

Economics of Airships for Perishable Food Trade

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The flight of the world's first heavier-than-air powered vehicle took just 12 seconds in 1903ⁱ and heralded the birth of a new transport mode. In the days, months, and years that followed Kitty Hawk, it must have been evident that airplanes had a future, but not to what shape or extent. For the first 50 years, airships and airplanes were head to head competitors; particularly on the long endurance cross oceanic markets. The technological impetus given to airplanes by the exigencies of war settled the matter in favour of airplanes for the balance of the 20th Century. As we enter the 21st Century however, we may be about to witness the rebirth of large airships as a means of transporting perishable cargoes and passengers.

Except for infrequent use as billboards, camera platforms and novelty tours, commercial uses for airships ended three quarters of a century ago. For decades, the memory of the Hindenburg catastrophe, as well as technological advances in heavier-than-air flight, trucking, and maritime transport made the large airship seem a slow, cumbersome, and ultimately tragic detour in the history of transportation. Interest has been renewed in airships due to technological developments in a number of fields; including materials science, engines, weather forecasting, avionics and computer assisted design. With improved performance and cost profiles, large airships are being considered again, but for new roles in the movement of general freight, fluids, indivisible loads, and perishable food products as well as passengersⁱⁱ.

Interest in airships has been heightened further by their indirect advantages. These vehicles could mitigate several negative externalities associated with other forms of transport. Concerns about port, road, and airport congestion, and evidence of climate change have caused the economically advanced nations to reconsider their transportation systems. As most industrial countries are net importers of petroleum, the inherent fuel efficiency of airships is a further economic incentive. Consequently, many nations are taking a hard second look at airship technology.

Over the last 30 years, airship technology has gained a loyal following. At the time of this writing, at least a dozen firms in ten different countries are developing research prototypes and commercial airships. In addition, the U.S. Department of Defense has issued a request for information (DARPA, 2004) for development of an airship capable of carrying very large and/or heavy cargoes and personnel.

The creation of a new mode of transport can have profound economic effects. Improved service and lower transportation costs can stimulate new commodity flows, industrial activity and trade routes. In this paper, we consider the business case for using airships to transport Hawaiian pineapple/papaya to the U.S. mainland. The inherent strengths and weaknesses of airships, relative to other modes, are examined with a

particular view toward exploring this possible early application of long-distance transport. On a more general level, it is hoped that this paper will stimulate thought and discussion about the potential for airships to create a paradigm shift in freight and passenger transportation.

Global Food Trade and Transportation

The history of global food distribution is punctuated by turning point developments in transportation and storage technology. The spice market was first to attain global dimensions. The improvement of sailing ships over camel caravans opened up the spice trade between Europe and East Asia.ⁱⁱⁱ Two hundred years later, the advent of steam power enabled marine transport to link the continents together and form a global grain market. Subsequently, the development of freight railways and mechanical refrigeration enabled markets for frozen meats and dairy products to become globally traded.

As ships became faster, refrigerated transport connected international markets for storable temperate zone fruits and vegetables, like apples and potatoes. The first tropical fruit that gained a global market was bananas.

Airplanes are responsible for the latest integration of world markets for food and perishables. Airfreight of perishables is important in some long-distance markets, such as intercontinental movements of fresh flowers, seafood and some higher value tropical fruits. However, the absolute volumes of air shipments of perishables are small, relative to world production. The world trade of perishables is reminiscent of the spice trade when the relatively expensive camel caravans were the only means of transport. A latent demand for high quality perishables far exceeds the effective demand for the quantity supplied at the current price.

