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ADMIN: Reason(s) Not Eligible

John Z. Duling Grant Application

Please note: This application may only be submitted July 1 - October 1.

If you have any questions, please email bduke@treefund.org or call 630-369-8300 x200.

Applicant

Principal Investigator

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Degrees	Ph.D.
Relevant citations authored	Kane, B. Compatibility of toothed ascenders with arborist climbing ropes. Arboriculture & Urban Forestry 37(4):180-185. Kane, B., S. Brena, and W. Autio. 2009. Forces and stresses generated during rigging operations. Arboriculture & Urban Forestry 35(2):68-74. Kane, B. 2007. Friction coefficients for arborist ropes passing through cambium saver rings. Arboriculture & Urban Forestry 33(1):31-42.
Has this investigator previously received funding from the TREE Fund?	Yes
If yes, was the funding for this project?	No
Previous TREE Fund awards	Most recent award was TREE Fund #10-HJ-01 in 2010: "Growth and Dynamic Motion of Cabled Trees with Co-dominant Trunks"

Co-Principal Investigator (if applicable)

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Relevant citations authored	
Has this investigator previously received funding from the TREE Fund?	No

If yes, was the funding for this project?	No
Previous TREE Fund awards	

Students/Interns (if applicable)

Student/Intern 1

Name	Mark E. Novotny
Department or major	not yet determined
Status	

Student/Intern 2

Name	
Department or major	
Status	

Student/Intern 3

Name	
Department or major	
Status	

Project

Project title	Measuring forces at multiple locations in rigging systems
Research area	Risk assessment and worker safety
Project summary	Arboricultural rigging carries a very high degree of risk. Climbers must estimate how much force will be generated when rigging pieces of wood, and where the cut pieces will move when being rigged. Heavy pieces of wood swinging around or shock-loading the tree have very high momentum. If they collide with the climber or the tree, severe or fatal injury, tree failure, or both can be the result. Despite the risk and the development of new gear and techniques intended to reduce the risk, very few rigorous studies have quantified the forces generated while rigging, making it impossible to know with certainty whether new gear or techniques actually reduce the risk. This proposal describes a project to measure rigging-induced loads at multiple points in a rigging system, and compare the effect of varying components of a rigging system on the loads. In particular, a variety of ropes, blocks, and rigging loads will be tested to determine their effect on loads measured at different points in the rigging

system.
These measurements will be used to determine the friction in rigging blocks and lowering devices (e.g., Port-A-Wrap, GRCS).
Understanding the effect of friction has important implications for safety. Depending on the amount of friction in a rigging block, failure of the rigging rope or the anchor point (block, sling, or tree) will be more likely. Knowing how much friction a lowering device provides helps tree workers anticipate how many wraps on a lowering device are needed to carry an expected load.

Statement of problem

Rigging is inherently dangerous. Rigging branches and wood from trees can induce very large impulse loads, especially when the rigging involves shock-loading from rigged pieces that are abruptly decelerated to prevent them from damaging a target below. Rigging structurally-deficient trees exacerbates the danger because defects like decay, cracks, and weakly attached branches reduce the load-bearing capacity of the tree.

Rigging-induced loads are borne by the rigging gear. At the very least, rigging gear includes a lowering rope and an anchor point. The anchor point can be on the tree from which branches and wood are being removed or it can be on a nearby tree. A very simple rigging system includes a lowering rope passed over a branch union and tied to a lower branch being removed. A ground worker holds the lowering rope (perhaps taking a wrap around the trunk of the tree to add friction which reduces the force the ground worker must apply to hold the load).

Simple rigging systems have limitations. Among these are inflexibility in choosing the location of the anchor—it is mostly restricted to locations of branches, and greater rope abrasion that results from rope-on-bark friction. Friction between the rope and the bark reduces the length of lowering rope that carries the rigging-induced load. This means that fewer rope fibers must carry the load, which increases the likelihood of rope failure.

