Development of Unmanned Cargo Airships According to the Requirements of Northern Canada

J. K. Bock, SLTA, Berne-Coldewei, Germany
U. Apel, University of Applied Sciences, Bremen, Germany
B. Prentice, University of Manitoba, Winnipeg, Canada

Abstract
This paper describes the layout of a lighter-than-air cargo carrier for autonomous unmanned operation in areas with tenuous infrastructure and under the pressing need for substantial cargo exchange in Northern Canada [1]. This requires a coordinating ground system for UAV-type monitoring and control, weather forecast and strategic operations schemes. For reasons of economy and ecology, hydrogen shall be used as both lifting and fuel gas in combination with liquefied methane. The method of externally suspending payloads permits expedient cargo exchange and avoids environmental damage due to footprints at ecologically sensitive pickup locations.

1. INTRODUCTION

1.1 Canadian Scenario

The northern territories of Canada provide substantial resources of economic interest w.r.t. minerals, lumber etc. The development of an appropriate transportation system, however, requires a minimum impact on the ecology and living conditions concerning, i.e. vegetation, wildlife and ethnology. Figure 1 presents a physical map of Canada showing The Boreal forest occupies approximately 35 percent of Canada's landmass. Ice roads are used in conjunction with all-weather roads to access cutting areas. The Tolko Company in Manitoba, for instance, has a forest management license 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 [2]. Land that is cut-off by national parks, lakes and native reserves is inaccessible, or only accessible by ice roads.

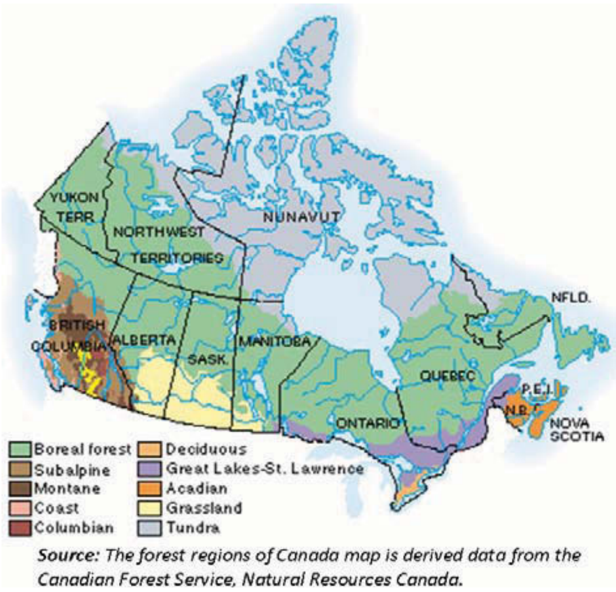

Figure 1: Vegetation Map of Canada

It is very expensive to build access roads and they must be open to all travelers, which increases maintenance costs, they cross numerous water courses and they must meet stringent environmental standards. Finally, when an all-weather road is abandoned, the land must be returned to its previous state. Restoration of these roadways can cost as much or more than the road's original construction cost. Hence, forest industry is very conscious of the need to reduce its physical impact on the forested lands and is looking for solutions [3].

Figure 2: Unsafe Ice Roads Due to Global Warming [4]

Ice roads used to be proven as a viable solution during the winter season, yet due to the effect of global warming, the available periods of operation have been drastically shortened.

Figures 2 and 3 demonstrate some dramatic consequences of insufficient stability of ice roads in recent years.

Figure 3: Frequent Accident Due to Ice Instability [4]

1.2 Aspects of Transportation Economy

From the standpoint of transportation economy and energy requirement, the following scale applies for bulk cargo:

- Waterway transportation provides the lowest cargo rates due to the high buoyancy of water and relatively low fuel consumption, yet limited to open-water seasons
- Railways are an efficient system of transportation due to high possible capacity and relatively low energy requirement
- Trucks represent today the most flexible – hence economically attractive – mode of transportation, although fuel requirement and personnel costs per ton of payload are higher than for the previously described systems, but limited to highways and seasonal ice roads
- Air transportation into inaccessible regions is confined to VTOL systems, i.e. helicopters and/or LTA systems [2]

Helicopters have been proven to be suitable cargo carriers in practically inaccessible areas, yet with limitations in range, high direct operating costs (DOT), high noise levels, substantial down-wash and contamination by kerosene exhaust fumes.