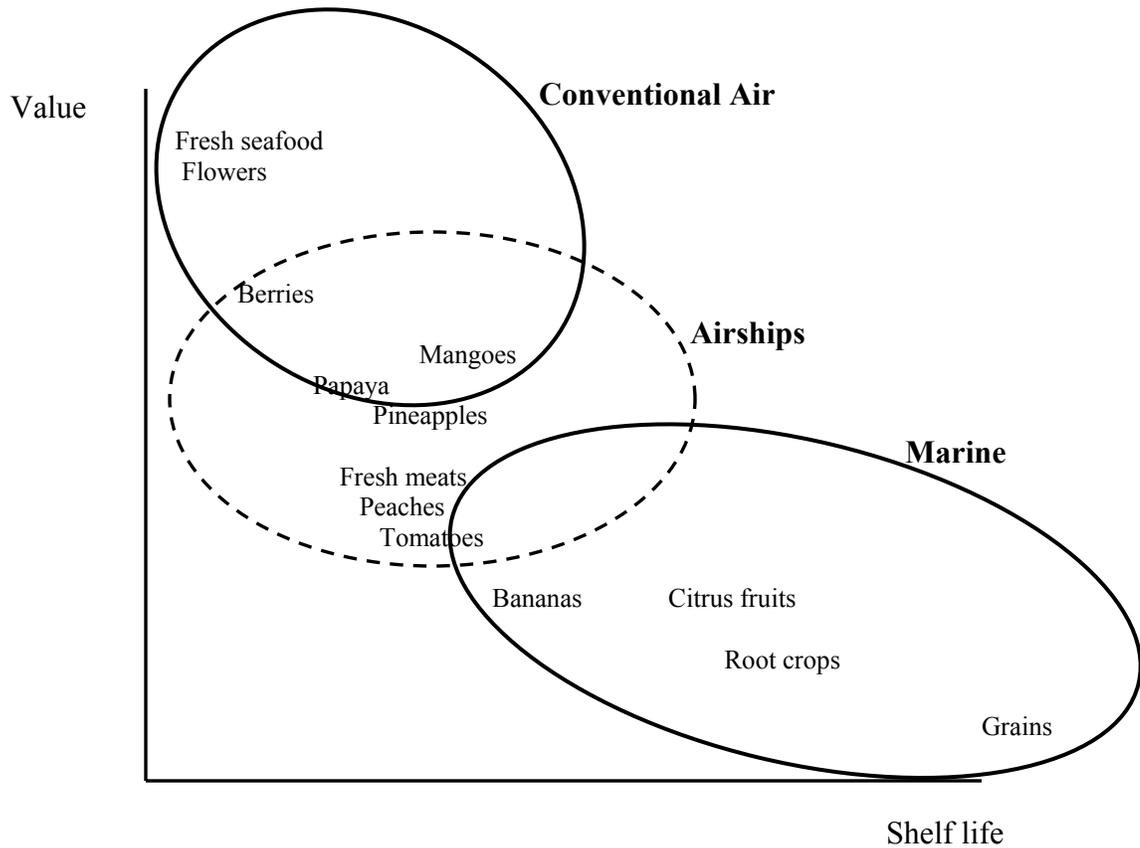
The failure of the airplane to have more than marginal impacts on perishables transported is reflected dramatically in the modal split of produce movements within the U.S. Despite the very long distances produce is frequently moved within the U.S., less than one quarter of one percent is by air (USDA, 2003). Over half of what is shipped by air is from an origin having no truck or rail alternatives, Hawaii. But even for Hawaii, less than half of its produce shipments to the mainland are by air.

Airships have the potential of improving the market share of air transport in existing produce markets and expanding the range of products and markets for which air transport is used to ship produce. Figure 1 illustrates the general relationship between product values and shelf life, and identifies the principal transport mode for intercontinental trade. As is well-known, highly valued and perishable goods, such as flowers and fresh seafood [and people], are the near-exclusive province of conventional air transport, while goods at the other end of the spectrum, such as grains, slowly and cheaply ply their way between the world's land masses in ships. Goods in the middle, such as fresh meats and medium valued tropical fruits, may be carried by either mode. Airships (dashed circle) could split the difference. While slower than conventional air,

airships would be three to five times faster than marine transport with freight rates somewhere between air cargo and intermodal ocean container shipment.