To address limitations of simple rigging, arborists have adapted rigging tools from other disciplines (e.g., pulleys and blocks) and developed new tools (e.g., friction devices like the Port-a-wrap). A primary advantage of using a block with a rotating sheave is that the lower sheave friction allows more of the rope to extend under load, reducing the likelihood of rope failure. However, a more even sharing of the load between the lead and fall of the rope increases the load at the anchor point, which may increase the likelihood of its failure. New rigging blocks (X-Rigging rings, SafeBloc) have been developed to address the latter concern, but a better understanding of the friction between different types of lowering ropes and various types of blocks (those with a rotating sheave and those without) is integral to reducing risk in rigging. Similarly, knowing the amount of friction provided by a lowering device will improve tree workers' ability to safely and efficiently manage rigging loads.

Significance of your proposed project as it relates to the profession of arboriculture or

A better understanding of how rigging systems carry loads is critical to improving tree worker safety. There are many anecdotal examples of rigging system failure. Failures can be of the gear or the anchor,

urban forestry	and climber injury or fatality is almost certain. Failure of the lowering rope may be less likely to injure the climber than failure of the anchor, but damage or injury to a ground worker is still very likely if the lowering rope fails. “Climber’s Corner” features at conferences often address the risks of rigging, and new gear has been developed with the intention of reducing the risk to tree workers and property. However, without careful measurements and statistically rigorous analyses, guidelines to reduce the likelihood of failure remain, at best, educated guesses based on individual or collective experience. Cursory or sloppy measurement and analysis of rigging loads may be more problematic because it gives a false sense of confidence that a new technique or tool limits risk. Collected empirical data can also be used to validate computer models of rigging systems. Engineering tools like finite element analysis (FEA) efficiently investigate parameters related to the likelihood of failure of an anchor or gear, but must be based on rigorous empirical data. FEA can be used to determine which input factors (e.g., rope length and elasticity, mass of the rigged piece, diameter and modulus of rupture of the branch, etc.) most affect the likelihood of failure. Bartlett Tree Experts and N.A.T.S fully endorse this project (see attached letters).
Description of what is currently known about proposed project area	Very little empirical work has investigated loads in climbing and rigging systems, even though climber fatalities have occurred (Ball and Vosberg 2004). Blair (1989) recommended rigging larger pieces to reduce the number of cuts made with a chainsaw. He did not measure the actual cutting time, so it is unclear that this approach would reduce the likelihood of being cut. It is also unclear whether the risk is greater when cutting with a chainsaw or when the rigged piece loads the rigging system. Removing large pieces—especially when shock-loading the rigging—can induce very large loads which, in turn, induce large stresses on rigging gear (rope, block, sling, friction device) and the tree itself (Kane et al. 2009). It is possible to cause any part of the rigging system to fail (including the tree), and structurally-deficient trees, which are often rigged for removal, have a reduced load-bearing capacity. Kane et al.’s (2009) study highlighted three important aspects of rigging loads. First, they demonstrated that mass of the piece or top was the best predictor of loads measured at the rigging block and in the fall of the rope. Mass accounted for almost 70% of the variation in rope tension and 80% of variation in force at the block for rigged pieces (i.e., branchless trunk sections). It accounted for more than 90% of the variation in rope tension and force at the block for tops. Measured loads also greatly exceeded the mass of tops and pieces when shock loading the rigging. In contrast, other factors (e.g., fall distance, angle and depth of the felling notch, and length of rope in the rigging system) accounted for less than 5% of the variation in rope tension or force at the block for pieces or tops. Secondly, they showed that theoretical predictions of rope tension assuming a falling rock climber (Pavier 1998) did not accurately predict measured

tension due to rigging loads. Third, their work revealed differences when rigging branched tops compared to pieces of the trunk, illustrating the effect of a slender stem’s deflection, acting like a shock absorber, to reduce the impulse load.