The utilization of airships – on the other hand - has already been extensively discussed, albeit with particular emphasis on the properties of presently available airship types and concepts of related hybrid systems. Since the selection of suitable carrier types affects the environment of the scenario in question w.r.t. demands of available clear space, ground operation equipment and foot print limitations, it is mandatory to select a system that relies primarily on aerostatic lift and maneuverability in addition to a practical cargo exchange concept.

Using hydrogen as the most effective lifting gas may cause concern, mainly w.r.t. the "Hindenburg" syndrome. The adjective ”unmanned”, however, indicates that neither crew nor passengers will be at risk. Moreover, the omission of ”man-rated” requirements may result in substantial savings w.r.t. human interfaces and deadweight of the overall system, thus essentially improving the flight economy. On the other hand the adjective ”autonomous” indicates the import of robotic elements that would relieve a major part of pilot’s workload, hence remote control by human flight operators could primarily concentrate on strategies in the cases of delicate and unexpected situations.

A further aspect of hydrogen is its future-oriented role as an ecologically ”clean” fuel. Liquefied hydrogen provides the highest energy content per kilogram. In realistic view, however, one may not expect ready availability of liquid hydrogen in remote areas. Hence liquefied methane or natural gas (LPG), respectively, would provide a viable alternative fuel with high hydrogen content. Both types of fuel are suitable to collect exhaust condensation water as maneuvering ballast.

1.3 Boundary Conditions for Airship Operation

The boundary conditions for airship operation are primarily characterized by the following generally known phenomena:

- High winds, gusts, torrents
- Precipitation: rain, hail, snow
- Topology: mountains, elevation, ground conditions (e.g. swamps, desert etc.)
- Prevailing temperature, barometric pressure, moisture

Further boundary conditions concern the preservation of intact wildlife and - as a political issue - the culture and lifestyle of the scattered native population living in the territories concerned.

As far as the meteorological conditions are concerned, Figure 4 presents a 5-year mean (from January 1996 to December 2000) of wind energy potential in Watt/m2 based on the Canadian Meteorological Center (CMC) daily 24-hour forecasts (standardized to a 25 km resolution), indicating average modest wind conditions (blue color) which would favor lighter-than-air operations.

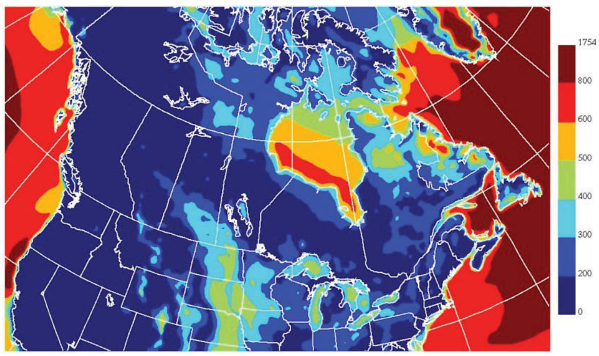

Figure 4: Wind Atlas of Canada (Color Scale Indicating Watts per Square Meter) [5]

Operations are based on a fleet concept which would allow optimum adaptability to the varying transportation demands, whereas flight and ground control procedures are governed by the principle of hazard evasion; e.g. quick takeoff capability in case of gust warning and subsequent temporary evasion to alternative airfields.

1.4 Key Issues of Airship Economy

The key issue of transportation by means of airships remains to be the economy, especially in comparison with the various alternatives. To be included are the overall costs, environmental impacts and follow-on direct and indirect expenses. A straight forward solution would be road construction or possibly a railroad spur; however construction and subsequent maintenance expenses are – as previous examples have shown – exorbitant and will only pay off, if those roads or spurs are being continuously used by paying surface cargo carriers. Needless to say that one cannot argue on the basis of net ton-kilometer costs (DOC) of a truck or railroad freight car without consideration of all incurring follow-on items such as

- routing distance
- line maintenance
- investment depreciation
- wildlife protection provisions
- additional ranger activities
- settlements with local population
- district administration
- additional necessary environment protection measures

Quite a number of present day's abandoned railroad tracks are giving proof that a rather high utilization factor is required to justify economical line operation.

