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GROUND-HANDLING SYSTEMS FOR CARGO AIRSHIPS

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Introduction

Cargo airships are being proposed as a means of year-round transport to remote communities that avoids the need to build expensive ground-handling infrastructure. This is an appealing claim given the cost of building and maintaining infrastructure in locations with sparse populations. Approximately 26 airship projects can be identified worldwide that range from conceptual drawings to actual manufacture of airships. In addition, nine companies operate about 40 airships. These are small blimps used for TV filming and advertising, leisure flights, scientific studies and remote surveillance. Current transport airship concepts include a broad spectrum of innovations in structural design, buoyancy control and ground handling systems (GHS). Although some scaled prototypes have been built and flown, the only full-scale transport airship is the HAV *AirLander* that flew in August 2016. Most cargo airship designs are at an advanced conceptual stage. Prototypes could be flown within two years, and could be turned into certified production aircraft within three to four years, if finances were available.

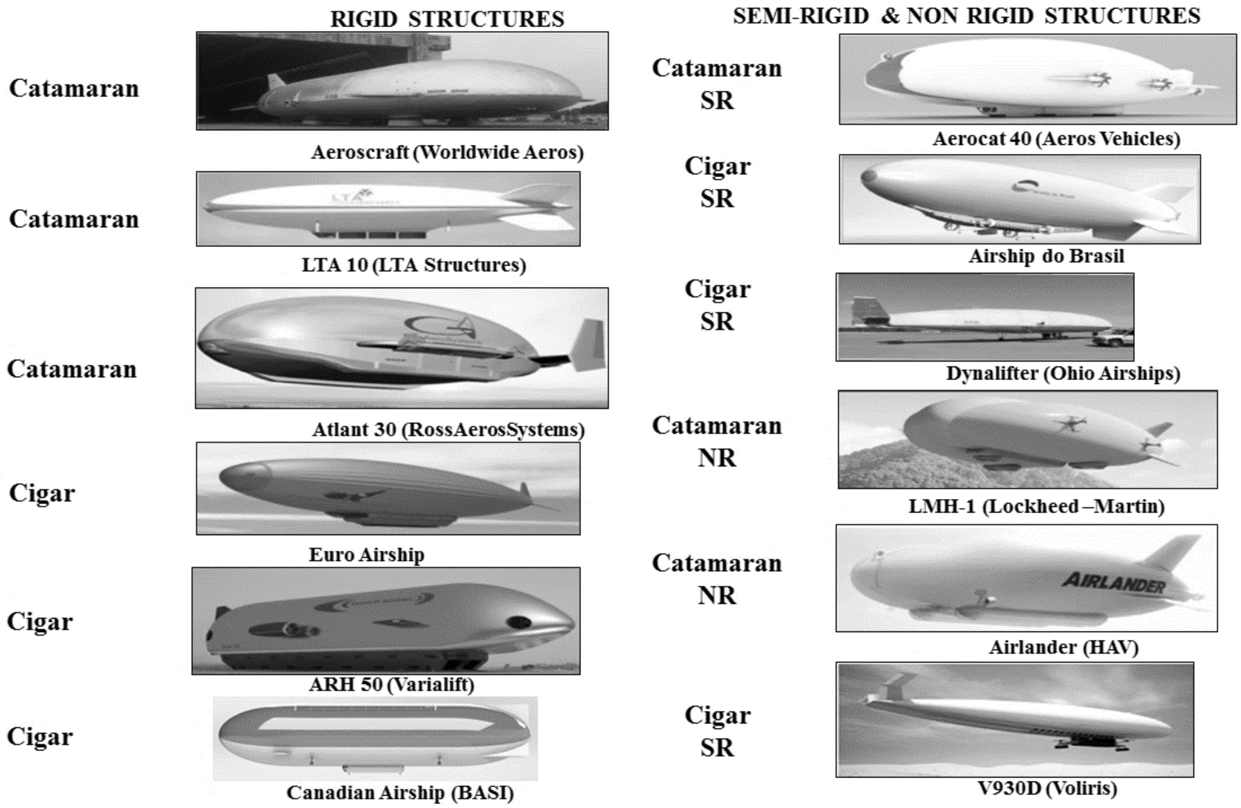
The purpose of this article is to examine the requirements for airship ground-handling and the methods proposed for goods transhipment in remote areas. The first section briefly reviews the leading airship design alternatives. This is followed by an examination of existing docking and mooring practices and proposals for future development. The paper concludes with some thoughts on the alternative of fixed ground-handling infrastructure versus autonomous landing systems for cargo airships.