The results from this project (Kane et al. 2009) provided guidelines for practitioners to rig trees safely and mostly aligned with work carried out by Detter and colleagues (Detter 2008; Detter et al. (2008). All of the studies were a useful starting point for future investigations, but each was limited. Detter et al. (2008) tested a very small sample of trees, precluding rigorous statistical analyses and hypothesis tests. Kane et al. (2009) conducted a rigorous experiment and statistical analyses, but considered only one species. To maintain experimental control, all trees were morphologically similar and all trunk pieces (except tops) were cut to the same length.

In unpublished work conducted in 2008 and 2010, Kane (In Review for publication in Urban Forestry & Urban Greening), continued collecting data to address limitations of Kane et al. (2009). The follow-up data collection tested trees of the same species and similar morphology, but pieces were cut to different lengths, accelerations near the rigging point were measured in addition to measurements of force at the block and rope tension, and some pieces were gradually lowered to the ground (“letting pieces run”) rather than shock-loading the rigging system. Data collected in 2008 and 2010 (Kane, In Review) measured a threefold increase in force at the block when shock-loading compared to letting pieces run.

Although removing less massive pieces and letting pieces run clearly reduces the loads on the rigging, which, in turn, reduces the likelihood of failure of the rigging gear and the anchor (usually the tree being rigged), it is not always possible to follow these guidelines. Under severe loading conditions like shock-loading to rig large pieces of wood, it is critical to minimize the rigging-induced loads.

From a strictly mechanical perspective, two competing rigging scenarios arise to reduce loads on different parts of the rigging system. In the first scenario, friction at the anchor point is minimized to allow a greater length of lowering rope to carry the rigging load. Especially if the rope is more elastic, doing this will reduce the impulse load because the rope can stretch more to absorb the kinetic energy of the rigged piece. Minimizing friction at the anchor is usually accomplished with a conventional rigging block, although no block is completely without friction (Donzelli 1999). If a greater length of rope carries the impulse load, the rope itself is less likely to fail (Donzelli 1999). However, reducing friction in the block (or other anchor) to share the rigging load between the lead and fall of the rope, the reaction force at the anchor (whether the block, sling, or tree part to which they are attached) will increase. In the idealized case of a frictionless anchor, the anchor must carry a load that is twice what the rope itself carries (assuming that the fall and lead of the rope remain parallel).

Instead of reducing friction in the anchor to reduce the likelihood of rope failure, increasing friction reduces the reaction force that the anchor must carry because the lead of the rope will carry more of the load than the fall. New rigging products (e.g., X-rigging rings and the SafeBloc rigging system) take this approach, but there are many variables that influence whether increasing friction truly reduces the likelihood of failure or simply shifts the analysis to another component in the rigging system. In other words, reducing the load at the anchor, while reducing the likelihood of failure of the block, sling or tree, may increase the likelihood of failure in the lead of the lowering rope. To analyze the risk in each of these scenarios, many parameters must be carefully considered: type of rope, length of lead and fall of the rope and the angle made between them at maximum load, magnitude of impulse load, load-bearing capacity of the tree itself, and perhaps others not yet known.

The two alternatives for rigging to reduce rigging-induced loads are mutually exclusive, but assume failure of different components of the rigging. Understanding better the magnitude of friction for different combinations of ropes, blocks, rope lengths in the lead and fall, and loads is critical to understanding the likelihood of failure of the rigging system. Without rigorously collected and analyzed empirical data, no assessment of the likelihood of failure will be valid.

Donzelli (1999) measured friction in three common rigging blocks, using a conventional testing method: raising and lowering known masses while measuring tension in the fall of the rope. This was a reasonable approach considering the absence of data at the time, but it does not reflect the impulse loads commonly experienced when rigging a tree (especially when shock loading). It was not possible to precisely measure the friction supplied by the block used in the follow-up study (Kane, In Review) because forces were only measured at two points (at the block and in fall of the rope) and the angle made by the lead of the rope when it was under maximum tension was not measured. With high speed videography, Detter (2008) reported that the angle between the lead and fall of the rope at maximum rope tension varied between 32 and 42 degrees from the vertical. This work was limited by a very small sample size which made it impossible to determine whether factors like stem deflection, notch depth and angle, mass and length of the piece, and varying aspects of the rigging system affected the angle. In the follow-up study (Kane, In Review), friction coefficients were calculated for an expanded range of angles presented by Detter (2008): 20 – 50 degrees.

