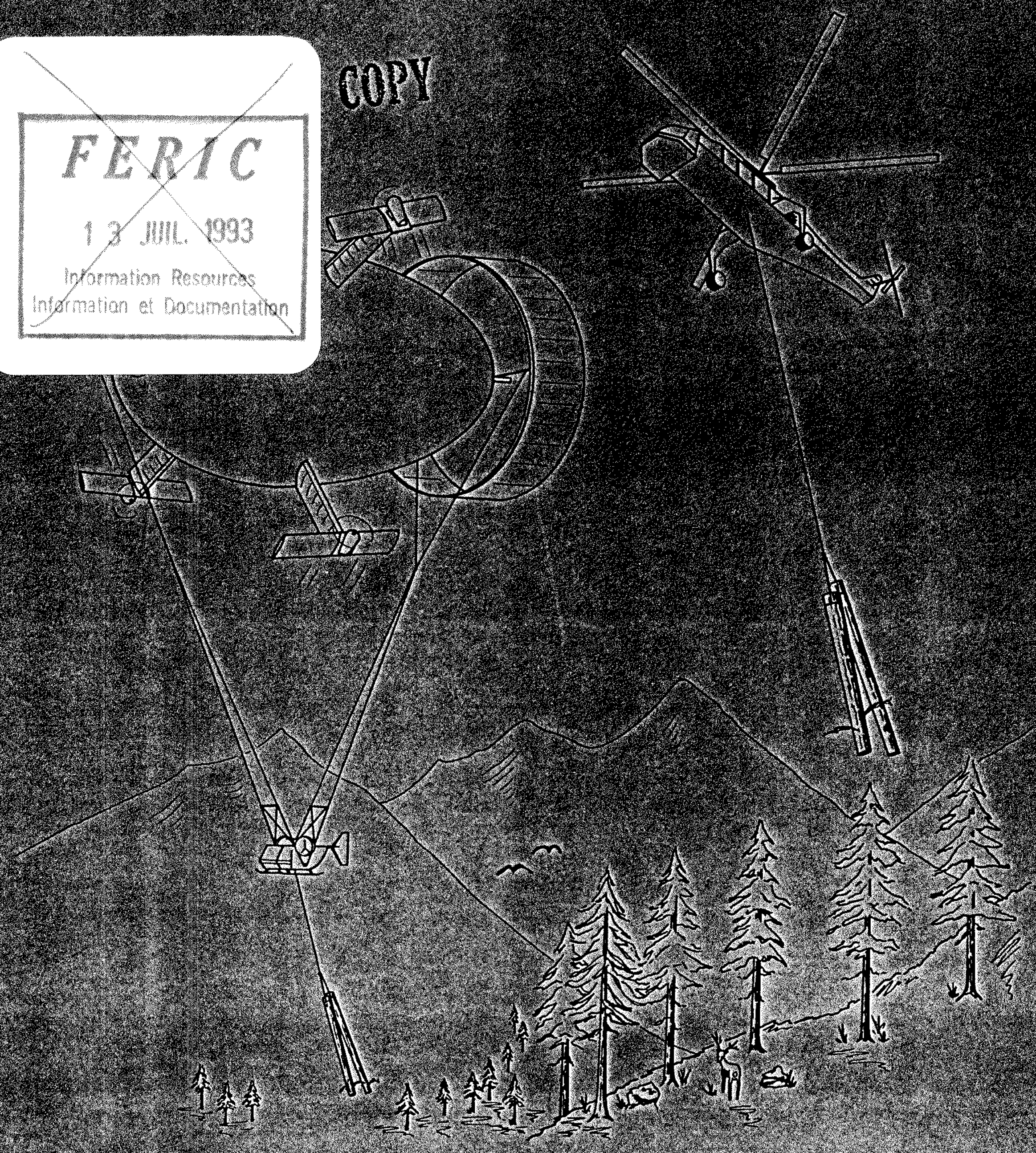
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

LOGGING WITH HEAVY-LIFT AIRSHIPS

Daniel Y. Guimier
G. Vern Wellburn

Technical Report No. TR-58
May 1984



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PREFACE

In 1976, a special meeting of the B.C. Coastal members of FERIC's advisory committee met to consider a project to conduct trials of the use of tethered balloons for logging. The meeting rejected the proposal on the grounds that enough information was available to show that tethered balloons would not provide a solution to effective logging in mountainous terrain. The meeting recommended that FERIC investigate ways to improve helicopter logging and to study any new developments of free-flying vehicles suitable for logging.

As a response to this meeting FERIC contacted Dr. Tim Wood of the National Research Council, Mr. Fred Phillips of Canadair Ltd., Mr. Virgil Binkley of the U.S. Forest Service and others. We also began a literature survey, attended lectures on the use of aircraft for logging and conducted studies.

In 1978, we introduced Messrs. Doolittle and Crimmins, developers of the Cyclo-Crane, to a group of B.C. Coastal logging companies. Four of these companies agreed to support the development of the Cyclo-Crane; a fifth company joined two years later. FERIC acted as the project coordinator until the formation of AeroLift, Inc. in 1981. Daniel Guimier was assigned to the project and assisted in the development from 1979 to 1982.

We would like to thank the following people for their help:

The staff - past and present	AeroLift, Inc.
Ken Boyd	Pacific Forest Products Ltd.
Harry Dembicki	B.C. Forest Products Ltd.
Otto Forgacs	MacMillan Bloedel Ltd.
Bob Fuller	Boeing Aircraft Company
Mel Hallett	Tahsis Company Ltd.
Monty Mosher	Pacific Forest Products Ltd.
Fred Phillips	Canadair Ltd. (now retired)
Brent Sauder	MacMillan Bloedel Ltd.
Bob Sitter	Whonnock Industries Ltd.
Clive Whittenbury	Silver Grizzley Logging Company Ltd.

Daniel Y. Guimier is a registered Professional Engineer in the Province of British Columbia. He graduated as a mechanical engineer in 1975 from the École Nationale Supérieure des Arts et Métiers in France. He then enrolled in a graduate program in the Faculty of Forestry at the University of British Columbia and obtained a M.A.Sc. degree in 1977. In September 1977 he joined FERIC to work on logging equipment design and development. From 1979 to 1982 he worked full time on the Cyclo-Crane development and was resident in both Bozeman, Maryland and Tillamook, Oregon.

G. Vernon Wellburn, P. Eng. R.P.F. joined FERIC as manager of the Western Division in 1975. Previously he worked for 23 years in various positions in the forest industry on Coastal B.C. and was a special lecturer in forest harvesting in the Faculty of Forestry at U.B.C. from 1971 to 1975. He worked on and supervised highlead, slackline and Wyssen skyline logging operations. He participated in the development of tethered balloons and helicopters for logging. In 1976 he attended the trial and evaluation meetings of the Aerocrane Concept and has been associated with the development of the Cyclo-Crane since 1978.

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SUMMARY

This report outlines the need and requirements of free-flying vehicles suitable for logging. It traces the development of the Cyclo-Crane and other heavy-lift airships and compares the projected costs of airship logging with current helicopter and conventional cable logging costs. Airships are being developed for transportation, surveillance and other missions. This report deals only with the mission to move heavy loads short distances (up to 2 km).

Helicopters have been used successfully to log inaccessible timber in steep rugged terrain and to reduce the environmental impact from logging roads and yarding on sensitive forest sites. The helicopter is an ideal machine. Its essential characteristics include:

- ability to lift and lower a load vertically;
- ability to place the hook or load accurately;
- fast acceleration;
- fast turning ability;
- ability to fly in winds gusting up to 90 km/hour; and
- ability to land and wait in case of reduced visibility or severe storms.

The major disadvantage of large helicopters is high owning and operating costs.

The Cyclo-Crane (invented by A.G. Crimmins) and the Aerocrane (invented by D.B. Doolittle) both combine the aerostatic lift of an airship with aerodynamic lift from inexpensive airplane-type wings. In both cases the helium supports all the dead load and half the payload. When unloaded the machine must power down.

In 1979, four B.C. forest industry companies supported the building of a working model of the Cyclo-Crane. They were joined in 1981 by a fifth company. FERIC coordinated the project until the formation of AeroLift, Inc. and continues to monitor it. The construction of a 1.8-tonne lift experimental model was completed in 1982. Unfortunately, this machine was damaged in a severe storm during initial testing. It has been rebuilt and tests will resume in 1984 under a U.S. Forest Service testing contract.

The Piasecki Heli-Stat, which combines airship lift with helicopter rotors, and the Van Dusen LTA 20-1, which uses Magnus force to generate lift, are other airship concepts under development which may be suitable for logging.

The major factors which affect the cost of aerial logging are:

- the owning and operating cost of the machine;
- the turn or cycle time from woods to landing (includes pick-up and drop and flight time);
- the volume per turn (depends on machine capacity and logs available at pick-up point); and
- delays (including mechanical and weather) which reduce the volume of logs moved per year.

We estimate that the Cyclo-Crane, designed for 12-tonne payloads, will be cheaper to own and operate than a large helicopter. It will be slower in flight and turning but will carry a larger load. The Cyclo-Crane should be as mechanically reliable as a helicopter but may be more sensitive to weather and it will require a prepared site for mooring at night and during storms.

Based on these assumptions, we estimate that a 12-tonne Cyclo-Crane will have the following production and cost:

Hours per Year	1600
Turn Time	5.13 min
Volume per Turn	10.67 m^3
Volume per Shift	873 m^3 (308 cunits)
Volume per Year	174 000 m^3 (62,000 cunits)
Purchase Price	$7 122 000 (Canadian)
Ownership Cost	$ 756/hour (excludes interest)
Machine Operating Cost	$ 927/hour
Support Equipment	$ 164/hour
Woods Crew	$ 182/hour
Landing Machines	$ 234/hour
	$2 265/hour (excludes interest)

The cost of yarding is estimated to be $20.77/$m^3$ and total cost on the truck including felling and spur roads but excluding main road, supervision and interest charges is $27.23/$m^3$ ($88.79/cunit).

This cost compares with a current cost of logs on the truck of $44.00/$m^3$ for helicopter logging and $25.51/$m^3$ for cable logging under difficult conditions.

Much of the high quality mature timber throughout the world is located in inaccessible areas or on sensitive sites where it cannot be logged economically with current methods. The Cyclo-Crane and other airship developments show promise to fulfill this need.

SOMMAIRE

Ce rapport esquisse les grands traits du besoin et des exigences des véhicules volants libres qui conviennent à l'exploitation forestière. Ce rapport décrit le développement du Cyclo-Crane et d'autres véhicules volants à chargement lourd pour l'exploitation forestière et compare les coûts projetés des aéronefs avec les coûts d'exploitation des méthodes conventionnells par cables ou par hélicoptère. Des aéronefs sont maintenant développés pour la surveillance des transports ainsi que d'autres tâches. Ce rapport traite exclusivement de la tâche de mouvoir de lourds chargements sur de courtes distances (jusqu'à 2km).

Les hélicoptères furent utilizés avec succès pour exploiter la forêt en terrains abrupts et accidentés ainsi que pour réduire l'impact sur l'environnement causé par les chemins forestiers et le débardage sur des sites forestiers fragiles. L'hélicoptère est un appareil idéal. Ses charactéristiques de base incluent:

1. Capacité de lever et de descendre un chargement verticallement;

2. Capacité de positionner avec précision un crochet ou un chargement;

3. Accélération rapide;

4. Capacité de tourner rapidement;

5. Capacité de voler dans des vents allant jusqu'à 90 km/heure; et

6. Capacité d'atterir et d'attendre en cas de visibilité réduite ou de fortes tempêtes.

Le principal désavantage des gros hélicoptères est le coût élevé de propriété et d'opération.

Le Cyclo-Crane inventé par A.G. Crimmins et l'Aérogrue inventé par D.B. Doolittle combinent la levée aérostatique d'un aéronef avec la levée aérodynamique à partir d'un type d'ailes d'avion non coûteuses. Dans les deux cas, l'hélium supporte toute la charge morte et la moitié du chargement. Lorsque déchargé, l'appareil doit réduire de puissance.

En 1979, quatre compagnies de l'industrie forestière de la Colombie-Britanique ont subventionné la construction d'un modèl d'essais de Cyclo-Crane. Une cinquième compagnie se joignit à eux en 1981. FERIC coordonna le projet jusqu'à la formation de Aerolift Inc. et continue de contrôler le projet. La construction d'un model expérimental d'une capacité de 1.8 tonnes fut complété en 1982. Malheureusement, cet appareil fut endommagé lors d'une grosse tempête au cours des premiers essais. Celui-ci fut reconstruit et les essais vont reprendre en 1984 sous un contrat d'essais du Service de Forêts des Etats-Unis.

Le Piasecki Heli-Stat qui combine la levée de l'aéronef avec des rotors d'hélicoptère et le Van Dusen LTA 20-1 qui utilise les forces de Magnus pour générer la levée sont d'autres concepts d'aéronefs en développement qui peuvent être appropriés pour l'expolitation forestière.

Les principaux facteurs affectant le coût d'exploitation forestière par voie aérienne sont:

- le coût de propriété et d'opération de l'appareil;
- le temps d'un cycle aller-retour du bois à la jetée (incluant la cueillette et le dépot ainsi que le temps d'envol);
- le volume par cycle (dépend de la capacité de l'appareil et de la disponibilité des billes au point de cueillette); et
- délais (incluant les bris mécaniques et les conditions atmosphériques) qui réduisent le volume de billes transportées par année.

Nous estimons que le Cyclo-Crane, conçu pour une charge de 12 tonnes, sera plus économique à posséder et à opérer qu'un gros hélicoptère. Le Cyclo-Crane sera plus lent pour l'envolée et les virages mais transportera un chargement plus lourd. Le Cyclo-Crane devrait être aussi fiable mécaniquement qu'un hélicoptère mais plus dépendant des conditions atmosphériques et requirera un site spécialement aménagé pour l'encrage durant la nuit et lors de tempêtes.

En se basant sur ces hypothèses nous croyons qu'un Cyclo-Crane de 12 tonnes aura une production et un coût suivant:

Heures par année	1600
Temps par cycle	5.13 min.
Volume par cycle	$10.67m^3$
Volume par quart	$873m^3$ (308 cunits)
Volume par année	174 $000m^3$ (62 000 cunits)
Coût d'achat	$7 122 000 (canadien)
Coût de propriété	$765/heure (excluant intérêts)
Coût d'opération de l'appareil	$927/heure
Equipement de support	$164/heure
Equipe forestière	$182/heure
Machines à la jetée	$234/heure
	$2265/heure (excluant intérêts)

Le coût de débardage est évalué à $20.77/m^3$ et le coût total sur camion incluant l'abattage et chemins secondaires mais excluant le chemin principal, la supervision et les intérêts est de $27.23/m^3$ ($88.79/cunit).

Ce coût se compare avec le coût actuel de billes sur camion de $44.00/m^3$ pour les opérations forestières avec hélicoptère et de $25.01/m^3$ pour les opérations forestières avec cables dans des conditions difficiles.

Une bonne partie des arbres à maturitiés de très haute qualité à travers le monde sont situés sur des sites inaccessibles ou sur des site fragiles ou l'exploitation forestière ne peut être rentable avec les méthodes actuelles. Le Cyclo-Crane et les autres développements d'aéronefs démontrent des espoirs prometteurs pour rencontrer ces besoins.

INTRODUCTION

The forests of Coastal British Columbia are among the most challenging to log in the world. Primary log extraction (yarding) is difficult because the old growth trees are large and grow on steep and rugged slopes. Specialized methods and equipment have been developed over the years to overcome these difficulties. Cable logging is the most common method of yarding the logs from the stump to roadside. Logs are then loaded on trucks. As the easier areas are logged, road networks must be built in increasingly difficult terrain. Investment in roads is steadily increasing and, at the same time, cable yarding productivity is decreasing. The result is high primary logging costs. The impact of logging on the environment is also a concern. Innovative techniques are needed.

The magnitude of the problem can be illustrated by a few figures. The volume of mature timber on the Coast of B.C. is 3336 million cubic metres (COFI, 1981) - this is enough timber to build 167 million homes. It would take over 100 years to liquidate the supply at the present yearly harvesting rate (30 million m /year); this is assuming that all the Coastal mature timber is economically accessible and that it can be logged without endangering the environment. Hedin (1978) shows that 47 percent of the mature timber on the Coast is on slopes exceeding 50 percent. Yarding costs, road construction and maintenance costs grow exponentially with slope and terrain roughness; roads often cost more than $100 000/km to build. Part of the forest inventory is economically inaccessible to existing methods.

In addition to economically inaccessible areas, some sites are too sensitive and fragile to cable log. Slope movement, erosion, landslides and stream siltation resulting from logging activities are major concerns. Sauder, E. (1984) concludes that "...within logging areas, roads are the major source of slope failure...". Ground gouging, ploughing and rutting are common with cable systems such as highlead because logs are not fully suspended during yarding. Dyrness (1972) found that soil disturbance is reduced with skyline and balloon logging systems.

Large tracts of forest, assumed to be unharvestable with technologies used today, are being deleted by the Ministry of Forests from the allowable annual cut. As an example, 17 percent of the Queen Charlotte Timber Supply area (395 800 ha) has been deleted from Queen Charlotte Islands' timber supply inventory because of environmental sensitivity to logging and terrain stability constraints. The MOF assumes that 10 percent of these areas will ultimately be available if logging systems are developed that will not cause excessive environmental impact (Sauder 1984).

Other forest areas, such as hanging valleys and small isolated patches of timber, are not physically accessible by conventional cable methods.

It is estimated that, in total, 10 to 15 percent of the Coastal inventory is inaccessible by standard cable techniques (Giordano, 1971).

The B.C. logger has long dreamed of a "skyhook" that would pick up the logs from distant sidehills and deposit them gently on the valley bottom. His dream has been partly fulfilled by the introduction of heavy-lift helicopters. The technical success of the helicopter as a logging machine has created a need for a machine that would operate like a helicopter but at a lesser cost. Starting in the early 1970s, after decades of technological stagnation, airships are making a comeback and appear to offer the potential of fulfilling the logger's dream. Many new heavy-lift-airship (HLA) concepts have been proposed, two of which (the Cyclo-Crane and the Heli-Stat) are presently being developed primarily for logging applications.

FERIC first demonstrated the advantages of a free-flying logging machine in "Coast Logging: Highlead Versus Long-Reach Alternatives" (Sauder, B. 1977). The Aerocrane, invented by D.B. Doolittle, was used as an example in the analysis. The Aerocrane development preceded the invention of the Cyclo-Crane by A.C. Crimmins in 1978. FERIC recognized the potential of the Cyclo-Crane and encouraged the formation of a consortium of several major Coastal logging companies to finance the development of a prototype. This development commenced in 1979; testing of the prototype is scheduled for the summer of 1984.

This report reviews the potential of heavy-lift airships for aerial logging in B.C. and describes the progress in the development of the Cyclo-Crane to date. Based on the Cyclo-Crane experience and on studies of helicopter logging, the report also reassesses the economics of logging with HLAs; it defines the factors governing the cost of logging with HLAs and their expected low and high value limits. As an example, logging cost is calculated for a 12-tonne Cyclo-Crane assuming likely values for the various factors. A sensitivity analysis allows the reader to determine the impact on cost if different input values are assumed. The following questions are addressed:

- How much will an HLA produce?
- How much will it cost to own and operate?
- What is the cost of logging with an HLA?
- What is the sensitivity of this cost to various factors?
- How does HLA logging compare with helicopter or cable yarding?

A 12-tonne Cyclo-Crane is used as an example, but many of the cost and production figures apply to HLA logging in general.

THE AERIAL LOGGING MISSION

Three logging systems using HLAs can be conceived.

The first one is inspired by present helicopter logging techniques; the HLA would replace the helicopter as a yarder (Figure 1).

The second approach would use a large HLA (50 to 100 tonnes) to fly a cable yarder and other traditional equipment into a setting. The logs would be conventionally yarded and assembled into bundles, and the bundles would then be flown by the large HLA down to a valley road and loaded on trucks (or to tidal water for booming and towing).

A third approach, presently experimented with by the U.S. Forest Service, consists of pre-bunching the logs in the setting with an all-terrain yarder; a medium-sized HLA (20 to 30 tonnes) would yard the pre-bunched logs to a landing.

Only the first alternative is investigated in this report. It is envisioned that the HLA would perform the primary transport of the felled trees from the stump to a landing. The trees would be felled by crews flown to the site with a small support helicopter. Access to the logging area would be limited to easily-built main roads. Road density would be such that the area logged would be within a maximum of 2000 metres of a landing. The landings or drop zones would be large enough to handle sorting and processing of the yarded trees and logs. Logging trucks, loaded at the landing, would transport the logs to the customer or water for transport.

The HLA would normally fly empty to the setting and pick up a turn of logs matching its lift capacity. Other pick-up techniques could be developed, but it is presently envisioned that, as in heli-logging, the HLA will hover accurately over the pick-up point and place the hook in the hands of a "hooker" on the ground (Figure 2). The hooker attaches the preset chokers to the hook and leaves the pick-up area before the turn of logs is lifted and yarded away. The ground hooking crew first estimates log weights, presets chokers on logs and prepares turns of suitable weights; then the crew directs the aircraft to the pick-up area and hooks on the turn. Weight estimating and hooking are labour intensive and dangerous operations because of the broken steep ground and the density of logs, branches and brush impeding the mobility of the crew. The HLA can carry sophisticated hooks or grapples and offer opportunities to mechanize the pick-up method further.

After yarding the turn, the loaded HLA heads for the landing. This is normally a downhill flight. The logs are then placed within the drop zone and released (Figures 3 and 4). The landing crew removes the logs from the drop zone, recovers and packages the chokers and processes the logs. Logs or trees can be bucked, limbed, scaled and sorted by species or grade. The logs are then loaded on trucks.

The logging mission requires that the HLA possess four basic characteristics:

Load Capacity

The HLA should have sufficient lift to pull the turn free from the ground and other logs or trees. The force required to "break-out" the turn can be substantially higher than the weight of the turn (Sauder, E. 1979). (The optimum load capacity for Coastal B.C. logging is discussed further in the section on economics.)

Hovering and Manoeuvering Accuracy

The HLA should be able to locate itself and hover precisely over the pick-up area even in moderately windy and gusty conditions. Helicopter pilots can accurately place the cargo hook, located at the end of a 60-metre tag line, within easy reach of the hooker on the ground.

Flying and Manoeuvering Speed

The HLA should manoeuver, accelerate and fly forward fast enough to achieve economically acceptable production levels. Turn time and its impact on cost is discussed in detail in the section on economics.

Performance in Adverse Weather

An HLA in a logging mission will work close to the ground, trees and sidehills. This is a hostile environment for an airship. A useful HLA should be able to keep logging in moderately difficult weather and should survive the worst West Coast storms at its mooring.

Setting locations in relation to the landing will vary. In B.C., settings will rarely be further than 2000 metres horizontal distance from the landing and the difference in elevation will normally not exceed 1000 metres. The optimum flight path will depend on the terrain and on the aircraft flight characteristics. The cost study is based on the setting conditions defined in Table A.

Note to HLA inventors:

It is recommended that developers of flying vehicles experience the logging mission first-hand before proceeding. The real world of logging can be much more difficult than imagined.

TABLE A. Characteristics of a Typical Setting for Aerial Logging.

Average Horizontal Distance from Pick-up Point to the Landing	1000 m
Difference in Elevation	300 m
Slope of Flight Path	30%
Flight Path Length	1044 m

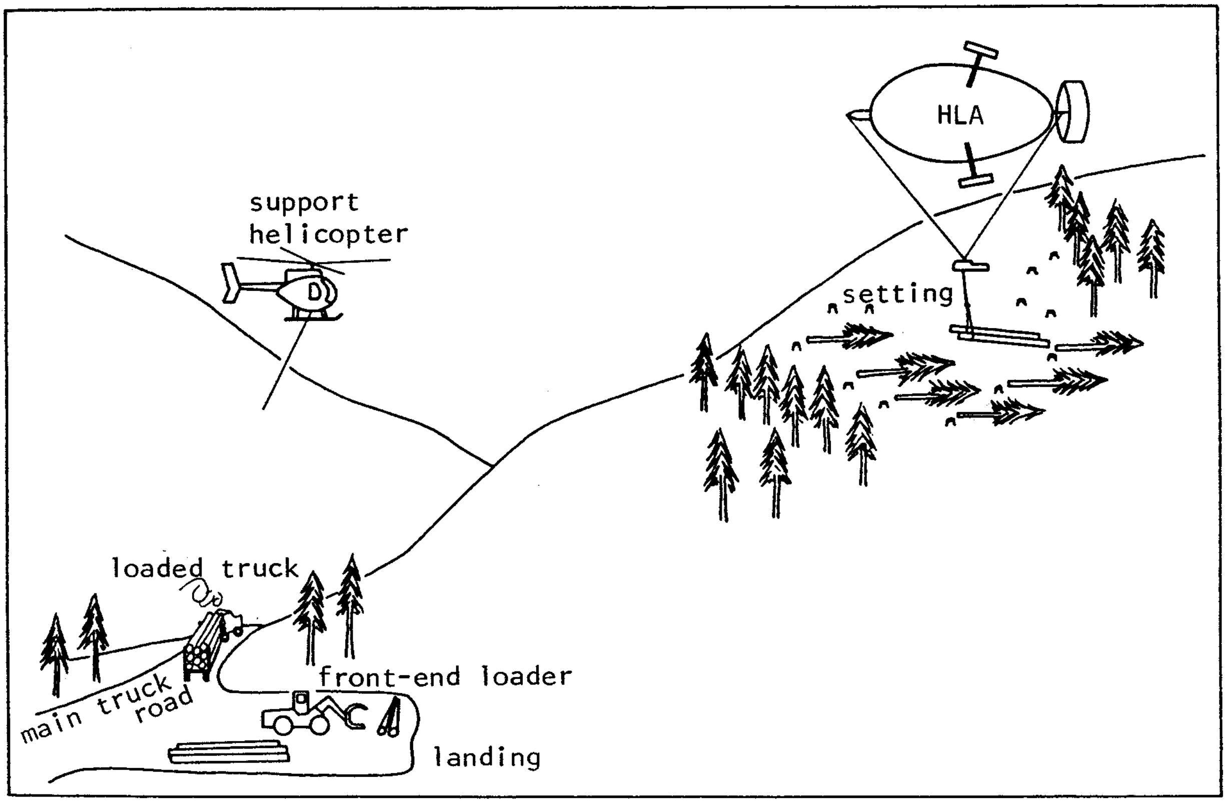


FIGURE 1. HLA Logging.

FIGURE 2. Hooking a Turn of Logs.

FIGURE 3. View of Drop Zone from a Logging Helicopter.

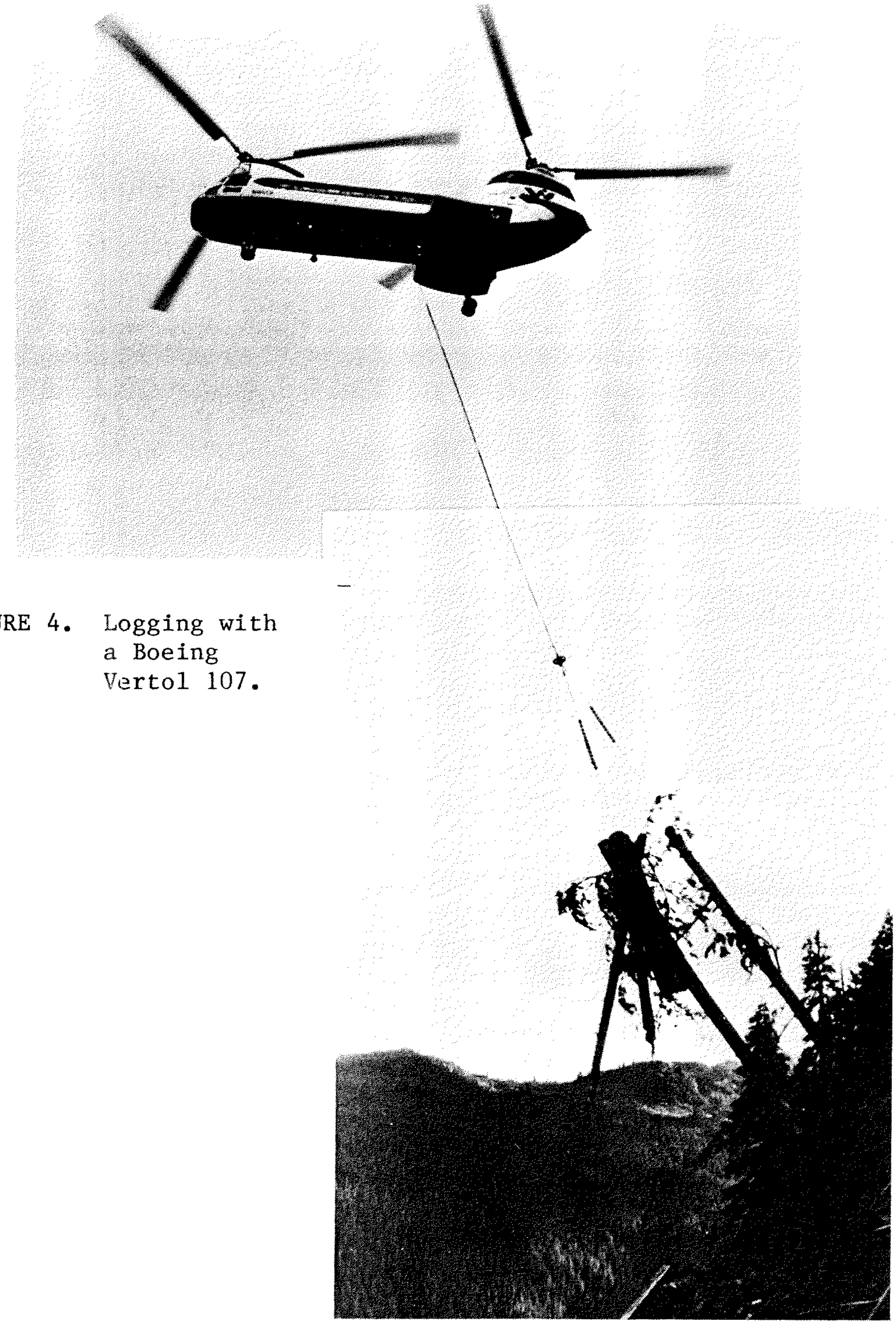


FIGURE 4. Logging with a Boeing Vertol 107.