The competition for the dominant design of a transport airship is producing many different variants. Figure1 presents pictures of the cargo airships currently under consideration. The most significant differences are whether the airship has a rigid or an inflatable structure, and whether it has a traditional cigar shape, or is a flattened catamaran shape. The semi-rigid (SR) and non-rigid (NR) structures are both inflated, but the semi-rigid airship has an internal frame, or keel, to help distribute loads.

Each design has economic and operational trade-offs. An airship with a rigid structure must be bigger than an inflatable airship in order to carry the same load because a rigid airship must first overcome a greater deadweight. However, in a rigid airship the lifting gas is contained at atmospheric pressure, whereas in the inflatables (semi-rigid and non-rigid blimps) the gas is pressurized. Consequently, the inflatable airships leak more than the rigid designs. The feasibility of year-round operations of cargo airships in the cold temperate and Arctic climates has yet to be proven. Rigid airships are more robust and less sensitive to temperature changes than inflatables. But the only airships to have visited the Arctic, did so during the milder seasons and not for prolonged periods.

Buoyancy control is another key design issue. A lighter-than-air vehicle has a constant lift. If weight is removed, the buoyancy must be offset in order for it to return to earth. The catamaran designs, also known as "hybrids" are heavier than air when empty, so in theory, they could drop off cargo and return without the need to take on new cargo or to load ballast. This, too, has been yet to be demonstrated in practice. Some other airship designs are proposed that use a combination of lifting gas compression and ballast to offset the change in buoyancy. Again, each design presents trade-offs. The catamaran designs consume more fuel because they depend on aerodynamic lift to carry their load. Systems using gas compression require pressure tanks and more energy to power the compressors that add "dead weight" to the airship. Airships that require ballast must have water or other material available at its destination that can be loaded to offset its cargo delivery. Loading ballast typically requires some ground support, or at least that ballast materials are available and ready to load.

Figure 1 Transport Airships Under Development



Although a dominant airship design has yet to emerge, many ideas have been stimulated by the opportunity to transport freight by airship. Ground-handling systems have received less attention. Many airship developers provide no description their transshipment approach, beyond the illustration of a cargo ramp. The two general methods are to operate from a fixed ground infrastructure or to operate the airship autonomously, like a helicopter. Both methods of transshipping cargo have advantages, but for any GHS solution to be acceptable, it must be fast, safe and low cost.

Airship Docking, Mooring and Transloading Requirements

The mooring and docking of an airship has a subtle difference. Docking involves landing and securing the airship on the ground in one spot regardless of the wind direction (Gibbens, 1975). Mooring consists of anchoring the airship on the ground such that it weather-vanes. An airship is difficult to hold against the wind because it is like a giant sail. As the wind changes direction, the airship should be able to move rather than stay in a fixed position.

Before examining alternative GHS solutions, it is useful to review some technical issues related to the physics and flight characteristics of airships. Airship landing operations are unfamiliar to most people, except perhaps for seeing a picture of large ground crews holding ropes. An airship's closest technical "relative" is a submarine, but these vehicles have the benefit of docking at the surface of the ocean. An airship literally docks at the bottom of an ocean of air, and must cope with changing wind conditions.

The generic concerns encountered in airship landing operations are: (1) damage to the fragile shell, (2) controlling the variable buoyancy, and (3) dealing with wind and weather (Khoury, 2004). Maneuvering the airship to a docking position without damaging the hull is the first challenge. The tail must be kept from hitting the ground, and the nose must be kept from running into the docking mast. The second problem area is the control of the airship's buoyancy. A reliable and accurate means for monitoring the lift status and the physical adjustment of the ballast/cargo weight is required. The third issue is to protect the airship's structure from wind and variable weather conditions. The first two problems are related to the airship's structural design, avionics and mechanical systems. The third problem relates to the GHS design.