Using the conventional testing approach (Donzelli 1999), the ratio of tension in the fall and lead of the rope that passed over a block varied with the mass being raised or lowered. The median value of all tests was 84% (Donzelli 1999), indicating that the effect of friction was not very large: equal tension in the fall and lead of the rope occur for a (hypothetical) frictionless block. Measurements in the follow-up study (Kane, In Review) produced ratios between 51% and 58% for the range of assumed angles between the lead and fall of the rope. This suggests that under impulse loading, the frictional properties of the block are quite different than when tested conventionally. If friction is greater in conventional blocks than typically believed, tension in the lead of the rope will exceed that in the fall of the rope, reaction force at the anchor will be less, and the presumed advantages of rigging systems such as the X-Rigging rings and SafeBloc may be moot.

References

Ball and Vosberg. 2004. Arborist News
Blair. 1999. Arborist Equipment. ISA
Detter. 2008. Arborist News.
Detter, Cowell, McKeown, and Howard. 2008. RR668 HSE Forestry Commission UK.
Donzelli. 1999. Journal of Arboriculture
Kane, Brena, and Autio. 2009. Arboriculture & Urban Forestry
Pavier. 1998. Sports Engineering

Summary of project goals

The goals of this project, which is part of a larger investigation on understanding the likelihood of failure of gear and anchors when rigging and climbing, are to:
1. Provide rigorous empirical data describing the loads in various parts of climbing and rigging systems.
2. Determine the effect of relevant parameters (e.g., the type of rope and block, magnitude of the impulse load) on loads at various places in climbing and rigging systems.
3. Data from 1. and 2. will be used to calculate friction coefficients under different loading scenarios for tools used in rigging like various types of blocks (e.g., conventional, X-Rigging rings, SafeBloc) and friction devices (e.g., Port-A-Wrap, GRCS).
4. Compare data from 1. and 2. with an existing finite element model (that has been developed in collaboration with colleagues in the UMass Department of Civil & Environmental Engineering) to assess the likelihood of branch failure under loads induced by different climbing systems (moving rope system, stationary rope system) and simulated falls.
5. Disseminate results in appropriate venues (conferences, tree climbing competitions, podcasts / webinars, scholarly journals and trade magazines) to ensure that practitioners have ready access to the practical application of the findings. Bartlett Tree Experts and North American Training Solutions (N.A.T.S.) will expedite this process and have pledged support (see attached letters).

Description of measurable outcomes expected

It is expected that results from this project will be readily translated into practice, which can reduce the risk associated with climbing and rigging. Although it would be difficult to measure the change in risk, it is possible to estimate the number of tree workers and arborists who are aware of the results and how it can change their rigging practice. This should improve worker safety over time.

In addition to publishing scholarly and professional papers describing the results, and presenting results at conferences, strategic partners on the project [(Bartlett Tree Experts and North American Training Solutions (N.A.T.S.)] can immediately incorporate results into their training programs. For Bartlett Tree Experts, this means that 800 tree workers and arborists throughout North America and in the United Kingdom will learn about the advantages and disadvantages (with respect to likelihood of system failure) of various rigging systems. In addition, last year, N.A.T.S. trained 4,850 tree workers (and had face-time with about 10,000) across North America. The outreach effort can be easily measured to gauge how many tree workers (and where they work) have better information on rigging systems. This will have an immediate, positive impact on tree worker safety.

Project plan including design, hypotheses, methodology and analyses

The null hypothesis to be tested in this project is: Independent variables (type of block, type of rope, length of rope in the lead and fall, impulse load, friction device) do not affect friction coefficients in the block through which the lowering line is run to rig a free-falling mass.

