FORESTRY TRANSPORT: CONCEPT FOR AUTONOMOUS UNMANNED AIRSHIP LOGGING

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Introduction

Northern Canada has substantial forests of economic interest, but transportation makes the cost of extraction high. Access roads that cross numerous water courses and difficult terrain are expensive to build and must meet stringent environmental standards. Once the forest is harvested, the road becomes a stranded asset. Worse still, if the road is abandoned and the land must be returned to its previous state, the restoration cost can equal the cost of the road's original construction. Hence, the forest industry is very conscious of logging road costs and is open to new transportation concepts.

This paper proposes an Unmanned Aerial Vehicle (UAV) for lighter-than-air transport of logs. For expedient cargo exchange, payloads would be suspended externally. For economic and ecological reasons, hydrogen gas is specified for aerostatic lift and as a fuel in combination with liquefied methane. For UAV-type monitoring and control, a ground coordination system is required to manage weather conditions and physical operations. The paper sets out the basic design and operational considerations for a logging airship, and concludes with a technology development plan.

Form follows Function

A UAV cargo airship for short-range operation is designed primarily to maximize adaptation to the specialized task rather than to minimize drag. The need for mooring leads to configurations with symmetry of rotation about the vertical axis, high maneuverability and minimum ground area requirements at maximum aerostatic lift. Figure 1, presents the most practical shape for short-range suspended cargo haul.

Mooring without a mast is an attractive feature for ground operations, i.e. during cargo exchange. The anchoring stays may serve as tie-downs against excess aerostatic lift until the ship is reloaded. The aerodynamically least favourable configuration meets the log hauling requirements for footprint, simplicity and adaptability.

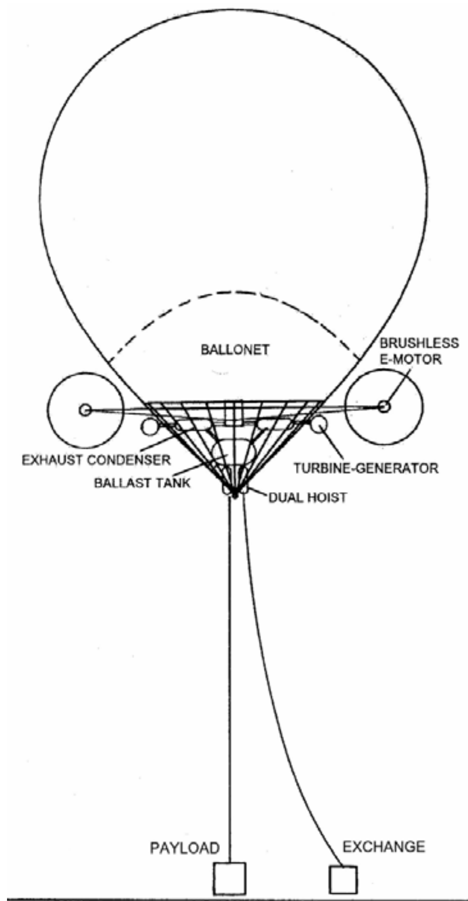

Figure 1 Conceptual Design UAV Logging Airship

The specific logging configuration has several advantages:

- the pointed shape provides a logical load concentration point for suspended payloads,
- suspended payloads can be quickly and conveniently exchanged,
- flight stability is enhanced by the low center of gravity, and
- the lower tip accommodates a coupling device to secure the craft during parking periods by means of a ground anchor.

The airship carries no external payloads when moored for parking. The excess lift is counteracted by a ground anchor and the craft stands upright as long as there is calm air. Wind blowing from any direction would cause the airship to lean, but the excess lift component would withstand the wind pressure up to a certain equilibrium angle. Snow loads slide off the surface and icing on metal surfaces (e.g. propulsion units) can be dealt with by appropriate means as applied in common aviation technology.

System Selection and Comparison with Helicopter Operation

The characteristics of helicopters and the proposed airship logger are summarized in Table 2. Lacking a detailed cost analysis, this table presents a qualitative comparison. The only obvious drawback of an LTA system is the necessity to provide ample compensatory counterweight (ballast) upon payload delivery. However, the aerostatic lift of the airship can be viewed as either a disadvantage or an advantage relative to the helicopter. The airship may need a system for ballasting, but the helicopter needs to burn a lot of fuel to lift itself and the payload.

