Advantage

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Contents



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# Helicopter yarding with the S-64E Aircrane: grapple yarding in retention and clearcut prescriptions in the Fraser Valley

**Abstract**

The Forest Engineering Research Institute of Canada (FERIC) studied a heavy-lift helicopter logging operation near Mission in the Fraser Valley region of British Columbia. An S-64E Aircrane was used to harvest retention and clearcut units on steep slopes. This report presents productivity and cost information for the helicopter logging operation, and discusses factors affecting the efficiency of the operation.

**Keywords**

Helicopter logging, S-64E Aircrane, Partial cutting, Retention, Clearcut, Productivity, Costs, British Columbia.

## Executive summary

FERIC has established an ongoing study of helicopter logging operations throughout British Columbia to provide information on the capabilities and performance of different helicopters in typical harvesting situations. In this study, an S-64E Aircrane was used for grapple yarding in retention and clearcut units on steep mountain slopes. Helicopter yarding had been prescribed for this area to address visual quality and terrain stability concerns.

The helicopter operation harvested 21 187 m$^3$. The falling phase averaged 372 m$^3$/shift in 312 shifts, the helicopter yarding phase averaged 604 m$^3$/shift in 35.1 shifts, and the loading phase averaged 662 m$^3$/shift in 32 shifts.

The cost of the operation was \$107.07/m$^3$. The falling cost, including helipad construction, was \$12.88/m$^3$ (or 12% of total cost); the helicopter yarding cost was \$89.59/m$^3$ (84%); and the loading cost was \$4.60/m$^3$ (4%). The cost of the S-64E Aircrane helicopter was estimated at \$77.29/m$^3$, or 86% of the yarding cost and 72% of the total cost.

Falling productivity was adversely affected by steep and broken terrain which made directional falling difficult. Additionally, the retention prescription in some of the harvest units may have contributed to low falling productivity. The trees were effectively laid out across the slope, which simplified the grapple yarding phase by promoting easier grapple placement. Overall, Canadian Air-Crane was satisfied with the quality of falling.

Average yarding productivity for this study was below the expectation of the cooperators and is substantially less than other comparable FERIC helicopter logging studies. Several factors influenced the helicopter's productivity in this study: high cull factor, small log size relative to the Aircrane's payload, long average flight distances, unfavourable winds, working in an urban/forest interface, and small harvesting units. Compared to these factors, the retention prescription had little effect on productivity.

This report examines several alternative helicopter logging scenerios for this site. The alternatives included increasing in-woods manufacturing, using a medium-lift helicopter, falling logs into bunches, using a rigging crew, using a two-pass system, and pre-bunching turns. The analysis demonstrated the importance of exploring alternative harvesting options prior to committing to a harvesting approach. The analysis suggested that increasing in-woods manufacturing would have likely produced the highest overall cost savings with the least amount of difficulty.

The study reflected some of the challenges associated with heavy-lift helicopter logging, and highlighted the need to address several important considerations when planning such an operation. These include the effects of in-woods log manufacturing on helicopter yarding productivity, the effect of piece size when selecting a yarding helicopter and rigging system, the effects of flight distance on yarding productivity, and the effects of seasonal weather conditions when scheduling time of harvest.

## Introduction

Forest engineers and planners recognize that helicopter logging is a highly specialized system with its own unique requirements for safe, cost-effective harvesting operations. However, information about the capabilities and performances of different helicopters in typical harvesting situations in British Columbia is scarce, as is information about site, stand, organizational and operational factors that influence helicopter logging productivity and cost. FERIC has established an ongoing project to study helicopter logging operations throughout British Columbia to provide this information.

This report presents the results of a case study of a heavy-lift helicopter logging operation performed in the Fraser Valley region of British Columbia. An S-64E Aircrane[1] equipped for grapple yarding was used to harvest retention and clearcut units in two cutblocks on steep mountain slopes that could not be developed for conventional cable harvesting. FERIC, Canadian Forest Products Ltd. (Canfor), and Canadian Air-Crane Ltd. cooperated in this study.

## Objectives

The goal of FERIC's project is to provide forest engineers with information on the capabilities, productivities, and costs of helicopters currently used for logging in British Columbia through an ongoing series of short-term case studies. The objectives of this case study were to:

- Describe the harvesting operation.
- Determine productivities and costs for the falling, yarding, and loading phases.
- Identify features of the site, stand, harvest plan, and harvest system organization that may have influenced harvesting productivity and cost.

## Site and stand descriptions

The study site consisted of two cutblocks on Crown land approximately 15 km

[1] The S-64E and S-64F Skycranes were originally manufactured by the Sikorsky Aircraft Corporation. In 1992, Erickson Air-Crane Inc. of Central Point, Oregon purchased the type certificates for the S-64E and F Skycranes, and currently holds exclusive manufacturing rights to them. These aircraft are now called the Erickson S-64E and F Aircranes.

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northeast of Mission, in the Chilliwack Forest District (Table 1). The cutblocks were on the same side of a southeast-facing slope and elevations ranged from 100 to 680 m above sea level. Terrain was steep and broken with slopes between 35 and 75%, shallow soils, and a moderate mass wasting hazard. The site was in the dry maritime Coastal Western Hemlock (CWHdm) subzone (Green and Klinka 1994). Forest cover consisted of old-growth Douglas-fir *(Pseudotsuga menziesii*) with secondary components of western hemlock *(Tsuga heterophylla*) and western red cedar *(Thuja plicata)*. Merchantable volumes for Cutblocks 1 and 2 averaged 621 and 686 $m^3$/ha, respectively.

## Harvesting prescription and plan

The study site was cruised and engineered by Canfor. Harvesting by helicopter was prescribed for this area to address visual quality and terrain stability concerns. The tree size, high log value, and need to minimize damage to residual trees indicated the use of a medium- or heavy-lift helicopter.[2]

The study site consisted of two cutblocks with irregularly shaped openings and contained an estimated 21 000 $m^3$ of merchantable timber (Figure 1). Cutblock 1 was 6.9 ha in total and consisted of one retention unit[3] or opening. Cutblock 2 was 24.4 ha in total, and comprised three small clearcuts (2.8 to 4.2 ha in size) and four retention units (1.2 to 3.2 ha in size). Two landings, or drop zones, were located downslope from the cutblocks. Landing 1, about 0.3 ha in size, was 1 400 m horizontal

