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Developing a Remotely Operated Falling Wedge

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Developing a Remotely Operated Falling Wedge

by

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1. Main research findings

- This project tested using a conical screw used by arborists to wedge over sections of trees. It was found that the threads did not strip even when very large torques were applied to the wedge; however, at the large torques required to initiate falling the wedge tended to bore a hole in the tree rather than separating the backcut. An additional problem found when using a conical wedge was that friction on the surface of the wedge produced a very large moment about the vertical axis of the tree and this threatening to break the holding wood.
- A scissor jack was developed as an alternative to the conical wedge, and this jack is called the Wood duck. It was found that the Wood duck did not require an external housing, could develop an mechanical advantage multiplying the input force, and that it could be easily driven by a cordless drill.
- To minimize the input torque required to drive the Wood duck it was important to reduce the friction in the rotating parts. When using a ball-screw to separate the arms of the Wood duck, with the ball-screw nut attached to one arm and a thrust bearing attached to the other arm, the Wood duck could be back-driven by applying a load to the outer surfaces of the jaws. However, the thrust bearing was under sized and failed early in testing. When replacing the thrust bearing with an aluminum-bronze washer this significantly increased friction. In future prototypes the trunnion holding the thrust bearing must be redesigned to allow the use of a larger thrust bearing.

- The required input torque for the Wood duck to produce an 89kN separation force is well within the rated maximum torque of the Milwaukee 0721-20 angle driver. The existing drill drivers have proven motors, drive trains, and battery systems; however, they also include parts that are not necessary for driving the Wood duck. The mass of the Milwaukee 0721-20 angle driver can be easily reduced by 1.5kg when the unnecessary angle drive unit is removed and this combined with mass savings in the jaws and arms should produce a complete system with a mass of less than 10kg.
- When using the Wood duck with the novel holding wood pattern developed by Lyons and Noll (2011), the success rate of falling trees increased from 78% found in the previous study to 91% found in this study. When using the Wood duck most of the failures were trees that began to fall before the Wood duck was inserted. Three of the four failures had a major imbalance in the direction of fall and if the faller had been permitted to increase the size of the tension strip for these trees, these failures could have been eliminated.

2. Executive Summary

Previous research has shown that a new holding wood system consisting of an uncut strip, called a tension strip, can be used in conjunction with a remotely actuated hydraulic flange spreader to remove the faller from the base of the tree when displacement is initiated (Noll and Lyons, 2010 and Lyons and Noll, 2011). The previous research was constrained by the desire to minimize the weight of the separation tool, and this limited the separation force of the hydraulic flange spreader to 44.5kN. This relatively small separation force limited the maximum size of the tension strip, and for trees that were imbalanced in the direction of fall this resulted in failures where the tree displaced before the flange spreader was inserted. Additionally, the relatively small separation force limited the ability of the flange spreader to overcome an imbalance opposite to the direction of fall. A tool with a larger separation force would permit the use of larger tension strips while still having a sufficient reserve to initiate falling of trees with significant imbalance opposite to the direction of fall. This paper describes the development and preliminary testing of a new falling tool (the Wood duck) that produces 89kN of separation force, has the potential to be remotely operated, and weighs less than 10kg.

The current prototype of the Wood duck is able to produce double the separation force of the previously used hydraulic flange spreader when applying an input torque at the maximum range for a battery operated drill. When testing the Wood duck under lab conditions it was found that the aluminum-bronze thrust washer used in the lower trunnion had a friction coefficient of approximately 0.12, and this resulted in a loss of about half the applied torque. It is assumed that most of the friction loss is due to the thrust washer because when a thrust bearing was used in the original configuration the Wood duck could be back-driven when a load was applied to the outside surface of the jaws.

A small field trial was conducted after adjusting the dimensions of the tension strip and the location of the weakening cut to account for the stronger separation force produced by the Wood duck. Using these adjusted dimensions and the Wood duck, the success rate was increased to 91% from the previous study (Lyons and Noll, 2011) which had a success rate of 78%. When using the Wood duck it was noticed that 3 of the 4 failures had a major imbalance in the direction of fall and if the faller had been permitted to increase the size of the tension strip for these trees, these failures could have been eliminated. It was also noted in the field trial that placing the Wood duck in the weakening cut rather than in the backcut did not appear to alter the input torque required to initiate falling; however, placing the Wood duck in the weakening cut did reduce unwanted loading on the holding wood and allowed for better placement of the tension strip.