Table 2: Comparison of UAV Logger versus Helicopter Performance

	UAV Logger	Helicopter
power requirement	low	high
speed	low	medium
noise level	low	high
down-wash	none	high
exhaust (CO2)	low	high
payload exchange	needs ballast	none
cost	lower	high

The airship's lower CO_2 emissions result from using alternative fuels and smaller engines. The airspeed of a helicopter is faster because the airship has lower propulsive power installed and experiences substantial drag of the hull. Lower airspeed, however, plays a minor role in the case of short-range operations with non-perishable goods.

The external suspension of the airship payload would follow methods already practiced in the field of helicopter logging. Neither an airship, nor a helicopter, touches the ground under normal operational conditions because of the external payload suspension. This avoids extensive area clearance on the ground.

Source: http://www.waldwissen.net/themen/forsttechnik/holzernte/wsl_helilogging_DE
Figure 2 Log Hauling by Helicopter

Lack of downwash in the case of the airship eliminates a nuisance to the ground workers, the potential hazard of flying debris. Figure 2 shows typical helicopter sling operations for logging. Note that the ground crew must deal with “slash” (logs, branches, etc.) and uneven surfaces. The stability of the hooking system is important to ensure operator safety. Loads can also be moved with mechanical grapplers.

Airship Harvesting Operations

Figure 3 illustrates a conceptual operation in which the logging area is separated by a river. The airships are ferrying logs from an outpost camp to a truck depot on a highway. The inevitable constraints of individual payload capacities may require sequential fleet operation. The number of circulating shuttle airships is limited by the necessary downtime periods for cargo exchange and servicing.

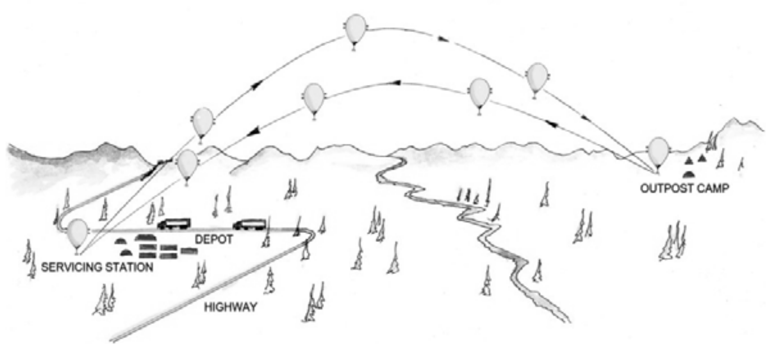

Figure 3 Field Scenario for Transport between a Servicing Station and an Outpost Camp

While the diagram in Figure 3 is conceptual, the problems of physical constraints in forestry are very real. For instance, the Tolko Company has a forest management license in Manitoba that encompasses a total area of 8.7 million hectares. Of this total only 3.7 million hectares are productive forest. The remainder is swamp, muskeg, rocks or lakes (Gibbons, 2008). Land that is cut-off by national parks, lakes and native reserves is also inaccessible, or only accessible by ice roads. Land that is separated by major rivers, like the Churchill River, may not be accessible without a bridge.

The stage length for a logging operation is expected to be somewhere between 20 to 100 km from a main corridor. The average payload transfer requirement dictates the number of daily shuttles in view of the payload capacity and downtime that has to be deducted from daily flight times.

For short-range operations, airspeed does not play a major role, but modular flexibility regarding fleet composition and adaptability to partially adverse ground conditions are matters of paramount concern. The payload exchange of the airship requires adequate preplanning of ground operations. For log hauling, an equivalent weight of water, ice or earth would be carried to the respective destinations where it is discharged in a controlled manner after the log(s) are attached for safe suspended transport.

Tools and machinery required at the work site could also be carried in a similar manner to resupply the outpost camps. The receiving sites would prepare an equivalent mass of return ballast in logs or other available materials in nets or bags.

Lift, Fuel and Propulsion

Hydrogen gas is envisioned for aerostatic lift, as well as a gaseous fuel. Hydrogen provides about 8 per cent more lifting potential than helium and is much less expensive. Given the UAV operation and remote location, the greater safety of helium is not warranted. Using gaseous hydrogen from the airship envelope as fuel gas in combination with methane may compensate for the weight loss of the burnt methane by the respective loss of lift due to hydrogen consumption.

The use of hydrogen gas for fuel also improves the flight economy, and serves as a routine refresher of the aerostatic lift. Under realistic conditions of standard flight operation, the lifting gas is permanently subject to inevitable diffusion and increasing impurities (e.g., water vapour) over the time of operation. Routine hydrogen replenishment thus maintains a high degree of purity for continuous carrier utilization.