During the docking operation, the forces and moments experienced by an airship are usually caused by inertial effects, steady wind effects, and atmospheric turbulence. The inertial effect is a consequence of the airship's mass undergoing accelerations. Steady wind conditions can be accounted for in the design of the GHS. Turbulence, however, is random and includes discrete wind gusts, and is unpredictable both in frequency and magnitude (Khoury, 2004). The inertial effects can be controlled by selecting appropriate mooring points on the airship and the mooring system so as to restrict any translation or angular rotation of the airship. Steady wind effects can be countered by the engines of the airship that hold the vehicle steady. Turbulence effects may require advanced transient Computational Fluid Dynamic testing on the airship and use of advanced materials with high strength to weight ratios for the GHS's structure.

Various techniques and operational procedures have been devised, tried and tested in the field for large and small passenger airships, but no cargo airship GHS has ever been developed. The GHS for the US Navy Blimps and the giant Zeppelins employed between 20 and 100 men to hold docking ropes. Such labour-intensive landing systems are no longer considered practical or economic. Computer controlled systems of vectored thrust can eliminate the need for large ground crews. However, cargo operations were only a small by-product of these passenger or military airships activities. They only had to hold them steady while refuelling and exchanging passengers.

In reviewing GHS systems, it is useful to note the design constraints and assumptions associated with an airship operation. These limitations and assumptions include:

1. A simple GHS design that accommodates easy, quick, gentle and safe docking.
2. High factors of safety to avoid any catastrophe due to ground turbulence.
3. Mechanisms to drive this system that are easy to maintain (high wear and tear resistance).
4. Overall dimensions that minimize the footprint of the airship.
5. Materials that possess high strength-to-weight ratio i.e. lighter materials are more economic.
6. Ability to operate in all-weather conditions and wind effects.
7. Flexible, user-friendly technology.
8. High operational efficiency and reliability with low maintenance costs.
9. Ability of ground handling equipment, e.g. forklift trucks, to access the cargo bay of the airship without risk of pitch or yaw movements of the airship.

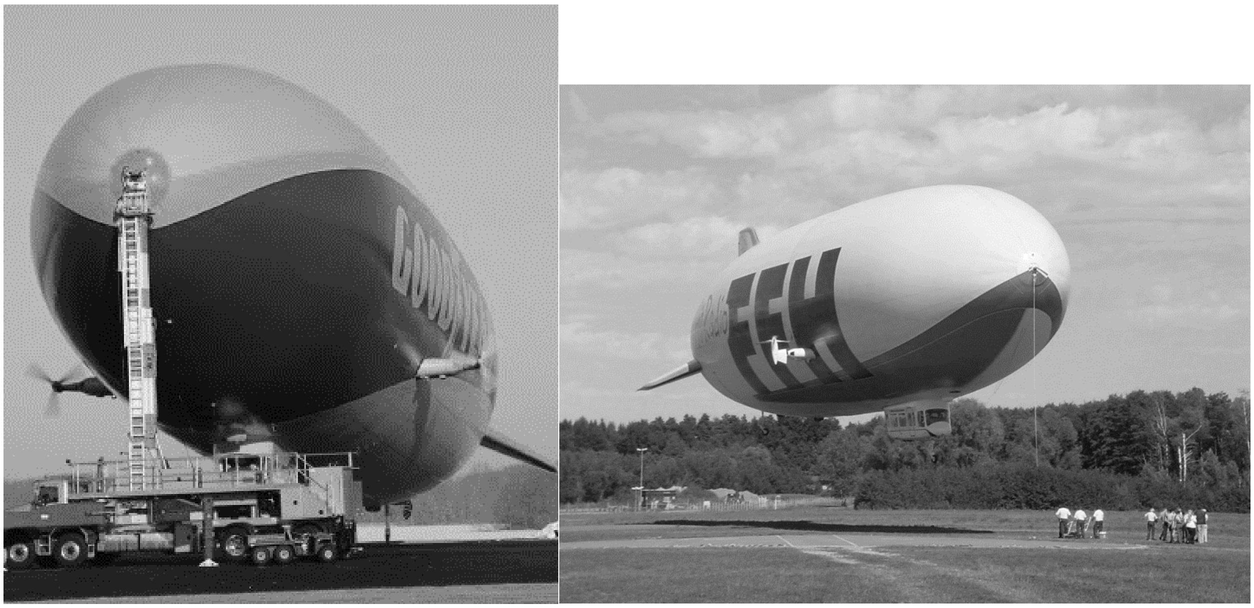
A successful GHS design must comply with all these requirements and constraints, while still being cost effective.