HLA DEVELOPMENTS

In 1978, Booz Allen Applied Research identified logging as the largest market for heavy-lift airships (Ardema 1978). Their report to NASA-Ames suggested that 2100 vehicles would be needed worldwide for logging, representing more than 30 percent of the world market for HLAs of less than 23-tonne load capacity. In 1980, Canadair, under contract for the National Research Council of Canada, evaluated the Canadian market for heavy-lift aerial vehicles and concluded that logging was the only HLA application with a large market (Jackes 1980).

Development has continued on two of the seven concepts investigated by Canadair: the Cyclo-Crane and the Heli-Stat. Other airships are also being developed but not primarily for logging. Among these are the Van Dusen LTA-20, and Airship Industries' AD-500.

1. The Cyclo-Crane

a) Background

The Aerocrane, invented by D.B. Doolittle, preceded the invention of the Cyclo-Crane. Both are hybrid flying vehicles which combine airships' aerostatic lift with airplanes' aerodynamic lift. The Aerocrane (Figure 5) consists of four rotor wings with tip-mounted engines projecting from a rotating spherical balloon. The pilot's compartment is suspended below and counter-rotates relative to the balloon. In addition to the buoyant lift of the balloon, dynamic lift is generated by the rotating wings. Fifty percent of the payload weight is supported by the aerostatic lift and 50 percent by the wings. In its unloaded configuration, the Aerocrane has to be powered down. Several Aerocrane models were built and tested between 1972 and 1978. Studies by All American Engineering, Princeton University, the U.S. Navy and Canadair demonstrated the simplicity and technical validity of the concept, but also showed that high Magnus drag would limit forward speed to the point of making it impractical for logging. In 1978, A.G. Crimmins proposed to turn the Aerocrane 90 degrees and rotate it around a horizontal axis using the winglets for lift and the rotors for forward thrust, and the Cyclo-Crane concept was born (Figure 6).

b) Concept

The Cyclo-Crane consists of an egg-shaped, helium-filled balloon pierced from front to back by a horizontal shaft. Four stalks are attached radially at 90-degree intervals around the balloon. The stalks consist of a wing, a blade, an engine and a propeller. They provide the propulsion, lift and manoeuvering systems of the Cyclo-Crane. An empennage (tail) is added for stability. The sling cables, attached to bearings at both ends of the horizontal shaft, are connected to a pilot station. The payload hangs from the pilot station.

The balloon and stalk assemblies are driven in rotation by the engines and propellers. The entire vehicle, excluding the tail, sling cables and pilot station, rotates at a speed of 0 to 12 RPM around the horizontal axis. The balloon lifts the gross structural weight of the vehicle plus 50 percent of the payload. The wings supply plus or minus 50 percent of the payload. In hover, the wings are parallel to the axis of rotation and are cyclically controlled to provide positive or negative lift (Figure 7). In forward flight the blade airfoils are collectively controlled and act as a large propeller to provide forward thrust (Figure 8).

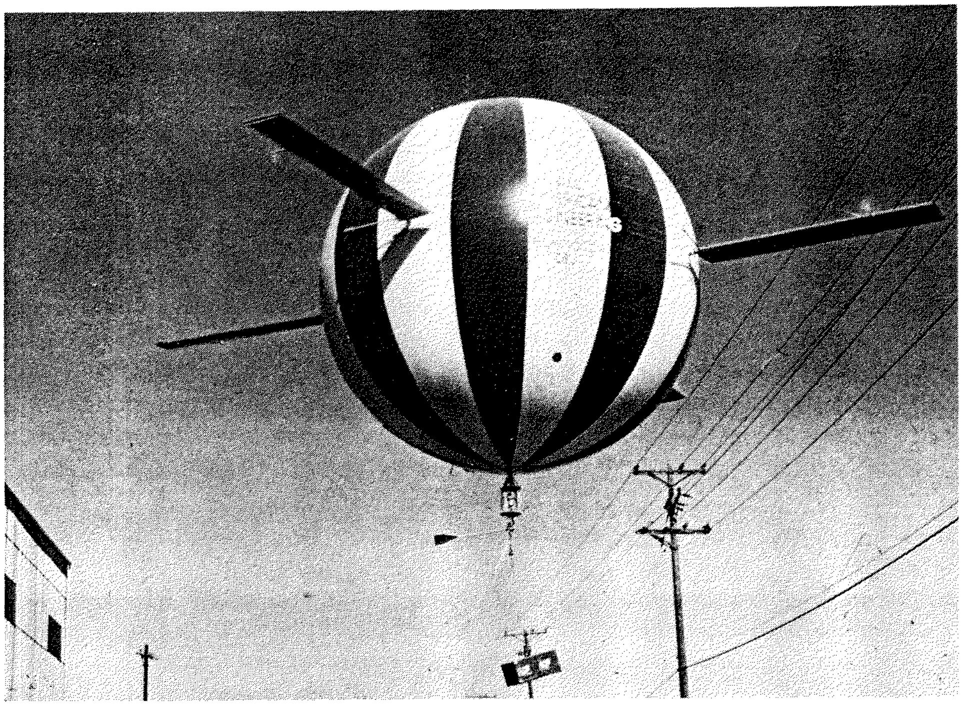


FIGURE 5. Aerocrane.

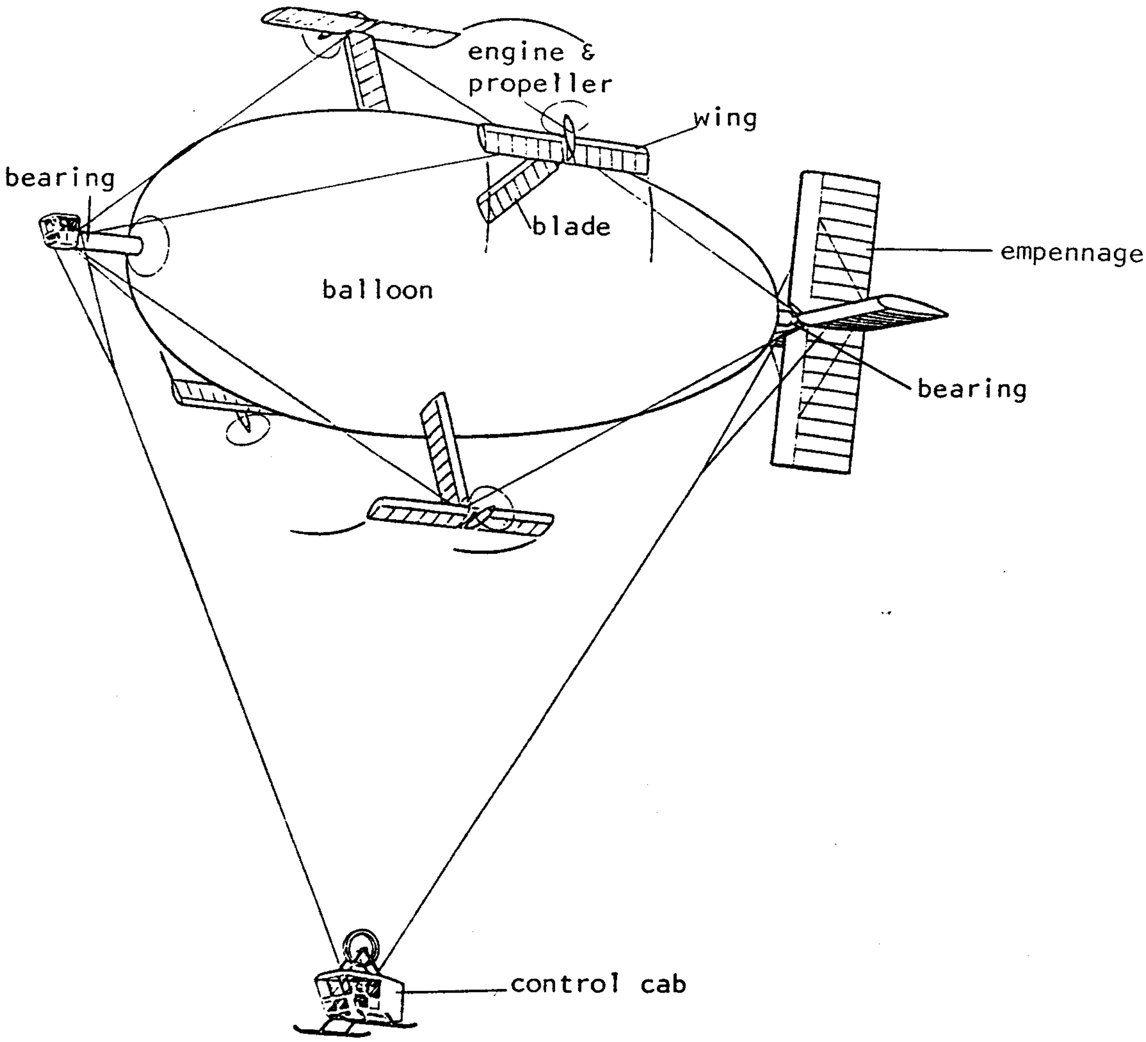


FIGURE 6. Cyclo-Crane.

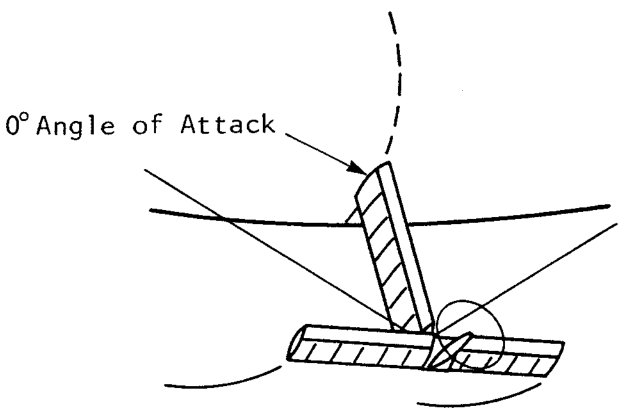


FIGURE 7. Stalk Configuration in Hover.

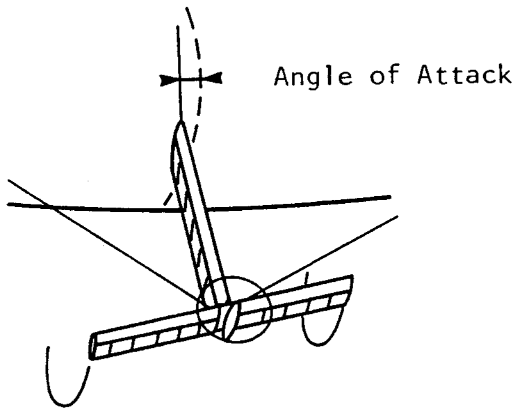


FIGURE 8. Stalk Configuration in Rotating Forward Flight.

As the vehicle accelerates forward, the stalk assembly is rotated so that the engines and fixed pitch propellers always face the true wind direction. At the same time, the speed of rotation around the horizontal axis is decreased so that the resultant airspeed over the wings and therefore the lift, are kept constant. When the Cyclo-Crane reaches maximum forward speed the stalks are aligned with the horizontal axis of the vehicle and the rotation stops (Figure 9). Cyclic commands on the blades provide pitch and yaw control. The Cyclo-Crane can be manoeuvered backwards or sideways by different combinations of cyclic and collective controls of the blades and wings.

The vehicle is controlled from the cab suspended by the sling cables. Control inputs and feedbacks are transmitted by telemetry between the cab and the rotating assembly. An automatic ballonet system controls helium pressure in the hull.

Safe mooring is one of the most critical constraints with any HLA. The Cyclo-Crane can be mast moored (Figure 10) or single-line moored. Mast mooring is the traditional method for mooring airships. The nose is attached at the mast top and the ship is left free to weathervane around the mast. Because of the heavy equipment required for mast mooring, single-line mooring has been proposed as a method of mooring the Cyclo-Crane at a logging site and will be tried with the 1.8-tonne prototype.

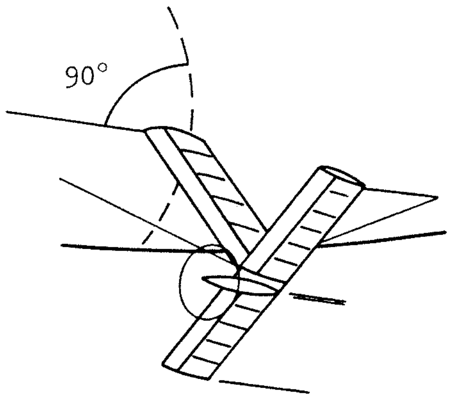


FIGURE 9. Stalk Configuration in Non-Rotating Forward Flight.

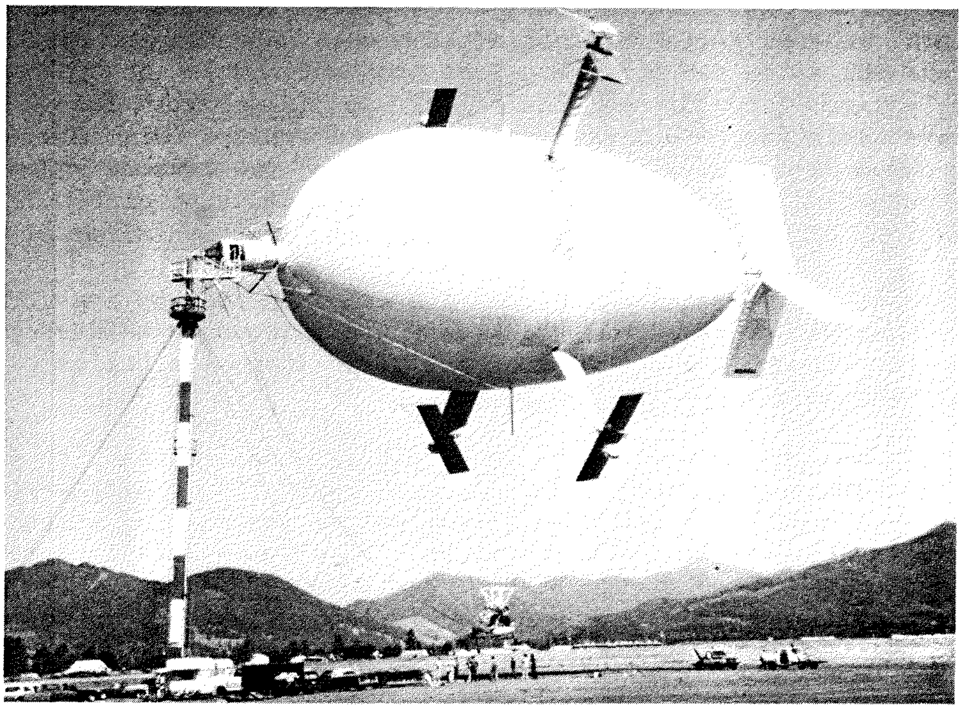
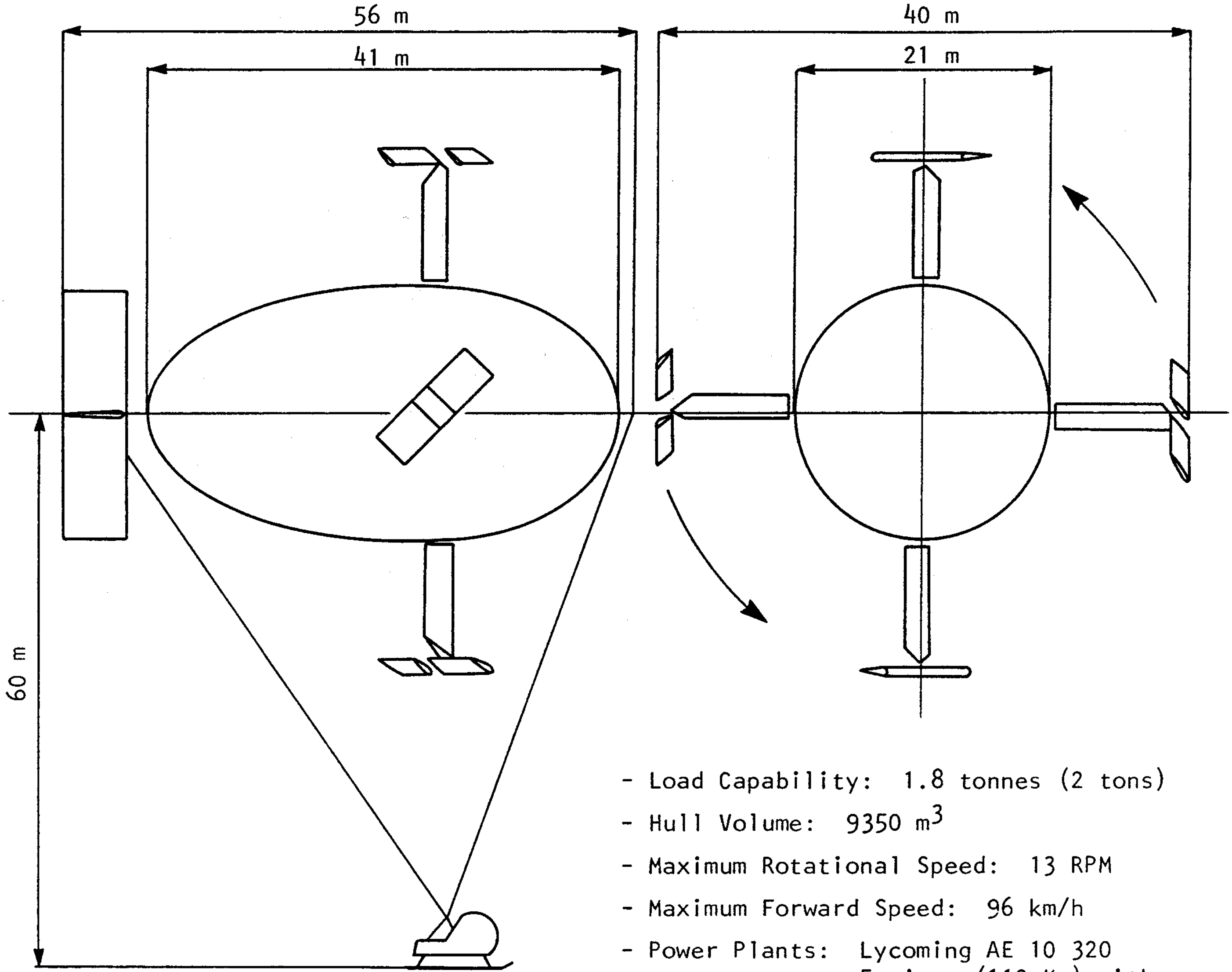


FIGURE 10. 1.8-tonne Cyclo-Crane Model Mast Moored.

c) Development

In June 1979, four major B.C. logging companies signed an agreement with the two inventors (Crimmins and Doolittle) to finance the design, construction and testing of a 9-metre long Cyclo-Crane model. The model was assembled and tested in November 1979 in a Navy hangar in Lakehurst, New Jersey. The model was not powered, but instead was towed to test the Cyclo-Crane's behaviour and stability. Wind tunnel tests were also performed on a small model at Princeton University. Following this initial phase, financing was secured, mainly from the B.C. logging companies, to build a 1.8-tonne load capacity model. AeroLift, Incorporated was formed and the work took place on the former U.S. Navy Base in Tillamook, Oregon in the existing large hangar facilities. The model was built by an AeroLift team of twenty engineers, mechanics, machinists and technicians under the supervision of the two inventors. Two major subcontractors were employed: ILC Dover designed, tested and fabricated the balloon and Schweizer Aircraft Incorporated fabricated the airfoils (wings, blades and tail) and part of the internal structure. Scientific and technical support was provided by the Aerodynamics Department of Princeton University and private consultants. Construction was on a "skunk works" basis. Only essential engineering calculations were performed. Design and documentation were kept to a minimum to economize time and money. The program emphasized hardware development and construction of a model that worked. The approach resulted in the successful construction of a model in the summer of 1982. Details of the model's characteristics are given in Figure 11.

In September 1982, a U.S. Forest Service contract was awarded to AeroLift, Incorporated to test the 1.8-tonne Cyclo-Crane model's performance.



- Load Capability: 1.8 tonnes (2 tons)
- Hull Volume: 9350 m^3
- Maximum Rotational Speed: 13 RPM
- Maximum Forward Speed: 96 km/h
- Power Plants: Lycoming AE 10 320 Engines (110 Kw) with 4-bladed propellers

FIGURE 11. Characteristics of the 1.8-tonne Cyclo-Crane Model.

On October 22nd, 1982 a storm struck the Oregon Coast while the model was moored on its mast. The model broke free and crashed into a nearby field and sustained heavy damage (Figure 12).

Reconstruction of the model has been underway since early 1983, financed by the insurance proceeds. The model will be tested in 1984.

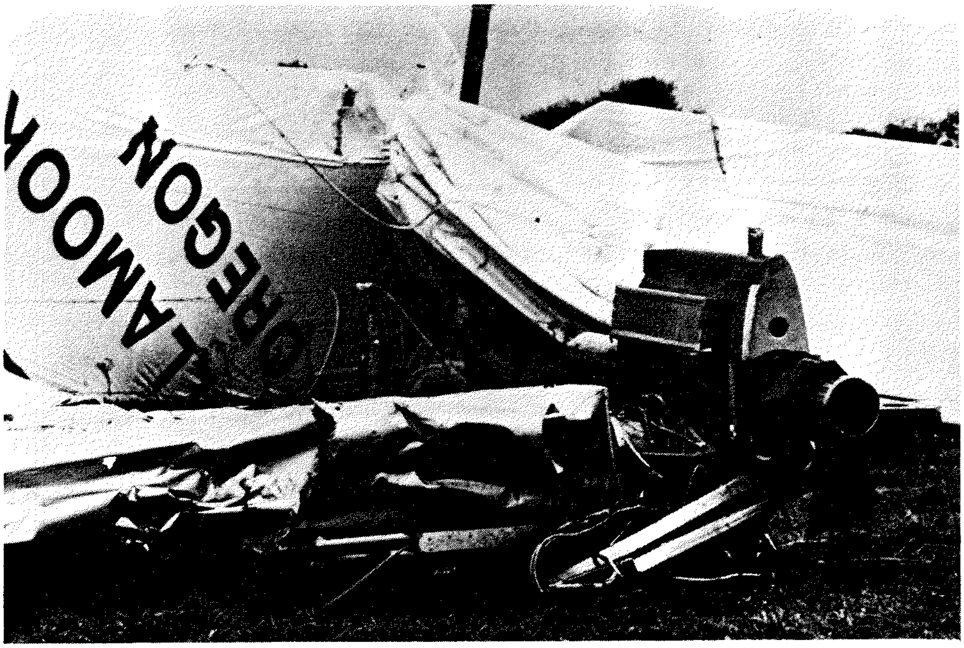


FIGURE 12. 1.8-tonne Model Cyclo-Crane Sustained Heavy Damage on October 22nd, 1982.

2. The Heli-Stat

The Piasecki Aircraft Corporation is presently under contract with the U.S. Forest Service to develop and fabricate a heavy-lift aerial logging airship called the Heli-Stat. The vehicle combines helicopter and aerostat technologies (Figure 13). The prototype being built uses four surplus Sikorsky H-34J helicopters connected by a frame. The weight of the helicopters and structure is supported by a 100-metre long U.S. Navy surplus airship. The helicopters supply the 21.5-tonne load carrying capacity of the machine. The prototype is being assembled in the Navy hangar in Lakehurst, New Jersey.

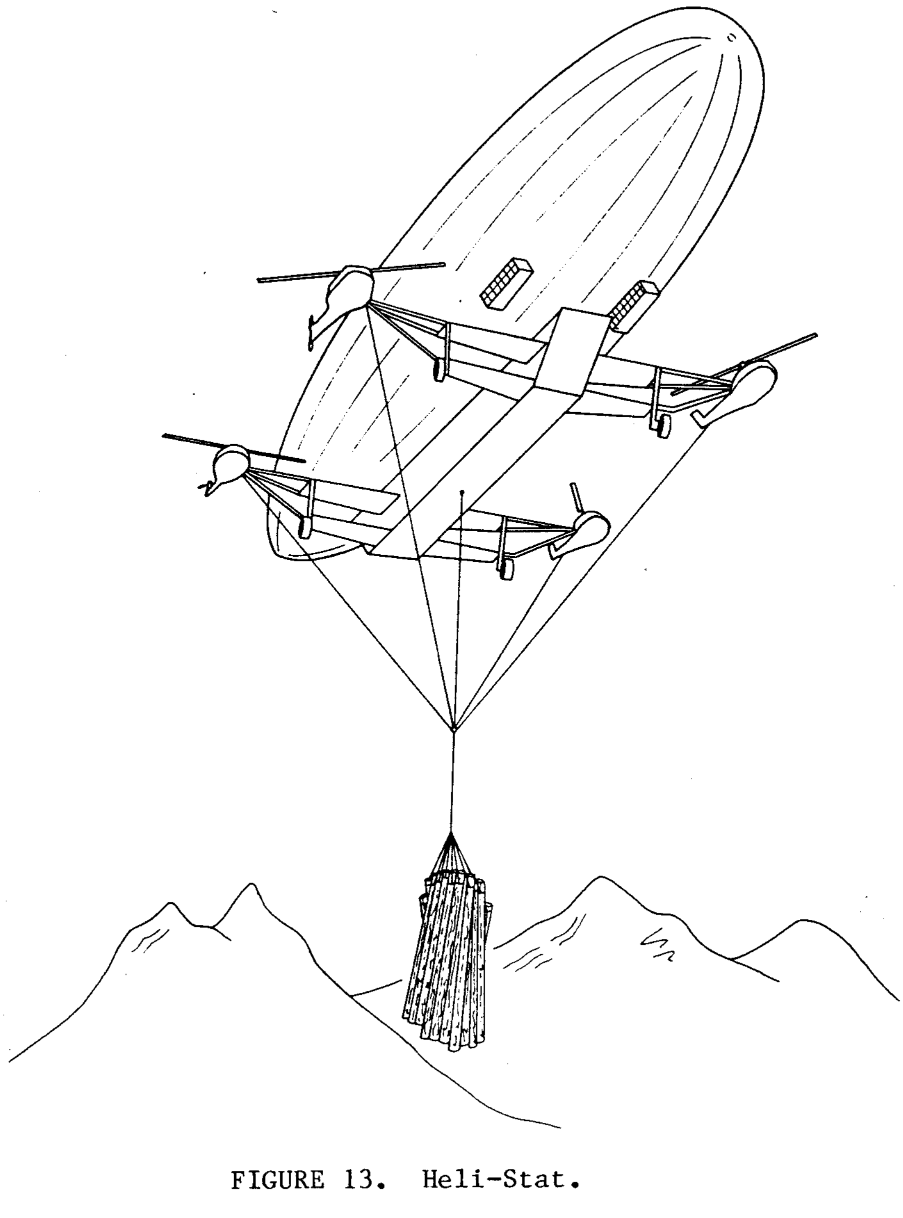


FIGURE 13. Heli-Stat.