Figure 4 provides a schematic overview of the envisioned propulsion, fuel and ballast system. The advantage of mixed fuel for buoyant flight is obvious: 1 kg methane at 1 bar contains an energy equivalent of about 15 kWh or for 100 kg an equivalent of 1500 kW/h, respectively. One cubic meter of hydrogen is capable of lifting 1.09 kg/m^3, thus lifting the weight of 100 kg methane by 100/1.09 = 91.7 cubic meters of hydrogen with an energy content of 3.50 kWh/m^3, i.e. corresponding to about 321 kWh. In other words, there is 21 per cent more propulsive energy available as compared to using methane as the only fuel.

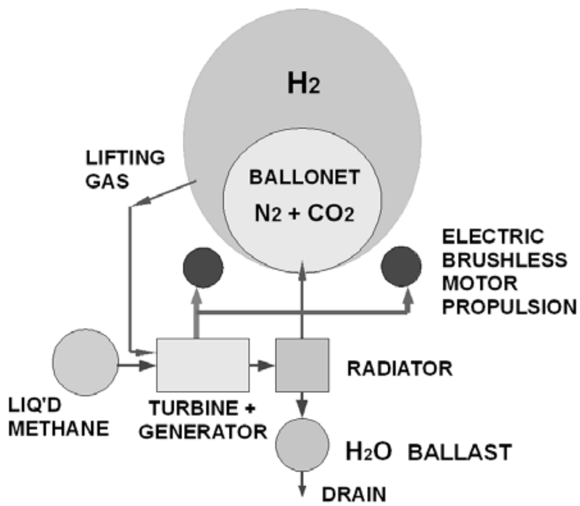

Figure 4: Schematic Overview of the Propulsion Fuel and Ballast System

A major part of the exhaust gas from the propulsion system is scooped up by the ducts of the condenser system. The gases are primarily nitrogen and carbon dioxide which are - as a fire safety measure – ducted into the ballonet to displace the oxygen in atmospheric gas. In addition, the exhaust contains a major portion of water vapor for the optional collection of safety ballast.

The propulsion subsystem consists of two APU (auxiliary power unit) turbines that drive electric generators. Electrical power is provided to two lateral propellers of 6 meter diameter, each of which is driven by a brushless electric motor of about 800 kilowatts. Figure 5 depicts a conventional APU for aviation use.

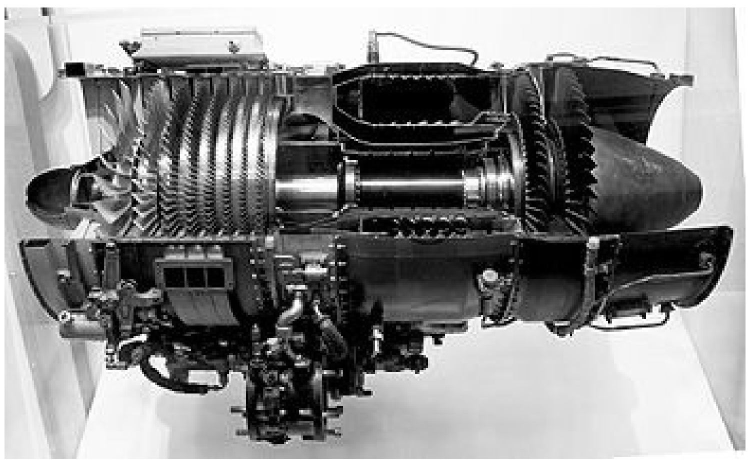

Figure 5 Typical Aircraft APU Turbine

Two lateral propellers are mounted on outriggers, as shown earlier in Figure 1. Directional control is achieved by differential thrust, while climb and descent are controlled by a combination of aerostatic trim and thrust control. The latter type of control results because the main thrust line is below the drag center point of the balloon. This creates an inclination of the vertical axis of the aerostat of up to 8 degrees. Consequently, a vertical component of the thrust vector becomes effective as additional lift, which can be instantaneously controlled by thrust variation.

This feature alleviates take-off and landing procedures; e.g. full throttle produces an extra lift component during take-off. Then, during cruise, the craft can be trimmed slightly “heavy” to compensate the thrust lift component. Finally during descent, throttle may be reduced for a controlled landing (in routine cargo operations this means payload touch-down).

Fuel Economy, Autonomy, Control And Monitoring

Two APUs are used for reasons of redundancy and economy. The nominal indicated airspeed near ground is about 72 km/h if both turbines are running in the standard case. If only one turbine is in operation, the nominal indicated airspeed will drop to about 57 km/h.