Several observations can be made for improving the Wood duck. The prototype Wood duck is still heavier than desired and this is mainly due to the large jaws and arms connecting the jaws to the trunnions. Initially there was concern that asymmetric loading could create a large moment that the jaws would have to support; however, the wood appeared to deform sufficiently to mitigate some of the asymmetry in the notch and the large moment was never realized. Thus, future versions of the Wood duck should explore reducing the size of the jaws and arms. The required input torque is at the upper limit for existing battery operated drills and at the maximum load the drill motor stalls or nearly stalls resulting in a very large drain on the battery. The aluminum-bronze thrust washer in the lower trunnion must be replaced with a thrust bearing and this may require redesigning the lower trunnion. The existing drill drivers have proven motors, drive trains, and battery systems; however, they also include parts that are not necessary for driving the Wood duck. The mass of the Milwaukee 0721-20 angle driver can be easily reduced by 1.5kg when the unnecessary angle drive unit is removed and this combined with mass savings in the jaws and arms should produce a complete system with a mass of less than 10kg.

3. Research problem

Motor manual tree felling remains an essential activity when harvesting timber on steep and broken terrain, and is still considered to be one of the most dangerous professions in the forest industry, especially in the Pacific Northwest (Paulozzi, 1987; WorkSafeBC, 2010 $_{a,}$ 2010$_{b}$). Unseen debris falling out of the canopy is one of the most common causes of fatalities and serious injuries when manually falling trees (Bentley et al, 2005; Helmkamp and Dek, 1999; Holman et al, 1987; Myers and Fosbroke, 1994; NIOSH, 1976), and this often occurs when a tree begins to displace during falling (Peters, 1991). Thus, removing the faller from the base of the tree when it begins to displace could greatly improve safety.

Previous research has shown that a new holding wood system consisting of an uncut strip, called a tension strip (Figure 1), can be used in conjunction with a remotely actuated hydraulic flange spreader to remove the faller from the base of the tree when displacement is initiated (Noll and Lyons, 2010 and Lyons and Noll, 2011). The previous research was constrained by the desire to minimize the weight of the separation tool, and this limited the separation force of the hydraulic flange spreader to 44.5kN. This relatively small separation force limited the maximum size of the tension strip, and for trees that were imbalanced in the direction of fall this resulted in failures where the tree displaced before the flange spreader was inserted. Additionally, the relatively small separation force limited the ability of the flange spreader to overcome an imbalance opposite to the direction of fall. Thus, a tool with a larger separation force would permit the use of larger tension strips while still having a sufficient reserve to initiate falling of trees with significant imbalance opposite to the direction of fall. The objectives of this paper are to describe the development and preliminary testing of a new falling tool that produces 89kN of separation force, has the potential to be remotely operated, and weighs less than 10kg.