2. CARRIER SYSTEM

2.1 Air Lift and Operational Constrains

Experiences in Northern Canada and Siberia have shown that conventional aircraft transportation is a viable means for servicing remote areas; effective – but not necessarily economical, considering the total operating cost (TOT). With more and heavier payload to be transported, runway requirements may soon exceed the potentials of an outpost station in two ways:

- the topology does not allow the necessary runway lengths
- the ground properties are not suitable for heavy localized aircraft loads

Luckily there are lakes in some areas allowing amphibious flight operations, although there are obvious technical limits w.r.t. cargo capacities. The basic conditions for an aerial transportation system may thus be condensed to the following requirements:

- high payload carrying capacity
- minimum ground operations area
- limited ground pressure (footprint)

Conventional aircraft could thus be excluded, unless they could operate from rivers and/or lakes or, in wintertime, from hard frosted plains. Considering summertime soft grounds and receding permafrost due to climatic change, the limitations are quite obvious.

Helicopters have been proven to be effective means of aerial servicing in Arctic Siberia and lumber hauling in British Columbia. Their requirements w.r.t. ground conditions are quite modest. Unfortunately, the development of heavy cargo helicopters beyond a certain limit involves specific technological problems. Moreover, the increasing ground pressure will represent another limitation. Under these circumstances, airships may be well suited to satisfy the conditions of both substantial cargo capacities, due to the aerostatic lift which efficiently reduces the ground pressure of the carrier.

2.2 Selection of a Suitable Airship Configuration

As already stated, efficient cargo airships should operate autonomously (i.e. unmanned) using hydrogen both as lifting and fuel gas. A further requirement for satisfying cargo efficiency is short-range operation; in other words, keeping the necessary fuel quantity within narrow bounds with no substantial impact on the maximum payload capacity. Candidate airship types may therefore not be designed in perfect streamline shape for minimum drag, but primarily for maximum adaptation to the outpost environmental conditions.

For instance, a Hindenburg-type cargo carrier with a 100 metric tons payload capacity and having an overall length of 245 meters would require a mooring mast and with a clear weathervane circle of about 500 meters diameter (about 0,2 square kilometers). However, this may not be feasible for standard outpost operations.

A further approach to eliminate the need for a mooring provision with a weathervane circle is to select configurations with symmetry of rotation about the vertical axis, i.e. spherical [6] and possibly lenticular airships.
Thrust controlled spherical airships have been proven to be highly maneuverable and require minimum ground area at maximum aerostatic lift, while lenticular configurations are favored for hybrid designs with VTOL capabilities.

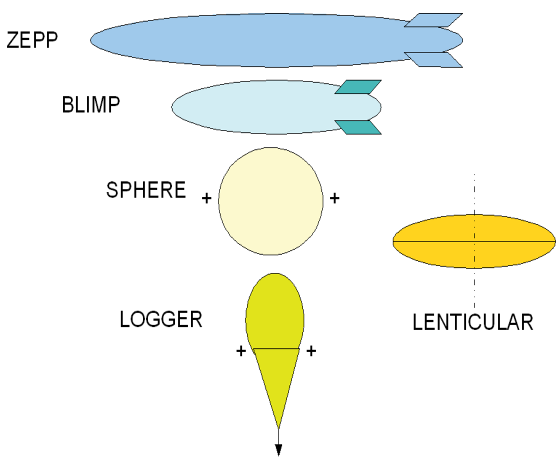

Figure 5: Candidate LTA Configurations for Buoyant Flight

Peripheral mooring without a mooring mast provides another attractive feature for ground operations, i.e. during unloading cargo, the anchoring stays may serve as tie-downs against temporary excess aerostatic lift until the ship is reloaded [7]. Figure 5 gives an overview of the various candidate configurations, whereas the most practical shape for short-range suspended cargo haul has the least appearance with a conventional airship.