Figure 6 indicates the reduction of payload capacity as a function of operational ranges due to the weight of the fuel required under various wind conditions. This chart is prepared for a nominal payload of 8 tonnes to demonstrate the impact of the cargo/fuel trade-off. It is unlikely that harvesting distances as long as 300 kilometres would be employed. Consequently, as is evident in the diagram, the loss of productivity with distance of haul is relatively minor. The optimal economic payload size for airship logging is an empirical question.

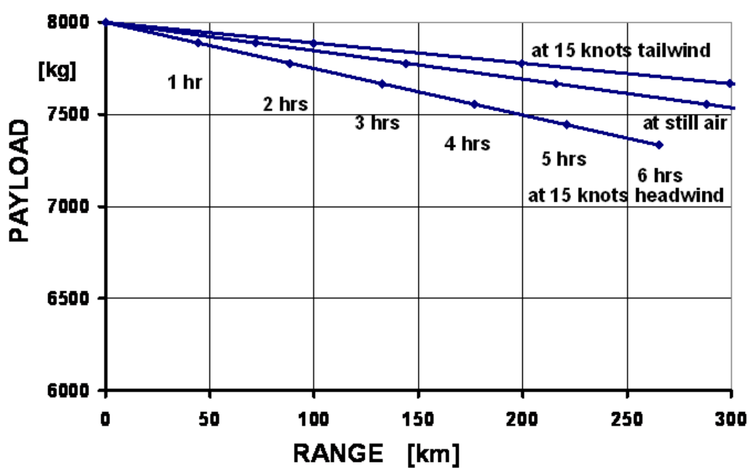

Figure 6 Payload Capacity as a Function of Range and Wind Conditions

Headwinds appear to be more detrimental than tailwinds are beneficial. In most logging operations, however, the transit will be a simple out and back, The airship loses productivity into the headwind, but gains when it returns.

Some specific aspects and requirements regarding airship operations that deserve special attention are:

- GPS and altimeter
- Doppler radar to determine the crosswind angle at low cruise speed
- Hydrogen gas monitoring and control
- Liquid fuel tankage monitoring and control
- Ballonet/hull cavity oxyhydrogen gas monitoring and flush control
- Video link for ground cockpit virtual flight control
- Icing monitoring, etc.

Unmanned Aerial Vehicles (UAVs) fly autonomously in accordance with pre-programmed flight plans, and they are also guided by remote control and complex dynamic automation systems. UAVs are generally preferred for missions where a human observer would be at risk (e.g. military and police missions), or where routine missions are too tedious or expensive for pilot operation. Higher payload capability is an additional advantage. All human interface installations (except for maintenance work) can be deducted from the overall mass, e.g. cockpits, accommodations, etc.

Ground Station Requirements

Two boundary conditions need to be observed for the design of a viable infrastructure. First, airships need a major assembly, servicing, maintenance, overhaul and shelter hangar. This could be a central base on a provincial or regional level. Second, many outpost bases are needed that provide the necessary airship operation interfaces to sustain the forestry operations.

Ground handling provisions for outpost camps concern mooring and cargo handling provisions. The camps must have space prepared for quick cargo exchange and ballasting to maintain aerostatic equilibrium. Appropriate material handling equipment for quick ground transfer of cargo is already in use. A robust weigh scales may be advisable to adjust payloads before pickup to safeguard equilibrium, but foresters are very good at estimating mass based on log diameter, species and length.

Logs would be carried from the outpost camps to a transshipment infrastructure facility herein called “servicing station”. These depots would satisfy the following conditions:

- location at a road, railroad and/or navigable river or canal
- storage facilities for liquid methane (natural gas) and pressurized hydrogen, as well as for payloads from the outpost(s) and supplies for the outposts, and intermediate trans-loading yards
- service facilities necessary for cargo transfer from/to the outpost(s)

Flight Operations

A specialized team must be dedicated to all activities involving airship operation to create a continuous transportation supply chain:

- controlling / dispatching landings and takeoffs
- mooring and safeguarding LTA carriers
- acceptance and handling of incoming cargo
- preparation and handling of outgoing cargo weighing and balancing

It would be appropriate for the ground crew to be equipped for airship remote control during the landing and takeoff phases. This applies to servicing stations and where routine operations and ballasting are concerned. A primary task of the servicing stations is refueling liquefied methane and replenishment of gaseous hydrogen for a two-way flight. Fuel reservoirs are not practical for outpost stations.

The Flight Operations Control Center (FOCC) should be a centralized organization to provide an instant overview of the ongoing UAV activities, preferably with respective displays. The main objective of this organization is to ensure safe and efficient performance of the fleet on the basis of telemetry data via satellite. This implies the potential of overriding on-board automated system commands via virtual cockpits wherever necessary.