3. The Van Dusen LTA 20-1

Van Dusen Commercial Development Ltd. has been developing the LTA 20-1 in Ottawa, Ontario since 1978 (Figure 14). The logging version of the LTA 20-1 combines buoyant helium lift with engine thrust and Magnus lift to provide 14 tonnes of net load capacity. The balloon is a 23-metre diameter sphere rotating around a horizontal axis. The rotation of the sphere combined with forward air speed generates the Magnus lift (a phenomenon used by golfers to lengthen a drive). The two engines located at the end of the horizontal shaft can be rotated to provide lift and/or forward and manoeuvring thrust. The spherical-shaped balloon allows the vehicle to be turned around rapidly which is an advantage for short missions. The LTA 20-1 is controlled from a gondola suspended below the sphere. The shape of the gondola improves the aerodynamic characteristics of the vehicle by modifying the airflow around the sphere. Van Dusen also proposes to build a 55-tonne load capacity airship for long-range, very high lift applications. The 55-tonne model would use air ballast for payload compensation.

A 6.1-metre diameter model LTA 20-1 was built and flown in 1981. The concept is presently being refined with the assistance of the Institute For Aerospace Studies in Toronto.

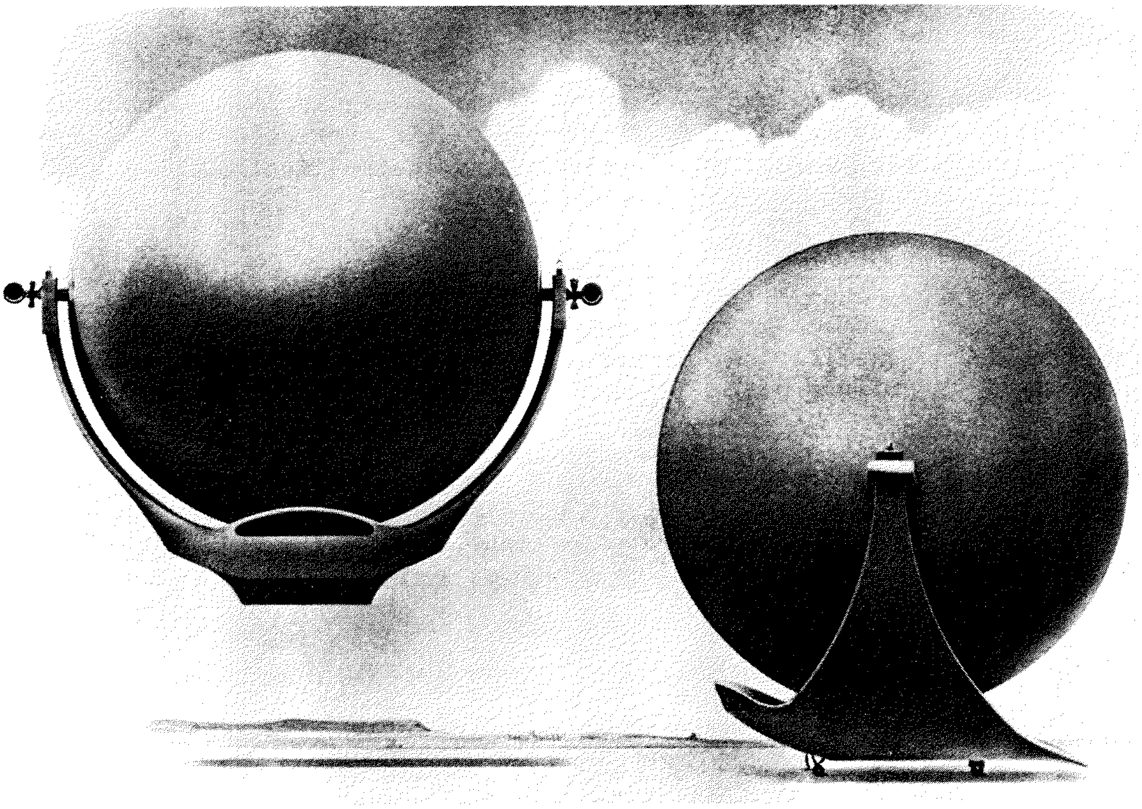


FIGURE 14. Van Dusen LTA 20-1 uses Magnus Effect to Generate Lift.

ECONOMIC ANALYSIS

Although the 1.8-tonne model Cyclo-Crane has not yet flown, its construction to date has provided invaluable information on cost and operational characteristics. Original logging cost studies based on preliminary information (Wellburn 1978) can now be updated using more realistic assumptions. A 12-tonne Cyclo-Crane is used as an example in the cost calculations, but the economic analysis applies to HLA logging in general. The projected characteristics of a 12-tonne Cyclo-Crane are given in Appendix I. Factors affecting the cost are defined within high and low limits. The sample calculation is done using values the authors believe most closely represent reality. Several somewhat arbitrary assumptions had to be made, but the sensitivity analysis allows the reader to study the effect of varying some of the major assumptions.

HLA YARDING PRODUCTION

The production of an aerial logging operation is limited by the volume of logs that the HLA can transport from the setting to the landing. The HLA production in cubic metres is a function of the turn time and the average volume carried per turn.

1. Turn Time

A complete HLA logging turn is shown in Figure 15. It consists of a flight empty from the landing area to the pick-up area, terminal time, flight back loaded and terminal time at the landing.

a) Flight time empty

Flight time empty from the landing to the pick-up is a function of the HLA's acceleration, deceleration and the cruise speed and the length of the flight path.

Appendix I ends with an analysis of the speed, acceleration and flight time for a 12-tonne Cyclo-Crane. For the typical setting described in the logging mission, the Cyclo-Crane accelerates at 1.15 m/s^2 and cruises at 100 km/h. Empty flight time is 1.0 minutes.

b) Flight time loaded

Flight time loaded from the pick-up to the landing is assumed to be the same as flight time empty because normally loads are carried down from mountains to valleys.

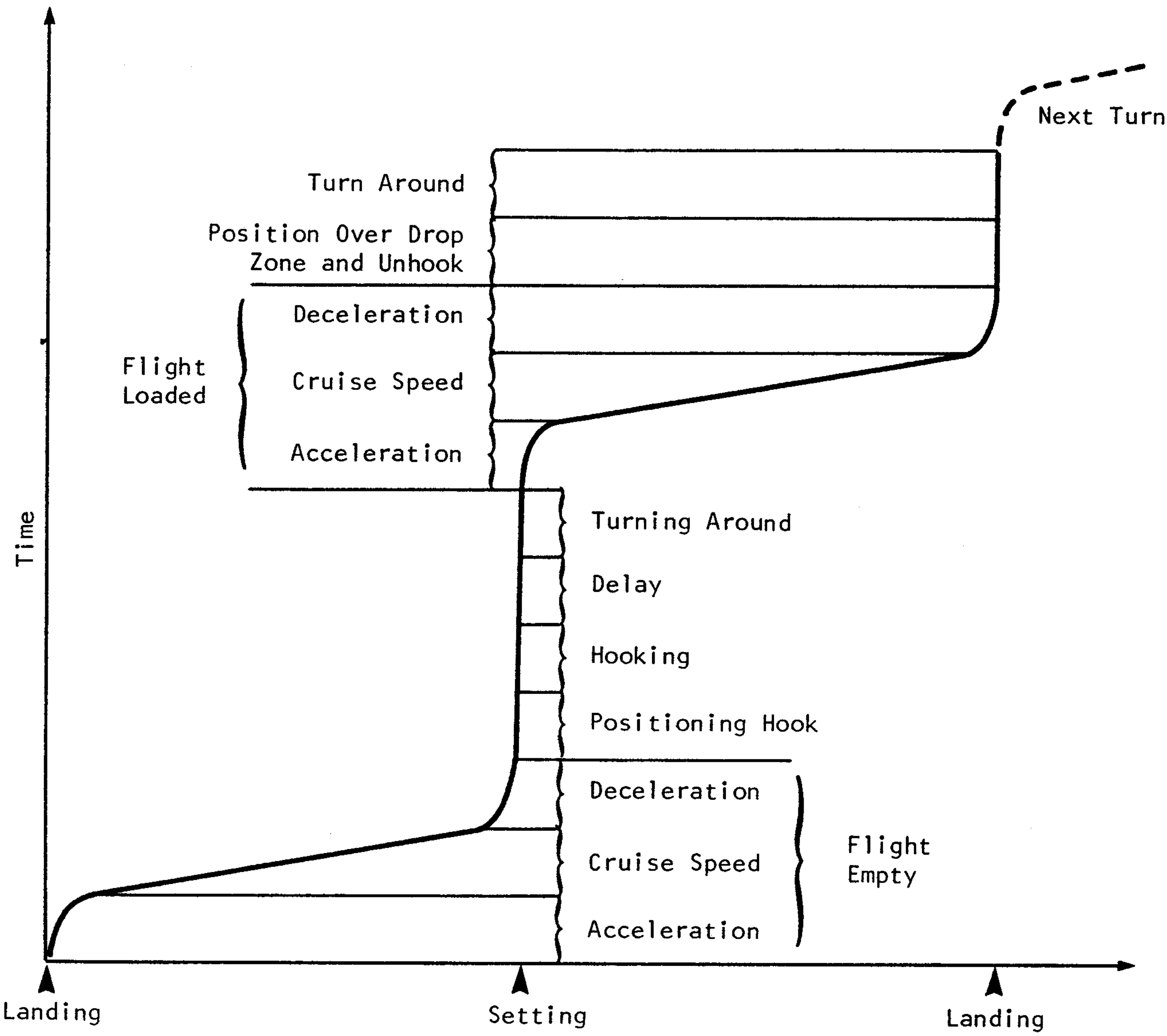


FIGURE 15. HLA Turn Time.

c) <u>Terminal time at the setting</u>

Once at the pick-up point, the HLA pilot has to spot the hooker and hover precisely over him to deliver the hook. He must then wait until the turn is hooked-on and the hooker has moved to a safe location. The turn is then yarded free. Miscellaneous delays can occur if the turn is too heavy, resulting in an abort, or if the logs and branches are tangled.

The airship must turn at each end of the flight. Doolittle has calculated that it would require an average of 0.4 to 0.5 minutes to turn a 10 to 16-tonne Cyclo-Crane. This would vary with local wind conditions.

d) Terminal time at the landing

The HLA has to deposit the logs smoothly and accurately on the landing, release the chokers and accomplish a 180-degree turn to point itself towards the setting.

Except for the two 180-degree turns (totalling between 0.8 and 1 minute), terminal times for HLAs are expected to be similar to those experienced by helicopters. (This is assuming that the precision hovering characteristics of the HLAs are identical to those of helicopters.) Appendix II analyzes helicopter turn times and shows that terminal times vary between 2 and 2.5 minutes. Terminal time for an HLA, like the Cyclo-Crane, varies between 2.8 and 3.5 minutes (including 180-degree turns).

EXAMPLE:

Turn Time Summary - 12-tonne Cyclo-Crane

Horizontal Distance	1000 m
Slope	30%
Flight Empty	0.98 min
Flight Loaded	0.98 min
Terminal Time	3.17 min (2.8 to 3.5 min)
Total Turn Time	5.13 min

e) Turn time comparison: Cyclo-Crane - Helicopter

Figure 16 shows how turn time for a 12-tonne Cyclo-Crane varies with distance and compares it with similar helicopter data from Appendix II.

2. Volume per Turn

A major advantage of HLAs is that they can carry large loads. The average volume carried per turn is not a function of the aircraft capacity alone, but also depends on the size, number and distribution of the logs in the setting.

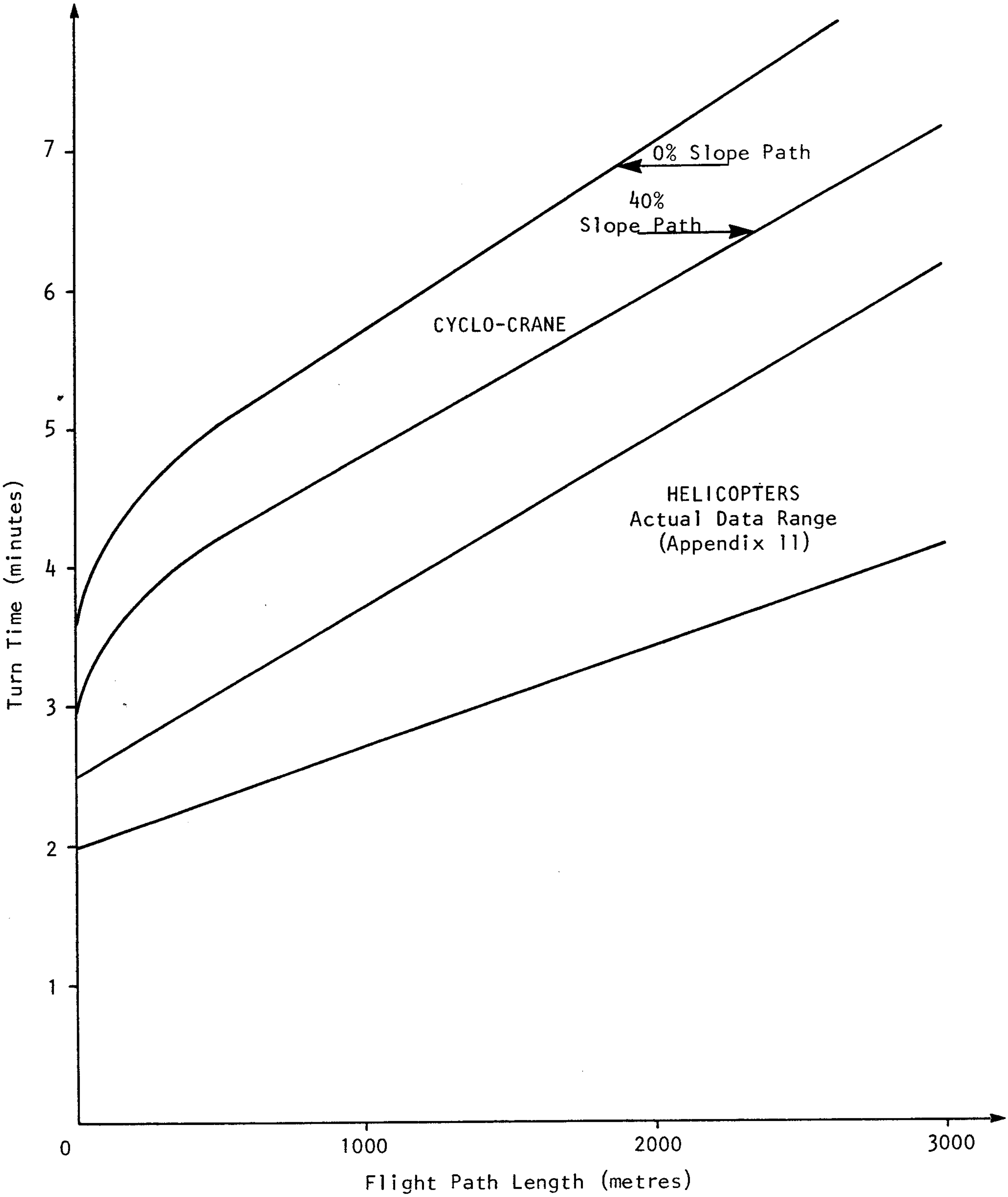


FIGURE 16. Cyclo-Crane Turn Time Versus Helicopter Turn Time.

Average volume yarded per turn is calculated as:

HLAs load capacity x load factor/log density

Volume per Turn	m^3
Load Capacity	kg
Load Factor	no unit
Log Weight per Net Cubic Metre	kg/m^3

a) <u>Log weight per net cubic metre</u>

This value is defined for aerial logging purposes as the <u>gross</u> weight of the log (including bark, branches, defects and rot) <u>divided</u> by the <u>net</u> scaled volume of the log. Log weight varies with species, site (dry versus wet), butt-log versus top-log, quality of limbing, amount of defects, etc. Table B gives average log weight values for Coastal B.C.

TABLE B. Green Log Weight per Net Cubic Metre for Coastal B.C. Species.

Species	Hemlock	Douglas-fir	Balsam	Cypress	Cedar
Log Weight per Net Cubic Metre (kg/m^3)	1172	1032	955	800	710

Depending on the species mix logged, log weight per net cubic metre typically varies from 800 to 1000 kg/m^3. The average used in this study is 900 kg/m^3.

b) <u>Load factor</u>

The load factor is equal to the average payload carried per turn, divided by the lift capacity of the HLA. The load factor depends on the ability of the ground crew to estimate the size (weight) of the turn and on the number and sizes of the logs within reach of the pick-up point.

The graph shown in Figure 17 has been obtained by simulating the logging cycles of an HLA for various setting conditions (Hartsough 1982). It shows that the load factor increases if one of the following conditions occurs, everything else remaining equal:

- if the average piece size decreases; or
- if the amount of timber within a choker length increases.

The average piece size can be decreased by doing more bucking in the woods. Although it results in an increased load factor, this is not a practical option because excessive bucking increases the number of pieces and produces lower value short logs.

The weight of timber within reach of the pick-up point can be increased by pre-bunching the loads. The USFS in Portland is presently experimenting with pre-bunching using a Kaiser-Spyder modified as a yarder.

The payload factor may increase or decrease when increasing the load capacity of the HLA. This is illustrated simplistically in Figure 18. If the load capacity is too small, one log represents a large fraction of the payload and the payload can be incremented in relatively large bites only; this results in a low payload factor. If the load capacity is too large, the number of logs required may not be available and the machine may have to fly with a partial load and reduce the payload factor. Appendix III analyzes the load factor for a setting typical of Coastal B.C. It shows that for load capacities from 5 to 15 tonnes, the load factors are fairly constant and equal to about 80 percent. Unless the wood is pre-bunched, HLAs of 20 tonnes or more

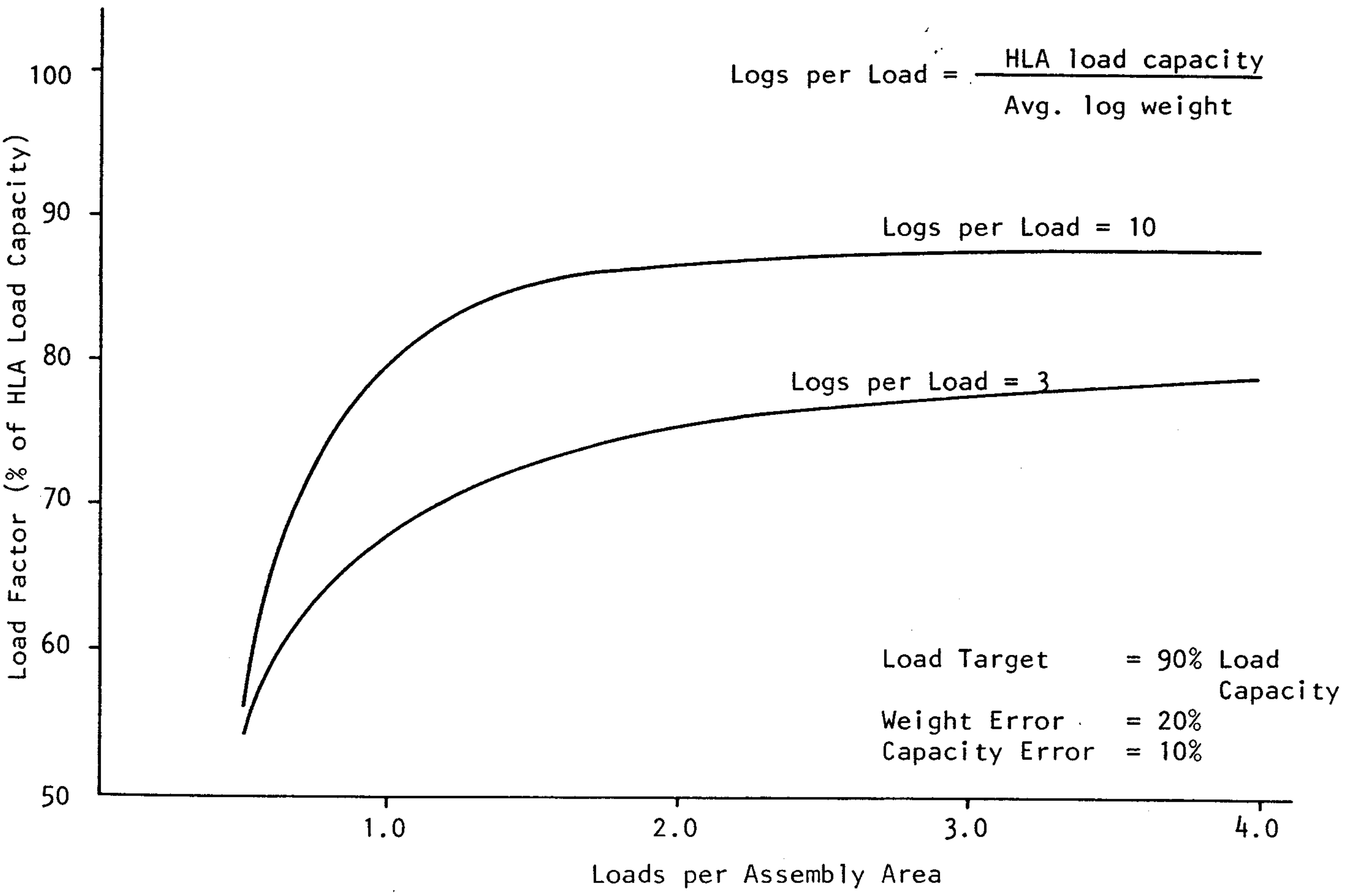


FIGURE 17. Load Factor Versus Number of Loads Within Reach of Pick-up Point.

INVENTORY OF LOGS IN PICK-UP AREA

Log Weights (tonnes)	2	3	4
Number of Logs	4	1	2
Symbolic Description			

TURNS FOR 5, 10 AND 15-TONNE CAPACITY VEHICLES

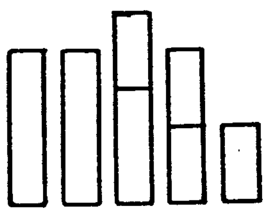
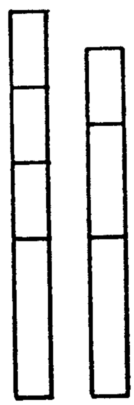
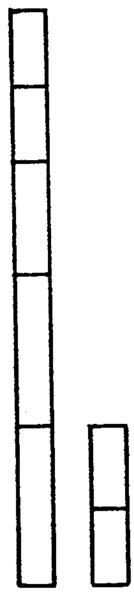
Load Capacity (tonnes)	5	10	15
Symbolic Description of Turns			
Number of Turns	5	2	2
Load Factor	76%	95%	63%

FIGURE 18. An Example to Show how the Load Factor Varies with Aircraft of Different Load Capacities.

would achieve low load factors because not enough wood would be available within reach.

As seen in Figure 17, the load factor does not change drastically above 1.5 loads per assembly area (i.e. 1.5 load capacity within reach). In order to achieve acceptable load factors, the HLA capacity should be such that the load density is 1.5 or more. Table C shows how this requirement translates in terms of volume per hectare required for various HLA sizes. It shows that 5 to 15-tonne HLAs would operate at acceptable load factors in most Coastal B.C. settings. A 20-tonne HLA would be too large if the logs were not pre-bunched.

TABLE C. Minimum Average Volume/Hectare Required to Achieve High Load Factors.

HLA Capacity	Minimum Volume Required* (m^3/ha)
5 tonnes	265
10 tonnes	531
15 tonnes	796
20 tonnes	1062

*Coastal B.C. average stand 600 m^3/ha
High density stand 800 m^3/ha

c) <u>Load capacity</u>

The optimum load capacity for a logging HLA is a complex quantity to define. It will ultimately be determined by the overall economics of the operation, i.e. what load capacity produces the minimum cost per cubic metre logged. Cyclo-Crane capacity versus logging cost is dealt with later in the Sensitivity Analysis.

Technical constraints, like available engine sizes, must also be considered in the choice of the ideal load capacity.

From an operational point of view, several factors may dictate payload capacity:

- the maximum tree (or log) weight
- the load density (weight within pick-up area)
- the number of logs per turn

As noted by Torney (1979), it would be desirable to yard all trees full-length so that bucking can be done under ideal conditions, thus optimizing the volumes and log grades. In the typical setting described in Appendix III, less than one percent of the trees weighed over 15 tonnes and less than 3.5 percent weighed over 10 tonnes. If a 10-tonne capacity HLA were used to log the setting, only 3.5 percent of the trees would have to be bucked; the remainder could be yarded full length and bucked at the landing as desired.

Table D shows the log sizes that can be lifted by 5, 10 and 15-tonne capacity aircraft. The preferred log length for Coastal hauling and water transport is 12.2 m (40 ft).

TABLE D. Log Size Limits for Three HLAs*.

HLA Load Capacity	Log Size		Log Volume
	Length 7.3 m	Length 12.2 m	
	Butt Diameter	Butt Diameter	
5 tonnes	100 cm	60 cm	5.6 m^3
10 tonnes	136 cm	117 cm	11.1 m^3
15 tonnes	294 cm	176 cm	16.7 m^3

*Using average log weight of 900 kg/m^3. Log sizes would be greater for cedar and less for hemlock.

Logs larger than 200 cm in diameter are rare and can be considered exceptions. It then appears that a 10-tonne capacity HLA can lift all logs providing the very large trees are bucked at 7.3 metres (24 ft).

A 10-tonne capacity HLA is adequate to log the majority of the trees full-length if desired and gives enough flexibility to buck the few large trees for grade and not for weight. We have noted previously that 15-tonne capacity is the upper limit that gives acceptable load factor without pre-bunching. The number of logs per turn will also limit the maximum load capacity. Torney (1979) has noted that "(for helicopter logging)....if more than five logs are required to complete a turn, the efficiency of the hook-up operation is reduced.... the chances of having a hang-up while lifting off the ground will increase with the larger number of logs."

A 15-tonne HLA with an 80 percent load factor will carry six 2.2 m^3 pieces in an average turn. As shown in Appendix III, with a typical log size distribution, some turns would have only one piece, while 30 percent will be made of eight pieces or more. As Torney suggested, this could result in delays during hook-up and lift-off; at the landing, the logs may end up jack-strawed and difficult to handle. A 10-tonne HLA would average four pieces per turn and 30 percent of the turns would have six pieces or more.

From an operational point of view, the ideal HLA would be from 8 to 16 tonnes and preferably in the lower part of the range to reduce the problem created by multiple-piece turns.

It is assumed in the example that the 12-tonne Cyclo-Crane averages 80 percent of its load capacity per turn.

EXAMPLE:

Volume Per Turn - 12-tonne Cyclo-Crane

Cyclo-Crane Lift Capacity	12 tonnes
Load Factor	80%
Log Density	0.9 tonne/m^3
Average Volume per Turn	10.67 m^3

3. Production

A typical cable yarding operation has 8 hours scheduled per shift. Excluding week-ends, statutory holidays and fire-season shut-downs, 200 days per year have productive shifts. The total number of hours per year averages 1600.

An aerial logging operation cannot be scheduled as a regular yarding operation because it is dependent on weather. As with balloon and helicopter operations, HLA logging will be shut down by wind and poor visibility. The operation might have to stop completely in winter months when the days are short and the weather is poor. Planning of HLA operations should take full advantage of long summer days and good weather (10-hour shifts, 7 days a week). This means that overtime will be paid to the crew.

As shown in Appendix IV, Port Alberni had 3448 daylight hours with less than 20 km/h wind and greater than 10 km visibility in 1982. By reducing the number of hours worked per day to a maximum of 10 in the summer and 8 in winter and allowing a 1.5 month winter break, the above number is reduced to 2240 hours. Mechanical and non-mechanical delays, as well as other weather conditions (like snow) will further reduce this figure. For several years, Whonnock Industries of Vancouver have logged between 2200 and 2300 hours per year with a Boeing Vertol 107 in the South-west Coastal B.C. area. This is a record achieved by taking full advantage of every minute the helicopter can fly. Silver Grizzly Timber Co. Ltd. averages much fewer hours with a Skycrane because of the more difficult weather conditions in the Prince Rupert area. HLAs are more susceptible to wind than helicopters and, similar to balloons used in logging, will have to be securely moored before dangerous winds occur. Only practical experience will tell how many hours an HLA could log in a year; it should be between 1000 and 2000 hours. Sixteen hundred hours per year is used in the example.

EXAMPLE:

Production - 12-tonne Cyclo-Crane

Hours per Year	1600	
Hours per Shift	8.0 (average)	
Productive Hours per Shift	7.0 (average)	
Turn Time	5.13 min	
Volume per Turn	10.67 m^3	
Turns per Shift	81.8	
Volume per Shift	873 m^3	(308 cunits)
Volume per Hour	109.1 m^3	(38.5 cunits)
Volume per Year	174 515 m^3	(61,629 cunits)

We also assume that an average of 8 hours are scheduled per shift out of which 7 are productive hours. One hour per day is required for mooring, fuel-up, routine maintenance, flying from the mast to the setting and personnel breaks.

HLA OWNING AND OPERATING COSTS

1. Investment Cost

The investment cost comprises the initial cost of purchasing the machine and the initial spare parts.