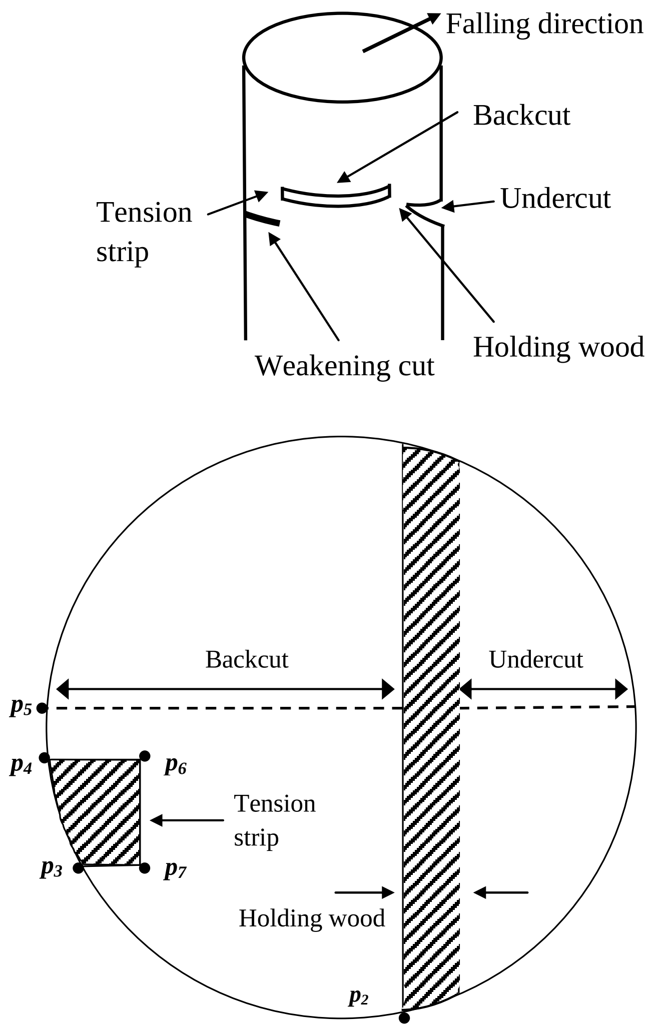

Figure 1, Cutting pattern Lyons and Noll (2011)

4. Methodology

4.1Concept selection

The hydraulic flange spreader used in the previous research (Noll and Lyons, 2010 and Lyons and Noll, 2011) was the FASTORQ HS10K. Flange spreaders differ from traditional bottle jacks used in falling trees in that only the jaws need to be inserted into the backcut; therefore, a large notch does not need to be cut into the stump to hold the jack. The existing HS10K system including flange spreader, hose, and hand pump has a mass of 13.5 kg, 7.6cm travel, requires a 11.5cm wide notch to fully engage the jaws, and produces a maximum separation force of 44.5kN. The HS10K system worked reliably; however, it was found that 44.5kN of separation force was not sufficient and the weight and awkwardness of carrying the long hydraulic hoses and pump through the forest was a real limitation.

Given the new commercially available cordless drills with output torques of up to 115Nm, there appears to be the opportunity to use a battery powered separation tool. The Rattlewedge (Conyfair, 2011) is a conical screw used by arborists to wedge over sections of trees. It would be simple to couple a Rattlewedge to a cordless drill and then use a remote control to actuate the drill; however, the separation force developed by the Rattlewedge was difficult to calculate and field testing was required to determine if this concept had merit. During field testing it was found that the Rattlewedge was simple to thread into the backcut, and even under very large torques (880Nm) the threads did not strip. However, when the required torque exceeded 400Nm the wedge tended to bore into the tree without producing separation. In addition, a very undesirable result of applying such a large torque to the Rattlewedge was that friction between the wedge and the top surface of the backcut produces a large moment about the vertical axis of the tree, and in some cases this moment produced a noticeable rotation of the tree which threatened the integrity of the holding wood. Two additional versions of the Rattlewedge were tried one with a highly polished surface to reduce friction, and another with the length of the cone increased. The modifications to the Rattlewedge did not dramatically improve the performance, and safety concerns terminated further testing of the Rattlewedge.

A battery powered gear driven separation tool has the potential to be light weight and operated by a wireless remote control. In addition there are commercially available battery operated drill drivers that produced the required input torque. The challenge was to develop a jaw and housing mechanism that could produce an 89.0kN separation load, while still minimizing weight. The existing gear driven flange spreaders with ratings greater than 89.0kN are too heavy (over 20kg) with little opportunity for weight reduction. The design criteria the new gear driven flange spreader are;

1. produce a separation force of 89.0kN when applying a 73.0Nm torque (which is available from existing battery operated drill drivers),
2. when open have a jaw separation of at least 7.5cm, and
3. weight (including drill driver and battery) of less than 10kg with the potential for further reduction.

Several methods were considered to meet the design criteria including minimizing the housing size, minimizing friction between rotating parts, and developing a mechanical advantage in the tool. A form of a scissor jack, with a ball screw replacing an acme screw, was selected for development because it was able to incorporate all the methods considered to meet the design criteria.