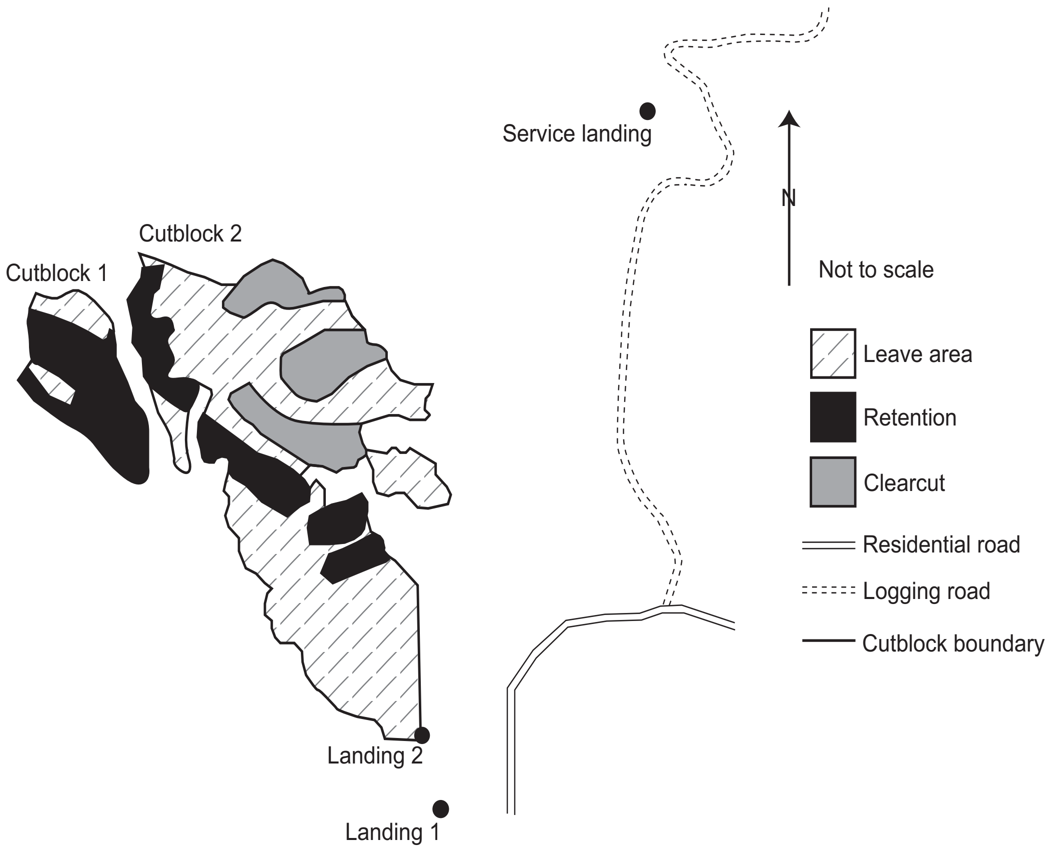
[2] Logging helicopters are commonly classified on the basis of their maximum rated payload as either light-lift (less than 10 000 lb.), medium-lift (10 000–15 000 lb.), or heavy-lift (more than 15 000 lb.).

[3] Retention unit, for the purpose of this report, is defined as an opening with a non-clearcut harvesting prescription (in this case, retaining 25 co-dominant and dominant trees per hectare with no species preference). Retained trees were selected by fallers. Selection criteria took into account windfirmness, Workers' Compensation Board of BC regulations, and other factors that could have influenced harvesting operations.

**Table 1. Site and stand descriptions**

| | Cutblock 1 | Cutblock 2 |
|---|---|---|
| Cutblock area (ha) | 6.9 | 24.4 |
| Site characteristics | | |
| Terrain decription | broken | broken, rocky knobs |
| Average slope (%) | 60 | 50 |
| Mass wasting hazard | moderate | moderate |
| Stand characteristics | | |
| Species composition (%) | | |
| Douglas-fir | 94 | 88 |
| Western red cedar | 0 | 10 |
| Western hemlock | 6 | 2 |
| Defects | | |
| Decay (% of gross) | 1 | 1 |
| Waste (% of gross) | 0 | 0 |
| Breakage (% of gross) | 4 | 4 |
| Merchantable volume ($m^3$/ha) | 621 | 686 |
| Forest health concerns | none | Laminated root rot *(Phellinus weirii)* |

Figure 1. Harvest plan map for Cutblocks 1 and 2.




distance at 35% slope from the centre of Cutblock 1, and 925 m horizontal distance at 52% slope from the centre of Cutblock 2. (See Appendix I for an explanation of horizontal distance.) Landing 2, 160 m north of Landing 1, was an existing 0.2-ha cable yarding landing located 1 275 m horizontal distance at 39% slope from the centre of Cutblock 1, and 800 m horizontal distance at 63% slope from the centre of Cutblock 2. It was used only as an overflow landing when Landing 1 became congested. A 0.1-ha service landing used for helicopter refuelling and maintenance was situated approximately 4 km northeast of the log landings.

Figure 2. S-64E Aircrane helicopter.

The successful bidder, Canadian Air-Crane, performed the yarding phase using an S-64E Aircrane helicopter equipped with a 545-kg (1200 lb.) custom grapple. The helicopter was unavailable during the summer, so yarding was delayed until early fall.[4]

## Helicopter specifications

The S-64E Aircrane is a twin-turbine, heavy-lift helicopter (Figure 2). It has a rated maximum payload of 20 000 lb. and its target payload is typically 13 000–15 000 lb. in grapple yarding mode and 14 000–16 000 lb. in hook (choker) mode. Currently, 17 S-64E Aircranes are certified for commercial use worldwide.[5] Key specifications for

[4] The area was known to be prone to frequent low cloud and unfavourable wind conditions for much of the year. Therefore, Canfor proposed that the cutblocks should be harvested in mid-summer to take advantage of the most favourable weather and long daylight hours.

[5] Dave Hayes, Canadian Air-Crane, personal communication, October 2003.

the S-64E Aircrane and other helicopters used for logging in British Columbia are shown in Appendix II. More information about the Aircrane is presented in Dunham (2002a).

## Study methods

A FERIC researcher was on-site during most of the harvesting operation and collected shift-level and detailed-timing information. Shift-level information for the falling, yarding, and loading phases was supplied by cooperators and included shift production reports, data summaries for helicopter cycles, and daily operating reports. During the yarding phase, FERIC frequently discussed the progress of the harvesting operation with Canfor and Canadian Air-Crane personnel to identify site, stand, layout, and organizational factors that influenced the helicopter's productivity.

Shift-level and detailed-timing records were used to estimate average turn times, flight distances, number of turns, and total weight of logs yarded from the two cutblocks. Scale summaries supplied by Canfor were used to convert turn weights to volumes.

Ownership and operating costs for the S-64E Aircrane were estimated using a modified version of the costing methodology in Guimier and Wellburn (1984), plus information from the Official Helicopter Blue Book and Helicopter Equipment Lists & Prices (HELP) (HeliValue$, Inc. and Helibooks Ltd. 1999) (Appendix III). Hourly costs for the other machinery involved in the harvesting operations were calculated using FERIC's standard costing methods (Appendix IV). Labour costs were based on the IWA British Columbia Coast Master Agreement using 2002 rates. FERIC's cost estimates do not include stumpage or profit. The costs presented in this report are FERIC's estimates only and are not the actual costs incurred by either the licensee or the helicopter contractor.

## Results and discussion

### Description of the harvesting operation

Canfor used its own crews and equipment for falling, processing logs at the landing, and loading trucks. At the time of the study, Canfor's crews had considerable experience with helicopter logging in retention units. Falling was completed on both cutblocks before yarding began. Fallers were ferried to and from the falling sites daily in a McDonald Douglas 500E (MD 500) support helicopter operated by Highland Helicopters Ltd. of Richmond, B.C. Fallers installed helipads, built from on-site materials, primarily for their own access and safety needs as well as for the yarding phase project manager's needs. Trees were felled cross-slope and no tree jacking was done.

Typically helicopter logging operators carry out comprehensive in-woods log manufacturing to minimize the amount of unmerchantable wood yarded to the landing. In this operation, however, the cooperators agreed the stems would be left tree-length and largely unmanufactured because of the relatively small volume per tree and short overall tree lengths.