Current and Past Ground-handling Practices

The only airships in service today are small advertising blimps and the semi-rigid Zeppelin airships. The GHS usually consists of a mobile mooring mast, or a mooring tower designed for airship docking operation. Advertising blimps are relatively small in size and experience low wind and inertial loads. The mast or tower has a fitting on its top that allows for the bow of the airship to attach its mooring line to the structure. The blimp approaches close enough to attach a line, and subsequently it is pulled into the docking point. Blimps are very light and can be subject to pitch and yaw movements when moored on the ground. Technically, a blimp is flying at the mast, such that it can move in yaw (side to side) or in pitch (tail rising and falling). This makes is it difficult to refuel or exchange cargo unless winds are calm.

The Zeppelin NT, which stands for "new technology", proved that airships can be sufficiently controlled by the pilot to eliminate the need for a large ground crew. Figure 2 presents a photograph of a semi-rigid Zeppelin NT landing and another attached to a mobile low mooring mast. The airship on the left is one of three Zeppelin NTs that has been purchased by Goodyear to replace their blimp fleet. This airship has a light frame inside that carries about half the loads. The rest of the stresses are carried by the inflated envelope. Although its landing procedure is different than a blimp, the Zeppelin NT is moored to the mast the same way.

Figure 2 Zeppelin NT landing to pick up passengers and attached to a mobile low mast



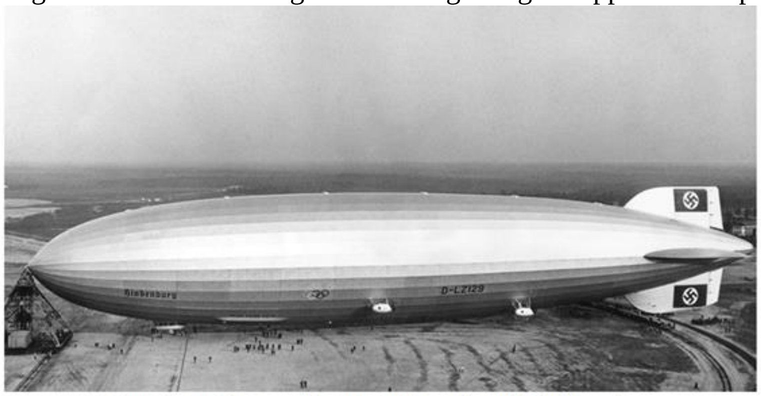
The standard approach to mooring small blimps and semi-rigid advertising airships may not necessarily be safe or practical for transport airships. Simply as a function of displacement, rigid airships are extremely large, heavy and experience high wind and inertial loads while docking. Most cargo airship designs depend on engine thrust for control at low speeds like the Zeppelin NT. Whether or not this is sufficient for docking is unproven.

Several mast heights were tried by the large British and German rigid airships. Generally, the lower mast was considered superior, but these airships were always operated as if flying at the mast. Sudden winds could move them around and in one famous case, the US Navy airship ‘Los Angeles’, was pointed vertical at the mast.

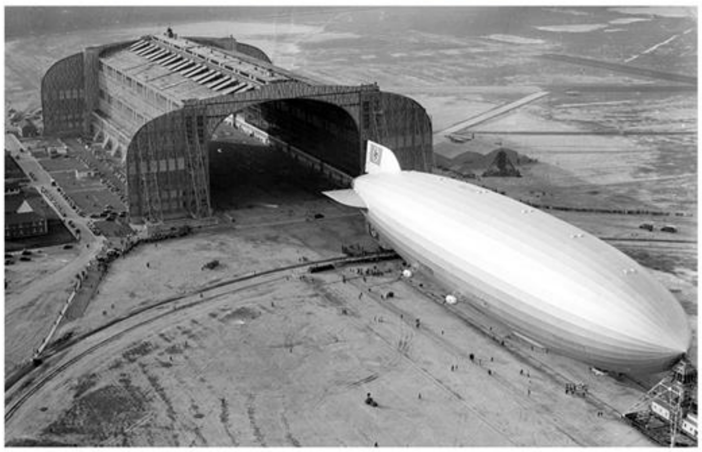
The giant Zeppelins dealt with the problem of yaw and pitch control by building a circular railway track around the mast, with the radius of the Zeppelin’s length. Rail cars on the circular track were attached to the bottom fin of the Zeppelin to control its pitch and slow yaw movements. The mast and track are illustrated in top picture of Figure 3 with the Hindenburg. Passengers and supplies, as well as some cargo, were handled safely. The tail anchor car can be clearly seen on the track, in the lower picture of Figure 3, where the Zeppelin is being readied to move into the hangar.