4.2 Wood duck design

The scissor jack developed in this project was named the Wood duck due to the duck-bill shape of its jaws and its use on trees (Figure 2). A Nook Industries 750-0200-SBN7202 ball-screw was specified for its rated capacity, minimum rotational friction, and favourable input torque to output force ratio. The upper trunnion is attached to the ball-screw nut. Initially a SKF 51202 V/HR11Q1 ball thrust bearing was housed in the lower trunnion for further reduction of rotational friction. The maximum outside diameter of the thrust bearing was constrained by the size of the trunnion and the inside diameter was constrained by the diameter of the ball-screw shaft. These constraints resulted in a bearing that was underrated for the application; however, we still hoped to gain some useful insight into the effect of friction in this tool. Unfortunately the bearing failed before detailed testing began and the thrust bearing was replaced with an aluminum-bronze washer. One significant observation before this replacement was made was that applying a load to the outside of the jaws would back drive the ball screw. However, the increased friction of the aluminum-bronze washer overcame this feature and the Wood duck could not be back-driven by applying a force to the outside of the jaws.

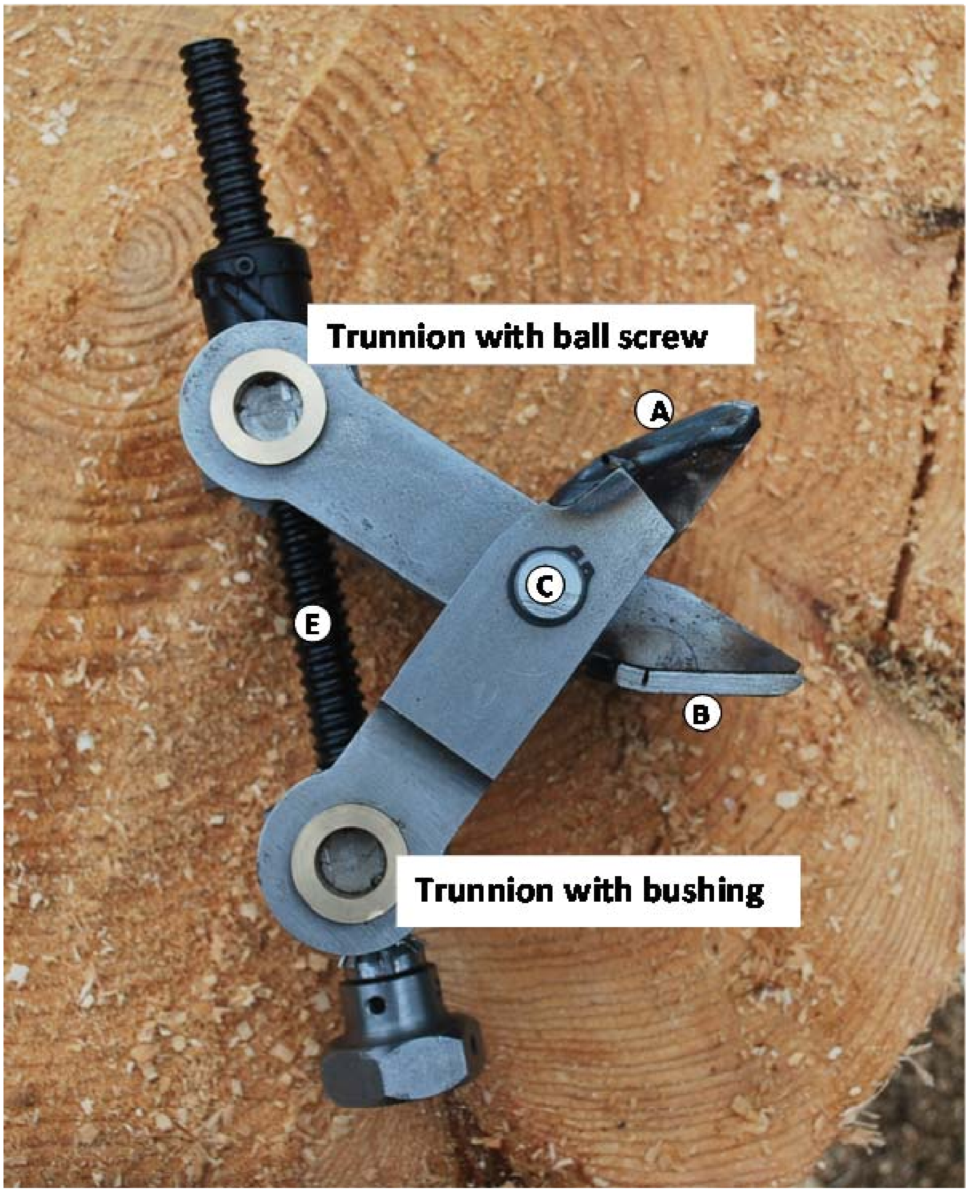
Trunnion with ball screw
A
C
E
B
Trunnion with bushing