2.2 Darwin's System Selection and Comparison With Helicopter Operation

Summarizing the vital requirements and candidate LTA systems, one must conclude that the aerodynamically worst configuration is the most suitable one to meet the adverse environmental conditions w.r.t. footprint, simplicity and adaptability (see Figure 6) While a spherical airship provides attractive features such as limited mooring space and amphibious operation, the specific logger configuration provides the following advantages [8]:

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

During parking periods, the logger carries no external payloads, while excess lift is being counteracted by the ground anchor; the craft stands upright as long as there is calm air. Wind blowing from any direction will cause the logger to lean, while the excess lift component will withstand the wind pressure up to a certain equilibrium angle. Snow loads, as well, may cause the logger to lean, 01but at the same time snow may slide off the surface and relieve the balloon. Icing on metal surfaces (e.g. propulsion units), however, should be avoided by appropriate means as applied in common aviation technology.

The method of external suspended payload transportation deserves a comparison with methods already practiced in the field of helicopter lumber hauling. Figure 7 a+b show typical photos of helicopter operations in Alpine regions.
Lack of downwash in the case of the airship eliminates a nuisance to the ground workers, the potential hazard of flying debris. Figure 7 a+b 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 [10].

Neither LTA logger nor helicopter touch the ground under normal operational conditions due to the utilization of external payload suspension, thus avoiding extensive area clearance on the ground and additional ground pressure. In other words, both systems leave a moderate footprint in the natural environment.
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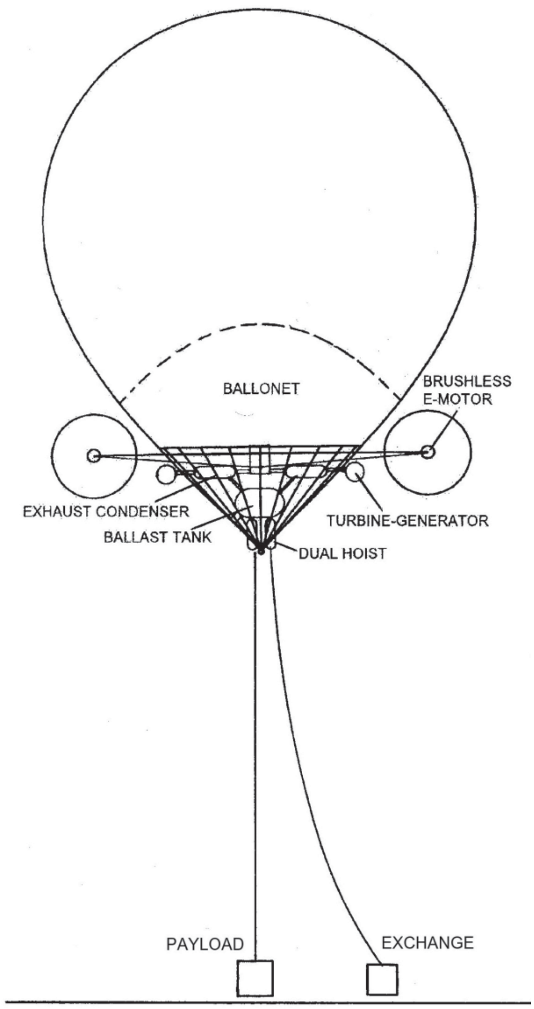

Figure 6: Logger Baseline Configuration

Figure 7a+b: Lumber Hauling by Helicopter [9]

Subsequent Table 2 summarizes characteristic features of both techniques

Lacking a detailed cost analysis, this table presents a first qualitative comparison in favor of an LTA system. The only obvious drawback (see bold letters) is the necessity to provide ample compensatory counter-weight (ballast) upon payload delivery.

Table 2: Comparison of UAV Logger versus Helicopter Performances

	UAV Logger	Helicopter
power req'mt	low	high
speed	low	medium
noise level	low	high
down-wash	none	high
exhaust (CO2)	low	high
payload exchange	**needs ballast**	no problem
cost	lower	high

In detail: Due to the fact that no power is required to generate lift, the aerostatic system has an inherent advantage. On the other hand, airspeed will be less than the one of a helicopter for reasons of the lower propulsion power installed and the substantial drag of the hull. Lower airspeed, however, plays a minor role in the case of short-range operations.