Considerable uncertainties remain regarding the cost of operating airships, but it appears clear that large airships could be profitable offering rates above those typical for marine transport, but well below those of conventional air. As such, airships could greatly expand long distance trade of mid-range value/perishability goods. Moreover, except over extremely long distances, such as Australia to Europe, airships would also be attractive for high value/perishability goods.

Figure 1: Value, Shelf Life, and Dominant Transport Modes in Intercontinental Movements of Foodstuffs and Ornamentals



Inherent Advantages and Disadvantages of Airships

Each mode of transport has unique strengths and weaknesses, in terms of total logistics costs and service. These advantages tend to dictate their uses (ships—big volume, slow, cheap; air – low capacity, fast, costly; etc.). Airships can travel relatively fast (80 mph) and have sufficient endurance for long trans-oceanic flights. They are ideally suited for bulky low value cargo like lettuce or green peppers because they are

limited only by the weight of fuel and cargo. As huge displacement vehicles with static lift provided by Helium gas, airships can have voluminous cargo holds.

Like all modes of transport, airships have to trade off cargo payload against vehicle range, speed and capital costs. The data necessary to quantify the optimum vehicle and operating characteristics for specific markets is beyond the scope of this paper. Rather, these will be considered conceptually.

Speed

Conventional air transport is the greyhound of intercontinental commerce. Its great speeds are purchased in terms of extremely limited cargo capacities and very high costs per unit weight. The plodding ox is marine transport. Despite technological advances, even the fastest container ship operates between 20 and 30 mph (e.g., see Lloyd's Register), far slower than the average speeds of any other mode. The saving graces of marine transport are high capacity, long range, and low cost per unit weight. As noted earlier, if both perishability and value are very high, conventional air transport dominates. When the reverse is true, marine transport is ideal. But most goods are not at the extremes of value and perishability. Over distances required for intercontinental trade, neither the cost premiums required for conventional air nor the very slow speeds of marine transport may be attractive. It is here that airships have the greatest potential.

Being lighter than air, fuel consumption is required only for forward motion of airships. As with all transport modes, fuel consumption per unit distance is an increasing function of speed. At a cruising speed of 40 mph, an airship could travel approximately twice the distance without refueling that it could if it were flying at 80 mph. Alternatively, more freight could be carried at a slower cruising speed because less fuel is consumed.^{iv}

On the cost side, the advantage of going faster is an increase in vehicle utilization and reduced crew costs. The return on capital is determined by the number of revenue ton-miles per year. If the airship travels faster, the fixed costs of the airship are spread over more trips. To the extent that cargoes are time sensitive, speed can also be rewarded through rate enhancements. So, not only are fixed costs spread over more trips, each trip garners more revenue than would be the case with lower speeds.

Adding to the complexity of the optimal cruising speed for an airship is weather conditions. A strong headwind, or tailwind, could make a significant difference to the time of the voyage. A zero-sum "wind" game could be expected on single route, but with good information and experienced pilots, the wind could be managed to advantage^v.

Little impact from topography

Relative to other modes, airships have a comparative advantage when operating across rougher terrains with less developed surface transport infrastructures,^{vi} and where inter-modal transfers occur. With the exception of higher mountain ranges, physical

barriers of topography impose few limitations on airships, which do not require lengthy landing facilities. Airships can travel over land or sea, and can thrive in tropical or frigid air masses. Consequently, they can serve remote road-less land masses or island archipelagoes equally well as the more developed and populated, continental areas.

Transfers associated with ocean-land boundaries can be over flown and intermodal transshipments can be performed with minimal infrastructure. This could reduce the numbers of such transfers in a point-to-point movement and, as the location of transfers are not tied to geographic features, such as coastlines, allow transfers to occur in non-congested locations. Airships are capable of delivering door-to-door service for large indivisible loads, but, in most cases, regular freight would be interlined with truck and intermodal rail for final delivery. Again, such transfers could occur away from congested areas^{vii}.