The mast-track system of ground handling works well in principle, but it would have problems for use remote areas. The Hindenburg was 247 meters long, which would require 1.5 kilometers of rail track. Notwithstanding the cost of building the track, creating a level, circular road bed in the Canadian Shield or Arctic would be a huge expense. Also, it is unclear how a circular rail track system would accommodate airships of different lengths.

Figure 3 Ground handing and mooring of rigid Zeppelin airship



Zeppelin at the mast, illustrating the rail track for the tail



Zeppelin being readied to move into the US Navel Lakehurst, N.J. hangar

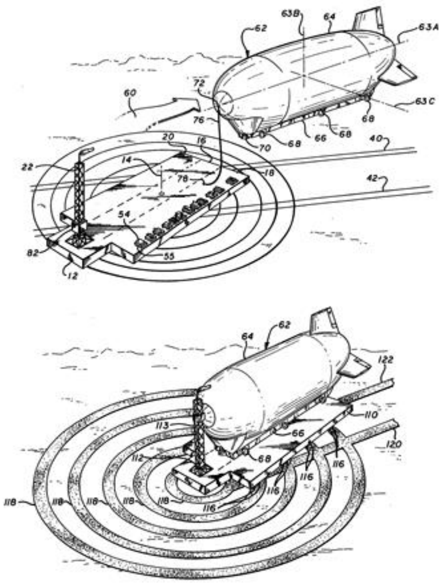
Proposed Docking, Mooring and Transshipment Proposals

A cargo docking system must have the structural stiffness, flexibility, controllability, wind load resistance, and quick and safe freight transferring capabilities. An idea patented by the Lockheed Corporation in 1995 and 1996 meets some of these criteria (Belie, 1995 and Wood, 1996). These patents are illustrated in Figure 5. In this case, the airship approaches from downwind and drops a line that is connected to a winch that pulls the airship to a docking tower. The platform rotates like a turntable to keep the airship oriented into the wind. Containerized cargo is aligned on the side of the platform, having been delivered from a warehouse on one of the parallel rail tracks. As one container is loaded, another is removed from the airship on the other side of the platform. The principal improvement for the second patent is the telescoping mast.

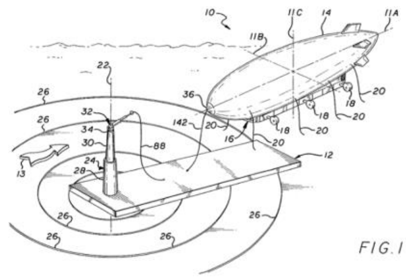
The Lockheed approach has a number of advantages. First, the turntable requires less space because its longest dimension is shorter than the airship. The system appears capable of accepting different sizes of airships. The prepositioning of the cargo speeds up the transshipment of the containers to the airship, while the use of the turntable keeps the ground crew in the same relative position to the airship. If the wind changes, the entire structure rotates simultaneously.

The weakness of this design, which was never tested in practice, is control of the airship's pitch. This is not addressed in the patent description. Another issue for use in remote areas is the scale of operations. The construction of rail tracks for loading containers could be possible for large transoceanic airships, but not for smaller airship serving remote communities or mining operations. It is also worth noting that the length of the turntable must be similar to the length of the airship in order to connect to the mast at one end, and balance the load in the middle.

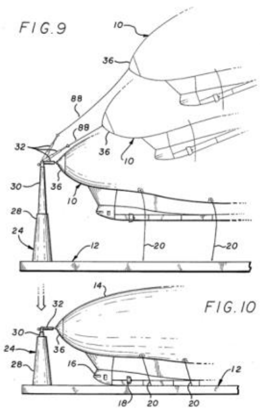
Figure 5 Lockheed's combination docking and cargo handling system for a lighter-than-air vehicle.