The ecological aspect of low CO_2 emission is self-explanatory due to the use of liquefied methane with predominant hydrogen content.

The main problem of payload exchange for maintaining the balance of aerostatic lift and load requires adequate preplanning of ground operations. For lumber hauling e.g., an equivalent quantity of water, ice or dirt – but also tools and machinery required at the work site - could be carried to the respective destinations where they will be discharged in a controlled manner after the log(s) (payloads) had been attached for safe suspended transportation.

For general transportation of equipment and supplies to be delivered in the field service, the receiving outposts must be prepared to likewise compose an equivalent mass of return ballast in nets, bags and/or suitable containers.

2.3 Lift, Fuel and Propulsion

As previously outlined, hydrogen gas shall be utilized as lifting power, as well as gaseous fuel, since hydrogen provides about 8 per cent more lifting potential as compared with helium [11]. Using gaseous hydrogen from the aerostat as an additional fuel gas in combination with methane may compensate the weight loss of the burnt methane by the respective loss of lift due to hydrogen consumption.

The re-dedication of lifting gas to a fuel gas does not only improve the flight economy, but it serves also to warrant a routine refresher of the lifting gas since – under realistic conditions of standard flight operation - the lifting gas will be permanently subject to inevitable diffusion and increasing impurities over the time of operation. Routine hydrogen replenishment will thus maintain a high degree of purity for continuous carrier utilization in practice.

Figure 8 provides a schematic overview of the envisioned propulsion, fuel and ballast system:

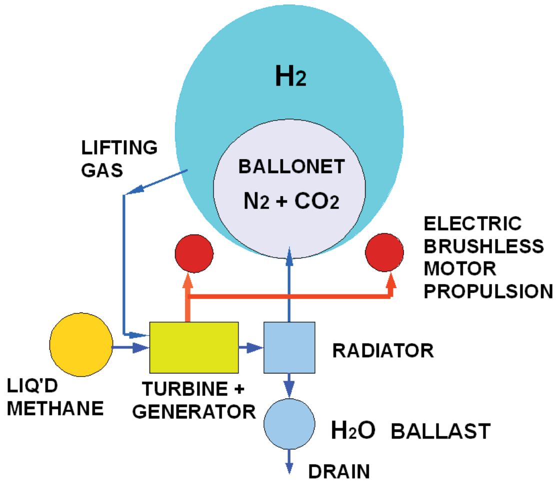

Figure 8: Gas / Fuel / Propulsion / Ballast - Concept

It should also be noted that methane requires less weight than kerosene for the same energy content, yet with considerably less CO_2 output:

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 with methane as the only carburant.

For buoyancy control there are two features to be observed and to be regarded in mission planning:

- using methane (LPG) only will make the carrier "light" and will result in a climbing mode,
- using hydrogen only will make the carrier "heavy" resulting in a descending mode

Both features combined are thus means for perfect equilibrium trimming.

3. SUBSYSTEMS

3.1 Propulsion

Two APU-type turbines provide the electric energy for two lateral propellers of 6 meter diameter; each will be driven by a brushless electric motor of about 800 kilowatts, which would correspond to the parameters of one "Hindenburg" diesel engine. The essential difference is the overall efficiency of this combination:

- "Hindenburg":
  Propeller efficiency 90 per cent
  Diesel efficiency 30 per cent
  Overall 27 per cent

- "Logger":

Propeller efficiency	80 per cent
Turbine efficiency	45 per cent
Generator / Motor	90 per cent
Overall	32 per cent

Figure 9: Typical Aircraft APU Turbine

Figure 9 depicts a conventional APU (auxiliary power unit) for aviation use.

A major part of the exhaust gas from the propulsion system will be scooped by the ducts of the condenser system. The gasses are primarily nitrogen and carbon dioxide which will - as a fire safety measure – be ducted into the ballonet to displace the atmospheric inside oxygen [12]. In addition the exhaust will contain a major portion of water vapor for the optional collection of safety ballast.