The S-64E Aircrane was configured for grapple yarding with a 545-kg grapple and 45-m (150-ft.) longline. Its crews and equipment were scheduled to work between 10 and 12 hours per shift. The scheduled shift length decreased during the operation as daylight hours available for flying decreased. Additionally, helicopter yarding shifts were restricted to 10 hours on weekends and holidays in accordance with municipal noise bylaws because the work sites were close to farms and private residences.

The yarding crew consisted of the helicopter pilot and co-pilot, four engineers who performed helicopter maintenance, and an on-site project manager.

Yarding began in the clearcut units. The intention was to complete yarding in each unit before moving to the next unit. However, the Aircrane often had to yard from several units within a single shift to adjust for frequent unfavourable wind conditions.

The helicopter engineers had an on-site truck-mounted service trailer, two standard highway fuel tanks, an aircraft refuelling system, and two standard highway tractors (one mounted with a short fuel tank and the other with a flatdeck for transporting oil). Maintenance time for the Aircrane varied depending on the number of flight hours flown each shift. Usually, two engineers performed pre-flight maintenance and were on-site for the first half of the yarding shift to carry out refuelling and maintenance checks. They were replaced mid-shift by the other two engineers, who did the refuelling and maintenance for the second half of the yarding shift and performed the necessary post-flight maintenance. Each crew worked about an 8-hour shift. The engineers rotated their work schedules between pre-yarding, yarding, and post-yarding shifts.

At the end of each yarding cycle the Aircrane returned to the service landing for about ten minutes, the pilot and co-pilot changed positions, and a "hot" refuelling was performed. During every third refuelling break, an additional ten-minute mechanical check was performed. Following every sixth yarding cycle, the Aircrane shut down for a 45- to 60-minute maintenance break.

During yarding operations, the project manager spent 50–60% of his time walking in the logged areas and marking logs for clean-up yarding. Highland's MD 500 helicopter was used almost daily to ferry the project manager in and out of the cutblocks. Highland's hangar base was nearby, so the support helicopter was called out when required and did not remain on-site during idle periods.

Log clearing and decking were done by Canadian Air-Crane using a Caterpillar 980B wheel loader. The loader operator worked a 10- to 12-hour shift that coincided with the yarding shift.

Log bucking and loading were performed by Canfor crews and equipment on a scheduled 12-hour shift (with the exception of three loading shifts which were performed by Canadian Air-Crane after yarding was completed). A Madill 3800B loader spread the decked logs for processing by the landing buckers and loaded the manufactured logs onto trucks for hauling to Canfor's sortyard at Harrison Mills. Log bucking, loading, and hauling were generally not done on weekends and holidays to minimize overtime costs.

## Harvesting productivity and cost

A total net volume of 21 187 m$^3$ was harvested from the two cutblocks.

### Shift-level study

Overall, the falling phase averaged 372 m$^3$/shift with production (SWP), the helicopter yarding phase averaged 604 m$^3$/SWP, and the loading phase averaged 662 m$^3$/SWP (Table 2). The total per-unit stump-to-truck harvesting cost was estimated at $107.07/m$^3$ (Table 3). Yarding comprised the largest portion of the harvesting cost (84%), followed by falling (12%), and loading (4%). Average falling and loading phase costs for this study are similar to phase costs calculated in other recent FERIC helicopter logging reports (Dunham 2002a; Krag and Evans 2003). However, the average yarding cost for the two cutblocks in this study is considerably higher. A high cull factor, the time required to bunch logs for grappling, long flight distances, and restrictions placed on the operation because of its proximity to residential and agricultural developments contributed to the high yarding cost.

**Falling.** Falling operations began in May and, except for a two-week period in June, continued steadily until the sites were completed in early September. In 57 days of falling during this period, a crew of 5 to 6 fallers worked 312 shifts to fall timber and build helipads, and the support helicopter recorded 129 flight hours of support. In addition, five scheduled falling days were cancelled because fog and low cloud prevented the MD 500 from ferrying the fallers into

**Table 2. Shift-level productivities for the falling, yarding, and loading phases**

| | Cutblocks 1 and 2 |
|---|---|
| Falling | |
| Scheduled shifts worked (no.) | 57 |
| Non-productive shifts (no.) | 5 |
| Average fallers per scheduled shift worked (no.) | 5.5 |
| Total productive faller-shifts worked (no.) | 312 |
| Production per scheduled shift worked ($m^3$) | 372 |
| Production per faller per 6.5-h falling shift ($m^3$) | 68 |
| Yarding | |
| Logging helicopter | |
| Potential shifts (no.) | 40 |
| Non-operating shifts (no.) | 0 |
| Shifts with production at other sites (no.) | 4.9 |
| Shifts with produciton at study site (no.) | 35.1 |
| Average flight-hours per productive yarding shift (no.) | 6.9 |
| Production/SWP ($m^3$) | 604 |
| Loading | |
| Shifts worked by Canfor's loader (no.) | 29 |
| Shifts worked by Canadian Air-Crane's loader (no.) | 3 |
| Average loaders per shift (no.) | 1 |
| Total loader shifts worked (no.) | 32 |
| Production per 12-h loading shift ($m^3$) | 662 |

**Table 3. Estimated costs of falling, yarding, and loading**

| | Falling ($/$m^3$) | Yarding ($/$m^3$) | Loading ($/$m^3$) | Total ($/$m^3$) |
|---|---|---|---|---|
| Prime costs | | | | |
| Yarding helicopter | - | 77.29 | - | 77.29 |
| Support helicopter | 3.21 | 0.92 | - | 4.13 |
| Other equipment | - | 1.41 | 1.74 | 3.15 |
| Chainsaws | 0.84 | 0.10 | 0.16 | 1.10 |
| Labour | 6.18 | 0.75 | 2.31 | 9.24 |
| Subtotal | 10.23 | 80.47 | 4.21 | 94.91 |
| Other costs | | | | |
| Mobilization | - | 0.44 | 0.01 | 0.45 |
| Crew transport | 0.25 | 0.42 | 0.11 | 0.78 |
| Supervision | 1.77 | 1.03 | - | 2.80 |
| Crew room and board | - | 0.86 | 0.01 | 0.87 |
| Overhead | 0.63 | 5.78 | 0.26 | 6.67 |
| Project costs | - | 0.59 | - | 0.59 |
| Subtotal | 2.65 | 9.12 | 0.39 | 12.16 |
| Total | 12.88 | 89.59 | 4.60 | 107.07 |

the cutblocks. Because the decision to cancel a scheduled falling shift was made before the support helicopter was requested, no helicopter charges were incurred for the cancelled shifts.

The steep and broken terrain, coupled with the retention prescription for some of the units, made directional falling difficult and contributed to low falling productivity. Falling production averaged 68 $m^3$/faller-shift for this study, considerably less than the 94 $m^3$/faller-shift reported by Dunham (2002a), but similar to the 71 $m^3$/faller-shift reported in Krag and Evans (2003). Dunham's study consisted of clearcuts only, whereas this study and Krag and Evans consisted of clearcuts and partial cuts which likely accounts for some of the productivity difference.

Overall, Canadian Air-Crane was satisfied with the quality of falling. In particular, the trees were effectively laid out across the slope, which simplified the grapple yarding phase by promoting easier grapple placement on logs.

**Yarding.** Helicopter yarding began in mid-September. The Aircrane needed 35.1 productive shifts to complete the yarding phase. No scheduled shifts were lost to weather or mechanical problems. Yarding operations were interrupted for a three-day period in early October when the Aircrane was moved to another project. Additionally, near the end of the project, the Aircrane worked 1.9 shifts at another site in the area when poor weather prevented yarding at the study site.