U.S. Patent 5,431,359 July 11, 1995

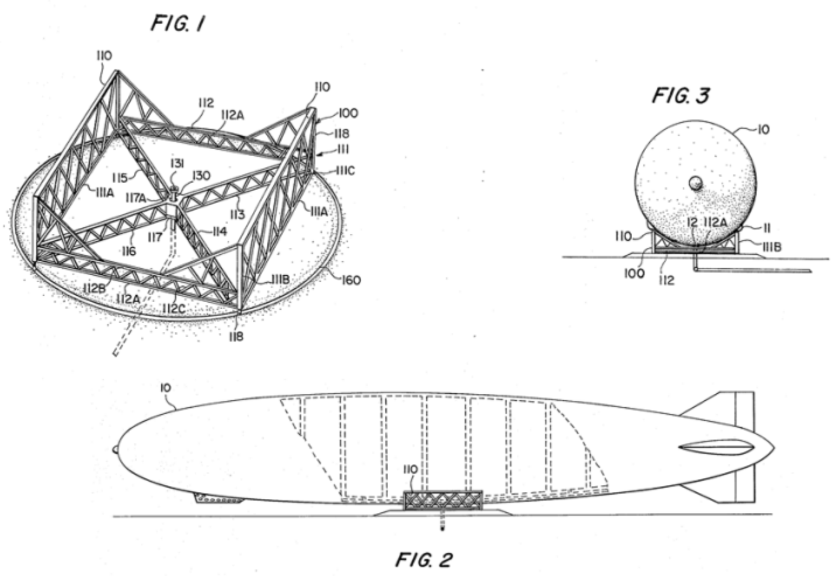


U.S. Patent 5,497,962 Mar. 12, 1996



An earlier patent was issued to Milne (1976) for a cradle system for docking a rigid airship on a turntable, as illustrated in Figure 6. The invention is summarized as a docking device for a dirigible. “The device includes a cradle member for supporting a docked dirigible, the cradle securing the dirigible while docked and having structural components to support the dirigible in a horizontal position. The cradle is rotatably mounted to allow the docked dirigible and cradle to rotate around a pivot point to align the dirigible with the prevailing wind direction.” The purpose of this invention is for the transfer of natural gas that at the time was contemplated to be moved by large airships. Milne (1976) is silent on how the airship will be landed onto the docking device.

Figure 6 Milne’s docking device for a dirigible with a conduit for transshipping natural gas



U.S. Patent 3,972,493 Aug. 3, 1976

BASI (2017) proposes landing an airship vertically on a circular turntable in a manner similar to a helicopter landing on a ship at sea. As the airship approaches the landing pad, the pilot dispenses a mooring line using pneumatic controls inside the cockpit. A ground crew member connects this line (or lines) to a winch that is located close to the landing platform on the turntable. Meanwhile, the pilot uses aerostatic lift and vectoring thrust to keep the position the airship nose into the wind, relative to the turntable landing spot. The airship is winched down to the locking position. Hydraulic locks, built into the turntable secure the frame of the airship firmly to the deck of the turntable. After locking is secure ballast can be loaded on to increase the airship's mass and ready the vehicle to unload cargo.

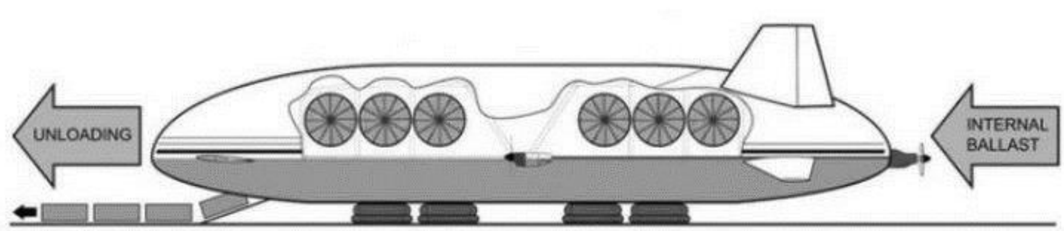
An apron around the outside of the turntable is necessary for truck loading docks and cargo handling. In order to ensure safety of the ground crew, the turntable is able to momentarily lock the deck in position so forklift trucks can drive on and off. A wireless remote control and pin-gear drive interface system is used to rotate the turntable such that the nose of the airship always points in the direction of the wind. The turntable is built like pieces of a pie that can be moved into a remote location and assembled on site.