The capital cost of the machine has to be estimated since no full size HLA is presently in production. Table E gives the results of several cost studies. The capital cost projections for existing concepts vary between $576 000 and $824 000 per tonne payload. This cost is 1/2 to 2/3 that of a heavy-lift helicopter.

The theoretical look at HLA costs presented in Appendix V shows that the balloon-helicopter combination has a lesser potential for reducing capital cost than the balloon-airplane combination. However, the only balloon-airplane combination presently built, the Cyclo-Crane, requires a heavy structure and the resulting cost of the machine is higher than expected.

It is estimated that 5 percent of the capital cost will be spent for parts inventory.

TABLE E. Capital Cost per Tonne of Load Capacity (HLAs).

HLA	Reference	$/Tonne Payload	Production Run Of
Heli-Stat	Jackes (1980)	710 000*	50 aircraft
Cyclo-Crane	"	576 000*	50 aircraft
Cyclo-Stat	"	618 000*	50 aircraft
Skyship 2000 (traditional blimp)	Munk (1983)	824 000	Unknown
Van Dusen LTA-20	Magnus Aero. Corp. (1983)	714 000	-
Cyclo-Crane	Appendix I	821 000	10 aircraft
		600 000	50 aircraft
Heavy-lift Helicopter	Appendix V	1 100 000	-
Balloon + Helicopter (Theoretical)	Appendix V	623 000	-
Balloon + Small Airplane (Theoretical)	Appendix V	76 000	-

*Cost adjusted to 1983 Canadian dollar values using a 10 percent inflation factor per year.

EXAMPLE:

Investment Cost Summary - 12-tonne Cyclo-Crane

Load Capacity	12 tonnes	(8 to 16 tonnes)
Cost per Tonne	$ 600 000	
Acquisition Cost	$7 122 000	(50 craft per year)
Parts Inventory (5%)	$ 356 100	
Total Cost	$7 478 100	

2. <u>Ownership Cost</u>

Ownership cost includes depreciation, interest and insurance. Helicopters are generally depreciated over 10 years with 0 percent to 25 percent residual values. The same schedule is used for HLA. Bernstein (1977) used 10 years with 25 percent residual for the Aerocrane, and Jackes (1980) and Laurie-Lean (1981) used 10 years with 0 residual. Our study assumes a 10-year amortization period with a 10 percent residual value. Interest is based on 12 percent of the annual average investment (A.A.I.) and is accounted for in a later section.

It is assumed that the HLA can be insured at a yearly cost equal to 8 percent of the capital cost of the machine. A lower premium rate can be negotiated if it is shown that HLAs can be easily repaired. Based on the history of airships and balloons, insurance companies may be reluctant to insure airships. Logging balloons are usually not insured because the premium is considered prohibitive and the balloon cost is small.

EXAMPLE:

Ownership Cost Summary - 12-tonne Cyclo-Crane

		$/Year	$/Hour
Annual Operating Hours	1600		
Acquisition Cost	$7 122 000		
Parts (5%)	$356 100		
Depreciation			
Years	10		
Residual	10%		
Annual Cost		$640 980	$400.61
Average Annual Investment	$4 593 690		
Insurance			
Percent of L.T.A. Cost	8%		
Annual Cost		$569 760	$356.10
Total Annual Ownership Cost (excludes interest)		$1 210 740	$756.71

3. Annual Operating Cost

Annual operating cost comprises all costs considered independent of the number of hours the HLA flies in a year. They include the cost of the crew permanently assigned to the craft (i.e. pilots, mechanics, watchmen), helium and hull maintenance and non-productive flights.

a) Personnel

It is assumed that one pilot and one co-pilot fly the HLA. The pilot flies the aircraft mainly by visual reference to the ground, concentrating on positioning the hook within the hooker's reach at the setting and depositing the logs carefully within the drop zone. The co-pilot monitors the gauges for the engines and controls, and checks the load cell indicator to ensure optimum payload. Because of the strenuous nature of the mission, a permanent crew of two pilots and two co-pilots will be required to keep the HLA logging, fly the support helicopter, take time off and rest. (Helicopter logging operations normally have a team of five pilots and co-pilots on staff per logging helicopter.)

It will be imperative, when logging with an expensive HLA, to achieve high mechanical availability. It is therefore projected that two mechanics (one mechanic and one electronics technician) should stand by each Cyclo-Crane. In addition, to guard against bad weather, ballonet malfunction, and intruders, a permanent watch would be desirable at the mooring site.

b) Other yearly costs

Helium and hull maintenance are accounted for on a yearly basis, rather than per flight hour. The helium contained in the hull leaks out and also becomes contaminated, mainly by air. Both cases reduce lift. In the case of the Cyclo-Crane, 5 percent helium leakage or 5 percent contamination would reduce the load capacity by over 25 percent. Leakage is easily taken care of by periodically topping up the hull. In the case of logging balloons, normal hull leakage is 10 to 15 percent of the volume yearly. Additional leaks occur if the hull is torn. One balloon logging operator has a helium tube trailer standing by each logging balloon in case of accidental loss of helium. Contamination is a more difficult problem to solve. In some cases, it is easier to vent contaminated helium and replenish the hull with pure helium. Logging balloons are normally deflated every two years and the hull recoated on the inside. An HLA, like the Cyclo-Crane, cannot be deflated easily once fully assembled. Contaminated helium must be circulated through a purifier to remove the impurities. The yearly cost of leakage and purification is estimated at 30 percent of the cost of the original fill of helium.

Non-revenue flight costs cover the cost of ferrying the HLA between home base and logging site and between logging sites. Non-revenue hours are estimated as 5 percent of productive hours and are charged at the hourly operating cost calculated in the next section.

EXAMPLE:

Annual Operating Cost Summary - 12-tonne Cyclo-Crane

		$/Year	$/Hour
Salaries			
Pilots			
- Yearly Salary	$50 000		
- Number & Total Salaries	4	$200 000	
Mechanics			
- Yearly Salary	$37 500		
- Number & Total Salaries	2	$ 75 000	
Watchman		$ 25 000	
Fringe Benefits (35%)		$105 000	
Total Yearly Salaries		$405 000	$253.13
Other Costs			
Helium, % Per Year & Cost	30%	$ 70 258	
Non-Productive Flight		$ 48 005	
Total Other Yearly Costs		$118 263	$ 73.91
Total Annual Operating Cost		$523 263	$327.04

4. Direct Hourly Operating Cost

Direct hourly operating cost includes the cost of all consumables and maintenance.

a) Fuel and oil

The fuel consumption of an aircraft depends on the average power used. Turbo prop and piston engines consume about the same volume (0.44 litres) of fuel per kilowatt per hour. However, fuels used by the two types of engines are different. Fuel accounts for 10 to 20 percent of the cost of running a helicopter. HLAs are more fuel efficient than helicopters because a large part of their lift comes "free" from the buoyancy of helium. However, at high speed, HLAs are fuel inefficient because of the high drag. A 12-tonne Cyclo-Crane uses approximately the same quantity of fuel as a Boeing/Kawasaki Vertol 107 (4.5-tonnes payload).

Jet A fuel costs 41 cts/litre in bulk delivered to a remote area. Oil is accounted for as 1.5 percent of fuel costs.

b) Engines

Labour for the routine maintenance of the engines is supplied by the mechanic on staff. In addition, a reserve for engine overhaul is charged on an hourly basis. Remanufactured engine costs and Time Between Overhaul (TBO) for various engines, are given in Appendix I. Engine reserve cost is the remanufactured engine cost divided by TBO. In the example, the 12-tonne Cyclo-Crane is powered by four Pratt and Whitney turbo prop engines.

c) Non-engine maintenance

Maintenace costs grow with the complexity of the machine. The Cyclo-Crane is a complex machine with sophisticated controls for the airfoils and ballonet; damage to the hull and structure would also be costly to repair. Only experience would yield precise cost figures for Cyclo-Crane maintenance. For the 12-tonne Cyclo-Crane we assumed that maintenance, other than engines, would cost $200 per flight hour.

On a yearly basis, maintenance costs represent less than 7 percent of the acquisition cost of the Cyclo-Crane.

EXAMPLE:

Hourly Operating Cost - Summary 12-tonne Cyclo-Crane		
		$/Hour
Fuel		
Litres per Hour	649	
Dollars per Litre	$0.41	
Hourly Cost		$264.10
Oil (1.5% of fuel)		$ 3.96
Maintenance		
Engines		$132.00
Other		$200.00
Total Hourly Operating Cost		$600.06

5. Support Equipment Cost

a) Ground equipment

Several pieces of land-based machinery will be needed to moor, inspect and maintain an HLA. In the logging context, a permanent home-base with elaborate facilities could be centrally located within 50 km of the operation, while a temporary mooring and maintenance facility could be set up within a few kilometres of the logging area. The HLA could return to home-base in case of major storm warnings, for major repairs and during a possible winter shut-down. The temporary base would be used for overnight mooring, for routine inspection and maintenance, and in case of light storm warnings.

In the 12-tonne Cyclo-Crane example, ground support equipment consists of mast mooring equipment, a helium supply tube-truck, a helium purifier, a trailer shop and a mobile crane (or other device) to access the engines and other parts of the craft.

b) Support helicopter

A support helicopter will be essential in an HLA operation. It will perform the following tasks:

- transport of personnel and equipment to and from the logging area;
- standby in case of personnel accident;
- assist the HLA operation in returning chokers to hooking crew; and
- tow the HLA in case of loss of control and/or power.

EXAMPLE:

Support Equipment Cost - 12-tonne Cyclo-Crane

SUPPORT EQUIPMENT COST		$/Year	$/Hour
Ground Equipment			
Mooring	$200 000		
Helium Supply & Purif.	$ 50 000		
Mobile Shop	$ 50 000		
High Ranger	$ 80 000		
Total Ground Equipment	$380 000		
Depreciation (10 years, 25% residual)			
Annual Cost		$28 500	$ 17.81
Average Annual Investment	$251 750		
Insurance			
Percent of Capital Cost	1%		
Annual Cost		$ 3 800	$ 2.38
Ground Support Operating Cost			$ 10.00
Total Ground Support			$ 30.19
Support Helicopter			
Acquisition Cost	$540 000		
Depreciation (7 years, 25% residual)			
Annual Cost		$57 857	$ 36.16
Average Annual Investment	$366 428		
Insurance			
Percent of Capital Cost	8%		
Annual Cost		$43 200	$ 27.00
Hourly Operating Cost	$158.45		
% of Logging Hours & Cost	45%		$ 71.30
Total Support Helicopter			$134.46
Total Support Equipment			$164.65

The Bell Jet Ranger or the Hughes 500D make suitable support helicopters. Experience in helicopter logging indicates that the support helicopter flies 40 to 50 percent of the hours flown by the large machine.

6. Total HLA Cost

Total HLA cost is the sum of the owning, operating and equipment support costs. Total cost per hour is calculated for previously defined utilization and production.

EXAMPLE:

Total HLA Cost Summary - 12-tonne Cyclo-Crane
(does not include interest)

	Cost/Hour
Ownership Cost	$ 756.71
Annual Operating Cost	$ 327.04
Hourly Operating Cost	$ 600.06
Support Equipment	$ 164.65
Total HLA Costs (excluding interest)	$1 848.46

LOGGING COSTS

1. Road and Landing Costs

Logs may be dropped directly into the water if the timber area is located within 2 km of a body of water suitable for processing and sorting. Water drops require no road or landing construction. However, settings within an acceptable distance from a water drop are few, compared to the total areas loggable in B.C. Logs have also been delivered by helicopter to the side of existing roads for direct loading on trucks. This report considers only the case of woods landings.

a) Roads

A major advantage of aerial logging systems over traditional cable systems is that they require fewer hillside roads. Aerial logging systems require main valley-bottom truck roads to connect landings and access the area being logged. Roads should be laid out so that settings to be logged are within 2 km of a landing (or drop zone) (Figure 19).

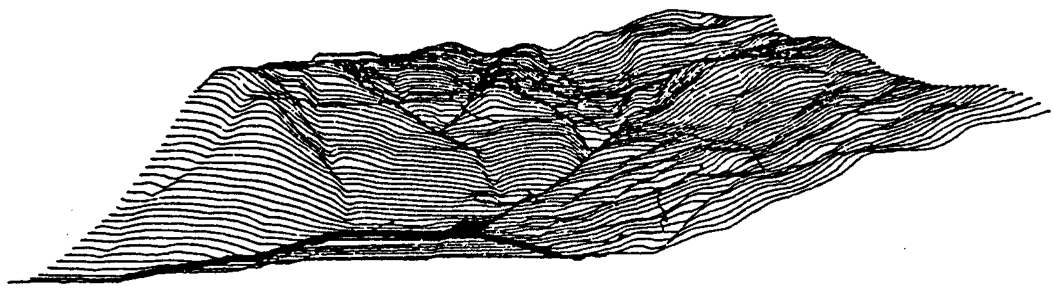
For traditional cable systems, yarding distance is normally kept under 400 metres which requires access by spur roads built on side slopes. Access and spur roads are expensive to build in rugged rocky terrain and are often environmentally unacceptable.

In theory, roads spaced for 2 km and 400 m maximum yarding distance should develop 200 hectares and 40 hectares per kilometre, respectively. Actual loggable areas developed by one kilometre of road are about half the theoretical values, as seen in Table F. Between 60 to 100 ha of area loggable by the aerial system is developed by 1 km of road, versus 16 to 25 ha developed for cable systems.

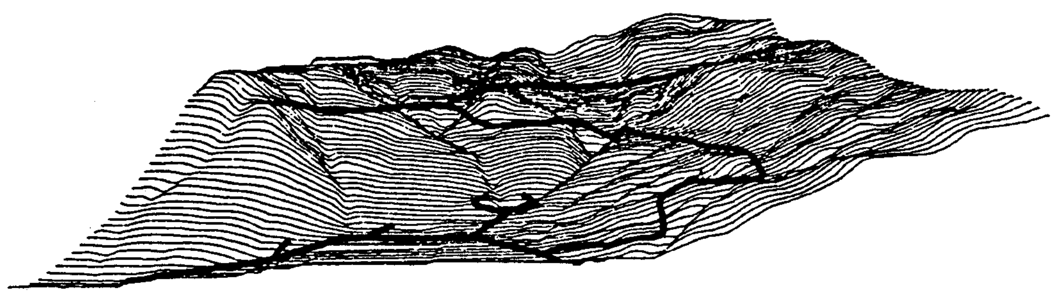
TABLE F. Loggable Area Developed by One Kilometre of Road (ha/km).

Reference	Cable Yarding	Aerial System	Comments
Mosher (1980)	19 17	96 59	Excludes main road Includes main road
Sauder, B. (1977)	26	116	Excludes existing main road
Nagy (1983)	32	-	Excludes main road

Valley bottom main roads are usually wider than branch roads, but are much easier and less expensive to build. Branch roads through rocky terrain require expensive rock blasting. Table G gives average road construction costs typical for Coastal B.C.



Aerial System



Cable System

FIGURE 19. Comparing Road Networks for Aerial and Conventional Systems.

TABLE G. Road Construction Cost per Kilometre for Different Terrain Conditions (Nagy 1983).

Road Type	Road Cost ($/km)
Main - Flat Ground	70 000 - 80 000
Branch Road - Easy	60 000
Medium	80 000
Difficult	120 000 - 140 000

As a result of the reduction in road density and road cost per km, an aerial system can reduce road cost per cubic metre of log, by a factor of 4 to 8 (Wellburn 1978).

b) Landings

Typical woods landings for helicopter logging have been described by Sauder, E. (1979) (Figure 20). They consist of two distinct areas which can be adjacent or separate:

- a log dropping and processing area; and
- a service area for the aircraft.

HLA landings would be similar. One log dropping and processing area, 100 m x 200 m, can handle up to 1000 m^3 per day. If the HLA delivers more than 1000 m^3 per day, a larger area or a second drop area is required. The service area contains the fuel-up, helium back-up, and mooring facilities. For HLAs it is imperative that the service area be in a sheltered location. If the Cyclo-Crane is mast moored at the service landing, a circular area 300 metres in diameter will have to be cleared.

A 100 m x 200 m landing will cost approximately $4.00 per m^2 to build (including stumping, clearing and some ballasting), or a total of $80 000 per landing. There will be a landing every 3 km of road, servicing 180 to 320 hectares of loggable forest.

EXAMPLE:

Roads and Landings - 12-tonne Cyclo-Crane		$\$/m^3$
Hectares per Kilometre	80	
Volume per Hectare (m^3)	600	
Volume per Kilometre (m^3)	48 000	
Road Cost per Kilometre	$60 000	
Road Cost		$1.25
Hectares per Landing	240	
Volume per Landing (m^3)	144 000	
Landing Cost (each)	$80 000	
Landing Cost		$0.56
Total Road and Landing		$1.81

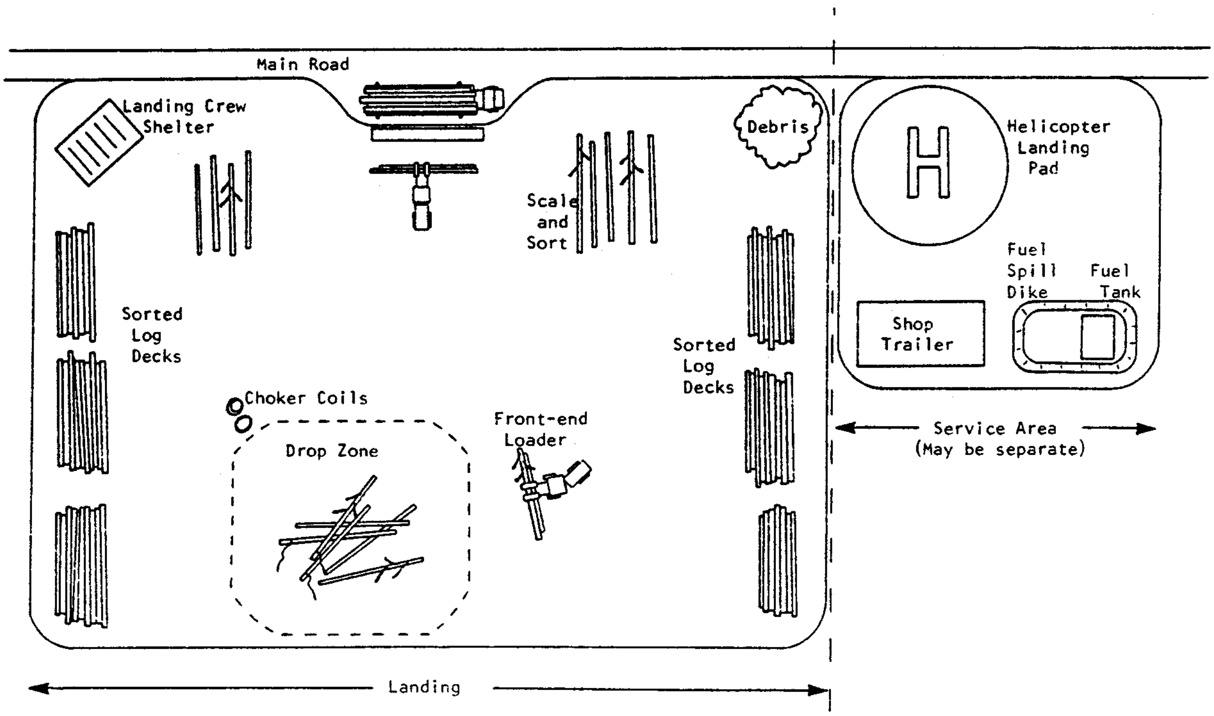


FIGURE 20. Typical Landing for Helicopter Logging.

c) Equipment required

For the total production of 171 660 m^3, 3.6 km of roads and one or two landings will be required yearly. It is estimated that the following equipment will be needed to build the roads and landings.

EXAMPLE:

Capital Invested for Road Building*

	Acquisition Cost	Yearly Usage	Pro-rated Cost
Backhoe 235	\$ 390 000	25%	\$ 97 500
D7 Tractor	\$ 278 000	25%	\$ 69 500
Front-end Loader	\$ 244 000	25%	\$ 61 000
Gravel Truck	\$ 110 000	25%	\$ 27 500
Rock Drill	\$ 220 000	25%	\$ 55 000
Total	\$1 242 000		\$310 500

Depreciation Period	5 years
Residual Value	25%
Average Annual Investment	\$263 925

*Based on data from Nagy (1978) and Krag (1981 and 1982).

2. Felling and Bucking

Felling and bucking for HLA logging requires care. The trees should be directionally felled parallel to the contours to avoid criss-crossing and reduce the chance of hang-ups during pick-up. Because of the large load capacity of the aircraft, few trees will require bucking but trees too heavy for the aircraft will have to be bucked completely so that logs do not remain attached. Fallers are flown in and out of the setting by the support helicopter. This eliminates the need for the faller to walk long distances with his gear and should increase daily productivity. Based on general felling experience on the Coast, a production of 80 m^3 per faller per shift is assumed.

EXAMPLE:

Felling and Bucking Summary - 12-tonne Cyclo-Crane

Felling and Bucking		$/Hour	$/m³
1 Faller ($/h)	$25.10		
Fringe Benefits (35%)	$ 8.79		
Saw	$ 2.50		
Total Cost/Faller		$ 36.39	
Production/Faller/Shift (m^3)	80		
Fallers Required	11		
Total Felling and Bucking		$400.24	$3.67

3. Woods Crew (Hooking)

Similar to helicopter logging practices, the men hooking the turns in the woods for an HLA can be organized in teams consisting of:

- one hooker; and
- one chokerman.

(A different crew organization can be used; the production per man-hour would be similar).

The team presets the chokers onto the logs, estimates log weights, prepares optimum turn sizes, directs the aircraft to the pick-up point and hooks on the turn. The aircraft alternates pick-ups between the different teams. Production figures from helicopter experience are given in Table H.

TABLE H. Woods Crew Production per Team per Hour.

Average Piece Size (m^3)	0.91	2.18
Production/Team/Hour (m^3)	17	64

Production is higher if the average piece size is larger because fewer logs have to be hooked per turn. A production of 40 m^3/h is used in the example. Although the average shift time is 8 hours, overtime is paid for time worked over 8 hours and for weekends and holidays. The overtime paid is estimated at 20 percent of the workers' salary.

EXAMPLE:

Woods Crew - 12-tonne Cyclo-Crane		$/Hour	$/$m^3$
1 Rigging Slinger ($/h)	$14.55		
1 Chokerman ($/h)	$13.67		
Maximum Production/Crew (m^3/h)	40		
Crews Required	4		
Woods Crew Basic Cost		$112.88	
Overtime Pay	20%	$ 22.58	
Fringe Benefits	35%	$ 47.41	
Total Woods Crew		$182.87	$1.68

4. Landing Crew and Equipment

Several activities take place on the landing. The chokers are removed and coiled ready to be taken back to the woods. The trees or logs are picked up by a front-end loader and transported to the bucking area, where they are manufactured into logs of optimum values. The logs can then be presorted by the front-end loader and stored, awaiting loading on trucks.

It is assumed that:

- one front-end loader can handle up to 160 m^3/h;
- landing buckers average 75 m^3/h; and
- one chaser will be required for each 35 m^3/h of production.

EXAMPLE:

Landing Crew - 12-tonne Cyclo-Crane

		$/Hour	$/m³
Loader Operator ($/h)	$14.55		
980 Loader ($/h)	$70.00		
Maximum Production (m^3/h)	160		
Number Required & Cost	1	$ 84.55	
Landing Bucker ($/h)	$16.81		
Bucking Saw ($/h)	$ 2.50		
Number Required & Cost	2	$ 38.62	
Chaser ($/h)	$13.67		
Maximum Production (m^3/h)	35		
Number Required & Cost	4	$ 54.68	
Overtime	20%	$ 20.57	
Fringe Benefits	35%	$ 36.00	
Total Landing Crew		$234.42	$2.15

5. Loading Crew and Equipment

A front-end loader can be used to load the logs onto the trucks. It is assumed that one front-end loader can load up to 160 m^3/h with the assistance of a second loader. No overtime is included for loading and hauling.

EXAMPLE:

Loading Crew - 12-tonne Cyclo-Crane

		$/Hour	$/m³
980 Loader ($/h)	$70.00		
Loader Operator ($/h)	$14.55		
Second Loader ($/h)	$13.67		
Fringe Benefits (35%)	$ 8.47		
Maximum Production (m^3/h)	160		
Crews Required	1		
Total Loading Crew		$106.69	$0.98

CAPITAL INVESTMENTS AND INTEREST COSTS

Interest costs are normally accounted for, by the logging companies, as a head office charge rather than charged directly to the logging operations. In order to allow the camp manager to compare HLA cost with other costs, interest is calculated and presented separately. Capital expended for equipment acquisition and the resulting average annual investment were presented in each section when applicable. Interest costs are calculated based on 12% yearly interest and 1600 hours yearly utilization.

EXAMPLE:

Capital Investment & Interest Cost Summary -
12-tonne Cyclo-Crane

	Acquisition Cost	Average Annual Invest-ment	Interest Cost $/Hour
Aircraft & Parts	$7 478 100	$4 593 690	$344.53
Ground Support Equipment	380 000	251 750	18.88
Support Helicopter	540 000	366 429	27.48
980 Loader (landing)	312 230	265 395	19.90
980 Loader (loading)	312 230	265 395	19.90
Road Building (pro-rated)	310 500	263 925	19.79
Total	$9 333 060	$6 006 584	$450.49

Investment per 1000 m^3 logged is $54 372.

CYCLO-CRANE LOGGING COST SUMMARY

This section summarizes the costs defined in the preceding sections. The final result is the cost of felling, bucking, yarding, sorting and loading logs on a truck at the landing. The cost includes road development cost for the area, equipment amortization and operation, and labour. Not included in this cost are hauling, final sorting and booming, camp administration and accommodation, employee transportation, stumpage and royalties, forestry and labour supervision.

EXAMPLE:

Logging Cost Summary - 12-tonne Cyclo-Crane

Hours per Year	1600	
Production per Hour	109.1 m^3	(38.5 cunits)
Production per Year	174 515 m^3	(61,629 cunits)

	$/Hour	$/$m^3$	$/Cunit
Road and Landing Costs		$ 1.81	$ 5.11
Felling	$ 400.24	$ 3.67	$10.39
Yarding			
Aircraft Ownership Cost	$ 756.71	$ 6.94	$19.65
Annual Operating Cost	$ 327.04	$ 3.00	$ 8.49
Hourly Operating Cost	$ 600.06	$ 5.50	$15.58
Support Equipment	$ 164.65	$ 1.51	$ 4.27
Woods Crew	$ 182.87	$ 1.68	$ 4.75
Landing Crew	$ 234.42	$ 2.15	$ 6.09
Total	$2 265.74	$20.77	$58.82
Loading	$ 106.69	$ 0.98	$ 2.77
Total Cost Loaded on Truck (excluding interest)		$27.23	$77.10
Total Interest Costs	$ 450.49	$ 4.13	$11.70
Total Cost Loaded on Truck		$31.36	$88.79

SENSITIVITY ANALYSIS

Equally as important as the actual bottom line cost in the example, is how the cost varies as certain assumptions vary. For instance, how is the cost/m^3 loaded on the truck affected by the capital cost of the HLA? How does it vary with payload or with the number of productive hours per year? A sensitivity analysis was conducted by varying one factor at a time.

The factors investigated in the sensitivity analysis from the most to the least significant are:

- the load factor;
- the productive machine hours per year;
- the terminal time;
- the acquisition cost of the HLA;
- the load capacity;
- the average yarding distance;
- the acceleration;
- the cruise speed; and
- the slope of the flight path.

Results of the sensitivity analysis are shown in Figure 21 and given for plus or minus 25% variation from the base values in Table I.

1. Load Factor

As explained previously, a load factor is applied to the HLA load capacity to calculate the average payload. This factor reflects the fact that because logs are discrete quantities, it is difficult to systematically make up a turn that matches the HLA load capacity exactly. Experience has shown that helicopters usually have a load factor of about 80 percent. For lack of better actual data, this number was used as a base for the 12-tonne Cyclo-Crane example. Messrs. Doolittle and Crimmins, inventors of the Cyclo-Crane, disagree with that number. They argue that the Cyclo-Crane is significantly different from a helicopter in its design and principle, that the structure, the power plants and airfoils can easily sustain frequent overloads and that, therefore, a 12-tonne Cyclo-Crane will average 12 tonnes of logs per turn (a load factor of 100 percent). The effect on the logging cost would be quite significant as shown in Table I.

2. Hours per Year

It is critical to keep the HLA logging for as many hours as possible per year. Costs escalate quickly if the HLA operates less than 1000 hours in a year.