The two lateral propellers are mounted on lateral outriggers as shown in Figure 6. Directional control will be achieved by differential thrust, while climb and descent will be controlled by a combination of aerostatic trim and thrust control. The latter type of control results from the fact that the main thrust line is below the drag center point of the balloon, thus creating an inclination of the vertical axis of the aerostat in the order of up to 8 degrees. Consequently, a vertical component of the thrust vector will become effective as additional lift, which can be instantaneously controlled by thrust variation.

This feature alleviates take-off and landing procedures; e.g. full throttle will produce an extra lift component during take-off. Then, during cruise, the craft must be trimmed slightly "heavy" to compensate the thrust lift component. Finally during descent, throttle may be reduced for a controlled landing ("landing" w.r.t. routine cargo operations means payload touch-down).

3.2 Economy, Autonomy, Control and Monitoring

Two APUs are installed for reasons of redundancy. The diagram Figure 10 indicates the payload transport efficiency as a function of range under standard wind conditions and fuel requirements. The tick marks on the curves represent the respective hourly time scale. Needless to say that extended missions with reduced payload are possible, as ell as ferry flights beyond the 1000 km mark.

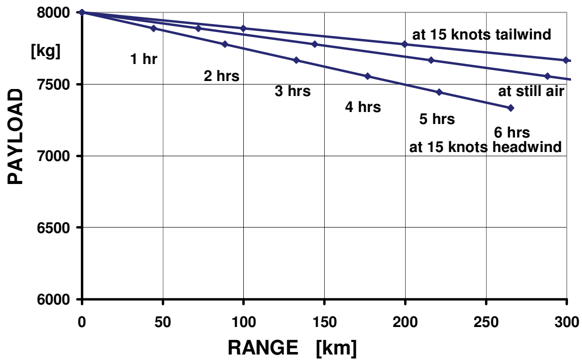

Figure 10: Transport Efficiencies as a Function Of Operational Ranges

Unmanned Aerial Vehicles (UAVs) fly autonomously not only in accordance with pre-programmed flight plans, but 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 would be too tedious and/or expensive for pilot operation.

One additional aspect is the weight-saving effect, since all human interface installations (except those for maintenance work) can be deducted from the overall mass balance, e.g. cockpits, accommodations etc. Since the UAV technology is already quite developed, major items could be readily adapted. There are, however, specific aspects and requirements regarding LTA operation that deserve special attention, e.g.

- 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.

4. INFRASTRUCTURE MODELING

4.1 Ground Station Philosophy

For the design of a viable infrastructure scenario for the intended purposes, there are two boundary conditions to be observed:

- There has to be a major assembly, servicing, maintenance, overhaul and shelter hangar for more than TBD carrier airships. This shall be the central base on a State, national or continental level
- There shall be a plurality of outpost bases for sustaining forestry as well as for ecologically acceptable exploitation of remote natural resources, which shall only provide an absolute minimum of necessary airship operation interfaces

Between those extreme conditions, there shall be at least one intermediate infrastructure facility, herein called

”servicing station” for routine supplies and depots which shall satisfy the following conditions:

- being located at a road, railroad and/or navigable river or canal
- being closely enough situated relative to the outpost(s) to be serviced as to warrant most efficient cargo transfer
- providing storage facilities for liquid methane (natural gas) and pressurized hydrogen, as well as for payloads from the outpost(s) and supplies to the outposts and/or intermediate lumberyards
- providing all servicing facilities necessary for cargo transfer from/to the outpost(s)

Short-range operation to a field station to field stations implies that cargo should only be carried to the nearest convenient airport with road, railroad and/or waterway connections as an intermediate nodal points, because fully equipped airship stations with adequate hangar servicing facilities with all necessary resources will be scarce, even within a prospective scenario of a whole air barge fleet in operation. In this context, it is worthwhile to classify in detail airship landing sites in the subsequent manner:

- ”Classical” airship base with hangars and all necessary provisions for assembly, full servicing, maintenance and repair
- Servicing stations for one or a number of outpost stations with mooring provisions and all facilities required for fuelling and replenishment of lifting gas. Hangars, if any, may be provisional ones.
- Cargo transfer facilities from airship to alternative means of transportation, i.e. road, rail and/or water way, are mandatory.
- Outpost or Field stations with mooring facilities for pick-up cargo and delivery at the interesting points of resource exploitation will be provided only with the bare necessities for efficient operation.