Cost Analysis

The strengths and weaknesses of airships in meeting cargo-carrying needs can be itemized, but the levels of those strengths and weaknesses may be the subject of debate. At present cargo airships are on the drawing board or in the scale model prototype phase. Consequently, “hard” data on their costs of manufacture and operation simply do not exist. It is left for the economist to make assumptions, and the strongest case is made for the scenario that requires the fewest or weakest assumptions. A search for a historical precedent would logically yield the scenario requiring the fewest assumptions regarding this as yet non-existent modern heavy lift airship. Semi-rigid or non-rigid operational models reached their design zenith in the 1950’s, immediately preceding their demise. However, these designs generally had a useable lift of only a few tons. Even the larger designs (e.g. ZPG-3W), would have a useable lift of less than 15 tons, and this in an airship of about 400 feet in length – a not inconsequential scale.

In contrast, rigid designs, some of which flew successfully for years, provided a useable lift of up to 80 tons, with longer projected life cycles and faster point-to-point delivery speeds. While assumptions could be made to contemplate a semi-rigid or non-rigid heavy lift craft (possibly along the lines of the Cargolifter CL160), but current projections dealing with costs of construction and operation of a ship meeting lift requirements, the rigid design moves us closer to the target.

The advocates of semi-rigid or non-rigid designs point to the structural qualities of new fabrics, such that these fabrics could replace the internal framework of the rigids. Indeed, the WWII and later non-rigids of the US Navy were strong evidence of the feasibility of that concept. The capabilities of the modern fabrics under consideration are nothing short of astounding^{viii}. However, new LTA and hybrid vehicles are, as yet, untested in the field in full scale. Consequently, an updated rigid design may require fewer assumptions, thereby satisfying *Occam’s Razor*.

Significant size economies

Like ocean-going ships, airships are subject to significant economies of size. Large airships could have ton-mile freight costs much lower than fixed-wing airfreight. The consideration of economies of size has been pushed furthest by the hybrid designers who envision airships with a useful lift up to 10 times any rigid airship ever built.

The extent of anticipated size economies are reflected in the cost estimates of Advanced Technologies Group Ltd. (ATG) of the UK. This research team has developed the Skyship 500/600, Sentinel 1000, and the AT-10 airships. They are in the planning stages of a family of hybrid airships capable of carrying from 20 MT up to 1,000 MT of cargo. The estimated freight costs for this family of hybrid airships are presented in Table 1.

Table 1: ATG Cargo Freight Rates Estimates

Airship Cargo Capacity	Freight Rates \$ per tonne kilometer
20 MT	\$1.50
200 MT	\$.20
1,000 MT	\$.06

The 20 MT hybrid airship would actually be slightly more costly than conventional airfreight. At 200 MT, according to ATG, costs would be comparable to trucking and for the very largest of their planned vehicles, with 1,000 MT capacity, freight rates would be comparable to marine freight (Advanced Technologies Group). It should be emphasized that ATG's cost estimates are based upon computer simulations, rather than experience under real world conditions. Moreover, these rates do not apply to a defined mission or level of utilization. Whether ATG, AVI^{ix}, Areos^x or another firm, will be able to realize a hybrid airship with these costs is unknown, because nothing beyond a demonstration model has been built. However, these economies of size are an indication of the longer run promise of airship technology.

Looking again at technology that existed in the early part of the 20th century, it is clear that there were efficiencies associated with the larger scale vehicles. Even within the group of rigid airships from the 1920's and 1930's, the larger vehicles had higher cargo capacities as a percent of gas dead-lift. As illustrated in Table 2, the extremely successful LZ127 Graf Zeppelin was designed to contribute about 33 to 34 percent of its gas dead-lift to "useful lift", which we may consider to be cargo lift, as would the larger Graf Zeppelin II (in both cases, adjustment has been made based on helium inflation, not hydrogen).