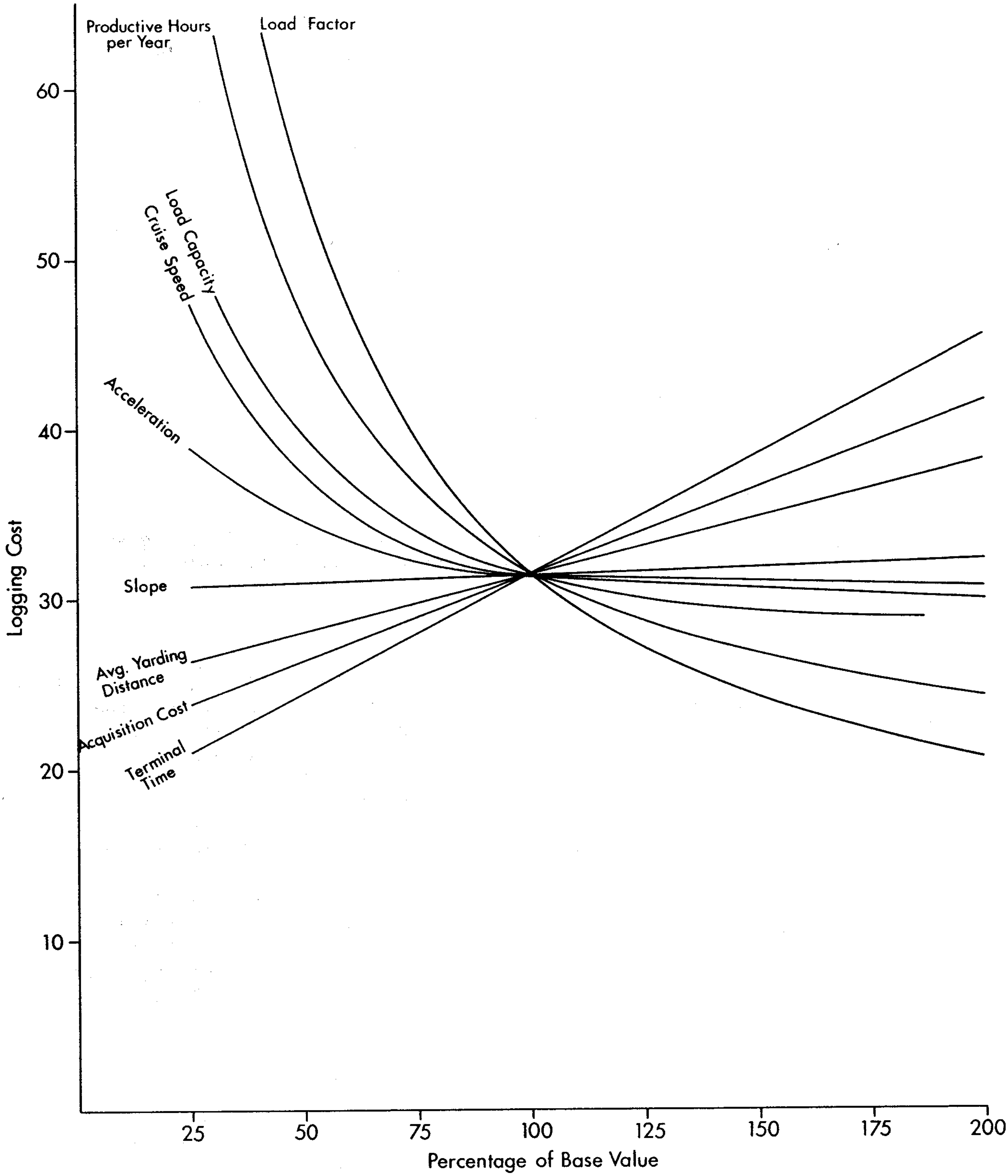


FIGURE 21. Logging Cost Sensitivity to the Major Factors.

TABLE I. Logging Cost Sensitivity to Major Factors.

	Base Value	25% Increase		25% Decrease	
		High Value	% Logging Cost Change	Low Value	% Logging Cost Change
FACTORS:					
Load Factor	80%	100%	-16%	60%	+26%
Productive Machine Hours Per Year	1600 h	2000 h	-9%	1200 h	+15%
Terminal Time	3.2 min	4.0 min	+11%	2.4 min	-13%
Acquisition Cost	$7.1 MM	$8.9 MM	+8%	$5.3 MM	-8%
Load Capacity	12 t	15 t	-6%	9 t	+10%
Average Yarding Distance	1000 m	1250 m	+4%	750 m	-5%
Acceleration	1.15 m/s^2	1.43 m/s^2	-1.2%	0.86 m/s^2	+1.7%
Cruise Speed	92 km/h	115 km/h	-1.1%	69 km/h	+3.4%
Slope of Flight Path	30%	37.5%	+0.1%	22.5%	0

3. Terminal Time

There is a large potential cost saving in the reduction of terminal times in the setting or at the landing. The 55 seconds required to turn the Cyclo-Crane around 180 degrees twice increases the logging cost by more than 10 percent. Alternate methods of turning the Cyclo-Crane will be tried during the test of the 1.8-tonne prototype. An HLA design that could ferry back and forth without turning, or that could turn around very quickly (like the Aerocrane), would have an advantage for logging.

4. Acquisition Cost

As seen in Figure 21, logging cost grows almost linearly with the HLA's acquisition cost. The sensitivity analysis assumes that only ownership costs (interest, depreciation, insurance) change when the acquisition cost varies. In actual fact, maintenance and other operating costs may increase in ratio with the acquisition cost.

5. Load Capacity

Logging costs decrease as the load capacity increases. This is because cost components, like the yearly salaries for the pilots and mechanics and the cost of the support helicopter, remain constant over the range of load capacities and are distributed over a greater volume produced by the larger aircraft. Ownership costs per cubic metre are almost constant because the acquisition cost of a Cyclo-Crane varies almost linearly with its load capacity. In this analysis, the power installed on each Cyclo-Crane was such that the cruise speeds were the same over the range of load capacities. The larger Cyclo-Cranes proportionally require less power than the smaller ones and, as a result, use proportionally less fuel; consequently, the hourly operating cost per cubic metre is less for larger Cyclo-Cranes. Logging efficiency decreases with the small machines owing to the increase in the number of pieces; the same landing equipment is needed but handles less volume. Very small cost reductions are achieved with Cyclo-Cranes of 15-tonnes or greater load capacities.

6. Average Yarding Distance

It is important to plan the drop zone close to the setting being logged. However, because of the fixed time required to accelerate, to position the hook and turn around, logging cost is not very sensitive to yarding distance in HLA logging.

7. Acceleration

Logging cost escalates if the HLA is very slow to accelerate and reach cruise speed. Increase in acceleration above 1.15 m/s^2 (or 1.2 g) does not reduce the logging cost significantly. The sensitivity analysis was done for absolute changes in acceleration, everything else remaining constant. In actual fact, changes in acceleration rate would result from a change in the horsepower used, which would affect operating costs. As a result, the sensitivity analysis overestimates the impact of acceleration on logging cost.

8. Cruise Speed

No significant decrease of the logging cost occurs for changes in cruise speed for a given yarding distance. Increases in cruise speed will permit the HLA to transport logs economically over larger distances. Increasing cruise speed capability does not decrease the logging cost if the yarding distance is too short for the vehicle to accelerate and reach maximum speed.

9. Flight Path Slope

Because an HLA will normally fly unloaded up to the setting and fly down heavy, it takes advantage of its buoyancy and weight to accelerate and move forward. Assuming the horizontal flight distance is constant, steeper slope paths yield lower logging costs; within practical limits however, the effect of varying flight slope is small.

The slope of the Cyclo-Crane flight path is limited to 40 percent because of the possible interference between the wings and sling cables. From very steep mountains the vehicle must extend the path and flight time and logging costs will increase.

10. Conclusion of Sensitivity Analysis

The sensitivity analysis allows the reader to make his own estimate for many of the factors and, using Figure 21, evaluate their impact on the cost of logging with an HLA.

The results can vary widely with the assumptions made. In our example, using assumptions that appeared the most realistic, we calculated a cost of $31.36/m^3. Obviously, if the machine does not operate properly, the logging costs will be high and unpredictable. From an optimistic point of view, using a load factor of 100 percent with a machine logging 2000 hours per year, purchase price 25 percent less than our base value and a turning time of 30 seconds would result in a logging cost of $20.70/m^3.

HLA LOGGING VS HELICOPTER LOGGING

1. Technical Comparison

The helicopter is the only free-flying vehicle presently available for logging (Figure 22). With its nearly unlimited mobility, it is well suited for the job. Its flexibility and minimal set-up time makes it ideal to log isolated patches of high value timber.

A helicopter can easily be parked and secured and does not require an elaborate mooring area. Gusty winds and fog affect both the helicopter and HLA operations.

A technical limitation of helicopters is their load capacity. The ideal load capacity range defined for HLA logging in a previous section (page 26) is 8 to 16 tonnes. As shown in Table J, the S-64 (Skycrane) is the only helicopter presently used for logging that falls within this range; the S-64 is no longer produced by Sikorsky and therefore is not a long term solution to aerial logging. The smaller helicopters have difficulty in old-growth heavy timber where logs have to be bucked very short or even split to match the useful load. S-61L, Vertol 107 and Super Puma operators circumvent the problem by a careful selection of the settings they log, and with elaborate bucking rules to minimize log degrading. Matching the helicopter to the setting is important. It would be equally as costly to use a large machine in an area where the timber is small and scattered as to use a small machine in a setting with heavy dense timber.

The safety hazard of helicopter logging is another drawback. Logging is a very stressful operation, both for pilots and machine. The potential for accident demands trained crews and rigid maintenance procedures; insurance cost is high and inclement weather limits operating time. Experience will define hazard levels for HLA logging. HLAs are more susceptible to wind, which limits the annual operating hours. The risk of machine damage is higher at the mooring site, but in flight, the available buoyancy allows the HLA to float in case of loss of power. It will also be slower than helicopters and probably less stressful to pilots although the slow rocking motion could be a problem. The sheer size of an HLA will be a constraint in a logging environment when the machine has to work close to rugged sidehills and trees.

Helicopters use sophisticated and light weight mechanical technology necessary to transmit power from the engines to the rotor blades at high speeds; this results in high purchase and maintenance costs. HLAs have less constraining weight limitations and can use less expensive mechanical technology.

Because of the drag, HLAs do not reach the high forward speeds of helicopters.

Almost all the technical differences between HLAs and helicopters will be reflected in the costs. The impact of those differences is analyzed in the following section.

TABLE J. Technical Characteristics of Heavy-Lift Helicopters.

	Sikorsky S-61L	Super Puma AS-332C	Boeing Vertol 107-II	Sikorsky S-64E Skycrane	Boeing Chinook 234UT
Useful Load* (kg)	4 000	4 250	4 500	8 250	11 500
Power Rating (kW)	2 060	2 600	2 060	3 312	4 380
Cruise Speed (km/h)	222	287	247	175	269
Used in Logging	Yes	Yes	Yes	Yes	No (but could be)

*Load capacity in logging configuration.

2. Cost Comparison

Heli-logging cost was calculated for a 4 to 4.5-tonne helicopter (like the S-61L, AS-332C and V-107-II), for the Skycrane and for the Chinook. Except for the Chinook, the costs are based on actual experience from using a helicopter in a logging environment. The format of the cost study is similar to that used for the 12-tonne Cyclo-Crane example. Where appropriate, some assumptions were modified to reflect technical differences between machines. Details of the cost analysis are presented in Appendix II. A summary is given in Table K.

TABLE K. Logging Cost Comparison -
12-tonne Cyclo-Crane Versus Helicopters.

	12-tonne Cyclo-Crane	Vertol 107-II	S64E Skycrane	V234UT Chinook
Acquisition Cost	$7 122 000	$5 000 000	$8 500 000	$16 500 000
Hourly Cost (includes support equipment)	$2 239	$2 375	$5 035	$7 178
Production/Shift (m^3)	858	571	1 047	1 460
Cost ($/$m^3$)				
Roads and Landing	1.81*	1.60	1.60	1.60
Felling	3.67	4.58	3.67	3.67
Yarding				
Aircraft	16.95	29.20	34.59	34.10
Woods Crew	1.68	2.56	1.68	1.68
Landing	2.15	2.87	2.15	2.15
Loading	0.98	1.49	0.98	0.98
Total on truck ($/$m^3$) (excludes interest)	$27.24	$42.30	$44.67	$44.18
Interest	4.13	4.74	4.08	5.25
Total on truck ($/$m^3$) (includes interest)	$31.37	$47.04	$48.75	$49.43

*Includes mooring area.

All three types of helicopters yield basically the same cost per cubic metre for logs loaded on trucks at the landing. The smaller helicopters, like the S-61 or V-107, are less expensive to operate, but have higher labour costs in felling, hooking and landing operations, owing to the smaller piece size average and the resulting increase in the number of pieces.

Helicopter costs for all helicopters but the Chinook were compared to B.C. heli-logging operators' cost. Actual helicopter logging costs can be lower than those presented in this study if:

- the helicopter was acquired at a lower purchase price than assumed;
- the operator is more efficient than average;
- the flight path is shorter than the 1000 m assumed; or
- the logs are dropped in water rather than on land.

The 12-tonne Cyclo-Crane has an operating cost similar to that of a 4 to 4.5-tonne helicopter and a shift production almost equivalent to that of a Skycrane. As a result, the cost of logging with a Cyclo-Crane is less than 70 percent of that of helicopter logging.

FIGURE 22. Logging with a Skycrane.

HLA LOGGING VS CABLE LOGGING

1. Technical Comparison

There is no technical resemblance between an HLA and a cable yarder (Figure 23). Cable systems are ground-based machines with all the advantages and disadvantages that this implies. As discussed earlier, cable systems require elaborate road networks which have to be planned and constructed long before logging can start. Cable logging does not have the mobility of aerial systems and cannot react rapidly to changing production strategies or market demands.

Cable logging has been practiced in Coastal B.C. almost since logging started and the labour force is well trained and experienced. Specialized cable logging machinery has been developed over the years and is still evolving. Cable systems are less weather dependent than aerial systems. Workers can work normal hours and shifts and still utilize the equipment about 1600 hours per year. Overtime work is not a must as with helicopter logging. An HLA would produce as much wood per hour as three to four cable yarders, but should it or a crucial piece of its support equipment break down, the whole production stops. Breakdown of one cable yarder does not halt the production of an entire camp.

Environmental impact of yarding sensitive areas is a potential problem with a cable yarder (Sauder, E. 1983).

Cable yarding is a labour intensive and strenuous operation; aerial logging eliminates many of the difficult tasks of conventional yarding such as carrying heavy blocks or cables to the back end of a setting, pulling slack on chokers or walking long distances.

2. Cost Comparison

Appendix VI investigates the cost of conventionally cable yarding a setting in difficult conditions. It is assumed that the ground is steep and rugged. As a result, the road cost is high and the yarding production is low. In addition, it is assumed that sufficient landings cannot be built and that the loader has to work side-by-side with the highlead yarder. Actual company cost of logging difficult settings are also presented. Trucking costs are not calculated in this study; they would be lower for aerial yarding than for cable yarding. The results are summarized and compared to the cost of logging with a 12-tonne Cyclo-Crane in Table L.

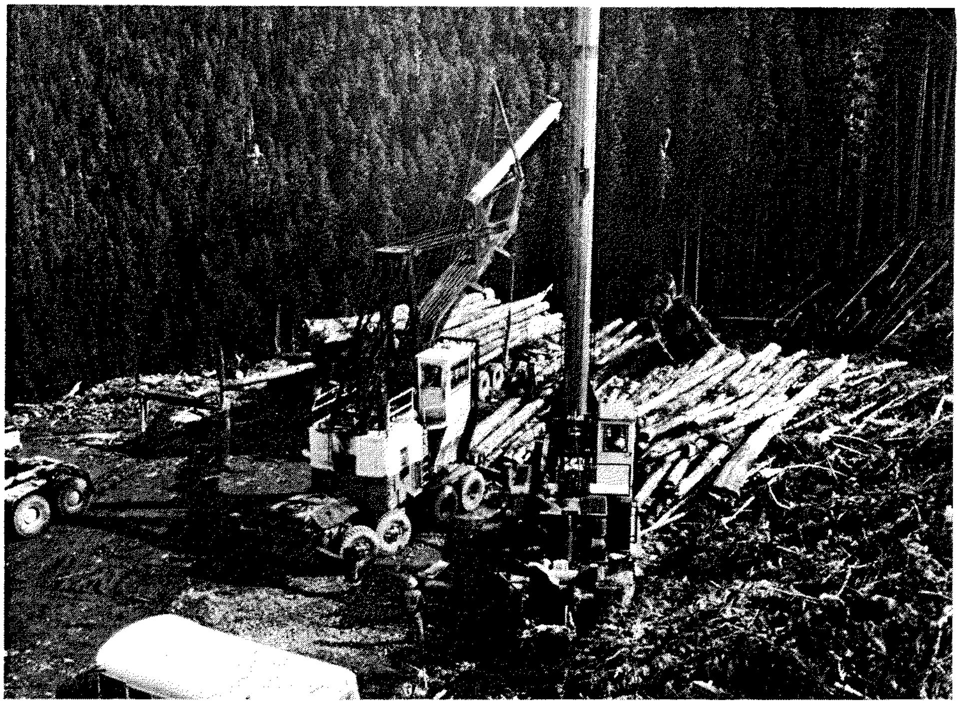


FIGURE 23. Conventional Highlead Yarding.

TABLE L. Conventional Cable Yarding in Difficult Conditions. (From Appendix VI)

	12-tonne Cyclo-Crane	Cable Yarding FERIC's Analysis	Cable Yarding Companies' Average
Cost $/m^3$			
Roads & Landings	$ 1.81	$ 11.22	$ 7.90
Felling	$ 3.67	$ 4.85	$ 4.38
Yarding	$ 20.77	$ 10.09	$ 8.79
Loading	$ 0.98	$ 5.98	$ 4.44
Total (excluding interest)	$ 27.23	$ 32.14	$ 25.51
Interest	$ 4.13	$ 3.03	--
Total (including interest)	$ 31.36	$ 35.17	--

Cyclo-Crane logging costs are at the same level as that which companies are presently spending to log their most difficult settings by conventional methods. Company costs are based on equipment of average age. FERIC's analysis, using all new equipment costs yields a higher cost for cable yarding in difficult ground conditions. Based on our analysis the Cyclo-Crane would be as economical as conventional yarding in areas with difficult logging conditions where road cost is high and conventional yarding productivity is low.

CONCLUSION

Aerial logging is an attractive alternative to conventional cable systems in environmentally sensitive areas and for settings requiring extensive and expensive spur roads. As opposed to conventional systems which require several years of planning and pre-logging road development, aerial logging requires short lead time and can respond quickly to changing trends in market demand. Aerial logging also eliminates some of the strenuous tasks associated with cable yarding.

Helicopters are being used successfully for aerial logging but their load capacity can be a limitation and their cost is high.

Heavy-Lift-Airships (HLAs) may use simpler technology than helicopters and have the potential of lifting heavier loads at reduced costs. A theoretical analysis of various aerodynamic-aerostatic lift combinations demonstrates that the "airplane-balloon" combination offers a greater potential for reducing aircraft cost per tonne of load capacity than the "helicopter-balloon" combination.

The Cyclo-Crane is a composite HLA that uses balloon buoyant lift and airplane type aerodynamic lift. The Cyclo-Crane's acquisition cost is projected to be 7.1 million dollars for 12-tonne load capacity. On a per tonne load capacity basis, heavy-lift helicopters cost more than twice that price. The study also shows that a 12-tonne Cyclo-Crane would operate at half the hourly cost of a Sikorsky S-64 Skycrane. Because of their large size, HLAs are expected to be less nimble and slower than a helicopter; it is projected that a 12-tonne Cyclo-Crane will take 65 percent more time to yard a turn of logs than a helicopter. However, because of its higher load capacity, the volume of logs yarded per turn by a Cyclo-Crane is higher.

Overall, taking into account the decrease in hourly operating cost, the increase in volume per turn and the decrease in speed, logs yarded by a 12-tonne Cyclo-Crane cost 30 percent less than logs yarded by helicopter.

Compared to cable yarding, road cost is reduced by a factor of 6 for aerial systems. However, flying the logs from the setting to a 1000 m distant landing with a 12-tonne Cyclo-Crane is expensive and accounts for 2/3 of the cost per cubic metre of the logs loaded on trucks. Overall, Cyclo-Crane yarding cost is near the level of the cost of cable yarding the most difficult settings on the Coast.

Helicopters are a mature development and it is unlikely that significant breakthroughs will occur to improve their cost and productivity. Cable logging is also a mature system which is unlikely to improve significantly, particularly where timber is scattered and terrain is broken. HLAs and the Cyclo-Crane used in the example are new technology which may improve with use and surpass our expectations. An optimistic assumption of the variables in our analysis shows that a 12-tonne Cyclo-Crane has the potential to log at costs below those experienced in many operations today.

In our example, we have assumed that the 12-tonne Cyclo-Crane can be built for $7.1 million, that it can precision hover as well or better than a helicopter, that it can operate at least 1600 hours per year, and that it can be safely moored in a logging environment. Under these conditions, Cyclo-Crane logging would be more economical than helicopter logging; it would also be cost competitive with conventional systems in the most expensive cable logging areas. In addition to the areas that are presently cable logged at high costs, an HLA like the Cyclo-Crane can also log areas classified as inaccessible. It is estimated that 10 to 15 percent of B.C.'s Coastal inventory (or 340 to 500 million cubic metres) is inaccessible by conventional systems for economic or environmental reasons. Included in the inaccessible inventory are large volumes of high value timber. An HLA like the Cyclo-Crane could be used to log these areas at reduced costs compared to helicopters.

HLAs could become viable logging machines for B.C. Research programs like the Cyclo-Crane, the Heli-Stat and the Van Dusen should be encouraged. Further innovation in HLA concepts could lead to a machine that would be simple, cheap and well adapted to the logging mission. The logger's "skyhook" dream can become reality.

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APPENDIX I

CYCLO-CRANE ACQUISITION COST AND PERFORMANCE

CYCLO-CRANE ACQUISITION COST

The acquisition cost of the vehicle is one of the major components of the overall cost analysis.

This acquisition cost analysis of the Cyclo-Crane is based on data generated by the construction of the 1.8-tonne model. It assumes that there will be no major design changes between the model and a production Cyclo-Crane.

In order to estimate the cost of the Cyclo-Crane and project it for various load capacities, the Cyclo-Crane is divided into the following components (Figure I-1).

- Structure
- Airfoils
- Envelope
- Engines
- Controls
- Cabs
- Helium

The cost of the structure, airfoils and envelope is based on their estimated weight, multiplied by the cost/kilogram (Figure I-2). It assumes that the same technology and the same materials are used through the range of sizes. Using more sophisticated technologies would reduce the weight but would also increase the cost/kilogram.

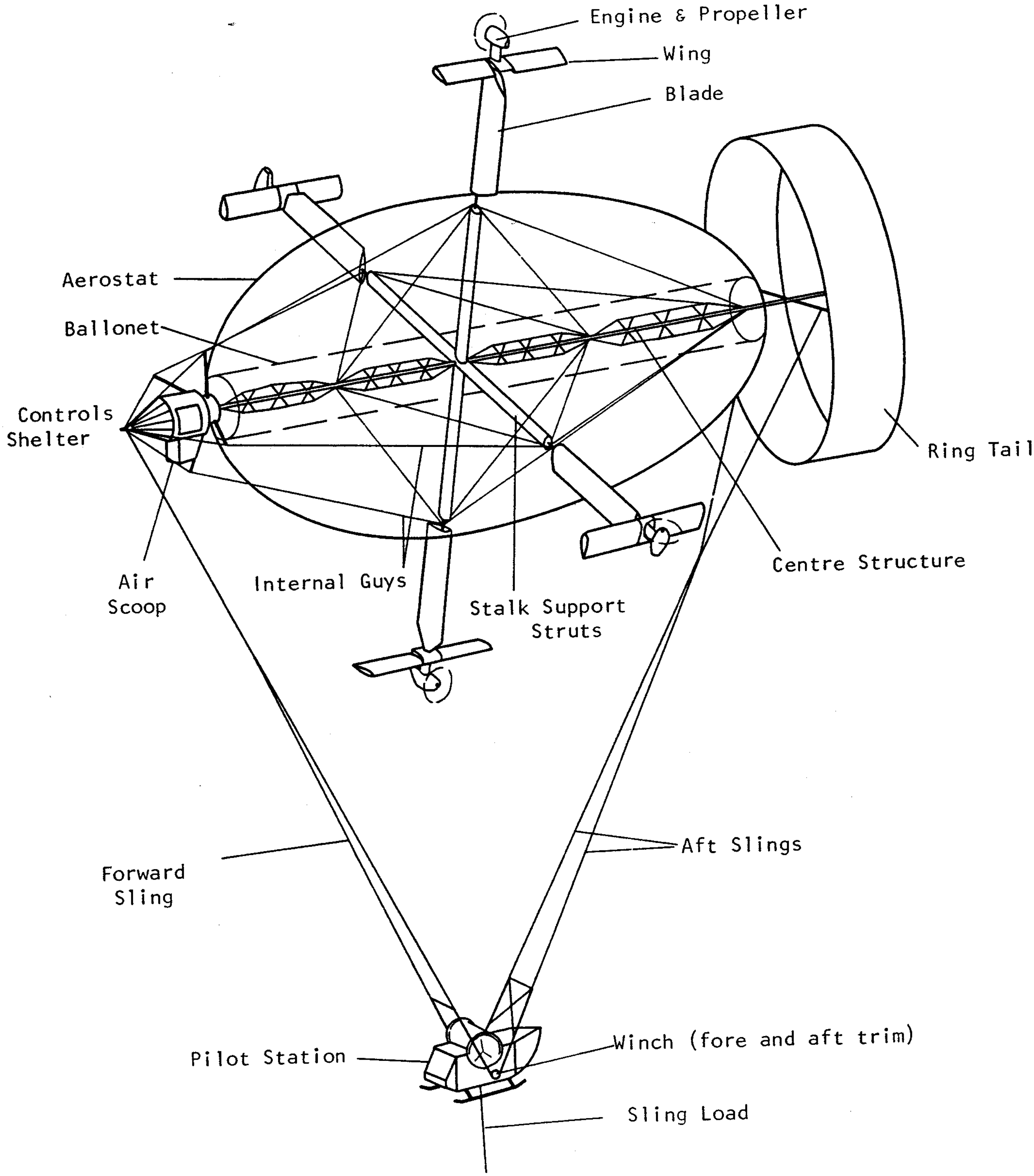


FIGURE I-1. The Cyclo-Crane Schematic View.

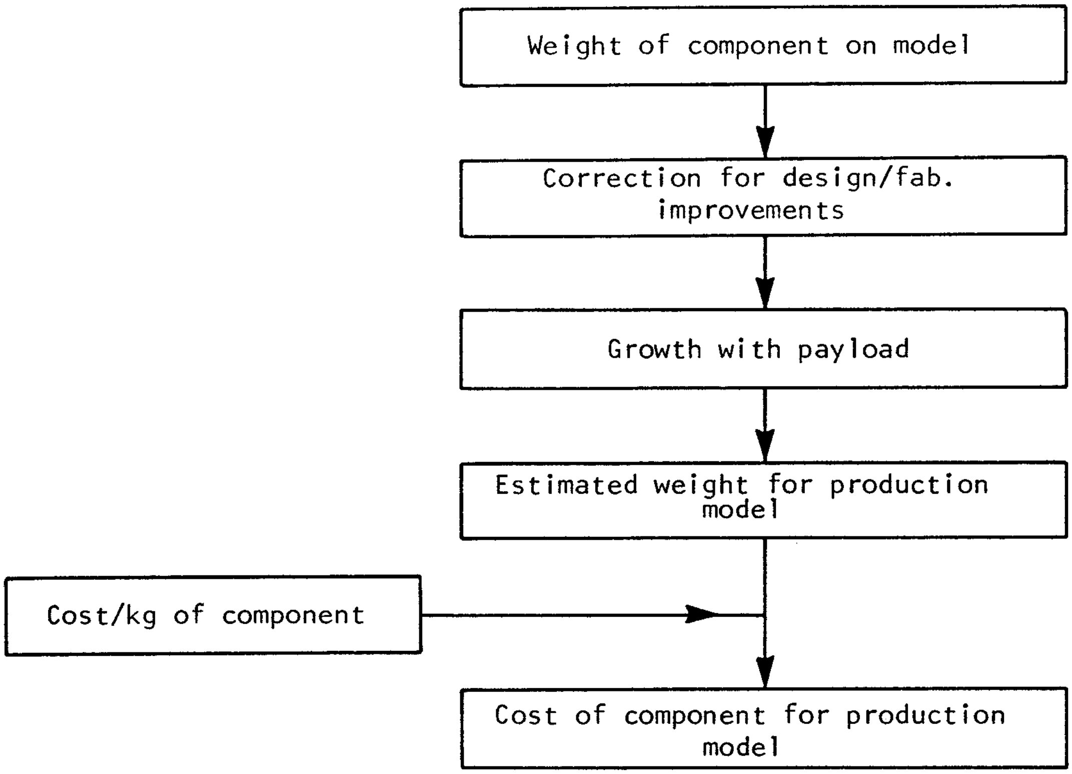


FIGURE I-2. Cost Estimation Procedure for Structure, Airfoils and Envelope.