Figure 2, Wood duck

As will be discussed in the testing section, the variability in the surfaces of a notch cut with a chainsaw precludes a fixed determination of the contact point location relative to the Wood duck pivot (point C, Figure 2). Thus, the following assumptions were used to estimate the required input torque; the maximum 89kN separation force is required when the distance between A and B (Figure 2) is 59.0mm, concurrently the horizontal distance from the center of the ball screw (E) to the pin (C) is 71.1mm, and the horizontal distance from the pin (C) to the expected contact points with the notch (A and B) is 43.2mm. The ratio of these two horizontal distances produces a mechanical multiplication of the axial load in the ball screw of 1.65; therefore, the required ball screw axial load to produce an 89.0kN separation force when ignoring friction in the pin bushings is

$$89.0\mathrm{kN}/1.65 = 53.9\mathrm{kN} \tag{1}$$

The torque lost due to friction at the upper thrust bushing, when assuming the coefficient of kinetic friction to be 0.1 and the average radius of the bushing to be 0.012m, is estimated at

$$53.9\mathrm{E3N} * 0.1 * 0.012 = 64.7\mathrm{Nm} \tag{2}$$

The Nook Industries 750-0200-SBN7202 ball screw requires $8.89E - 4$Nm of torque to lift a 1N load, thus, the required input torque to achieve the design separation load is

$$53.9\mathrm{E3N} * (8.89E - 4)\ \mathrm{Nm}\ /\mathrm{N} + 64.7\mathrm{Nm} = 113\mathrm{Nm} \tag{3}$$

The estimated required input torque of 113Nm is close to the 122Nm maximum rated torque of the Milwaukee 0721-20 right-angle drill, which indicates it is a reasonable starting point for the design. However, as will be discussed in the testing section, testing demonstrated how the increased friction of the aluminum bronze washer imposed a high load on the drill and an excessive drain on the battery, severely limiting its charge life. Therefore, future prototypes of the Wood duck will feature an enlarged lower trunnion to accommodate a suitable thrust bearing that will lower friction losses and put the tool well within the torque range of existing battery operated drills. The total mass of the Wood duck and Milwaukee 0721-20 angle driver is 11.8 kg (7.1kg and 4.7kg for the Wood duck and angle driver respectively), which is slightly over the target mass of 10kg. The angle drive is not required for operating the Wood duck and its removal will reduced the mass of the Milwaukee 0721-20 by 1.5kg. If additional mass savings can be found by optimizing the design of the jaws and the arms that connect the jaws to the trunnions, then it will be possible to produce a complete system with a mass of less than 10kg.

5. Results

5.1 Wood duck testing

Conclusive testing of the Wood duck's performance was difficult given the variability in operating and environmental conditions. For example, the dimensional variability of a notch cut with a chainsaw can result in asymmetric loading of the Wood duck and variability in positioning the jaw contact points. Secondly, variation in fibre quality and tensile properties frustrate accurate determination of the tension strip strength. Thirdly, lean, sweep and an asymmetric crown combine to produce an imbalance that affects the loads exerted on the tension strips. All these factors will affect test results, and when environmental factors such as wind are included this makes it very difficult to define a definitive set of tests to evaluate the performance of the Wood duck. However, preliminary tests are required to guide future development and two sets were conducted for this paper. The first set of tests attempted to determine the separation force produced for a given input torque, and the second set of tests was a field trial to determine if the success rate of the cutting pattern developed by Lyons and Noll (2011) could be improved when using the Wood duck.

