the rigging before it is directly below the anchor point, pulling the anchor not directly down, but laterally. We also know that the length

Figure 6c. Continued sequence maintains a damping effect through retention of lower limbs. Photograph courtesy of Jimmy Beaupre-Cauchon.

of the lever arm (or the height of the stem) plays a crucial role in the magnitude of that bending moment; for the same input force, the longer the lever arm, the larger the bending moment. So if we rig a 100-kg (220-lb) piece of wood from a 20-m (66-foot) tall stem, it would impart two times the bending moment for the same 100-kg piece on a 10-m (33-foot) stem. Now add in what we refer to as distance of fall (DOF), which is the distance the piece falls before it is caught in the rigging, and this too has a multiplication effect, where a long slender stem falling into the rigging will impart a higher force then that of a shorter stem of the same mass. Now consider standing on a thin narrow spar on a tall tree, about to negative rig a slender section above you. It may only have a mass of 100 kg, but since it is slender, it is very long (with a large DOF), and since you are near the top of the tree, the lever length is large. This scenario combines a large amount of potential energy to create a large bending moment on the stem, and while the rigging gear may well be up to the task of the forces at play, the large lever arm of the tall slender stem amplifies the stresses within the stem. So let us consider the application of damping in these instances and how we can find ways to mitigate the stresses we are placing on the tree and the gear we are using.

Climb safe!

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Matt Follett is a climbing arborist with a strong interest in preserving large trees in the urban environment. He is currently a PhD student at Université du Québec à Montréal (UQAM) focusing on the effects of pruning on tree resilience in the urban environment, as well as climber safety. Bastien Lecigne is currently a postdoctoral fellow in the Department of Biological Sciences, UQAM. He does research in Horticulture, Tree Architecture, and the application of Terrestrial Laser Scanning in the urban forest. Andreas Detter is a consulting arborist, expert witness, instructor, and researcher with Brudi & Partner Tree Consult, Germany. His extensive background includes tree biomechanics and climber safety research. Lothar Göcke is a design engineer with an extensive background in electrical engineering. He has worked to develop industry-leading tree motion sensors, sonic tomography systems, and tree pulling test equipment. Dr. Christian Messier is professor of forest ecology and urban forestry at UQAM and Université du Québec en Outaouais (UQO). He holds an NSERC/ Hydro-Québec Chair in urban forestry since 2009, working on tree growth, architecture, biomechanics, and urban tree planning. All images courtesy of the authors unless otherwise stated.

Crossword Puzzle

Clues

Across

1. Pruning system focused on creating specific shapes
3. The primary terminal shoot of a tree
7. The practice of caring for trees
8. Baum (in German)
9. Thin layer of meristematic cells
14. Boundary zone that separates healthy wood from damaged wood
16. Stem of grass, sedge, and bamboo
17. The stalk of a leaf
18. Junction of stem and branch
20. Limb of a tree
22. A semiformal system of pruning
23. A large, divided leaf structure
24. Selective pruning for dead and/or broken branches
26. Branches lacking a collar

Down

2. Pruning system that involves interweaving or tying branches
4. Incorrectly called a sucker
5. Damage to the bark of living branch or stem
6. Pruning cut that leaves a stub
10. Tree branch with largest diameter
11. One or more crown reduction prunings
12. Root shoots
13. Member of Arecaceae family
15. Removal of stems to stimulate new growth
19. Wound healing
21. Tree care professional
24. The upper part of a tree
25. The point of bud, shoot, and leaf growth

Terms and clues based on *Best Management Practices: Pruning*. 3rd Edition. 2019.

Crossword created by Simrat Singh.
Answer key on page 62.