A. STRUCTURE

1. Description

The structure includes all structural components like the centre structure (backbone), the stalk support struts, the internal and external bracing cables and spreaders, and the sling cables. Also included in the structural weight are components like the sling load winch, ballonet retraction system and fans, which are expected to grow at the same rate as the structural parts.

2. Weight

The total structural weight of the 1.8-tonne demonstrator is 2008 kg (4,427 lbs). It is assumed that after some redesign and with the use of higher grade aluminum for some components, a more realistic basic structural weight for a 1.8-tonne Cyclo-Crane would be 1814 kg (4,000 lbs).

3. Growth Factor

The combined increase in the cross-section of the structural members (like the bracing cables) and the increase in length, results in the total structural weight increasing faster than the load capacity. As an example, the combined increase of the cross-section and length of a bracing cable is investigated in Figure I-3.

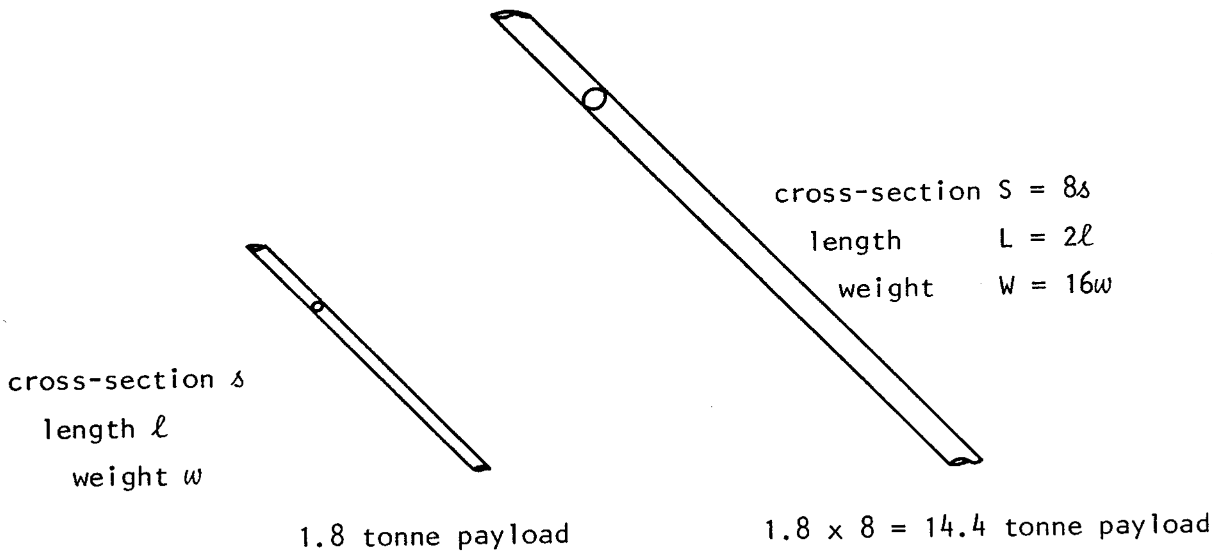


FIGURE I-3. Weight Increase of Structural Members.

For the 1.8-tonne vehicle, the sling cable is ℓ metres long and has a cross-section equal to s cm^2 and its volume is $s\ell$. To support the increase in load, the sling cable for the 14.4-tonne machine has a cross-section equal to $8s$ cm^2. In addition, because of the scale increase, the length is doubled, resulting in a cable volume of $8s \times 2L = 16sL$, which is 16 times larger than that of the model. The weight of a member is proportional to its volume and has also increased by a factor of 16.

4. Cost per Kilogram

The cost per kilogram of a structure obviously varies with the type of structure, the material used, the fabrication techniques, the size of the structure and the production quantity.

One can assume that the Cyclo-Crane structure is similar to that of other aircraft (i.e. riveted pieces of aluminum). Figure I-4 shows how the cost per unit weight of aircraft varies from small piston single engine airplanes up to multi-engine turbine helicopters. In Canadian dollars per kilogram, this cost varies from $68.40 for a small Cessna up to $1400 for a Boeing Chinook helicopter. The Cyclo-Crane is less weight sensitive than other aircraft and its structure can, therefore, be simpler. However, the sheer size of the structure, complicates fabrication and assembly. Also, even optimistic production estimates for the Cyclo-Crane (50 per year) are lower than production runs of small airplanes like the Cessna 150 or 172.

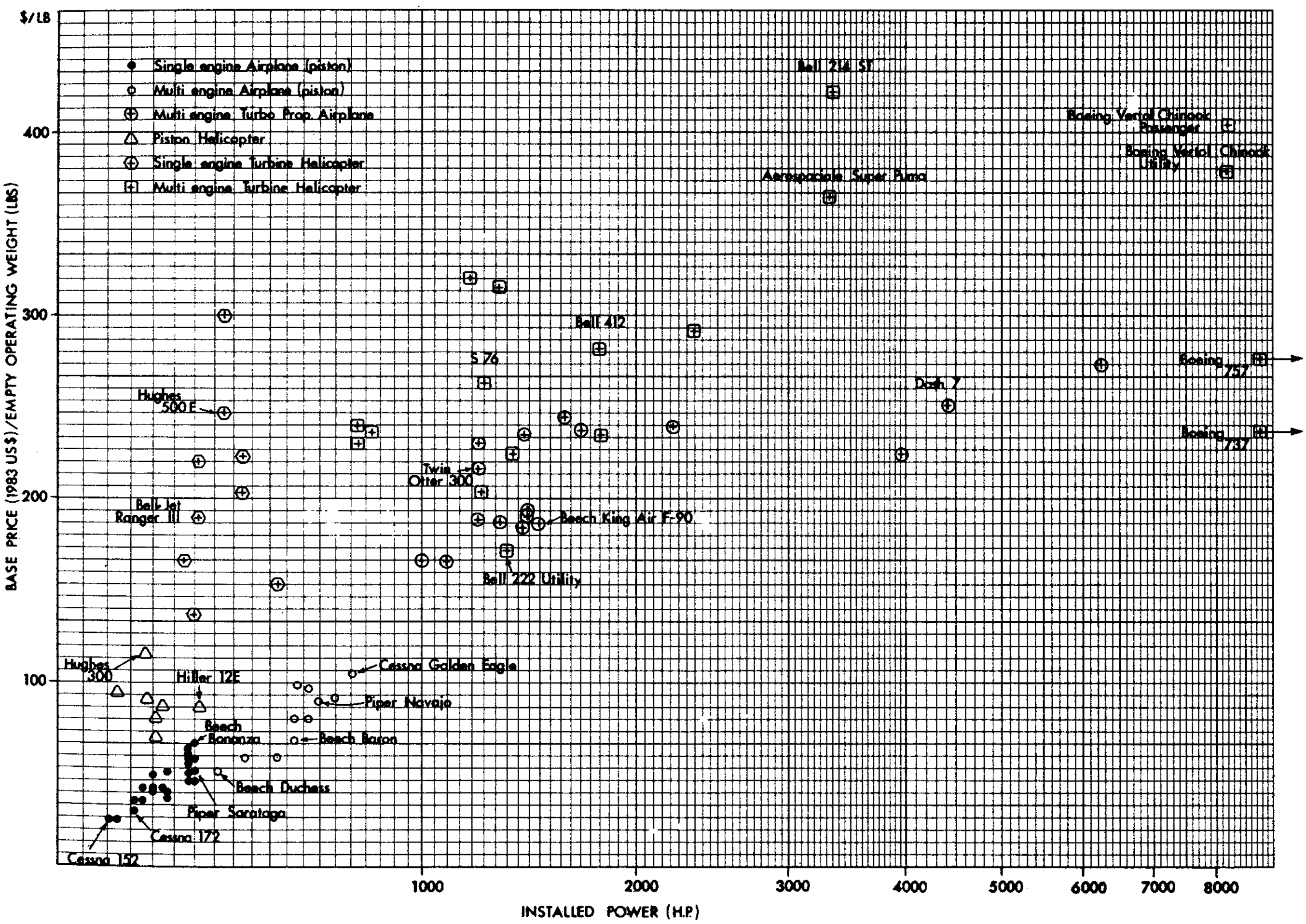


FIGURE I-4. Structural Cost/Kilogram for Various Aircraft.

Additional cost data can be obtained using Schweitzer Aircraft Company's cost of building part of the structure for the 1.8-tonne demonstrator. These costs are summarized in Table I-A.

TABLE I-A. Breakdown of Cost for the 1.8-tonne Cyclo-Crane's Structure and Airfoils, Based on Schweizer Aircraft Supplied 1980-81 Cost, Updated at 10% a Year to 1983 and Expressed in Canadian Dollars per Kilogram.

	Tooling and Engineering ($/kg)	Materials & Fabrication ($/kg)	Total ($/kg)
Wings and Centre Section	$210	$235	$445
Blades	118	199	317
Stalks and Crusiform	42	145	187
Total Average	$118	$191	$309

Tooling and engineering are initial costs amortized over the total quantity produced. Material and fabrication will also decrease with the quantity. If material and fabrication cost can be halved, cost per kilogram of Cyclo-Crane structures for production of 50 units per year could be below $100/kg based on Schweizer Aircraft's data.

Crimmins (1983) used the figure of $220/kg for his estimate of Cyclo-Crane cost. (This figure included structure and controls but excluded the hull and the engines.) It is hopefully too high. A figure of $82/kg is used in this report for the estimate of the structural cost of Cyclo-Cranes in high production (50 units per year). For lower production (10 units per year) the structural cost could be $120/kg.

B. AERODYNAMICS

1. Description

The aerodynamic components include the tail, the wings and stalks, and blades (including hydraulics in the stalks).

2. Basic Weight

The total weight of the aerodynamic components in the 1.8-tonne demonstrator is 2092 kg. They were efficiently designed by Schweitzer Aircraft and no weight savings are considered possible for the production vehicles.

3. Growth Factor

Airfoils are made of structure and skin. The structure will increase in weight as the 4/3 power of the load capacity. The skin is gauge limited and only increases as the 2/3 power of the payload. Doolittle (1983) expects that the overall weight increase of the airfoils will be linear with the load capacity. Therefore, the weight of aerodynamic components for a Cyclo-Crane of x-tonnes payload = 2092 (x/1.814) kilograms.

4. Cost Per Kilogram

The discussion presented for the cost of the structure also applies to the aerodynamic surfaces. A similar assumption of $82/kg for high production and $120/kg for medium production is used.

C. AEROSTATICS

1. Description

The aerostatic components include the hull, complete with ballonet, catenaries and pass-through hardware.

2. Basic Weight

The total weight of the aerostatics for the 1.8-tonne demonstrator is 2495 kg. No weight savings are considered for production vehicles.

3. Growth Factor

The weight of the aerostatic component will increase linearly with the payload (Doolittle 1983). Aerostatic weight for an x-tonne Cyclo-Crane = 2495 (x/1.814) kilograms.

4. Cost Per Kilogram

The aerostatics for the 1.8-tonne demonstrator cost $338/kg (includes research and development). This cost can probably be lowered below $150/kg for large orders.

Airship Industries of England sells the AD-600 standard airship (2.6-tonnes payload) for $764/kg and the Skyship 5000 (25-tonne payload) for $556/kg.

Crimmins (1983) used $220/kg as a conservative estimate for the aerostatic structure. We used $138/kg for the cost estimate for a Cyclo-Crane in high production (50+ units per year) and $200/kg for lower production (10 units per year).

D. BALLONET

The 1.8-tonne Cyclo-Crane model is designed with a 15 percent ballonet capability, which can accommodate 22 degrees C temperature variation and 610 metres altitude variation. Standard blimps normally have a 30 percent ballonet to allow flight at higher altitudes.

Ballonet calculation

The following formula yields the percent of ballonet required for given pressure and temperature variations.

$$1 + \text{percent ballonet} = \frac{\text{temperature ratio}}{\text{pressure ratio}}$$

Temperature ratio equals $(T + \Delta T)/T$

T = absolute reference temperature in degrees Kelvin (0 degrees K = -273 degrees C)

Assume T = 288 degrees K (or 15 degrees C)

ΔT = temperature variation in degrees Kelvin (or Centigrade)

ΔT = 22 degrees K (or 22 degrees C)

Temperature ratio = (288 + 22)/288 = 1.076

The temperature change allowance must account for superheat developed inside the balloon from direct sunlight.

Pressure ratio

The value of the pressure ratio is:

$1 - (1.1023 \times 10^{(-4)}) \times$ altitude in metres
(U.S. standard lower atmosphere, Cornish 1978)

i.e.	for 600 m	the ratio is	0.934
	800 m	"	0.912
	1000 m	"	0.890

Percent ballonet required

The percentage of ballonet required is calculated using the formulas presented previously, for 22 degrees C temperature variation and various altitude changes.

TABLE I-B. Cyclo-Crane Ballonet Requirement.

Altitude Change in Metres	0	600	800	1000
Percent Ballonet Required	7.6	15	18	21

As seen in Table I-B, each 200 m altitude change capability requires 3 percent additional ballonet.

For the logging mission, a minimum change of 800 metres would be desirable. The ballonet size of a production Cyclo-Crane should be 18 percent rather than 15 percent as in the 1.8-tonne model. Increasing the size of ballonet increases the size of the vehicle and, therefore, the structural weight and cost. Structural weights were adjusted for an 18 percent ballonet in the 12-tonne Cyclo-Crane example.

E. ENGINES

1. Description and Costs

Two types of engines (piston or turbine) can be used to power the Cyclo-Crane. Table I-C gives specifications and costs for engines of both types. Piston engines have less horsepower and are heavier than turbines, but are cheaper.

2. Power Requirement for the Cyclo-Crane

The minimum power requirement for a Cyclo-Crane is the power required to hover with full load. Table I-D shows the minimum power required for various sizes. However, to achieve useful forward speed, more than hover power is required. Table I-D also shows power requirements to fly at 20 m/s (72 km/h) and 25 m/s (90 km/h). It shows that doubling the power installed only increases the maximum forward speed by about 25 percent.

We used four PT6A-27 turbine engines for the 12-tonne Cyclo-Crane studied in this report.

TABLE I-C. Sample of Engines Available for the Cyclo-Crane.

Engine Type	Model	HP	Weight (kg)	Time Between Overhaul (hours)	1983 Prices (Cdn $)	
					New Engine	Remanuf. Exchange
Piston AVCO Lycoming	0-320-A,E	150	111	1700	$14 160	$10 705
	IO-320-B,C	160	117	"	14 550	11 000
	IO-360-B	180	122	"	19 880	14 990
	IO-360-A,C	200	133	"	21 310	16 085
	IO-540-C	250	170	"	28 100	21 180
	IO-540-A,B,E	290	187	"	32 110	24 185
	IIO-540-J	350	235	"	50 245	37 685
	IO-720-A,B,D	400	258	"	47 870	36 065
Turbine Pratt & Whitney	PT6A-27	680	137	3500	165 000	132 000
	PT6A-34	750	140	3500	178 000	
Turbine Allison 250	B17C	420	88	-	175 000	

TABLE I-D. Cyclo-Crane Minimum Hover Power Required in Forward Flight.

Payload (tonnes)	Hover Power (Minimum Power) (HP)	Power Required To Fly At	
		72 km/h (45 mph)	90 km/h (56 mph)
2	84	293	573
4	188	446	870
8	423	707	1380
12	679	946	1847
16	950	1163	2271

F. CONTROLS

1. Description

The pilot controls the craft from a cab suspended below the vehicle. The electrical signals from his control inputs are translated by a computer into wing or blade cyclic or collective commands. The commands are transmitted from the pilot station to the airfoils control system via telemetry. Controls feedback, engine control and status, and instrumentation signals are also transmitted via telemetry. The system would possibly also allow the Cyclo-Crane to be remotely controlled from the ground.

2. Weight

The weight of the electronics and controls is assumed to be constant regardless of the size of Cyclo-Crane and is estimated at 270 kg.

3. Cost

A cost of $440 000 for the controls was assumed. This cost includes hardware, software, installation on the craft, testing and adjusting.

G. CABS

1. Description

The pilots will ride in the lower cab. The nose shelter will contain electronics, ballonet control and instrumentation.

2. Weight

It is assumed that the pilot station and nose shelter will remain identical for vehicles of different sizes. We have assumed a weight of 360 kg.

3. Cost

A cost of $37 500 was assumed.

H. HELIUM

1. Volume Needed

In the design of an airship like the Cyclo-Crane, the volume of the balloon is easiest to adjust in the design and is, therefore, left to the last. The concept is such that half of the payload is supported by buoyant lift and half by aerodynamic lift. In the unloaded configuration, the aerodynamic lift is reversed to apply a downthrust opposing the buoyant lift. The volume of helium should be such that the buoyant lift equals the sum of the weight of all the components, plus the crew, the fuel and half of the payload. Once the gross weight is established, the volume of helium required can be calculated, assuming that one cubic metre of helium lifts 1.04 kg. Trial and error is needed to arrive at the final design, since the volume of helium required will affect the size of the balloon and structure.

2. Cost

The cost for an order of helium of more than 30 000 m^3 delivered F.O.B. Vancouver is $3.88/$m^3$.

I. 12-TONNE CYCLO-CRANE ACQUISITION COST CALCULATION

1. 12-tonne Cyclo-Crane Characteristics

- Load Capacity: 12 000 kg plus overload capability in hover
- Power Plants: Four Pratt & Whitney Turbo Prop Engines
- Power: Total cruise power 2000 HP (1472 kW)
- Ballonet: 18 percent
- Balloon
  - Volume: 78 800 m^3
  - Length: 82.8 m
  - Max. Diameter: 41.4 m
- Gross Weight: 62 774 kg

2. Weight and Cost Calculations (50 craft/year)

	Weight (kg)	$/kg	Cost ($)
Structure	23 204	82	$1 902 712
Airfoils	14 251	82	$1 168 588
Envelope	16 995	138	$2 345 310
Engines	544		$528 000
Controls	270		$440 000
Cabs	360		$37 500
Crew	250		
Fuel	900		
Half Payload	6 000		
Total Weight	62 774		
	Volume m^3	$\$/m^3$	
Helium	60 360	3.88	$234 195
Sale Price			$6 656 306
Provincial Tax	7%		$465 941
TOTAL ACQUISITION COST			$7 122 248

3. Weight and Cost Calculations (10 craft/year)

	Weight (kg)	$/kg	Cost ($)
Structure	23 204	120	$2 784 458
Airfoils	14 251	120	$1 710 130
Envelope	16 995	200	$3 399 000
Engines	544		$528 000
Controls	270		$440 000
Cabs	360		$37 500
Crew	250		
Fuel	900		
Half Payload	6 000		
Total Weight	62 774		
	Volume m^3	$\$/m^3$	
Helium	60 360	3.88	$234 195
Sale Price			$9 133 282
Provincial Tax	7%		$639 330
TOTAL ACQUISITION COST			$9 772 612

CYCLO-CRANE PERFORMANCE IN LOGGING

A. MAXIMUM SPEED AND ACCELERATION

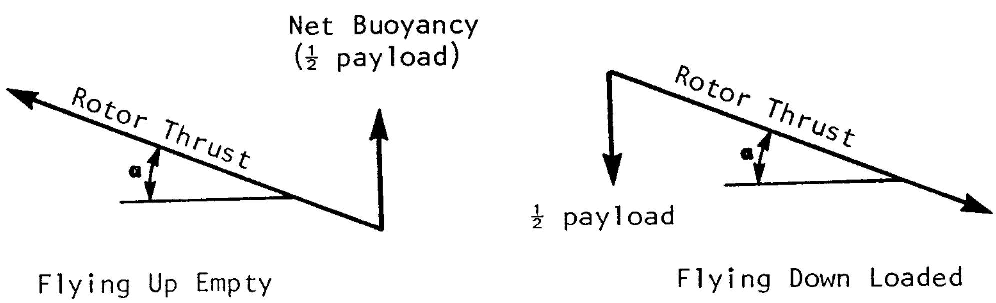
1. Given Data

Payload	PL	in kg
Thrust Power	HP	in watts
Propellers & Rotor Efficiency	e	70%
Gross Mass*	M	in kg
Aerostat Diameter	d	in m
Frontal Area	A	in $m^2 = \frac{Md^2}{4}$
Acceleration of Gravity	g	9.81 m/s^2
Air Density	ρ	1.29 kg/m^3
Drag Coefficient	C_D	0.1
Maximum Cruise Speed	v	m/s
Slope Angle	α	degrees

*Includes additional 20% for virtual mass of air around aircraft.

2. Assumptions

The power required for forward flight would normally be the sum of the induced power, the profile drag power, the rotating parasite power, and the forward parasite drag power. It is assumed that the only power required is for forward parasite drag, but to account for all power requirements a forward drag coefficient (C_D = 0.1) is used.



Slope of Flight Path

Speed and acceleration are calculated for the most favourable case when the Cyclo-Crane is flying up empty or flying down fully loaded. In each case, the imbalance between payload and buoyant lift (equal to half the payload) adds to the thrust of the rotor. It is assumed that this situation will occur in logging since the logs will be flown from the side hill down to the landing.

The maximum pitch angle on the Cyclo-Crane is 22 degrees. Therefore, the maximum slope for the course cannot exceed 22 degrees or about 40 percent.

3. Maximum Speed

At maximum cruise speed (acceleration = 0) and with the above assumptions, the following force balance equation is true.

$$\text{Rotor thrust} + g\,\frac{\text{Payload}}{2}\sin\alpha = \text{Drag load}$$

$$\text{or HP } e/v + g\,\frac{PL}{2}\sin(\alpha) = 0.5\rho A\,C_D\,v^2$$

4. Acceleration

Additional assumption

The acceleration is constant. For a level course, the acceleration is equal to 1/10 g or 0.98 m/s^2 and the deceleration rate is 2/10 g or 1.96 m/s^2 (Doolittle 1983). For a sloping course, the acceleration is increased and the deceleration is decreased owing to the imbalance between payload and buoyant lift.

$$\begin{array}{l}\text{Increase in acceleration}\\ \text{(Decrease in deceleration)}\end{array} = \frac{\text{Payload}}{2}\sin\alpha\,\frac{g}{\text{mass}}$$

5. <u>Example: 12-tonne Cyclo-Crane</u>

Payload	1 200 kg
Gross Weight	62 774 kg
Gross Mass (including virtual mass)	101 657 kg
Aerostat Diameter	41.4 m
Frontal Area	1 346 m^2

a) Thrust power 2000 HP (1472 kilowatts)

Slope (%)	Speed (m/s)	Acceleration (m/s^2)	Deceleration (m/s^2)
0	22.81	0.98	1.96
10	23.80	1.04	1.90
20	24.75	1.10	1.85
30	25.65	1.15	1.80
40	26.46	1.20	1.75

B. <u>FLIGHT-TIME (Figure I-5)</u>

1. <u>Given Data</u>

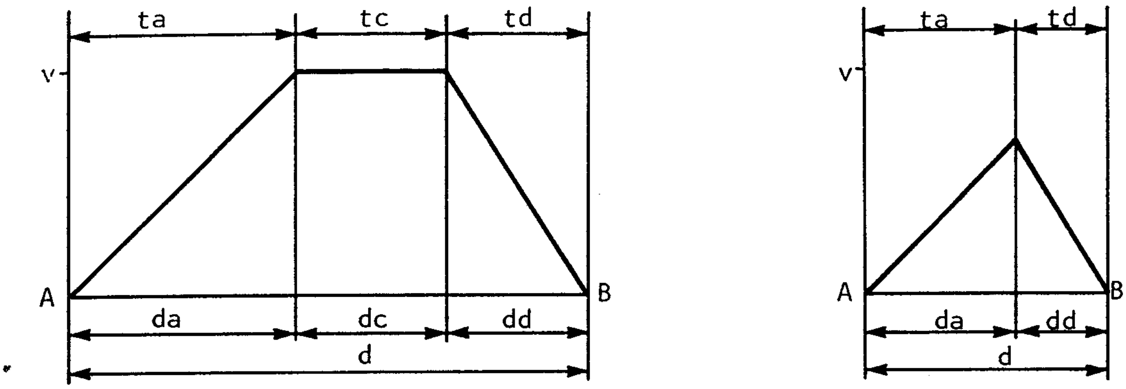
v = cruise speed (m/s)

accel = acceleration (m/s^2)
decel = deceleration (m/s^2)

d = flight path length (m)

2. <u>Assumptions</u>

Flight time from A to B consists of the acceleration and deceleration times and the flight at cruise speed (Case 1). If the distance from A to B is short, the vehicle cannot accelerate to full speed (Case 2).



Case 1 Case 2

FIGURE I-5. Flight Time.

3. Calculations

Acceleration time ta = v/accel
Acceleration distance da = ta (v/2)
Deceleration time td = v/decel
Deceleration distance dd = ta (v/2)

Case 1

d > da + dd
Distance flown at cruise speed dc = d - (da + dd)
Time at cruise speed tc = dc/v

Total flight time from A to B = ta + td + tc

Case 2

d < da + dd
Acceleration time = $\sqrt{2d\ (decel/accel)/(accel + decel)}$
Deceleration time = $\sqrt{2d\ (accel/decel)/(accel + decel)}$
Total flight time from A to B = Acceleration time + deceleration time

4. <u>Example: 12-tonne Cyclo-Crane</u>

- The flight distance is 1044 m and the slope of the flight path is 30 percent.
- Cruise speed: 25.65 m/s
- Acceleration: 1.15 m/s^2
- Acceleration time = 25.65/1.15 = 22.30 s
- Acceleration distance = 22.30 x 25.65/2 = 286 m
- Deceleration: 1.80 m/s^2
- Deceleration time = 25.65/1.80 = 14.25 s
- Deceleration distance = 14.25 x 25.65/2 = 183 m
- The 12-tonne Cyclo-Crane will reach cruise speed if the flight distance is greater than 286 + 183 = 469 metres
- Distance at cruise speed: 1044 - 469 = 575 metres
- Time at cruise speed: 575/25.65 = 22.42 s
- Total flight time from A to B = 22.30 + 14.25 + 22.42 = 59 s

APPENDIX II

HELICOPTER LOGGING

Helicopter turn times are presented based on actual data. Helicopter logging costs are calculated for the Boeing/Kawasaki Vertol 107, the Sikorsky S-64 Skycrane and the Boeing Chinook using a format similar to the Cyclo-Crane example. Hourly operating costs, crew production, support landing and equipment costs are modified to reflect differences between aircraft.

A. HELICOPTER TURN TIME

In this analysis, average turn time is defined as total helicopter flying time divided by the number of turns. Turn time includes flight times empty and loaded, hook-up and release time and positioning and abort delays. Helicopter turn time data from various sources are presented in Figure II-1. Variation between the different sources indicate differences between helicopters, operator efficiencies, slope of flight path and other operating conditions.

Turn time can be viewed as the sum of a fixed part (i.e. terminal time) and a variable part. The variable part varies with the slope of the flight path and increases with the flight distance. The fixed or terminal time can be obtained by extrapolating the data of Figure II-1 to a zero flight distance. According to Figure II-1, fixed or terminal time varies from 120 to 150 seconds for a helicopter logging operation.