At the start of the yarding phase, Canadian Air-Crane scheduled yarding operations to begin at 7 A.M. and end at 7 P.M. As the yarding phase progressed the hours of daylight decreased, so the average scheduled shift length was effectively reduced from 12.0 to 11.5 hours. To comply with local noise bylaws, yarding shifts on weekends and holidays were 10 hours, from 9 A.M. to 7 P.M. Scheduled starting and quitting times for the hydraulic loader were not affected.

Table 4 summarizes the Aircrane's time distribution for productive shifts assuming an 11.5-hour scheduled shift.[6] Pre- and post-shift maintenance and full or partial shifts lost for reasons unrelated to the project (e.g., working on non-study sites) were excluded. The Aircrane recorded 242 flight hours during the yarding phase. Scheduled in-shift maintenance and refuelling time totalled 58.5 hours, or 14.5% of the total scheduled hours. Therefore, flight time and associated service activities accounted for about 74% of the total time potentially available for yarding. Other causes of lost potential shift time were poor weather (15.4%), in-shift mechanical problems (6%), and ending the yarding shift early (4.2%).

The ratio of flight hours to scheduled hours was 60%. This is less than the ratio of 69% reported for helicopter grappling in Dunham (2002a) because of the weather delays experienced during this study. However, the ratio reported in Dunham (2002a) was based on only one day of helicopter grappling, with no weather delays.

**Table 4. Shift-level time distributions for productive shifts**

| | S-64E with grapple |
|---|---|
| Flight time (h) | |
| Total flight hours | 242.0 |
| Non-flight time (h) | |
| Scheduled maintenance (in-shift) | 27.0 |
| Refuelling | 31.5 |
| Unscheduled maintenance (in-shift) | 24.1 |
| Weather | 62.3 |
| Other | 16.8 |
| Subtotal | 161.7 |
| Total scheduled hours | 403.7 |
| Flight hours per productive shift | 6.9 |
| Ratio of flight hours to total potential hours (%) | 59.9 |

6 Canadian Air-Crane supplied the number of flight hours worked during the study, and FERIC estimated the distribution of non-flight hours from field notes and discussions with Canadian Air-Crane.

Therefore, the ratio observed in this study is probably more realistic as a long-term estimate.

Table 5 summarizes production statistics for the S-64E Aircrane. Overall, the Aircrane extracted a total payload of 57 278 000 lb., yielding an average weight-to-volume conversion ratio of 2 700 lb./m$^3$ based on 21 187 m$^3$ net scaled volume. On average, the logging helicopter completed 6.9 flight hours and 7 yarding cycles[7] per scheduled shift. Yarding turns[8] averaged 3.58 minutes and 4.6 logs. The average payload per turn was 14 000 lb. (5.2 m$^3$), for a load factor[9] of 70%.

The average yarding productivity of 87.5 m$^3$/flight-hour was below the expectation of cooperators and is substantially less than the 168.6 m$^3$/flight-hour reported by Krag and Evans (2003) and the 119 m$^3$/flight-hour reported in Dunham (2002a). Canadian Air-Crane expected average turn times of 2.9 to 3.1 minutes and an average load factor of 65%, which would have yielded a yarding productivity in the range of 252 000–269 000 lb./flight-hour. This would represent a volume production of 93 to 100 m$^3$/flight-hour based on the weight-to-volume conversion factor used in this study, or an increase of 5–12 m$^3$/flight-hour over the actual productivity.

**Loading.** Loading activities began at the same time as the yarding phase and were completed shortly after yarding was finished. The landing buckers worked 29 shifts to process logs at Landings 1 and 2. Canfor's hydraulic loader also worked 29 shifts and Canadian Air-Crane's wheel loader worked an additional 3 shifts to load logs at the landing, resulting in an average productivity of 662 m$^3$/12-h loading shift.

The log landings were smaller than preferred by Canadian Air-Crane pilots (Landing 1 was 0.2 ha in size and Landing 2 was 0.3 ha). However, long flight distances, short tree-length logs, and a high level of weather-related downtime were encountered by the helicopter during the loading phase. These factors allowed the landings to adequately accommodate the daily yarding production and the continuous log manufacturing and loading activities. Only minor congestion was experienced near the end of the project. This occurred when large amounts of waste wood, generated by tree-length processing at the landings, accumulated into large waste piles that began to encroach on

[7] A yarding turn is defined as the sequence of activities required to transport one load of logs from the stump to the landing. A turn consists of the following elements: flying from the landing to the hook-up site (fly empty); securing the load of logs (hook up); lifting the turn above the stand's canopy before beginning forward flight (break out); flying from the hook-up site to the landing with a load of logs (fly loaded); and placing and releasing the logs on the landing (unhook).

[8] A cycle is defined as the period of continuous flight operations between refuelling and/or maintenance breaks, during which a series of turns is yarded. In helicopter logging, typically 25–45 turns are yarded in a 50–90 minute cycle.

[9] Load factor is the actual turn payload divided by the helicopter's rated payload, expressed as a percentage.

**Table 5. Yarding production summary**

| | S-64E with grapple |
|---|---|
| Production totals | |
| Cycles flown [a] (no.) | 245 |
| Turns yarded (no.) | 4 054 |
| Logs yarded (no.) | 18 634 |
| Weight (lb.) | 57 278 000 |
| Volume yarded (m$^3$) | 21 187 |
| Production per SWP | |
| Cycles (no./SWP) | 7 |
| Turns (no./SWP) | 115 |
| Logs yarded (no./SWP) | 531 |
| Weight yarded (lb./SWP) | 1 631 850 |
| Volume yarded (m$^3$/SWP) | 603.6 |
| Production per cycle | |
| Turns (no./cycle) | 16.5 |
| Logs (no./cycle) | 76 |
| Weight (lb./cycle) | 233 800 |
| Volume (m$^3$/cycle) | 86.5 |
| Production per flight-hour | |
| Turns (no./flight-hour) | 16.8 |
| Logs (no./flight-hour) | 77 |
| Weight (lb./flight-hour) | 236 700 |
| Volume (m$^3$/flight-hour) | 87.5 |

[a] Number of yarding cycles was estimated by FERIC based on detailed-timing information.

the space available for dropping and processing the logs (Figure 3).

### Detailed-timing study

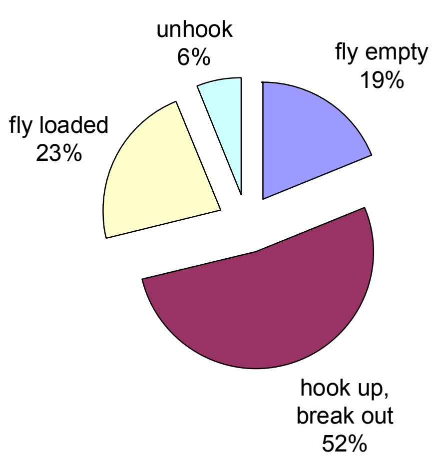
FERIC detail timed 15.5 flight hours, or 6% of total flight time. The average yarding cycle for the detailed-timing period was 59.2 minutes and the average turn time was 3.65 minutes. These times were for a horizontal yarding distance of 1 380 m and slope of 38%. Figure 4 shows the distribution of turn time based on activity. This distribution is very similar to that reported in Krag and Evans (2003). Turn payloads were not available for the detailed-timing period.