It is obvious that the facility requirements are considerably less for outpost stations, thus making it possible to efficiently service a potentially great number of individual field working stations.

4.2 Ground Handling Provisions

Ground handling provisions for outpost or field stations may be kept to a safe minimum. This concerns mooring and cargo handling provisions, whereas the latter will be part of the on-board hoist system to enable quick cargo exchange and ballasting to maintain equilibrium. In addition an appropriate number of carts, bogeys and/or sleighs have to be available to warrant quick ground transfer of cargo. The use of robust weighing scales to adjust payloads before pickup to safeguard equilibrium may be advisable.

The mooring system to be installed in servicing stations depends on the type of aircraft to be serviced, i.e. a logger-type carrier, likewise a helicopter, does in the rule not require extra mooring provisions except some certified ground anchors and possibly extra securing guy lines for the duration of parking periods

As previously stated, servicing stations must provide additional storage facilities for liquid fuel, pressurized hydrogen gas and cargo, i.e. goods to be transferred to the outposts. In exchange, not only lumber and/or other valuable resources will be imported from the outposts, but also waste, since particularly waste removal seems to be an increasingly important aspect w.r.t. environmental cleanliness.

Service stations must also provide for efficient interfaces (e.g. ramps, piers, hoists etc.) with the available means of mass transportation, i.e. roads, rails and/or navigable water ways.

5. OPERATIONS

5.1 Ground Operations

Ground operations at the outpost stations are mainly concentrated on the acquisition of natural resources, i.e. lumber, minerals and necessary preprocessing thereof. In the process of continuous transportation chain, a specialized team must be dedicated to all activities involving LTA operation, i.e.

- 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 seems to be appropriate that the ground crew will also be equipped for airship remote control during the landing and takeoff phases. This applies to servicing stations as well, as far as routine operations are concerned. In the case of the main airship base, remote control will also include all procedures within the scope of Integration and Test for new or overhauled airships, respectively.

One prime task of the servicing stations is refueling with liquefied methane and replenishment of gaseous hydrogen for a two-way flight, since fuel reservoirs are in general not practical for outpost stations. In particular, the servicing stations have to develop individual warehousing strategies to adapt to the materiel flow according to the schedules of the interfacing means of transportation (i.e. road, rail and/or canals).

5.2 Flight Operations

5.2.1 Organization and Coordination

The Flight Operations Control Center should be a centralized organization to provide an instant overview of the ongoing AUV 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.

Figure 11 sketches the multiple connections of the Flight Operations Control Center within the network of further authorities involved. Weather forecast represents the permanently predominant information, as the individual service stations will have to adjust their schedules in accordance with the weather synopsis.

5.2.2 Planning and Scheduling

Scheduling involves the optimum adaption of fleet operation to the given transportation requirements,

considering the capacity of the carrier units available. Items to be taken into consideration are:

- stage length (serving station to outpost)
- average per diem payload requested
- available area for airship parking
- turn-around downtime required for unloading/loading and servicing

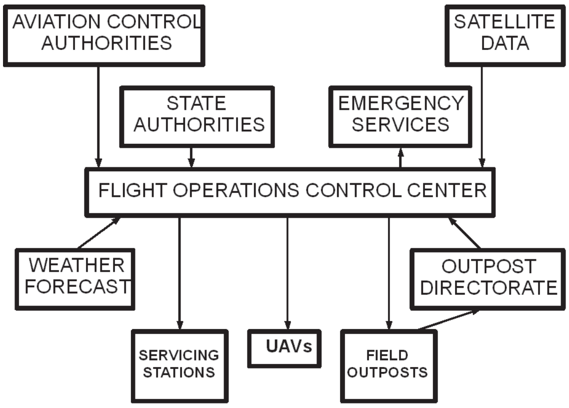

Figure 11: Flight Operations Control Center Intercommunication Network

The stage length is typically somewhere between 20 to 300 km in accordance with servicing routes of fixed-wing aircraft in Canada and helicopters in Siberia. The average payload transfer requirement dictates the number of daily shuttles in view of the payload capacity of each carrier, taking into account that the downtimes have to be deducted from daily flight times.