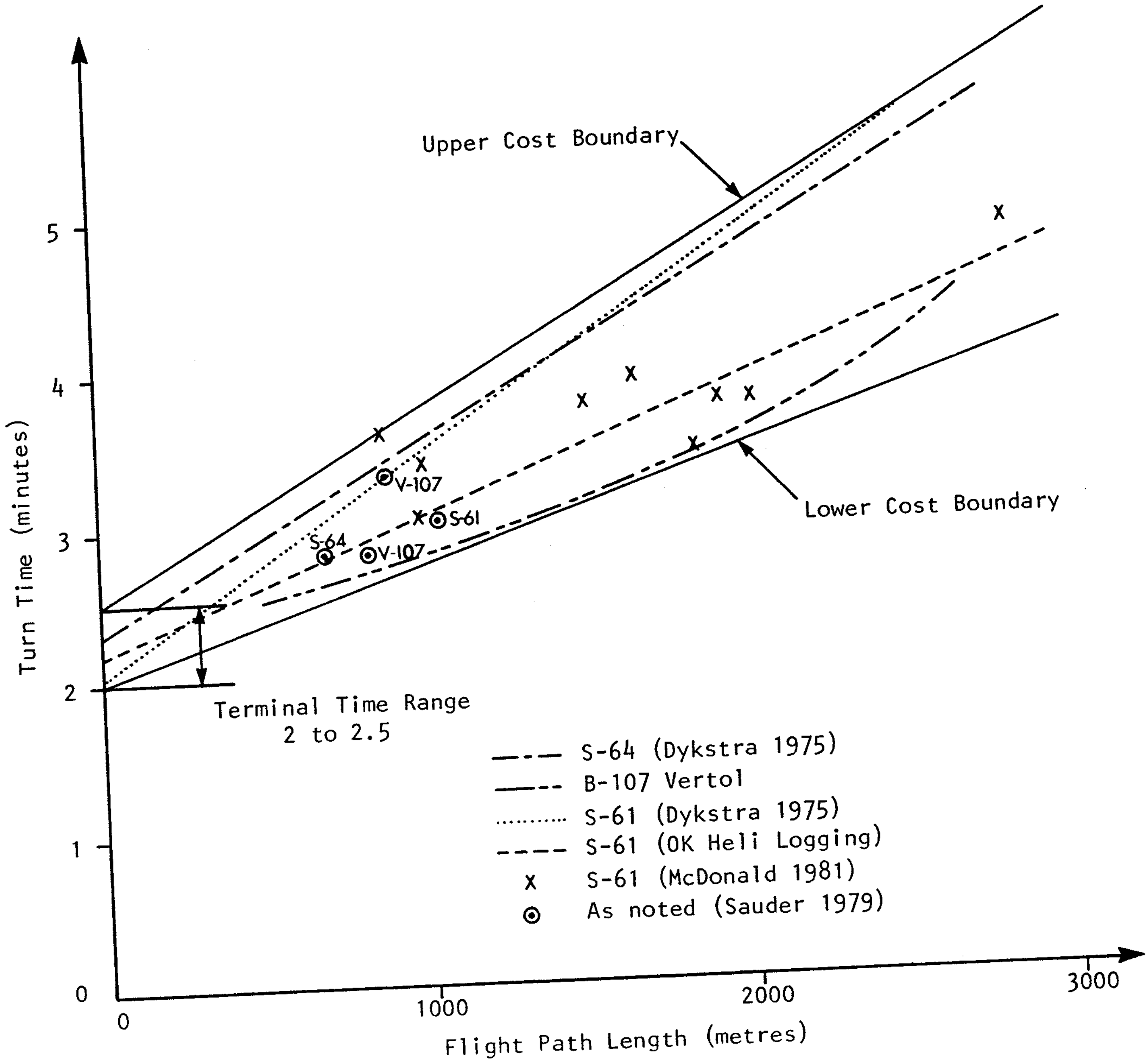


FIGURE II-1. Helicopter Logging Turn Times Versus Flight Distance.

B. BOEING/KAWASAKI VERTOL 107

Because of the smaller load capacity of the Boeing Vertol, logs will be bucked shorter and the average piece size will be smaller than for the Cyclo-Crane or the larger helicopters. The smaller average piece size will decrease production per man/hour in most phases of the operation and will be reflected in higher logging costs per cubic metre.

1. Aerial Logging Cost Summary

	$/Hour	$/m^3
Road and Landing Cost		$ 1.60
Felling	$ 327.47	$ 4.58
Yarding		
Aircraft Ownership Cost	$ 531.25	$ 7.44
Annual Operating Cost	388.40	5.44
Hourly Operating Cost	1 018.06	14.25
Support Equipment	147.12	2.06
Woods Crews	182.87	2.56
Landing Crews	205.23	2.87
Total	$2 472.93	$34.62
Loading	$ 106.69	$ 1.49
Total Cost Loaded On Truck (excluding interest costs)		$42.30
Total Interest Costs	$ 338.78	$ 4.74
Total Cost Loaded On Truck (including interest costs)		$47.04

2. Aircraft Characteristics

Payload (tonnes)	4.5	
Cruise HP (Watts & HP)	1 472 000	2 000
Total Acquisition Cost	$5 000 000	

3. Production

Slope of Flight Path	30%
Cruise Speed (km/h)	162
Horizontal Yarding Distance (m)	1000
Slope Distance (m)	1044
Timber Weight (t/m^3)	0.9
Load Factor (no unit)	0.8
Hook & Release (min)	2.17
Shift (h)	8
Productive Hours/Shift	7
Turn Time (min)	2.94
Volume per Turn (m^3)	4.0
Number of Turns/Shift	142.9
Production (m^3/Shift)	571.4
Volume per Hour (m^3/h)	71.4

4. Aircraft Costs (excluding interest costs)

a) Ownership Cost		$/Year	$/Hour
Annual Operating Hours	1600		
Acquisition Cost	$5 000 000		
Parts (10%)	$ 500 000		
Depreciation			
Years	10		
Residual	10%		
Annual Cost		$450 000	$281.25
Average Annual Investment	$3 475 000		
Insurance			
Percent of L.T.A. Cost	8%		
Annual Cost		$400 000	$250.00
Total Annual Ownership Cost		$850 000	$531.25

b) Aircraft Annual Operating Cost

		$/Year	$/Hour
Salaries			
Pilots			
- Yearly Salary	$50 000		
- Number & Total Salaries	5	$250 000	
Mechanics			
- Yearly Salary	$37 500		
- Number & Total Salaries	4	$150 000	
Fringe Benefits (35%)		$140 000	
Total Yearly Salaries		$540 000	$337.50
Other Costs			
Non-Productive Flight		$81 445	$ 50.90
Total Annual Operating Cost		$621 445	$388.40

c) Aircraft Hourly Operating Cost

		$/Hour
Fuel		
Litres per Hour	649	
Dollars per Litre	$0.41	
Hourly Cost		$ 264.10
Oil (1.5% of fuel)		$ 3.96
Maintenance		
Engines		$ 150.00
Other		$ 600.00
Total Hourly Operating Cost		$1 018.06

d) Total All Aircraft Costs $1 937.71

5. <u>Support Equipment Cost (excluding interest)</u>

		$/Year	$/Hour
a) **Ground Equipment**			
Acquisition Cost	$50 000		
Depreciation			
Years	10		
Residual	25%		
Annual Cost		$ 3 750	$ 2.34
Average Annual Investment	$33 125		
Insurance			
Percent of Capital Cost	1%		
Annual Cost		$ 500	$ 0.31
Ground Support Operating Cost			$ 10.00
Total Ground Support			$ 12.66
b) **Support Helicopter**			
Acquisition Cost	$540 000		
Depreciation			
Years	7		
Residual	25%		
Annual Cost		$57 857	$ 36.16
Average Annual Investment	$366 428		
Insurance			
Percent of Capital Cost	8%		
Annual Cost		$43 200	$ 27.00
Hourly Operating Cost	$158.45		
Percent of Logging Hours & Cost	45%		$ 71.30
Total Support Helicopter			$134.46
c) **Total Support Equipment**			$147.12

6. Roads and Landings

		$/Hour	$/m^3
Hectares per Kilometre	80		
Volume per Hectare (m^3)	600		
Volume per Kilometre (m^3)	48 000		
Road Cost per Kilometre	$60 000		
Road Cost			$1.25
Hectares per Landing	240		
Volume per Landing (m^3)	144 000		
Landing Cost (each)	$50 000		
Landing Cost			$0.35
Total Roads and Landings			$1.60

7. Felling and Bucking

1 Faller ($/h)	$25.10		
Fringe Benefits (35%)	$ 8.79		
Saw	$ 2.50		
Total Cost/Faller		$ 36.39	
Maximum Production/Faller/Shift	70 m^3		
Fallers Required	9		
Total Felling and Bucking		$327.47	$4.58

8. Woods Crew (Hooking)

1 Rigging Slinger ($/h)	$14.55		
1 Chokerman ($/h)	$13.67		
Maximum Production/Crew/Hour	25 m^3		
Crews Required	4		
Woods Crews Basic Cost		$112.88	
Overtime Pay	20%	$ 22.58	
Fringe Benefits (35%)		$ 47.41	
Total Woods Crews		$182.87	$2.56

9. Landing Crews

		$/Hour	$/$m^3$
Loading Operator ($/h)	$14.55		
966 Loader ($/h)	$62.00		
Maximum Production (m^3/h)	100		
Number Required & Cost	1	$ 76.55	
Landing Bucker ($/h)	$16.81		
Bucking Saw ($/h)	$ 2.50		
Maximum Production (m^3/h)	50		
Number Required & Cost	2	$ 38.62	
Chasers ($/h)	$13.67		
Maximum Production (m^3/h)	30		
Number Required & Cost	3	$ 41.01	
Overtime	20%	$ 17.84	
Fringe Benefits (35%)		$ 31.21	
Total Landing Crews		$205.23	$2.87

10. Loading Crew

980 Loader ($/h)	$70.00		
Loader Operator ($/h)	$14.55		
Second Loader ($/h)	$13.67		
Fringe Benefits (35%)	$ 8.47		
Maximum Production (m^3/h)	100		
Crews Required	1		
Total Loading		$106.69	$1.49

11. Capital Investment Costs

Annual Interest = 12%

	Acquisition Cost	Average Annual Investment	Interest Cost $/Hour
Aircraft & Parts	$5 500 000	$3 475 000	$260.63
Ground Support Equipment	50 000	33 125	2.48
Support Helicopter	540 000	366 429	27.48
966 Loader (landing)	261 000	221 850	16.64
980 Loader (loading)	312 230	265 395	19.90
Road Building (pro-rated)	182 700	155 295	11.65
Total Interest Cost	$6 845 930	$4 517 094	$338.78

Capital Invested/1000 m^3 logged = $60 000

C. SIKORSKY SKYCRANE S-64

The S-64 is no longer produced by Sikorsky Aircraft Company and only a few S-64s are still in existance. This aircraft cannot be considered as a long term solution for aerial logging.

1. Aerial Logging Cost Summary

	$/Hour	$/m³
Road and Landing Cost		$ 1.60
Felling		$ 3.67
Yarding		
Aircraft Ownership Cost	$ 903.13	$ 6.90
Annual Operating Cost	485.65	3.71
Hourly Operating Cost	2 962.92	22.63
Support Equipment		1.12
Woods Crews		1.68
Landing Crews		2.15
Total		$38.19
Loading	$ 106.69	$ 0.98
Total Cost Loaded on Truck (excluding interest costs)		$44.44
Total Interest Costs	$ 534.19	$ 4.08
Total Cost Loaded on Truck (including interest costs)		$48.52

2. Aircraft Characteristics

Payload (tonnes)	8.25	
Cruise HP (Watts & HP)	3 091 200	4 200
Total Acquisition Cost	$8 500 000	

3. Production

Slope of Flight Path	30%	
Cruise Speed (m/s & km/h)	45.00	162.00
Horizontal Yarding Distance (m)	1000	
Slope Distance (m)	1044	
Timber Weight (t/m^3)	0.9	
Load Factor (no unit)	0.8	
Hook & Release (min)	2.17	
Shift (h)	8	
Productive Hours/Shift	7	
Turn Time (min)	2.94	
Volume per Turn (m^3)	7.3	
Number of Turns/Shift	142.9	
Production (m^3/Shift)	1047.6	
Volume per Hour (m^3/h)	131.0	

4. Aircraft Costs (excluding interest costs)

a) Ownership Cost

		$/Year	$/Hour
Annual Operating Hours	1600		
Acquisition Cost	$8 500 000		
Parts (10%)	$ 850 000		
Depreciation			
Years	10		
Residual	10%		
Annual Cost		$765 000	$478.13
Average Annual Investment	$5 907 500		
Insurance			
Percent of L.T.A. Cost	8%		
Annual Cost		$680 000	$425.00
Total Annual Ownership Cost		$1 445 000	$903.13

b) Aircraft Annual Operating Cost

		$/Year	$/Hour
Salaries			
Pilots			
- Yearly Salary	$50 000		
- Number & Total Salaries	5	$250 000	
Mechanics			
- Yearly Salary	$37 500		
- Number & Total Salaries	4	$150 000	
Fringe Benefits (35%)		$140 000	
Total Yearly Salaries		$540 000	$337.50
Other Costs			
Non-Productive Flight		$237 034	$148.15
Total Annual Operating Cost		$777 034	$485.65

c) Aircraft Hourly Operating Cost

		$/Hour
Fuel		
Litres per Hour	1 363	
Dollars per Litre	$0.41	
Hourly Cost		$ 554.60
Oil (1.5% of Fuel)		$ 8.32
Maintenance		
Engines		$ 400.00
Other		$2 000.00
Total Hourly Operating Cost		$2 962.92

d) Total All Aircraft Costs $4 414.98

5. Support Equipment Cost
(Same as for the Boeing Vertol) — $/Hour

Total Support Equipment — $147.12

6. Roads and Landings
(Same as for the Boeing Vertol)

Total Roads and Landings — $1.60/m^3

7. Felling and Bucking — $3.67/m^3

Felling, bucking, hooking, landing operation and loading costs are assumed to be similar to that of the 12-tonne Cyclo-Crane.

8. Woods Crews — $1.68/m^3

9. Landing Crews — $2.15/m^3

10. Loading — $0.98/m^3

11. Capital Investment Costs

Annual Interest = 12%

	Acquisition Cost	Average Annual Investment	Interest Cost $/Hour
Aircraft & Parts	$ 9 350 000	$5 907 500	$443.06
Ground Support Equipment	50 000	33 125	2.48
Support Helicopter	540 000	366 429	27.48
980 Loader (landing)	312 230	265 395	19.90
980 Loader (loading)	312 230	265 395	19.90
Road Building (pro-rated)	335 000	284 750	21.36
Total Interest Costs	$10 899 460	$7 122 594	$534.19

Capital Invested/1000 m^3 logged = $52 000.

D. BOEING CHINOOK

1. Aerial Logging Cost Summary

	$/Hour	$/$m^3$
Road and Landing Cost		$ 1.60
Felling	$ 691.32	$ 3.67
Yarding		
Aircraft Ownership Cost	$1 753.13	$ 9.60
Annual Operating Cost	527.37	2.89
Hourly Operating Cost	3 797.47	20.80
Support Equipment	147.12	0.81
Woods Crews		1.68
Landing Crews		2.15
Total		$38.34
Loading		$ 0.98
Total Cost Loaded on Truck (excluding interest costs)		$44.18
Total Interest Cost	$ 958.33	$ 5.25
Total Cost Loaded on Truck (including interest costs)		$49.43

2. Aircraft Characteristics

Payload (tonnes)	11.5	
Cruise HP (Watts & HP)	4 379 200	5 950
Total Acquisition Cost	$16 500 000	

3. Production

Turn Time Calculation same as for the Boeing Vertol.

Turn Time (min)	2.94
Volume per Turn (m^3)	10.2
Number of Turns/Shift	142.9
Production (m^3/Shift)	1460.3
Volume per Hour (m^3/h)	182.5

4. Aircraft Costs (excluding interest costs)

a) Ownership Cost

		$/Year	$/Hour
Annual Operating Hours	1600		
Acquisition Cost	$16 500 000		
Parts (10%)	$1 650 000		
Depreciation			
Years	10		
Residual	10%		
Annual Cost		$1 485 000	$928.13
Average Annual Investment	$11 467 500		
Insurance			
Percent of L.T.A. Cost	8%		
Annual Cost		$1 320 000	$825.00
Total Annual Ownership Cost		$2 805 000	$1 753.13

b) Aircraft Annual Operating Cost

		$/Year	$/Hour
Salaries			
Pilots			
- Yearly Salary	$50 000		
- Number & Total Salaries	5	$250 000	
Mechanics			
- Yearly Salary	$37 500		
- Number & Total Salaries	4	$150 000	
Fringe Benefits (35%)		$140 000	
Total Yearly Salaries		$540 000	$337.50
Other Costs			
Non-Productive Flight		$303 798	$189.87
Total Annual Operating Cost		$843 798	$527.37

c) Aircraft Hourly Operating Cost

		$/Hour
Fuel		
Litres per Hour	1930	
Dollars per Litre	$0.41	
Hourly Cost		$ 785.69
Oil (1.5% of fuel)		$ 11.79
Maintenance		
Engines		$ 500.00
Other		$2 500.00
Total Hourly Operating Cost		$3 797.47

d) Total All Aircraft Costs $6 141.25

5. Support Equipment Cost $/Hour
(Same as for the Boeing Vertol)

Total Support Equipment $147.12

6. Roads and Landings
(same as for the Boeing Vertol)

Total Roads and Landings $1.60/$m^3$

7. Felling and Bucking $3.67/$m^3$

Felling, bucking, hooking, landing operation and loading costs are assumed to be similar to that of the 12-tonne Cyclo-Crane.

8. Woods Crews $1.68/$m^3$

9. Landing Crews $2.15/$m^3$

10. Loading $0.98/$m^3$

11. Capital Investment Costs

Annual Interest = 12%

	Acquisition Cost	Average Annual Invest-ment	Interest Cost $/Hour
Aircraft & Parts	$18 150 000	$11 467 500	$860.06
Ground Support Equipment	50 000	33 125	2.48
Support Helicopter	540 000	366 429	27.48
980 Loader (landing)	312 230	265 395	19.90
980 Loader (loading)	312 230	265 395	19.90
Road Building (pro-rated)	447 000	379 950	28.50
Total Interest Costs	$19 811 460	$12 777 794	$958.33

Capital Invested/1000 m^3 logged = $68 000.

APPENDIX III

HLA IN A TYPICAL COASTAL B.C. SETTING

1. Log Size Distribution on Typical Coastal Setting

Table III-A presents the log distribution by weight class for a typical Coastal B.C. setting based on data presented by Mosher (1983). The same data is presented graphically in Figure III-A. The timber density is 696 m^3/ha or 627 tonnes/ha. The trees are bucked for logging with a 5, 10 or 16-tonne HLA.

TABLE III-A. Log Distribution by Weight Class. (Trees bucked for three different HLAs)

Weight Class (kg)	91-1813	1814-3628	3629-9071	9072-14 514	14 514+	Average Log Wt. (kg)
Class Average (kg)	952	2721	6350	11 793	15 000	
Percent Number of Logs for a:						
16-tonne HLA (full tree logging)	73.6	12.4	10.7	2.5	0.8	2090
10-tonne HLA	71.2	13.2	15.6	-	-	2030
5-tonne HLA	68.0	32.0	-	-	-	1460

The 16-tonne HLA can yard all trees full length. For the 5 and 10-tonne, the trees are bucked so that no log is heavier than the HLA's load capacity. Only 3.3 percent of the trees have to be bucked for the 10-tonne HLA.

2. Load Factor

The load factor is equal to the ratio of the average payload carried by the HLA per turn and the HLA load capacity. The load factor can be estimated using the graph developed by Hartsough (1982) (Figure III-2).

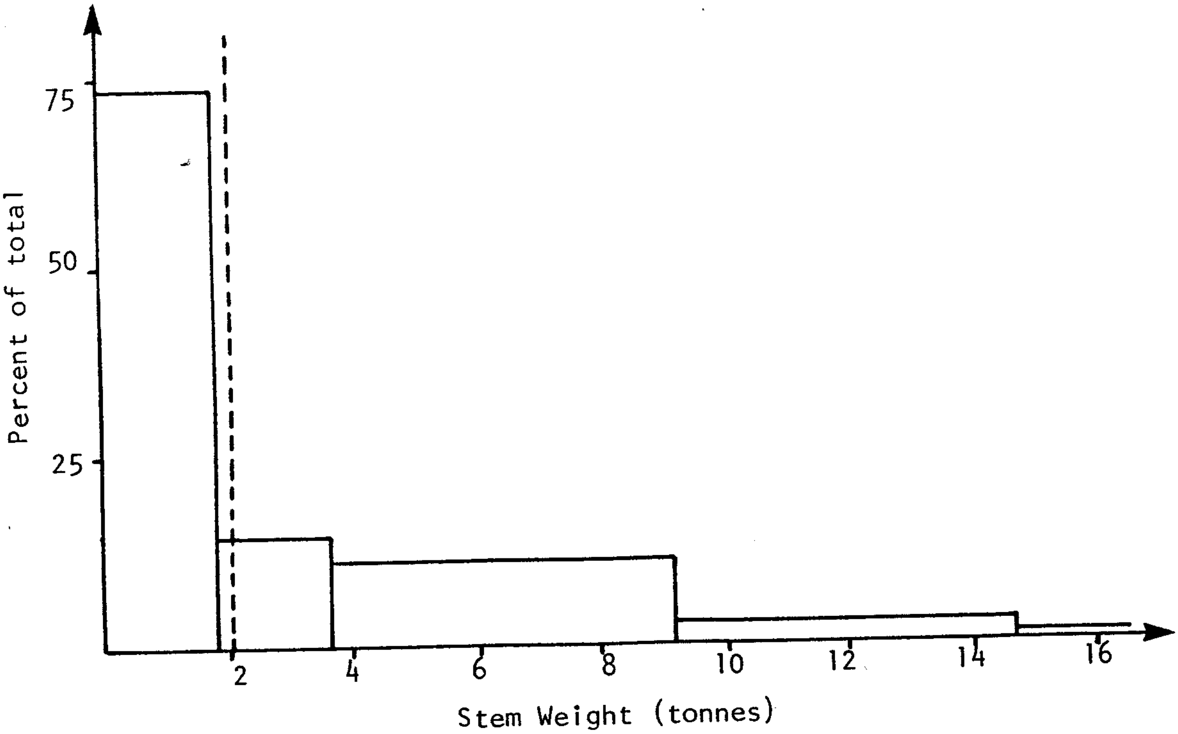


FIGURE III-1. Stem Weight Distribution in Typical Setting. (Actual data from Mosher, 1983)

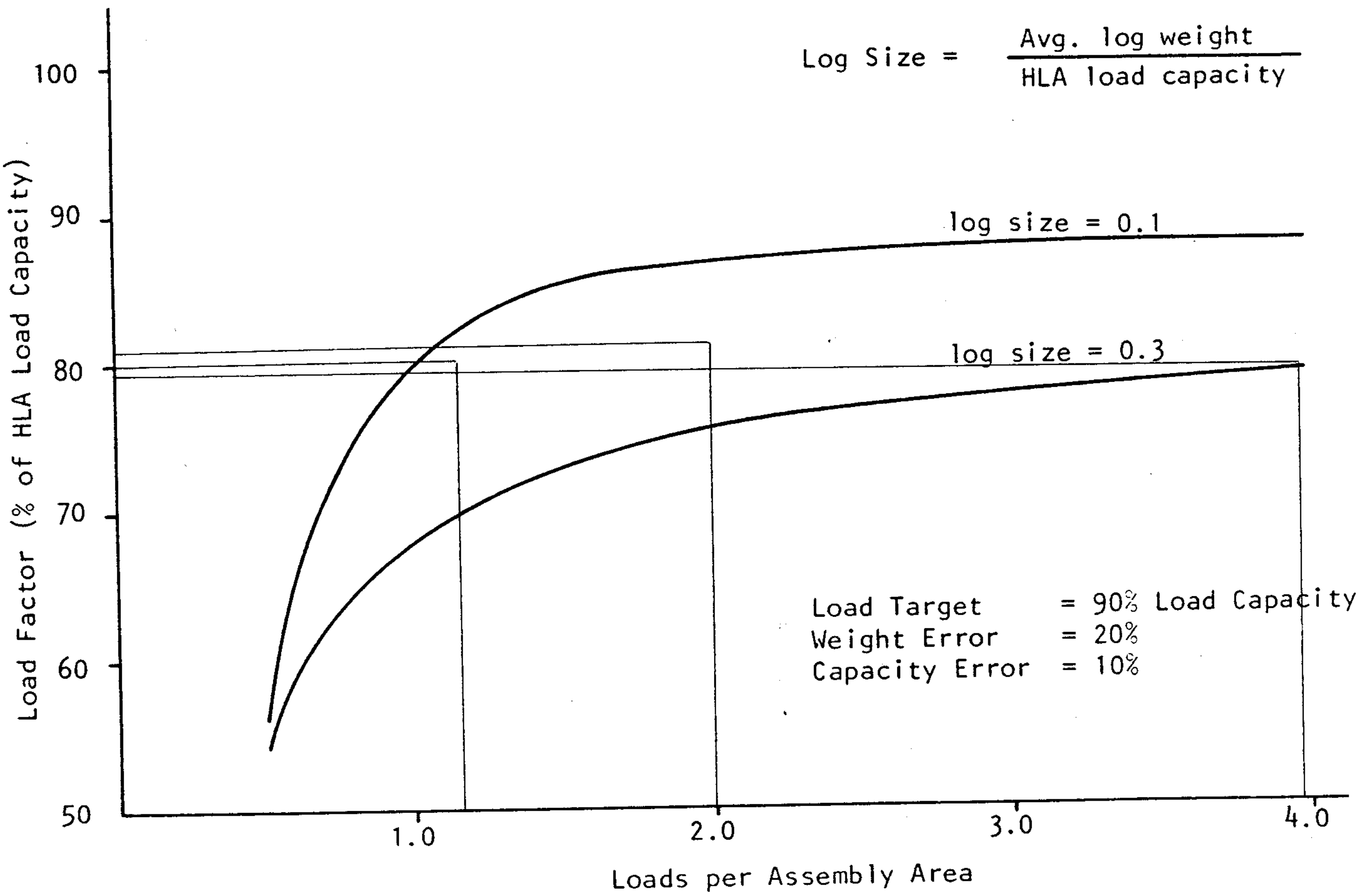


FIGURE III-2. Load Factor Versus Number of Loads Within Reach of Pick-up Point.

The load density for the typical setting is calculated as the average weight of logs within a choker (10-metre long) radius divided by the HLA load capacity.

Load factors for the typical setting are given in Table III-B.

TABLE III-B. Load Factors for a 5, 10, and 16-tonne HLA Yarding the Typical Setting.

HLA Load Capacity	Log Size Capacity	Load/ Assembly	Load Factor
16 tonnes	0.13	1.2	81
10 tonnes	0.20	2.0	84
5 tonnes	0.29	3.9	79

3. Number of Logs per Turn

The average piece weight in the typical setting is 2.09 tonnes. A 16-tonne HLA with a payload factor of 80 percent will bring an average of 6 pieces per turn. Some turns will have a single piece, others more than 10. A computer simulation was used to investigate the piece distribution per turn. The computer model assumes that the log weights distribute as shown in Figure III-1 and that a 16-tonne HLA is used to log the setting. The result of the simulation is given in Figure III-3.

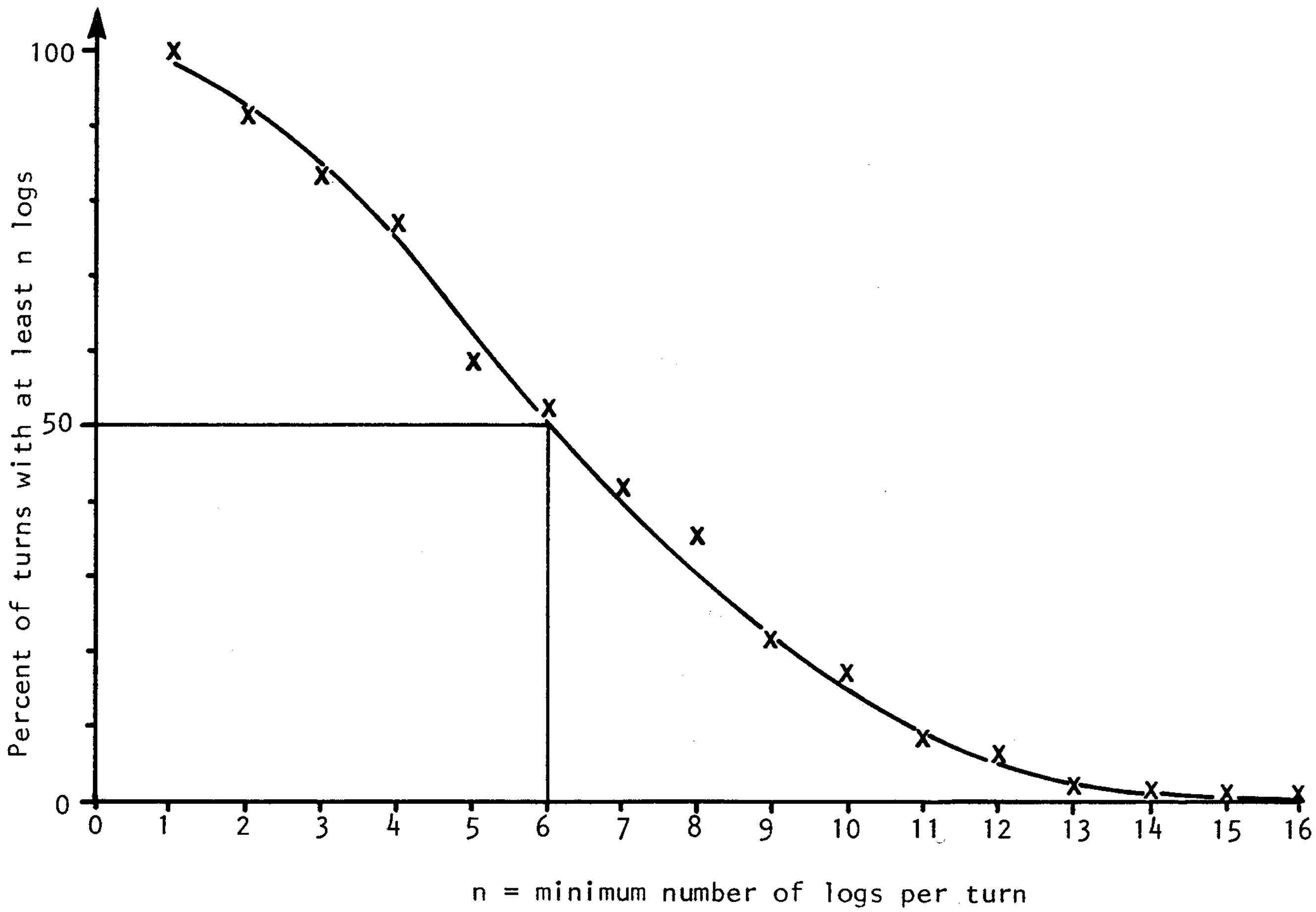


FIGURE III-3. Distribution of Pieces per Turn.