## Factors affecting helicopter yarding productivity

In the opinion of the cooperators, the main factors influencing the helicopter's productivity in this study were a high cull factor,[10] small log size relative to the Aircrane's payload, long average flight distances, unfavourable winds, working in an urban/forest interface, and small harvest units. In contrast, the retention prescription was thought to have had little or no effect on yarding productivity.

Figure 3. Waste wood at landing late in the project.

Figure 4. Turn time distribution based on detailed timing.




### Cull factor

Typically, helicopter logging contractors expect a weight-to-volume conversion ratio for coastal Douglas-fir stands of between 1 800 and 2 000 lb./m$^3$. Therefore, the conversion ratio of 2 700 lb./m$^3$ for this study is much higher than Canadian Air-Crane expected. The stand was largely free of defect (Table 1), so most of the increase was attributed to the cooperators' decision to leave stems full length for yarding owing to the small tree size. This decision maximized the average piece size for the helicopter but resulted in a low level of limbing and bucking in the cutblocks, so most trees were yarded with limbs and tops still attached. After yarding was finished, FERIC estimated a cull factor of 26% for the operation, based on the total weight yarded and a coastal weight-to-volume conversion ratio for Douglas-fir of 2 000 lb./m$^3$ (Appendix V). In other words, on average one-quarter of the helicopter's payload for each turn consisted of unmerchantable wood. Typically, helicopter logging contractors strive to keep cull to 4 to 7% by monitoring limbing and bucking quality very closely. The results for this operation underscore the importance of careful log manufacturing at the stump in helicopter logging operations.

### Small log size

The average piece size for this operation (1.14 m$^3$ and about 3 100 lb.) was relatively small in relation to the Aircrane's target payload of 13 000 lb., so the pilots had to bunch several logs at a time to achieve the desired turn weight. The detailed-timing data showed that the combined hookup and breakout time accounted for more than half of the total turn time (Figure 4), and that

[10] Cull factor is defined as the weight of unmerchantable material flown to the landing expressed as a percentage of the total weight of wood flown.

hookup and breakout time increased steadily as the number of logs per turn increased (Figure 5). One- and two-log turns, which required little or no bunching, had an average hookup and breakout time of 1.33 min/turn. In comparison, four- and five-log turns had an average time of 1.78–1.91 min/turn (the study average was 4.6 logs/turn). This suggests that bunching added about 0.5 to 0.6 min/turn to this operation. In other words, bunching appears to account for most of the discrepancy between expected and actual average turn times for this operation (3.0 and 3.6 min/turn, respectively).

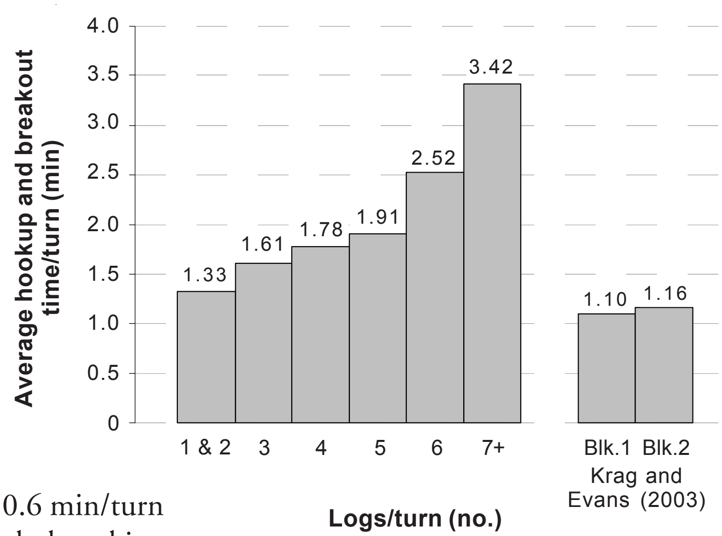



Figure 5. Average hookup and breakout times versus number of logs per turn.

Most of the in-cycle delays observed in Krag and Evans (2003) occurred during the hookup and breakout elements of the yarding cycle.[11] When in-cycle delay time (0.13 to 0.19 min/cycle) is added to average hookup and breakout times (1.10 to 1.16 min/turn for an S-64E Aircrane using a double hook-and-choker rigging system), the total hookup and breakout times in Krag and Evans (2003) are comparable to this study. In Krag and Evans, the logging helicopter did not have to bunch logs to build turns, but did have to wait for the hooktender to clear the hookup site before lifting the turn.

### Flight path distance and slope

The average effective horizontal yarding distance (Appendix I) of 1 050 m and flight path slope of 51% in this study exceed the ranges that Canadian Air-Crane considers to be optimum for the S-64E Aircrane, which is an average yarding distance of 600–800 m and a maximum flight path slope of 35%. As a result, Canadian Air-Crane expected turn times to average between 2.9 and 3.1 min, which is substantially longer than their desired range of 2.0 to 2.5 min/turn.

An analysis of the detailed-timing information indicates that the S-64E Aircrane in this study achieved a substantially higher average travel speed than in Krag and Evans (2003) (119 km/h in this study compared to 65 km/h for Block 1 in Krag and Evans [2003]). The longer average flight distances and slightly gentler flight path slopes in this study may have enabled the Aircrane to spend a larger proportion of total travel time at optimum airspeed. Another possibility is that yarding distance as defined in this study may have more closely approximated actual flight distance than in Krag and Evans (2003), where flight path slopes tended to become steeper as yarding distance increased.

### Wind conditions

Fifteen percent of potential yarding time was lost to poor weather conditions, of which about half was directly attributed to unfavourable winds. Gusty, shifting winds made the helicopter harder to control and often caused the helicopter to shut down. In contrast, the pilots were able to adjust more readily to steady wind direction and velocity by varying the tail rotor thrust and by selecting alternative flight paths, although this often increased flight distances and turn times.

### Urban/forest interface

Working in close proximity to residential and agricultural developments influenced the

[11] Ray Krag, FERIC, personal communication, November 2003.

helicopter's productivity in several ways. For example, shift lengths during weekends and holidays were reduced to conform to noise bylaws. Also, flight paths were constrained and in some cases flight distances were lengthened to observe "no fly" zones surrounding houses and farms. Finally, the service landing was located about 4 km from the log landings to try to reduce the level of noise affecting residents.

**Small harvest unit size**

Productivity was further reduced in the small, steep harvest units because bunching activities disturbed the felled timber and caused stems to slide downhill into adjacent standing timber. This made it more difficult and time-consuming for pilots to locate, set the grapple on, and extract stems.

## Comparing alternative harvesting scenarios

Forest engineers, planners, and helicopter logging contractors often need to explore various helicopter logging scenarios prior to harvesting a site to determine the best harvesting option. This study provided an opportunity to examine alternative harvesting scenarios. For simplicity, only two scenarios were analyzed in detail. Scenario 1 utilized the S-64E Aircrane but increased the level of in-woods manufacturing carried out during falling. Scenario 2 increased the level of in-woods manufacturing and used a medium-lift rather than a heavy-lift helicopter for yarding. Other major assumptions for both scenarios were:

- Falling productivity was decreased by 25% as a result of greater in-woods manufacturing.
- Cull factor was reduced to 10%.
- The weight-to-volume conversion factor was 2 000 lb./m$^3$.
- Loading productivity was unchanged.
- Bucking productivity at the landings was increased by 10% as a result of greater in-woods manufacturing.
- For Scenario 2, the medium-lift helicopter had a rated payload of 10 000 lb., had similar cruise speeds to the S-64E Aircrane, and achieved an average load factor of 75% and 6.9 flight hours/shift.
- For Scenario 2, the hourly cost for the medium-lift helicopter was $4 000/flight-hour (Dunham 2002b).