The inevitable constraints of individual payload capacities may require sequential fleet operation (see Figure 12). The number of operating shuttle airships, however, is limited by the necessary downtime periods for cargo exchange and servicing. Giving e.g. an average downtime of two hours, only 12 shuttles with 12 ships will be possible during a day without causing an aerial traffic jam.

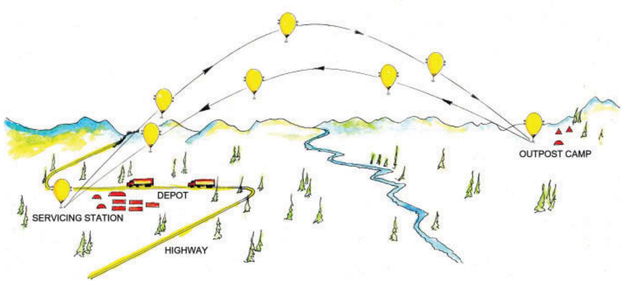

Figure 12: Field Scenario of a Transportation Chain For Apportionable Goods between a Servicing Station and an Outpost

Above all, the planner has to keep in mind the operational flexibility of the entire fleet under the Flight Operations Control Center due to permanently changing field and flight conditions. This allows quick redirection of carriers according to the prevailing strategic needs. Although transportation productivity may call for larger and faster (slender streamlined) ships, the topological field conditions may not at all favor space-demanding airships with extensive weathervaning radii at all. Moreover, the payload carrying capability of heavy lifter airships may - under realistic conditions - well exceed the actual mission requirements due to expensive overdesign.

In short-range operation, 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.

5.2.3 Emergency Operations

Primarily adverse weather conditions may dictate quick emergency operations. Unless sheltering hangars are available, evasion has been proven the best strategy so far. The Flight Operations Control Center will then – based on weather forecast information – issue an evacuation plan with provisions to park on selected airfields outside the foul-weather zone.

Spontaneous actions, however, will 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 should be launched immediately, unless safeguarding on the ground can be ensured. The departing ships may be temporarily radio-controlled by the ground crew until the Flight Operations Control Center takes over again.

6. DEVELOPMENT PLAN

A development plan [13] is foreseen on the basis of a realistic reference scenario and prevailing boundary conditions. The step-wise designs of candidate carriers within this plan involve appropriate model tests and a potentially scaled-down helium-inflated prototype before the first production of a hydrogen-inflated prototype. Parallel developments thus 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 sensor systems

The development plan commences, in the first phase, with the identification of critical technologies and the assessment of their impacts in the course of further progressing. In addition, applicable technologies must be identified w.r.t. their levels of readiness within the projected time table and milestones.

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 experiences w.r.t. the flight mechanics and practical maneuverability. Wind tunnel measurements will be required to verify the theoretic drag coefficients and flight economy.

The first prototype is foreseen to be a helium-inflated and radio-controlled craft for the study of operations in a realistic environment, i.e. transporting logs over characteristic ranges. These leap frog tests will encompass take-off and landing procedures, quick cargo exchange and mooring practice under various meteorological conditions. This prototype may be a manned ”experimental” craft to provide a redundancy w.r.t. automated systems and may later be qualified for numerous manned missions.

At the same time, practical experiences will be gathered to gradually develop a viable infrastructure for fleet operation. While this exploratory phase is not yet profitable w.r.t. transportation economy, but it may well represent solid grounds for the first serial production of prototypes.

Outposts of minor mining yield and/or remote settlements should be selected to demonstrate feasibility and economy under ecological constraints, even at moderate payload flow in the initial phase.

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 w.r.t. the economy of the general LTA development, as well as an important step in the direction of ”Green Aviation”.-

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