The average number of pieces per turn is six. Thirty percent of the turns have 8 pieces or more; 10 percent have 11 pieces or more.

APPENDIX IV

ANNUAL UTILIZATION

The annual vehicle utilization is a major variable in the analysis of the ownership and operating costs. Annual utilization will vary with the type of aircraft, its mechanical availability, the weather and the organization of the logging operation. Accurate estimates of the number of hours a particular HLA is capable of logging per year will have to be based on experience.

To illustrate the problem, calendar and weather data are presented for Port Alberni based on 1982 statistics (Figure IV-1). A non-leap year has 8760 hours, out of which 4438 are daylight hours. This figure does not have much practical significance; in reality many other imponderable factors reduce the operating hours; it is also impractical to think that every flyable daylight hour can be utilized. It would be, for instance, impossible to log for 16 daylight hours in June unless there were two shifts. In practice, an aerial logging workday can be limited to 10 hours in the summer and 8 or 9 when the days are shorter. Aerial logging could stop in mid-December and resume in February to provide the crew with a holiday period and the aircraft time for overhaul. Where winter conditions are severe, aerial logging with HLAs might have to stop for several months. In 1982, 2826 daylight hours could have been scheduled for aerial logging in Port Alberni. Reducing this figure for days with greater than 20 km/h wind and/or less than 10 km visibility, yields 2241 hours. After further reduction for 90 percent mechanical availability, there are 2107 hours left. Therefore, an HLA could have logged for 2107 hours.

Table IV-A shows differences in weather conditions between 1981 and 1982 for four locations in Coastal B.C. Vancouver has more wind but has generally better visibility than Port Alberni; as a result the two locations exhibit the same percentages of flyable hours. Port Hardy generally enjoys good visibility and ranks high. Prince Rupert has the worst record of the four locations.

TABLE IV-A. Weather Statistics for Four Coastal B.C. Locations and Two Years.

Locations	Vancouver		Port Alberni		Port Hardy		Prince Rupert	
Years	1981	1982	1981	1982	1981	1982	1981	1982
Daylight Hours With Wind <20 km/h and Visibility >10 km	3392	3490	3317	3448	3647	3737	3314	3153
Percent of Total Daylight Hours	76%	78%	75%	78%	81%	83%	74%	70%

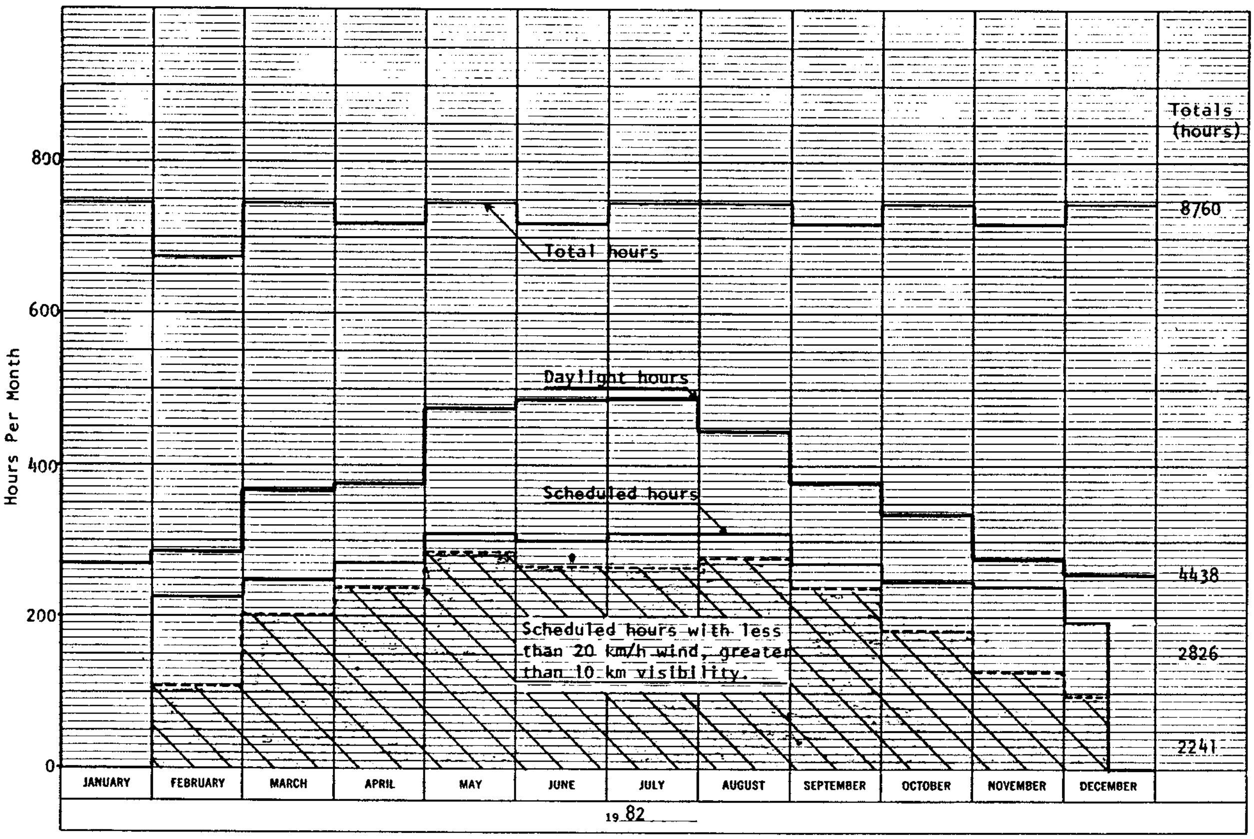


FIGURE IV-1. Calendar and Weather Statistics. (Port Alberni, 1982)

APPENDIX V

ANALYSIS OF AIRCRAFT LOAD CAPACITY AND COST

A. LOAD CAPACITY AND LOAD RATIOS

The total lift required by an aircraft is equal to its gross weight (GW). It is the sum of its basic operating weight (BOW) and its load capacity (LOAD).

1. Helicopters

Utility helicopters, used for logging, typically have a load capacity to gross weight ratio of 50 percent (Figure V-1); in other words, helicopters can lift an external payload roughly equal to their own weight. The rotor develops twice as much gross lift as needed to lift the payload alone.

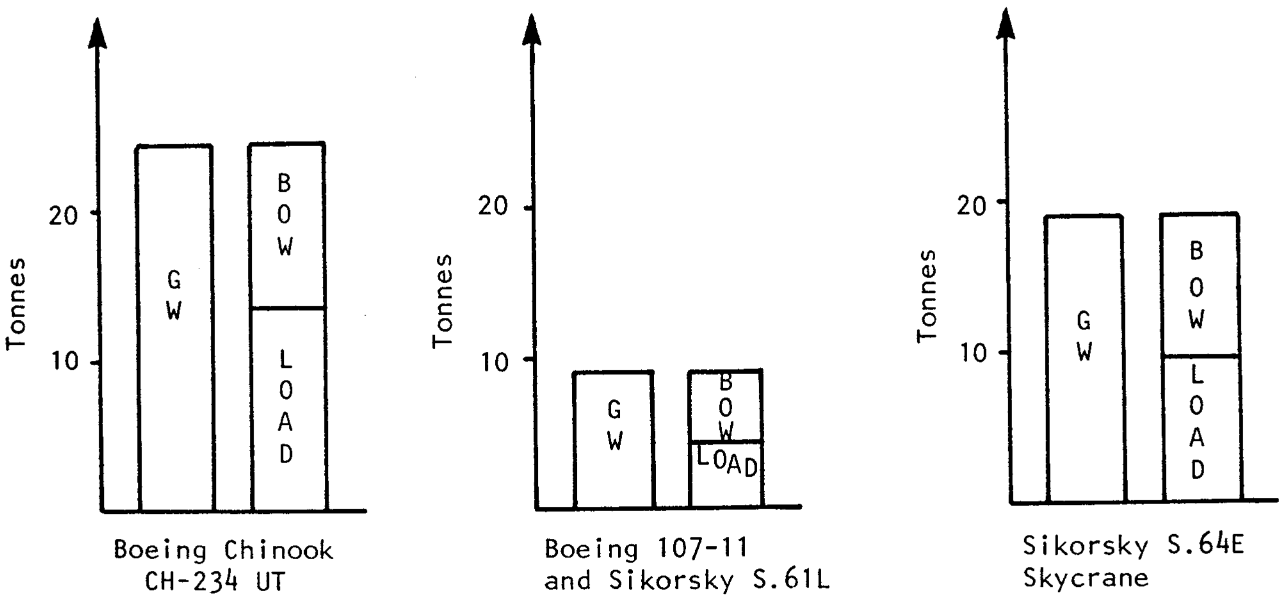


FIGURE V-1. Load Ratios for Helicopters.

The cost per kilogram of gross weight using acquisition costs for a new machine averages \$600/kg. A used aircraft can be purchased for less than \$400/kg.

2. Airplanes

The load capacity of small airplanes is 30 to 40 percent of the gross weight (Figure V-2). The cost per kilogram of gross lift is $50 to $80 for small piston airplanes and in the neighbourhood of $400 for small multi-engine turbo-prop planes (Twin Otter).

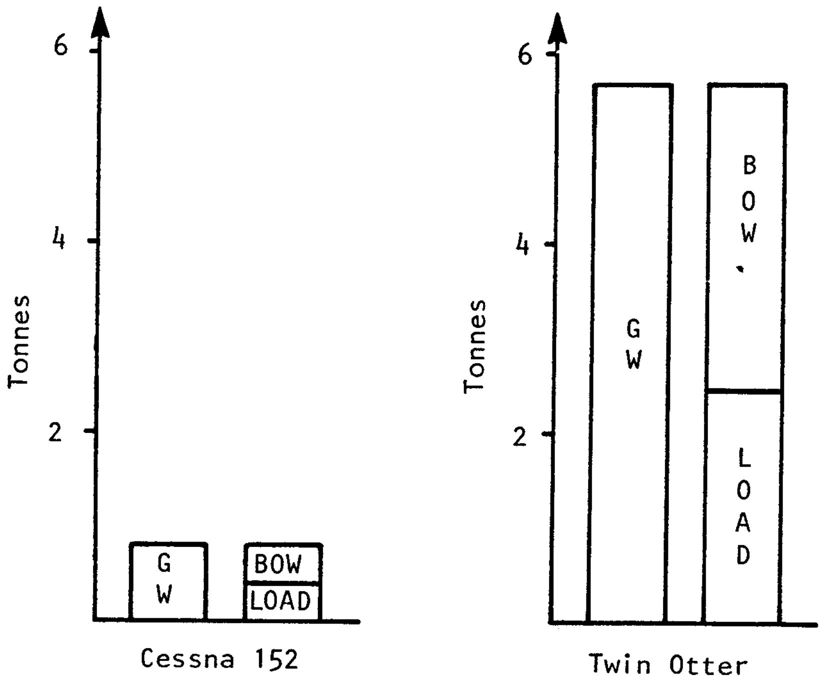


FIGURE V-2. Load Ratios for Airplanes.

3. Balloons

Helium lifts 1.04 kg/m^3. Some of the lift is used to lift the envelope, ballonet system and rigging. A logging balloon has a payload to gross lift ratio of about 70 percent (Figure V-3).

Natural shaped logging balloons cost $32 per kilogram of gross lift or $44 per kilogram of net lift.

Raven Industries estimates that shaped balloons cost twice as much as natural shaped balloons.

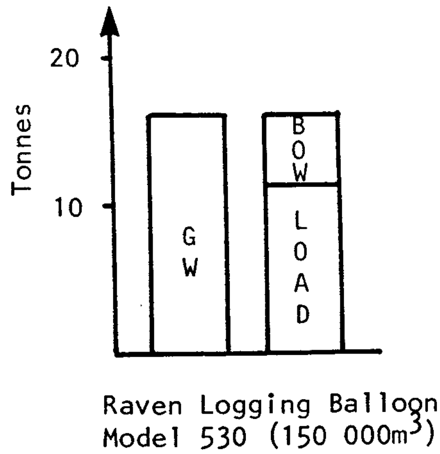


FIGURE V-3. Load Ratios for Balloons.

4. Heavy-Lift-Airships (HLAs)

An HLA can be considered a combination of aerodynamic lift (helicopter or airplane type) and aerostatic lift (balloon). A theoretical HLA is shown in Figure V-4.

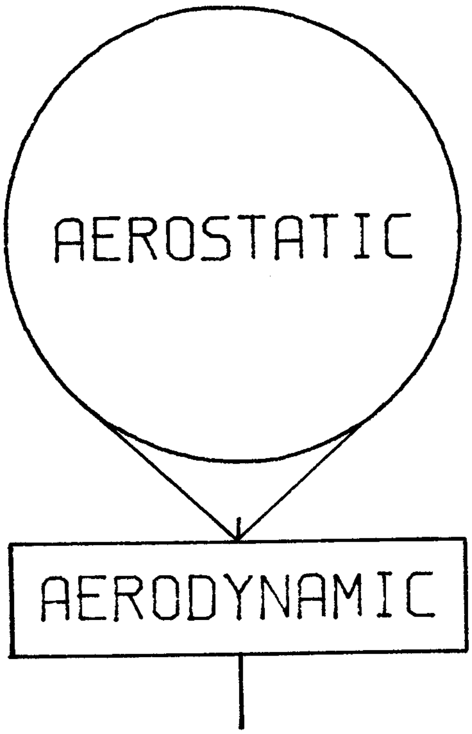


FIGURE V-4. Schematic Representation of an HLA.

Several systems can be defined in theory combining aerodynamic lift and balloons.

System 1 is a balloon coupled with one or more helicopters; the balloon lifts its own weight plus the weight of the helicopter(s). System 1 is neutrally buoyant (or slightly heavy) with zero payload (Helistat, Helicostat, Hybird type).

System 2 is a balloon coupled with the aerodynamic lift of light airplanes (Aerocrane, Cyclo-Crane type). The balloon lifts its own weight plus the weight of the aerodynamic systems plus half the payload. The aerodynamic system can lift half the payload up or down; the empty craft has to be powered down.

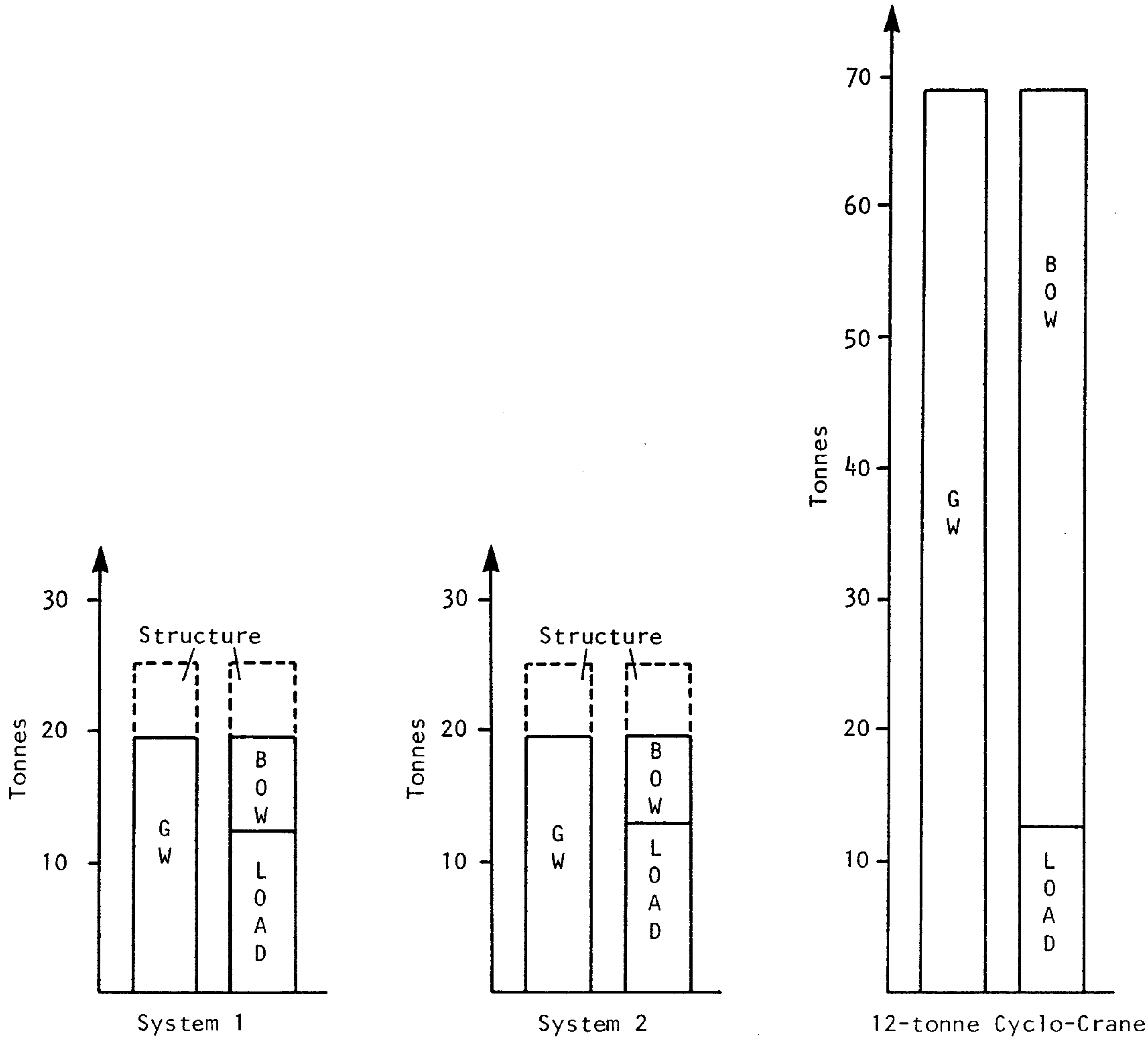


FIGURE V-5. Load Ratios for HLAs.

Load capacity to gross weight ratio for an HLA depends on the weight of the required structure (Figure V-5). Excluding structure, the load capacity to gross weight ratio of an HLA is over 60 percent.

The Cyclo-Crane is of System 2 type. Construction of the 1.8-tonne model has demonstrated the necessity for a very large and heavy structure for the Cyclo-Crane. Its load capacity to gross weight ratio is 17 percent.

B. COST PER TONNE OF LOAD CAPACITY

Table V-A summarizes the lift and weight data presented previously. Total cost and cost per kilogram of load capacity is calculated. Balloon lift is by far the cheapest. Helicopter lift is the most expensive. Among the HLAs, System 2, combining the lift of a natural shaped balloon and airplane lift, yields a low cost per kilogram of load capacity. System 1, combining helicopter and natural shaped balloons, has the potential of reducing the cost of a kilogram of load capacity by 56 percent as compared to straight helicopter lift. However, the costs presented for System 1 and System 2 exclude the cost of the extra structure required to link the aerodynamic lift to the aerostat. In the case of the Cyclo-Crane, the structure required increases the amount of aerostatic lift theoretically required and therefore the size and cost of the balloon.

Table V-A is very theoretical and simplistic. Costs are shown only to demonstrate the potential of various aerodynamic-aerostatic combinations.

TABLE V-A. Load Capacity, Weight and Cost for Various Aircraft.

SYSTEM	AERODYNAMICS				AEROSTATICS				LOAD CAPACITY			GROSS WEIGHT LOADED	LOAD CAPACITY /GROSS WEIGHT
	GROSS LIFT		NET LIFT (MAX.)		GROSS LIFT		NET LIFT						
	kg	$/kg	$	kg	kg	$/kg	$	kg	kg	Total $	$/kg		
Helicopter (CH 234 UT)	23 134	600	14 000 000	12 700	—	—	—	—	12 700	14 000 000	1 100	23 134	55%
Small Airplane Cessna 182	1 411	78	110 700	626					626	110 700	177	1 411	44%
Balloon (Natural Shaped)	—	—	—	—	15 600	32	500 000	11 000	11 000	500 000	45	15 600	70%
Shaped Balloon					15 600	64	1 000 000	11 000	11 000	1 000 000	90	15 600	70%
System 1*	12 000	600	7 200 000	6 600	7 714	32	246 900	5 400	12 000	7 446 900	620	19 714	61%
System 2*	6 000	78	468 000	2 640	13 371	32	427 900	9 360	12 000	895 900	75	19 371	62%
Cyclo-crane	6 000	78	468 000	2 640	62 774	100	6 277 400	9 360	12 000	6 745 400	562	68 774	17%

System 1 - Balloon-helicopter combination - no special structure

System 2 - Balloon-airplane combination - no special structure

APPENDIX VI

COST OF CABLE LOGGING IN DIFFICULT TERRAIN CONDITIONS

A. DESCRIPTION OF OPERATION

This Appendix attempts to define the cost of cable logging in difficult terrain conditions encountered on the Coast of B.C. The setting is assumed to be steep and rugged, and road construction to access the setting is difficult, but technically feasible. The timber density is average. Cable logging presents difficulties, but is possible. Because of ground steepness, large landings cannot be built and a loader has to work side-by-side with the yarder to pull the logs away and load them.

B. COST ANALYSIS

1. Road Cost (excluding interest costs)

The general road network to the setting will be a combination of main road and branch roads, mainly in difficult terrain. Road cost per kilometre will average $105 000. In the worst condition, 18 ha of loggable area are developed by 1 km of road.

Using the same assumption of timber density as in the HLA's cost study, road cost per m^3 can be calculated as:

Hectares per Kilometre (ha)	18	
Volume per Hectare (m^3)	600	
Volume per Kilometre (m^3)	10 800	
Road Cost per Kilometre	$105 000	
Road Cost		$9.72/$m^3$

Main-road maintenance is not included in our cost study. Spur-road maintenance is evaluated as $1.50/$m^3$.

Total Roads	$11.22/$m^3$

2. Felling & Bucking

Because of the extreme conditions, felling production will be low, or about 60 m^3/shift.

Felling & Bucking Cost	
Cost per Hour	$36.39
Cost per Shift	$291.12
Production per Shift (m^3)	60
Felling & Bucking Cost	$4.85/$m^3$

3. Yarding Cost (excluding interest costs)

The hourly cost of a new Madill Tower 009 yarder is calculated based on:

Life: 8 years
Residual Value: 15%
Acquisition Cost (including rigging and tax): $349 700

	$/Hour	$/Hour
a) Ownership Costs		
Depreciation Period: 8 years		
Residual Value: 15%		
Average Annual Investment: $219 655		
Depreciation Cost	$ 23.22	
Insurance Cost (1% of A.A.I.)	$ 1.37	
TOTAL OWNERSHIP COST		$ 24.59
b) Operating Cost (Nagy, 1983)		
Fuel and Lubricants	$ 14.77	
Repair and Maintenance	$ 32.51	
Supplies	$ 11.26	
TOTAL OPERATING COST		$ 58.54
c) Labour (Nagy, 1983)		
Total (6-man crew)	$ 87.91	
Fringe Benefits (35%)	$ 30.77	
TOTAL LABOUR		$118.68
d) Yarding Cost (excluding interest costs)		
TOTAL		$201.81

A highlead yarder's average production on the Coast is about 180 m^3 per eight-hour shift. Production in difficult settings could average 160 m^3 per shift, 20 m^3 per hour, or 32 000 m^3 per year.

Yarding Cost: $201.81/20 = $10.09/$m^3$

4. Loading Costs (excluding interest costs)

The hourly cost of a new hydraulic log loader is calculated based on:

Annual Utilization: 1600 h
Acquisition Cost: $474 010
(including tax)

	$/Hour	$/Hour
a) Ownership Costs		
Depreciation Period: 6 years		
Residual Value: 10%		
Average Annual Investment: $323 907		
Depreciation Cost	$ 44.38	
Insurance (1% of A.A.I.)	$ 2.02	
TOTAL OWNERSHIP COSTS		$ 46.40
b) Operating Costs (Nagy, 1983)		
Fuel & Lubricants	$ 11.84	
Repair & Maintenance	$ 38.12	
TOTAL OPERATING COSTS		$ 49.96
c) Labour		
Machine Operator	$ 15.33	
Overtime (12.5%)	$ 1.92	
Fringe Benefits (35%)	$ 6.04	
TOTAL LABOUR COST		$ 23.29
d) Landing Cost (excluding interest costs)		
TOTAL		$119.65

A loader can normally keep up with the production from two highlead sites. Because of the terrain conditions, a loader will be required full-time to clear the logs away from the cable yarder. The loader's production is dictated by the yarder's production (20 m^3/h).

Loading Cost: $119.65/20 = $5.98/m^3.

5. Capital Investment - Interest Cost

Yearly Interest = 12%

	Acquisition Cost	Average Annual Investment	Interest Cost $/Hour
Yarding	$ 349 700	$219 655	$ 16.47
Loading	$ 474 010	$323 907	$ 24.29
Road Building (pro-rated)	$ 310 500	$263 925	$ 19.79
	$1 134 210	$807 487	$ 60.55

Investment per 1000 m^3 logged is $37 371.

Interest cost is $60.55/20 = $3.03/$m^3$.

6. Highlead Logging Cost - Summary

	$/$m^3$	$/Cunit
Road Building & Maintenance	$ 11.22	$ 23.92
Felling	$ 4.85	$ 13.73
Yarding	$ 10.09	$ 28.57
Loading	$ 5.98	$ 16.93
Total Cost (excluding interest cost)	$ 32.14	$ 91.01
Interest Cost	$ 3.03	$ 8.58
Total Cost (including interest cost)	$ 35.17	$ 99.59

7. Actual Logging Costs

The four B.C. logging companies involved in the Cyclo-Crane Syndicate supplied us with actual logging costs. These costs (summarized in Table VI-A) represent the cost of logging their difficult settings (10 to 15 percent most difficult). The costs include labour and fringe benefits, equipment depreciation, insurance, operating costs and maintenance, and road amortization. Interest on capital investment is accounted for separately. Not included in the cost are hauling, sorting and booming, camp administration and accommodation, employee transportation, stumpage and royalties, forestry and labour supervision.

TABLE VI-A. Actual Cable Logging Costs Compared with Results of Our Analysis.

Cost $/m^3$	Source of Data					
	Company A	Company B	Company C	Company D	Companies' Average	FERIC'S Analysis
Roads	$ 8.80	$ 6.25	$ 7.03	$ 9.55	$7.90	$11.22
Felling	3.34	5.48	3.89	4.80	4.38	4.85
Yarding	7.13	8.54	10.85	8.64	8.79	10.09
Loading	3.64	3.50	5.85	4.76	4.44	5.98
Total	$22.91	$22.56	$27.62	$27.75	$25.51	$32.14
Interest	1.31					3.03
TOTAL	$24.22					$35.17

FERIC's cable logging cost study overestimates actual cable logging costs. This is partly owing to the fact that we assumed that new equipment was used whereas the company cost accounting is based on equipment of average age bought several years ago at a lower price. Equipment can also be run for longer than the amortization period that we assumed.

Low road costs reflect the company's ability to bypass low volume stands and isolated patches of timber.

APPENDIX VII

UNIT CONVERSIONS

1 cm	1 centimetre	:	0.39 inch
1 m	1 metre	:	3.28 feet
1 km	1 kilometre	:	0.62 mile
1 m^3	1 cubic metre	:	0.353 cunit
1 ha	1 hectare	:	2.47 acres
1 L	1 litre	: :	0.22 Imperial gallon 0.26 American gallon
1 kg	1 kilogram	:	2.20 pounds
1 t	1 tonne	:	2205 lbs
1 t/m^3	1 tonne per cubic metre	:	3.12 tons/cunit
1 kW	1 kilowatt	:	1.34 horsepower
C	degrees Celsius	:	5/9 (F-32) degrees