Table 6 compares the two alternatives to the actual outcome for this study.

Scenario 1 resulted in an estimated cost savings of $8.63/m$^3$ compared to the status quo. Although increased in-woods manufacturing would have resulted in a higher overall falling cost, the reduction in cull yarded to the landing would have increased the ratio of merchantable weight to total weight per turn. As a result, the increased falling cost would have been more than offset by the decreased yarding and loading phase costs.

Scenario 2 produced an even greater estimated cost savings ($10.75/m$^3$). Because the log size at this site was small relative to the Aircrane's target load factor, the Aircrane spent a large amount of turn time bunching the logs to achieve a desired average turn weight. Using a medium-lift helicopter with a lower rated payload but similar cruise speed abilities to the S-64E Aircrane would have resulted in a smaller number of logs per turn and substantially reduced bunching time.

Other commonly used alternative harvesting options might also have been feasible:

- Ensuring fallers understand the relationship between the logging helicopter's

**Table 6. Estimated costs for Scenarios 1 and 2**

| | Scenario 1 | Scenario 2 | This study |
|---|---|---|---|
| Falling ($/m$^3$) | 15.81 | 15.81 | 12.88 |
| Yarding ($/m$^3$) | 78.20 | 76.08 | 89.59 |
| Loading ($/m$^3$) | 4.43 | 4.43 | 4.60 |
| Total ($/m$^3$) | 98.44 | 96.32 | 107.07 |

target payload and the stand's average tree weight. They should be aware of the advantages of falling trees into bunches when the average tree weight is much less than the helicopter's target payload. In this study, falling logs into bunches would have reduced in-flight bunching time, and would have potentially increased average turn weight. Canadian Air-Crane has recently worked with falling crews to further train them to fall trees into bunches, and this has increased average yarding turn weights by 10–15%.[12] However, this strategy is only possible if a forest company hires a helicopter logging contractor prior to the start of falling and allows the helicopter contractor to work closely with falling crews during the falling phase, which usually occurs well in advance of the yarding phase.

- Using a rigging crew in conjunction with helicopter grappling. This option may have allowed the Aircrane to achieve a greater turn payload without adding additional time to hookup or breakout activities. However, the use of rigging crews can create safety and logistical concerns, and additional up-front costs not encountered with grapple yarding.
- Using a two-pass yarding system. A medium-lift helicopter could have been used to yard the smaller logs and the S-64E Aircrane to yard the remaining larger logs. This option may have reduced bunching time and ensured oversized logs did not need to be bucked to weight due to the payload constraints of the medium-lift helicopter. However, a two-pass system increases mobilization and demobilization costs, and can create additional planning and scheduling concerns. It is generally best suited to a stand with widely varying tree sizes.
- Pre-bunching turns for the S-64E Aircrane using a light-lift helicopter or "fly-in" small excavator. This option would have eliminated bunching time for the Aircrane, resulting in more turns per flight-hour, and may have also increased average turn weight. However, the time required for pre-bunching with a light-lift helicopter would have to be carefully considered to evaluate the economic viability of this option. Similarly, in-block terrain conditions would have to be carefully assessed to evaluate the operational feasibility of a small excavator.

In summary, increasing in-woods manufacturing would have likely produced the highest overall cost savings with the least amount of difficulty, but it is only one of several alternatives that might have been considered. Ultimately, this analysis demonstrates the importance of exploring alternative harvesting scenarios prior to committing to a harvesting approach.

## Conclusions

Due to visual quality and terrain stability concerns, Canfor harvested the study area using a heavy-lift helicopter grapple system. A total of 21 187 $m^3$ was harvested over a five-month period in 312 falling shifts. The falling crew, consisting of 5 or 6 fallers, averaged 68 $m^3$/6.5-hour shift. The S-64E Aircrane helicopter completed yarding in 35.1 productive shifts and averaged 603.6 $m^3$/11.5-hour shift. One hydraulic loader (a wheel loader was used in place of the hydraulic loader for three days) completed loading of trucks in 32 working days, averaging 662 $m^3$/12-hour shift.

FERIC estimated the total cost of falling, helicopter yarding, and loading at \$107.07/$m^3$. Falling accounted for \$12.88/$m^3$ or 12% of the total cost. Falling costs reflect the effect of steep, broken terrain and retention conditions. Loading accounted for \$4.60/$m^3$ or 4% of the total cost. Although the log landings were considered small, landing congestion was minimized because of long flight distances, relatively short tree-length logs, and a large amount of weather-related

[12] John Smith, Canadian Air-Crane, personal communication, January 2004.

helicopter downtime. Therefore, the yarding and loading productivities were relatively unaffected by landing size. Helicopter yarding accounted for $89.59/m$^3$ or 84% of the harvesting cost with the cost of the logging helicopter alone at $77.29/m$^3$ or 72%.

The key factors affecting yarding productivity and cost were the high cull factor resulting from yarding full trees; the small tree size relative to the Aircrane's working payload which necessitated bunching and increased turn time; the relatively long yarding distances which also increased turn time; unfavourable weather conditions, particularly gusty variable winds which resulted in downtime for the helicopter; constraints on hours of operation and flight paths imposed by working in an urban/forest interface; and the difficulties in finding and grappling stems that slid downhill into standing timber during bunching operations.

Several alternative helicopter logging scenarios were examined for this study site to explore their impacts. The analysis suggested that increasing in-woods manufacturing would have likely produced the highest overall cost savings with the least amount of difficulty.

## Implementation

This study reflects some of the challenges associated with heavy-lift helicopter grappling. The following recommendations should improve the efficiency of proposed helicopter yarding operations:

- Consider the effects of in-woods log manufacturing on helicopter yarding. FERIC estimated cull factor for the study at 26%, which is more than triple the commonly accepted range. Although stand and log quality was fairly good, cull factor was likely inflated because limited in-woods manufacturing was carried out. It is important to consider the pros and cons of decreasing turn time at the expense of increasing the proportion of unmerchantable to total weight of wood flown. This can be particularly significant for a helicopter logging contractor because most contractors in British Columbia are paid according to the project's net scale volume rather than total weight flown.
- Consider the effect of piece size when selecting a yarding helicopter and rigging system. The relatively small log size in relation to the Aircrane's target load factor for this project required the helicopter to yard an average of 4.6 logs/turn to achieve an acceptable turn payload. Multi-log yarding using a grapple required pilots to build log bunches which increased turn time. It is important for planners and decision makers to understand the requirements and characteristics of different helicopters and rigging systems and to compare these to characteristics of proposed harvest areas.
- Consider the effect flight distance has on helicopter yarding productivity. During this study, the average effective horizontal yarding distance was 1 050 m at 51% and the average turn time was 3.5 minutes, well beyond the 2–2.5 min/turn window preferred by most helicopter logging contractors. Additionally, working in close proximity to an urban area resulted in "no fly" zones which further increased flight distances. According to several recent FERIC helicopter logging studies, fly empty and loaded portions of the yarding turn generally comprise 40–50% of turn time, so minimizing flight distances and maintaining moderate flight path slopes (less than about 35% for the Aircrane) will minimize overall turn time. During harvest planning, it is also important for forest engineers to recognize that the actual flight distance for the helicopter can be much greater than the straight-line distance between the cutblock and the landing, especially if the flight path slope exceeds about 35 or 40%. As a result, turn time estimates based on straight-line flight distances may significantly underestimate turn times.