The methodology for this project will be broadly similar to conventional drop tests the work of Kane (2011), who followed the EN 12841-2006 Standard (Anonymous 2006) for testing rope grabs. In this method, a known mass free falls a specified distance (1 or 2 m) before loading a rope grab (e.g., a cam ascender) attached to a test rope. The maximum load and arrest distance are measured.

The test described in EN 12841-2006 (Anonymous 2006) will be modified to test rigging blocks and ropes. A series of Dillon EdXtreme dynamometers (11 kN capacity, accurate to 1 N, sampling at 1000 Hz) will be placed into the rigging system. One will anchor the block being tested and measure the reaction force which the block, sling, and anchor point must carry. This dynamometer will be attached to a fixed point capable of bearing substantial loads with only minimal deflection. A large, horizontal branch was used in previous tests (Kane 2011); laboratory facilities on the University of Massachusetts campus can also be used. Two additional dynamometers will measure tension in the lowering rope. For some tests, the additional dynamometers will measure tension in the fall and lead of the rope being tested. In other tests, one additional dynamometer will measure tension in the fall of the rope, and the second will measure tension in the rope after it passes through a friction device (e.g., a Port-A-Wrap or GRCS). Simultaneous measurement of loads at three locations will facilitate the calculation of friction coefficients in the block and at the friction device.

Fixed masses from 50 kg – 150 kg (greater if possible) will be attached to a separate rope that holds them in place prior to testing. A fixed free-fall distance (1 m) will be used, but the length of rope in the fall and lead of the lowering rope will be varied orthogonally (i.e., in multiples such as, 1 m, 2 m, 4 m). The total length of lowering rope will also be varied, but will be limited by the height of the anchor point. Loads will be recorded continuously and simultaneously from three dynamometers for the duration of the test (just prior to the free fall of the fixed mass until the mass stops moving once the lowering rope stops its downward motion) by a Dillon radio controller unit. The radio controller will be connected to a laptop that records the data for each dynamometer over time. Time histories of loads at three locations in the rigging will provide better insights into whether (and how) different rigging components (types of ropes and blocks) affect not just the magnitude of the load, but also its duration. The latter is important because a force of lesser magnitude that acts for a longer duration can be comparable to a force of greater magnitude that acts for a shorter duration.

Tests will be conducted in a stratified random fashion, with randomly selected combinations of rope and block tested with each fixed mass. The effect of friction in the block will be calculated as the ratio of tensions in the fall and lead of the rope. This is not the way Donzelli (1999) calculated friction coefficients, but doing so will allow a comparison of friction on conventional blocks with friction on blocks without rotating sheaves coefficients (e.g., X-Rigging rings and SafeBloc). The same approach can be used to calculate the friction provided by a Port-A-Wrap or GRCS. For those tests, the number of wraps taken around the friction device (measured as radians of the angle of rope contact with the device) will be varied in addition to varying the type of block and rope and the fixed mass. An analysis of variance (ANOVA) will be used to compare the effects of mass, type of rope, length of rope in the fall and lead, and type of block on friction (i.e., the ratio of tensions in the lead and fall of the rope). A separate ANOVA will be used to assess the effect the same independent variables, as well as the angle of rope contact with the friction device, on friction provided by the friction device (expressed as the ratio of rope tensions in the fall of the rope and in the rope after it has passed through the friction device).

Please note that the University's audit rules do not allow me to add voluntary cost-sharing amounts to the detailed budget requested on this form. Since waived overhead cost covers the required 10% matching, that amount is all that I can indicate in the budget. However, North American Training Solutions (N.A.T.S.) has pledged support to donate gear and offer in-kind labor to conduct the experiment, which are described in detail in their letter of support, emailed to Barb Duke under separate cover. Please note, third-party contributions are shown for informational purposes only.