Adverse weather conditions may dictate emergency operations. Unless sheltering hangars are available, evasion is the best strategy for airships. Based on weather forecast information, the FOCC can issue an evacuation plan with provisions to park on selected airfields outside the foul-weather zone.

Spontaneous actions may be required both at the outposts and at the servicing stations in the case of a sudden unexpected weather event. In these cases all affected airships would be launched immediately. The departing ships may be temporarily radio-controlled by the ground crew until the FOCC takes over again. Once in the air, an airship can ride out the storm and return to its base when it is safe to do so.

Development Plan

A development plan is foreseen on the basis of a realistic reference scenario and prevailing boundary conditions (Apel, 2009). Following computerized systems and operations simulation, the development plan provides a step-by-step testing procedure, starting with scaled radio-controlled indoor models to gather basic experience on flight mechanics and practical maneuverability. Wind tunnel measurements will be required to verify the theoretic drag coefficients and flight economy.

The step-wise designs of candidate carriers within this plan involve appropriate model testing and a scaled helium-inflated prototype before construction of the first production prototype. Parallel developments concern:

- propulsion system comprising a turbine generator system for electrically driven large-diameter propellers
- ballast water recuperation system
- safe hydrogen handling system

- avionics, automatics and sensors

The development plan commences, in the first phase, with the identification of critical technologies and the assessment of their impacts. Applicable technologies must be identified that can be ready within the projected time table and milestones.

The first production prototype (possibly in a reduced scale) is foreseen to the study of operations in a realistic environment, i.e. transporting logs over characteristic ranges. Tests will encompass take-off and landing procedures, quick cargo exchange and mooring practice under various meteorological conditions. At the same time, practical experience will be gathered to gradually develop a viable infrastructure for fleet operation.

The development of practical automation and remote control systems including software is considered to be comparable with large transport aircraft. The most innovative parallel development concerns the handling of hydrogen and aerostatic equilibrium control. This aspect is of utmost importance with respect to the economy of the airship, as well as an important step in the direction of “green aviation”.

Conclusion

The Canadian forest industry is sensitive to the need to share this natural resource with wild-life, indigenous peoples and other users. Logging roads are expensive to construct and maintain, and can also conflict with other environmental objectives. Aerial logging has been proven to be superior to road-based logging from an environmental perspective, but the costs and limitations of helicopters restrict their use to high value timber and short hauling distances.

The technological advances of UAV systems make autonomous airship logging a potential alternative that would offer the environmental benefits of aerial logging at costs comparable to surface transport. Although airship logging could be applied in most forested areas, it has particular appeal in Canada’s boreal forest. The

Canadian Shield presents difficult terrain for logging roads. The area is comprised of many lakes and water courses, swamps and muskeg, and protected areas, like Indian Reserves and Parks. In many cases, these barriers are not economically or politically possible to cross with logging roads. UAV airships could provide access to both real and virtual islands of harvestable forest land that are now stranded.

Most of the technology needed to build a UAV airship logger is at hand. The envelope materials, engines and many of the mechanical systems are readily available “off the shelf”. Some technology needs to be adapted, like the computer avionics systems, but this is more a matter of programming and simulation rather than new development. The principal challenges are found in the integration of technologies and creation of reliable systems. Ballasting and the ballast water recuperation system require design for this specific application. Safe systems for handling hydrogen and the methane fuel system have to be engineered. This technology is not without its challenges, but no “make or break” problems can be identified.

A UAV airship logger is a promising “green solution” that deserves research funding to explore its practicability. Canada has vast forest expanses, but it is not the only country that could benefit from aerial logging. The tropical forests of Brazil, the Congo and Indonesia could be harvest more sustainably if the cutting was more selective. In the case of Russia, Canada and Alaska, forest practices could be tailored to cut mature stands without damaging adjoining areas or cutting roads into virgin areas. Those who are concerned about wild-life preservation and carbon emissions should be as interested in UAV airship logging, as the commercial operators who are harvesting the trees.

This paper sets out the conceptual design and economic logic for the development of a UAV airship logger. An international team of academic researchers has been assembled to explore this idea. Now it is time to move forward with prototype testing and the development of commercial vehicles. The authors invite those who may be interested in funding or participating this project to make contact[1].

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[1] Contact can be made through ISO Polar, a not-for-profit research institute established to encourage the development of airship technology for sustainable transportation and logistics applications in the Northern Latitudes. www.isopolar.ca