- Consider seasonal weather conditions when scheduling time of harvest. Whenever possible, schedule harvesting for the most favourable period to reduce downtime. Canfor made every effort to harvest the study area during the summer months, because the study area was known to have poor weather conditions during the fall and winter months. However, scheduling conflicts with the helicopter delayed harvesting until the fall. As a result, the operation experienced considerable weather-related downtime.

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# Appendix I

## Estimating yarding distance for helicopter logging operations

This appendix is intended for forest engineers who are charged with planning and laying out cutblocks for helicopter logging projects.

**Yarding distance** is an important consideration when evaluating the feasibility and estimating the productivity and cost of a proposed helicopter logging project. However, estimated yarding distance for a given project can vary substantially depending on how the estimator interprets or "measures" yarding distance. To avoid confusion, therefore, it is important for the field engineer, supervisor, and heli-logger to have a common understanding of "yarding distance" when discussing proposed helicopter logging projects.

Typically, "yarding distance" (the distance the helicopter travels between the hookup site and the landing) can be defined in the following ways (see Figure A-1):

- Horizontal — the straight-line distance between the hookup site and the landing, measured as a horizontal (i.e., slope-corrected) distance.
- Slope ("chord") — the straight-line distance between the hookup site and the landing, measured along the slope.
- Flight distance — the total distance flown by the helicopter between the hookup site and landing, measured along the actual flight path.

In FERIC's helicopter logging reports, yarding distance is always defined as the horizontal straight-line distance between the hookup site and landing. FERIC adopted this definition because forest engineers traditionally use horizontal distance to describe yarding distances for other harvesting systems, and because horizontal distances and elevation changes can be measured directly from topographic maps and converted to slope (or flight) distance if necessary. Usually FERIC reports also present the elevation change and/or apparent slope, in combination with horizontal yarding distance, to fully describe the helicopter's typical flight path.

"Average yarding distance" (AYD) is an estimate of a helicopter logging project's average effective flight distance. Figure A-2 illustrates the method FERIC uses to calculate AYD for a helicopter logging operation consisting of more than one cutblock and/or harvest opening. In this situation, horizontal distances are measured from the centre of each unit to the centre of the landing(s) and then weighted by opening area or volume to calculate an effective, or "average", horizontal yarding distance for the entire project. The same technique is applied to estimate average vertical distances and average straight-line flight-path slope for the project.

It is stressed that straight-line distance (horizontal or slope) underestimates actual yarding or flight distance because in practice the logging helicopter's flight path between the hookup site and the landing is seldom perfectly straight. Provided there are no obstacles or hazards that prevent the logging helicopter from following the most direct path, however, straight-line distance reasonably approximates yarding distance for gentle and moderate slopes. While slope distance may be more accurate than horizontal distance when flight-path slopes exceed approximately 15%, the differences are relatively minor and FERIC considers horizontal distance to be the most practical measure of yarding distance for slopes up to 35–40%.

When the slope along the straight-line path becomes steeper than 35–40%, the logging helicopter usually follows longer, less direct flight paths to maintain an acceptable balance between travel speed and descent rate. Straight-line distance can substantially understate the actual yarding distance in this case, but predicting actual flight paths and flight distances is also difficult and requires experience and a sound understanding of the performance characteristics and capabilities of logging helicopters. In these situations, the forest engineer has the ability to influence yarding distance and flight-path slope through landing selection, and should involve the heli-logger early in the layout process to compare the advantages and disadvantages of the various alternatives. Horizontal distance can still be used as a measure of comparing yarding distances between the possible landing locations.

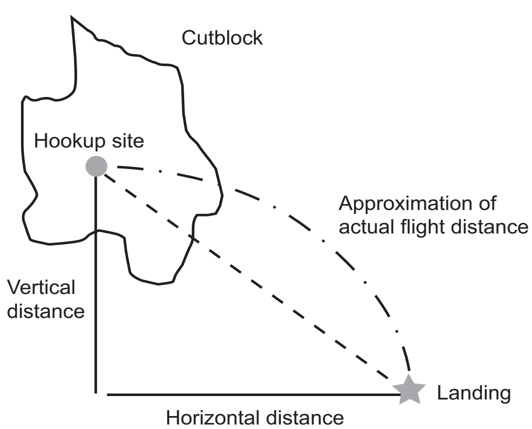



Figure A-1. Different ways of calculating yarding distance for a helicopter logging operation.

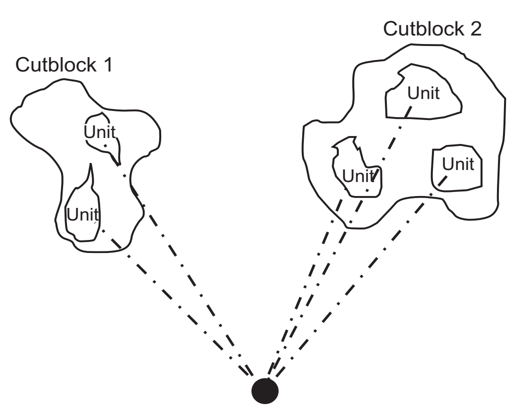
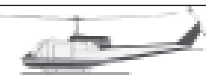
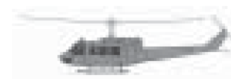
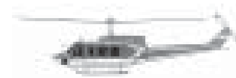
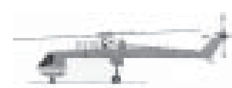
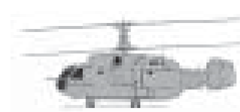
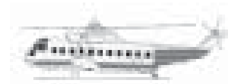



Figure A-2. Calculating effective average yarding distance for a project.

# Appendix II

## Specifications for helicopters commonly used for logging in B.C.[a]

| Manufacturer | Model | Rated payload capacity (kg) | Engines (no.) | Engine power[b] (kW) | Diameter main rotor (m) | Diameter tail rotor (m) | Diagram |
|---|---|---|---|---|---|---|---|
| Bell | 204B | 1 814 | 1 | 820 | 14.6 | 2.6 |  |
| Bell | 205A | 2 268 | 1 | 1 044 | 14.6 | 2.6 |  |
| Bell | 212 | 2 268 | 2 | 671 (each) | 14.7 | 2.6 |  |
| Bell | 214B | 3 636 | 1 | 2185 | 15.2 | 2.6 |  |
| Boeing | V-107 II | 4 773 | 2 | 932 (each) | 15.5 | n/a |  |
| Boeing | CH-234LR | 12 727 | 2 | 3 039 (each) | 18.3 | n/a |  |
| **Sikorsky**[c]<br>Sikorsky[c] | **S-64E**<br>S-64F | **9 072**<br>11 340 | **2**<br>2 | **3 356 (each)**<br>3 579 (each) | **22**<br>22 | **5**<br>5 |  |
| Eurocopter | SA-315B Lama | 1 134 | 1 | 640 | 11.0 | 1.9 |  |
| Kaman | K-1200 | 2 722 | 1 | 1342 | 14.7 (×2) | n/a |  |
| Kamov | KA-32A | 5 000 | 2 | 1645 (each) | 15.9 (×2) | n/a |  |
| Sikorsky | S-58T | 2 268 | 2 | 700 (each) | 17.1 | 2.9 |  |
| Sikorsky<br>Sikorsky | S-61N<br>S-61N Shortski | 3 629<br>4 084 | 2<br>2 | 1044 (each)<br>1044 (each) | 18.9<br>18.9 | 3.2<br>3.2 |  |

[a] Helicopter capabilities will vary with flight conditions and installed options.
[b] Engine power at takeoff.
[c] Now manufactured by Erickson Air-Crane Inc.