References

Anonymous. 2006. Mountaineering equipment—Rope clamps—Safety requirements and test methods. British Standards Institution, London

Additional references listed in the literature review section

Description of plan for disseminating the results of this project	Results will be actively distributed to tree workers and arborists in the United States and globally. At least one peer-reviewed article (in a journal such as Arboriculture & Urban Forestry or Urban Forestry & Urban Greening) and one professional publication (such as Arborist News or TCI magazine) will be published from the results. As stated above, results and their application will be disseminated

	through training efforts of strategic partners [Bartlett Tree Experts and North American Training Solutions (N.A.T.S.)] at local and centralized training programs throughout North America and in the United Kingdom. This is critical because N.A.T.S. trains thousands of workers every year and Bartlett has thousands of production employees. Many of these workers do not actively read journals. Results will also be presented at regional, national and international meetings and conferences. Brian Kane has presented over 170 seminars around the world on arboricultural biomechanics and tree worker safety, including many times at TCI Expo and the ISA Annual Conference. He has also regularly presented at regional meetings in New England (e.g., the Massachusetts Arborists Association, New England Chapter of the ISA, Massachusetts Tree Wardens and Foresters Association, and the Connecticut Tree Protective Association) and throughout the United States (since January 2016, he has presented seminars and workshops in California, Colorado, Kansas, and Washington). Development of a podcast or webinar similar to those produced by ISA's Educational Goods and Services team is also planned. Such media are easily hosted on the various UMass platforms (like Dr. Kane's webpage).
Project start date	05/01/2017
Project completion date	12/31/2019
Geographic range of project	USA & Canada

Budget

Compensation/Stipend

Proposed project budget	4171
Requesting from TREE Fund	4171
Funding from other sources	0
Value of in-kind support from other sources	0

Employee Benefits

Proposed project budget	829
Requesting from TREE Fund	829
Funding from other sources	0
Value of in-kind support from other sources	0

Travel (> 50 miles)

Proposed project budget	1200
Requesting from TREE Fund	1200
Funding from other sources	0
Value of in-kind support from other sources	0

Local Transportation (< 50 miles)

Proposed project budget	27
Requesting from TREE Fund	27
Funding from other sources	0
Value of in-kind support from other sources	0

Equipment (vehicles, growth chambers, etc.)

Proposed project budget	16500
Requesting from TREE Fund	16500
Funding from other sources	0
Value of in-kind support from other sources	$0

Supplies (paper, ink, toner, etc.)

Proposed project budget	0
Requesting from TREE Fund	0
Funding from other sources	0
Value of in-kind support from other sources	0

Contract Labor (contractor, speaker, etc.)

Proposed project budget	0
Requesting from TREE Fund	0
Funding from other sources	0
Value of in-kind support from other sources	$0

Other/Misc.

Proposed project budget	13409
Requesting from TREE Fund	2273
Funding from other sources	11136
Value of in-kind support from other sources	0
Description of other/misc. expenses	University of Massachusetts-Amherst charges 59.5% indirect costs, but the TREE Fund allows 10% (which is the requested amount listed). Matching funds are in the form of waived indirect costs (59% - 10%).

Total

Proposed project budget	36136
Requesting from TREE Fund	25000
Funding from other sources	11136
Value of in-kind support from other sources	0

Funds already received from other sources	0
Funds pending from other sources	0
Value of in-kind support already received from other sources	0
Value of in-kind support pending from other sources	0

How did you hear about this grant?	TREE Fund website

Applications will be scored on the following scale:

- Applicant is qualified (10 points)
- Applicant has experience (5 points)
- Project has potential to result in transformative research ideas or approaches (5 points)
- Project directly meets one or all TREE Fund priorities (10 points)
- Project has clearly stated need (10 points)
- Project is clearly linked to arboriculture and/or urban forestry (5 points)
- Research has practical application (10 points)
- Project design is scientifically sound, methods are clear and analysis is appropriate (15 points)
- Project is likely to result in peer reviewed publication (10 points)
- Objectives are achievable within proposed time frame (5 points)
- Objectives are achievable within proposed budget (5 points)
- Requested funds have potential to leverage future support from other funding sources (5 points)
- Requested funds are matched with at least 10% cash or in-kind (5 points)

Your application will not be available for editing after it has been submitted.
Please review your application for completion before submission.