The jaws of the Wood duck were designed to provide two stages of contact with the notch, in the first stage the contact point is closer to the pin and there is a higher mechanical multiplication for breaking the tension strip, in the second stage the contact point shifts farther away from the pin and permits a longer travel to keep pushing the tree until gravity can continue the motion. The exact contact point at a particular jaw position is difficult to estimate because the wood will deform to accommodate local stress concentrations, and in fact it is an area of contact with a non-uniform stress field rather than a point. To determine the separation force produced for a given input torque the Wood duck, equipped with the aluminum-bronze thrust washer was placed between two wood spacers on a Material Testing System MTS 810. The jaws were open so the distance between A and B was 59.0mm, which was similar to the distance used in the design calculations. In this position the forces applied by the load cell and support table were normal to A and B. A torque wrench was used to drive the Wood duck and for a given run the torque was initially set at 27.1 Nm and increased by increments of 13.5Nm up to 81.3Nm, the test was replicated five times. The maximum input torque for these tests was kept below the estimated maximum required load to ensure that the Wood duck was not damaged and that field tests could be conducted using the same prototype.

The relationship between the separation load and the input torque was very linear (Figure 3), and using input torque (T_{in}) as the response variable and jaw separation force (F_S) as the explanatory variable, simple linear regression gives

$$T_{in} = 1.31F_S + 9.42 \qquad (F_{STAT} = 363, \text{p-value} < 0.0001) \qquad (4)$$

Here T_{in} is in Nm, and F_S is in kN. Substituting (2) into (3) but leaving the coefficient of friction (μ) as a variable, and equating this to (4) with F_S set to 89.0kN results in an estimated μ of 0.12. This estimate of μ assumes the friction loss is primarily from the aluminum-bronze thrust washer and not from the bushings on the pins, which is a reasonable assumption given the Wood duck could be back-driven when the original thrust bearing was in place in the upper trunnion. This estimate of μ is similar to that used in (2) and this indicates that up to half the applied torque is lost to friction in the upper thrust bushing.

Previous work by Lyons and Noll (2011) found that a new cutting pattern (Figure 1) combined with a flange spreader that provided a maximum of 44.5kN of separation force, could be optimized to produce a 78% success rate. Here success is defined as displacement of the tree was initiated by the flange spreader, and failure is defined as the tree began to displace before the flange spreader was applied or the flange spreader was not able to initiate displacement. Given these results it was desirable to increase the strength of the tension strip to prevent trees from displacing before the Wood duck was inserted; however, the strength of the tension strip could only be increased so far before an imbalance opposite to the direction of fall combined with the strength of the tension strip resulted in the Wood duck not being able to initiate falling. Thus, after some initial trials the target dimensions of the tension strip were set at $p_4$to $p_6 = 75\text{mm}$, $p_6$to $p_7 = 150\text{mm}$, and $d_1 = 100\text{mm}$ (Figure 1).

A field trial was conducted where trees were sampled as the faller worked the stand to determine if the success rate of the cutting pattern developed by Lyons and Noll (2011) could be improved when using the Wood duck and the new target dimensions for the tension strip. A torque wrench was used to drive the Wood duck and for a given tree the torque was initially set at 27.1 Nm and increased by increments of 13.5Nm until displacement was initiated. Success (S)

and Torque (T) were collected as response variables. Success is a binary variable where $S(1)$ represents a tree that was successfully felled with the Wood duck, and $S(0)$ represents either a tree that began to displace from the stump before the Wood duck was actuated or a tree that could not be displaced by the Wood duck. Torque is the maximum torque applied to the Wood duck in order to initiate falling, and because the torque wrench was increased by 13.5Nm increments Torque is defined as the midpoint of the last increment before falling was initiated. Other covariates such as tension strip cross section area (TA), distance between the weakening cut and the backcut (d_1), tree species (Sp), tree height (Ht), stump diameter (D), wind (MW), and imbalance (MI) were recorded. Tree species has been reduced to two classes, where $Sp(0)$ is a red cedar and $Sp(1)$ is either a western hemlock or a Douglas-fir. Western hemlock and Douglas-fir have been combined because only three Douglas-fir were sampled and because of the similar mechanical properties of Douglas-fir and western hemlock. Wind and imbalance have three classes, where 0 is a minor effect in any direction or a major effect perpendicular to the direction of fall, 1 is a major effect in the direction of fall, and 2 is a major effect opposite to the direction of fall. Here, minor is a small effect for which it is difficult to judge the direction it is acting, and major is a large effect for which the direction can be accurately judged by the faller.