# Appendix III

## Helicopter costs[a] ($/flight-hour)

| | S-64E Aircrane | McDonald Douglas 500E |
|---|---|---|
| OWNERSHIP COSTS | | |
| Total purchase price (P) $ | 19 500 000 | 515 000 |
| Expected life (Y) y | 10 | 10 |
| Expected life (H) h | 24 250 | 10 000 |
| Scheduled hours/year (h) = (H/Y) h | 2 425 | 1 200 |
| Net flight-hours/year (fh) h | 1 924 | 960 |
| Salvage value as % of P (s) | 40 | 50 |
| Interest rate (Int) % | 9 | 9 |
| Insurance rate (Ins) % | 12 | 12 |
| Residual value (S) = ((P•s)/100) $ | 7 800 000 | 257 000 |
| Average investment (AVI) = ((P+S)/2) $ | 13 650 000 | 386 250 |
| Loss in resale value ((P-S)/(fh•Y)) $/flight-hour | 608.11 | 26.82 |
| Interest ((Int•AVI)/fh)/100 $/flight-hour | 638.51 | 36.21 |
| Insurance ((Ins•AVI)/fh)/100 $/flight-hour | 851.35 | 48.28 |
| Total ownership costs (OW) $/flight-hour | 2 097.97 | 111.32 |
| ANNUAL OPERATING COSTS | | |
| No. of pilots required for the operation (pil) | 5 | 1 |
| Annual pilot base salary (PS) $/y | 48 000 | 35 000 |
| Annual flight hours/pilot (pilh) h/y | 770 | 960 |
| Pilot flight-hour rate (pil$) $/h | 125 | 35 |
| Annual pilot flight pay (PF) = (pilh•pil$) $/y | 96 250 | 36 000 |
| Wage benefit loading (WB) % | 45 | 45 |
| No. of engineers (eng) | 5 | 0 |
| Engineer salary (ES) $/y | 109 000 | 0 |
| Fuel consumption (F) L/flight-hour | 2 082 | 106 |
| Fuel (fc)[b] $/L | 0.85 | 0.85 |
| Oil as a % of fuel (fp) % | 1.5 | 1.5 |
| Annual parts inventory (Inv) = % of P | 2.5 | 2.5 |
| Wages for the operation, including fringe benefits | | |
| Pilots (((PS•pil)+(pil$•pilh•pil)/fh) • (1+(WB/100))) $/flight-hour | 543.56 | 103.61 |
| Engineer ((ES•(1+WB/100))•eng)/fh $/flight-hour | 410.73 | 0 |
| Total wages (W) $/flight-hour | 954.29 | 103.61 |
| Fuel (F•fc) $/flight-hour | 1 769.70 | 79.50 |
| Oil ((fp/100)•(F•fc)) $/flight-hour | 26.58 | 1.19 |
| Maintenance $/flight-h | 1 664 | 215 |
| Parts inventory ((Inv/100)•(P/fh)) $/flight-hour | 253.38 | 13.41 |
| Helicopter registration fees ($/flight-hour) | 1.52 | 2.38 |
| Total operating costs (OP) $/flight-hour | 4 669.47 | 415.10 |
| TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/flight-hour | 6 767.44 | 526.41 |

[a] These costs are based on FERIC's standard costing methodology for determining machine and ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company.

[b] Includes cost of barging fuel to remote locations.

# Appendix IV

## Hourly equipment costs for loading [a]

| | Wheel loader 20–25 tonne class | Hydraulic log loader 45–50 tonne class |
|---|---|---|
| OWNERSHIP COSTS | | |
| Total purchase price (P) $ | 400 000 | 550 000 |
| Expected life (Y) y | 6 | 10 |
| Expected life (H) h | 12 000 | 10 000 |
| Scheduled hours/year (h) = (H/Y) smh | 2 000 | 2 000 |
| Salvage value as % of P (s) % | 30 | 30 |
| Interest rate (Int) % | 9 | 9 |
| Insurance rate (Ins) % | 3 | 3 |
| Salvage value (S) = (P • s/100) $ | 120 000 | 165 000 |
| Average investment (AVI) = ((P + S)/2) $ | 260 000 | 357 500 |
| Loss in resale value ((P-S)/H) $/h | 23.33 | 38.50 |
| Interest (((Int/100) • AVI)/h) $/h | 11.70 | 16.09 |
| Insurance (((Ins/100) • AVI)/h) $/h | 3.90 | 5.36 |
| Total ownership costs (OW) $/h | 38.93 | 59.95 |
| OPERATING COSTS | | |
| Fuel consumption (F) L/h | 25 | 30 |
| Fuel (fc) $/L | 0.40 | 0.40 |
| Lube and oil as % of fuel (fp) % | 10 | 10 |
| Annual tire consumption (t) no. | 1.5 | n/a |
| Tire replacement (tc) $ | 3 000 | n/a |
| Annual repair & maintenance (Rp) $ | 45 000 | 65 000 |
| Fuel (F • fc) $/h | 10.00 | 12.00 |
| Lube and oil ((fp/100) • (F • fc)) $/h | 1.00 | 1.20 |
| Tires ((t • tc)/h) $/h | 2.25 | n/a |
| Repair and maintenance (Rp/h) $/h | 22.50 | 32.50 |
| Total operating costs (OP) $/h | 35.75 | 45.70 |
| TOTAL OWNERSHIP AND OPERATING COSTS (OW + OP) [a] $/h | 74.68 | 105.65 |

[a] Excluding labour.

# Appendix V

## Weight-to-volume conversion factors used by helicopter logging contractors in coastal B.C.

| Species | Range | Average |
|---|---|---|
| Western hemlock | 2 000–2 200 lb./$m^3$ (910–1 000) kg/$m^3$) | 2 100 lb./$m^3$ (950 kg/$m^3$) |
| Western red cedar | 1 450–1 550 lb./$m^3$ (660–700 kg/$m^3$) | 1 500 lb./$m^3$ (680 kg/$m^3$) |
| Douglas-fir | 1 750–2 000 lb./$m^3$ (790–910 kg/$m^3$) | 1 900 lb./$m^3$ (860 kg/$m^3$) |
| Amabilis/grand fir | 1 750–1 850 lb./$m^3$ (790–840 kg/$m^3$) | 1 800 lb./$m^3$ (820 kg/$m^3$) |
| Sitka spruce | 1 600–1 700 lb./$m^3$ (730–770 kg/$m^3$) | 1 650 lb./$m^3$ (750 kg/$m^3$) |
| Yellow cedar | 1 760–1 800 lb./$m^3$ (770–820 kg/$m^3$) | 1 750 lb./$m^3$ (790 kg/$m^3$) |