Autonomous Ground-handling Systems

An alternative approach to ground handling is to design the airship to operate autonomously. Like a helicopter, these airships are designed to land wherever a level, cleared area is available that is about three times the length of the airship. The key to this approach is the development of modified hovercraft pads. The companies that are using this technology include Lockheed Martin, HAV, Worldwide Aeros, and Aerocat. A schematic of the unloading system of the Worldwide Aeros airship is illustrated in Figure 7. These autonomously-operated airships have been designed with a military application in mind, in which landing at unprepared locations is necessary and the airship operator cannot be certain that ballast material will be available at the site.

The air cushion system is used for maneuvering on the ground and for docking and mooring. For docking and mooring, the air cushions landing pads are designed to operate with the fans reversed. Normally, the air cushion created by the fans lets the airship move freely, but when the fans are reversed the air cushions act like suction cups to adhere the airship to the ground while cargo rolls on and off a ramp. It is not clear how these systems cope with the ingestion of gravel, debris or rocks. It could greatly increase the maintenance and wear of the blades if even small pebbles were being sucked through them. The transition from flying to landing and anchoring may be proven soon, if Lockheed-Martin progresses through FAA certification to deliver its first model in 2020.

Figure 7 A schematic of the landing and unloading system employed by Worldwide Aeros



Source: Aeros (2017)

The air cushion landing system reduces the need for ground infrastructure, but has a number of economic drawbacks for lighter-than-air transport. First, the air cushion pads, power systems and fuel add to the weight of the airship which displaces cargo lift. Second, the complexity of this landing gear adds to the cost of fabrication and maintenance of moving parts. The hovercraft pads are subject to wear and replacement. Finally, the system consumes energy to moor the airship on the ground, instead of being passively locked down. An advantage of this approach for transport in the North is the ability of these airships to land on open water or frozen lakes. Floatplanes were essential to the opening of the North, and are still widely used. These "hybrid" airships could be the "floatplanes" of the 21st century.

Discussion

An economic GHS should be designed to yield high operational efficiency and long-term reliability in a plurality of meteorological and infrastructure conditions. It must be capable of mooring and docking a transport airship quickly and safely. Ideally, it should be able to provide similar service for variety of airship designs. Greater utilization helps reduce average costs.

For emergency missions, like search and rescue, or infrequent re-supply operations, such as mineral exploration, an autonomous airship landing system may be the only solution. However, this is not how most freight shipments are handled. In general, transport vehicles do not simply stop anywhere and start unloading, unless they have no other choice. This is done in the Canadian Arctic with northern sealift, but only because the infrastructure investment in ports is lacking. Railcars move from siding to siding, trucks move from one loading dock to another, and cargo airplanes take off and land only at airports or at the minimum, a prepared landing strip. In cases where a regular daily service is required, handling equipment, ground power and fuel are desirable at the site. This favours developed transshipment terminals. The expense and weight of carrying handling equipment and infrastructure with the vehicle is unnecessary if it is available on the ground.

Most freight experiences one or two intermodal transfers before it reaches its final destination. A seamless means of transshipping freight is both physically and economically necessary. The costs of freight transportation can be divided between the linehaul and terminal activity. The linehaul costs are incurred when the vehicle is moving, while terminal costs occur when the vehicle is stationary. Given that all revenues are related to the linehaul, transport vehicle operators try to minimize their dwell time at the terminal. Consequently, the most rapid means of loading and unloading is of crucial economic interest, as long as it does not compromise safety.

In all likelihood, the autonomous airships will be the first to be used. It will be hard to obtain investment in long-lived ground-handling infrastructure before confidence can be gained that this technology is here to stay. Also, the first cargo airships do not have to be optimal. The freight rates into remote locations are often extremely high and can cover the costs of a more expensive autonomous airship design. Once the technology is established, more cargo airships that are dependent on developed ground infrastructure will emerge. Certainly, a market exists for both types of airship.

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