Initially the Wood duck was placed in the backcut beside the tension strip as was done in previous studies with the flange spreader. In this study the larger separation force produced by the Wood duck permitted the use of a tension strip with a large cross section. The large tension strip provides a strong surface to push against if the Wood duck is placed in the weakening cut instead of the backcut, and pushing directly on the tension strip might reduce the load required to initiate falling. In addition, placing the Wood duck in the weakening cut allows the tension strip to be centered in the backcut rather than offset. The class variable Inweak was used to indicate whether the Wood duck was placed in the weakening cut (Inweak(1)) or whether it was placed in the backcut (Inweak(0)).

Overall 44 trees were sampled in the Wood duck field tests, with 40 being successes and 4 being failures (Table 1). This increase of the success rate to 91%, from the 78% success rate of the previous study (Lyons and Noll, 2011), is a promising result. The increase in success rate was likely the result of the increased separation force supplied by the Wood duck and the increased strength of the tension strip. A particularly interesting result of the field tests conducted for this study is that all the failures were trees that began to fall before the Wood duck was applied, and that 3 of the 4 failures had a major imbalance in the direction of the fall. A major imbalance indicates the faller was very confident of the direction of the imbalance, and if he had been permitted to increase the strength of the tension strip for trees with a major imbalance in the direction of fall it may have been possible to approach a 100% success rate. The 91% success rate is creating one problem though. Failure is now a rare event and it is not possible to construct useful statistical models with Success as the response variable in these small field trials.

Table 1, Field test summary

Sp	**n**	**S(1)**	**Mean D (cm)**	**Mean Ht (m)**	**Mean TA (cm^2)**	**Mean d_1 (cm)**	**Mean T (Nm)**
Fd	3	3	60	36.2	126	11.0	70.5
Hw	18	15	53	34.7	107	10.1	44.9
Cw	23	22	71	28.1	124	10.1	54.7

Torque is an estimate of the maximum torque applied to the Wood duck for trees that were successfully felled with the Wood duck ($S(1)$). To determine which explanatory variables are significantly correlated with Torque consider the following two models.

$$T = b_0 + b_1 ML(1) + b_2 ML(2) + b_3 TA + b_4 d_1 + b_5 Ht + b_6 D + b_7 MW(1) + b_8 Sp(1) \quad (5)$$

$$T = b_0 + b_1 ML(1) + b_2 ML(2) \quad (6)$$

Note MW(2) was not included in (5) because all entries for this variable were zero and so it could be formed by a linear combination of the intercept. Considering (5) as the full model and (6) as the reduced model, *T* is not significantly correlated with *TA*, d_1, *Ht*, *D*, MW, or Sp (ESSF-stat =1.30, df_{Full} = 31, df_{Red} = 37, p-value = 0.288). *ML*(1), *ML*(2), and the intercept were all found to be significantly correlated with *T*. The coefficients for *ML*(1), *ML*(2), and the intercept in the reduced model are respectively -26.8 (p-value 0.002), 21.3 (p-value 0.045), and 43.8 (p-value < 0.001). Care must be taken when interpreting the lack of correlation between *T* and explanatory variables such as *D* and *Ht* because of the small sample size and the relatively narrow range in these attributes. If a larger range in *D* was sampled it could well begin to have a significant effect on the maximum torque required to initiate falling. The results from this study are promising, because for this stand it was possible to select a target *TA* and d_1 that produced a system that was insensitive to many of the variables that are important to consider when falling trees, and this greatly simplifies the job of the faller who might use this system.

When forming a full model by adding Inweak to the parsimonious model (6), and considering (6) as the reduced model it can be seen that Inweak is not significantly correlated with *T* (ESSF-stat =1.31, df_{Full} = 36, df_{Red} = 37, p-value = 0.261). This result indicates the mechanics of initiating falling by pushing either on the top surface of the backcut or the top surface of the weakening cut, does not have a significant effect on *T*. Even though *T* is not reduced when the Wood duck is placed in the weakening cut, it does provide more flexibility in locating the tension strip, and it does avoided having the load from the Wood duck near the holding wood which could compromise the holding wood. Thus, this study indicates it might be preferable to switch the location of the Wood duck from the backcut to the weakening cut.

5.2 Conclusions

Lyons and Noll (2011) developed a cutting pattern for motor manual tree falling where a hydraulic flange spreader was used to initiate displacement of a tree once the faller had retreated to a safe position. The success of the previous system was limited by the maximum separation force supplied by the flange spreader, the operational feasibility was limited by the heavy external hydraulic pump and the awkward hoses required for remote operation. The Wood duck, as described in this paper, has the potential to solve these problems.

The Wood duck can be driven by commercially available battery operated drills, and if these were fitted with remotely controlled switches this would eliminate the problem of handling long hydraulic hoses. In the current prototype of the Wood duck it is possible to produce twice the separation force as the previously used hydraulic flange spreader, when applying an input torque at the maximum range for a battery operated drill. When testing the Wood duck under lab conditions it was found that the aluminum-bronze thrust washer used in the lower trunnion had a friction coefficient of approximately 0.12, and this resulted in a loss of about half the applied torque. It is assumed that most of the friction loss is due to the aluminum-bronze thrust washer, because when a thrust bearing was used in the original configuration the Wood duck could be back-driven by a load was applied to the outside surface of the jaws.

A small field trial was conducted after adjusting the dimensions of the tension strip and the location of the weakening cut to account for the stronger separation force produced by the Wood duck. Using these adjusted dimensions and the Wood duck, the success rate was increased to 91% from the previous study (Lyons and Noll, 2011) which had a success rate of 78%. When using the Wood duck it was noticed that 3 of the 4 failures had a major imbalance in the direction of fall. This indicates in this trial that the combination of new cutting dimensions and increased separation force from the Wood duck were able to accommodate trees with a minor imbalance. If the faller had been permitted to adjust the cutting dimensions further then it would have been a relatively simple decision to adjust the dimensions of tension strip to account for a major lean in the direction of fall. It was also noted in the field trial that placing the Wood duck in the weakening cut rather than in the backcut did not appear to alter the input torque required to initiate falling; however, placing the Wood duck in the backcut did remove unwanted loading on the holding wood and allowed for better placement of the tension strip.

Several observations can be made for improving the Wood duck. The prototype Wood duck is still heavier than desired and this is mainly due to the large jaws and arms connecting the jaws to the trunnions. Initially there was concern that asymmetric loading could create a large moment that the jaws would have to support; however, the wood appeared to deform sufficiently to mitigate some of the asymmetry in the notch. Thus, future versions of the Wood duck should explore reducing the size of the jaws and arms. The required input torque is at the upper limit for existing battery operated drills and at the maximum load the drill motor stalls or nearly stalls resulting in a very large drain on the battery. The aluminum-bronze thrust washer in the lower trunnion must be replaced with a thrust bearing and this may require redesigning the lower trunnion. The existing drill drivers have proven motors, drive trains, and battery systems; however, they also include parts that are not necessary for driving the Wood duck. The mass of the Milwaukee 0721-20 angle driver can be easily reduced by 1.5kg when the unnecessary angle drive unit is removed and this combined with mass savings in the jaws and arms should produce a complete system with a mass of less than 10kg.

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7. Policy and prevention

The results from this project support Recommendation 9 from the BC Coroners report titled *Findings and Recommendations of a Death Review Panel Convened To Examine Three 2008 Workplace Incidents Involving Tree Fallers*. Recommendation 9 is directed towards the BC Forest Safety Council and to WorkSafeBC, and it recommends *That the Council and WorkSafeBC work towards development and adoption of alternatives to traditional methods for controlling falling hazards, by promoting research and pilot projects in this area.* The new tool developed greatly improves the success rate of the novel holding wood pattern developed by Lyons and Noll (2011). This new tool combined with the novel holding wood pattern has the potential to remove the faller from the hazardous position at the base of the tree when the tree begins to displace.

8. Dissemination of knowledge

This project was a one year contract, which is a condensed time for design, fabrication, and testing of a new tool. Thus, dissemination of the results from this project will occur after the contract has been completed.

8.1 Planned Publications

Lyons C. K., and James Ewart. *Wood duck; a new falling tool*. Submitted to Forest Science, June 2011.

8.2 Planned Field Demonstrations

Lyons C. K. *Demonstration of the Wood duck*. Presentation to Western Forest Products, Woss B.C., June 2011.

Additional copies of this publication may be obtained by contacting:

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