The Graf Zeppelin II, like its sister ship, the Hindenburg, was designed as a much more opulent craft than the Graf Zeppelin. Literally "floating hotels", these ships were designed with smoking rooms for the passengers, and their dual-deck quarters (reduced in the LZ130) even included a piano (albeit of aluminum construction). These features

contributed to the fact that while the empty weight of the Graf Zeppelin was only 122,000 lbs., the Hindenburg weighed, by various estimates, between 100 and 120 tons.

As the LZ130 approached completion, weight-saving design changes relative to the LZ129 had been incorporated (structural hull changes, radiators & piping, electrical system, and in particular, a reduction in the scale of the passenger quarters), such that the LZ130 weighed 12,000 lbs less than the LZ129. Although never built, the specifications of the LZ131 were well-documented. It would have used the basic LZ129 design with an additional hull section, bringing the envelope volume to just under 8 million cubic feet. Of particular interest to this analysis, was that this airship, with a 13% greater hull volume than the LZ129, would have weighed about 10 tons less than the Hindenburg. These weight savings would, in large part, have come through a new structural material, resembling American Alclad, which after heat treating, would have 25% better strength in compression^{xi}.

Even over a short period of time from 1936 to before the outbreak of WWII, significant weight-saving technological advances, coupled with increases in lift through scale of the airships, had pushed the feasible cargo lift as a percent of deadlift towards the 50% level. Had these vessels been redesigned to serve a cargo role, with no passenger quarters, it is likely their useful lift as a percent of helium dead-lift would have approached or exceeded 50 percent. The ZRCV, while never built, was expected to lift close to 300,000 lbs. In doing so, it also could have approached half of its dead-lift going to cargo. Van Treuren has suggested a 50% deadweight airship in previous work assessing the relative benefits of lift from helium vs. hydrogen^{xii}.

Table 2: Airship Useful Lift versus Dead-weight Lift

Airship Design	Envelope Volume (cu. ft.)	Useful Lift (lbs.)	Cargo Lift as a % of He Gas Dead-lift
Graf Zeppelin (LZ127)	3,700,000	62,300	34%
Hindenburg (LZ129)	7,063,000	115,000	33%
Graf Zeppelin II (LZ130)	7,063,000	127,000	36%
LZ131 (proposed)	7,994,750	181,000	46%
ZRCV (proposed 1936-1937)	9,330,000	297,000	50%?
Zeppelin NT	288,000	4,800	28%
Cargolifter CL160	19,500,000	352,416	30%

While there is evidence of efficiencies of scale, the efficiencies of technological development may be greater. The Zeppelin NT, a modern airship and closest in design to the large rigid airships of the past (although a semi-rigid design with a pressurized envelope rather than separate internal gas cells), could also contribute almost 30 percent of its gas dead-lift to cargo, despite the fact it is dwarfed by the behemoths of the past. In the absence of hard data, it is left to the imagination to hypothesize the efficiency of a modern design if the technological advances of Zeppelin NT could be applied to a ship the size of the Graf Zeppelin II or the LZ131.^{xiii}

By way of comparison, the Cargolifter CL160, with an envelope size proposed to be almost 3 times the volume of the Graf Zeppelin II, would be expected to only contribute about 30% of its gas dead-lift to cargo. As a non or semi-rigid craft, its lifting gas volume as a percentage of its envelope volume would be higher than for the rigid designs. It should be remembered, however, that this semi-rigid concept incorporated a complex and no doubt heavy cargo keel design to facilitate winching and lowering.

Evidence would suggest that the features of an updated rigid design could be the most efficient from the point of view of maximizing the percentage of gas dead-lift going towards cargo lift.

Perhaps more important in the context of ensuring the most efficient design from a cargo-carrying basis, the higher λ (airship length/maximum beam or diameter) of the rigid design ensures a higher top speed and superior fuel efficiency relative to the non-rigid or semi-rigid designs. When considering time-sensitive cargo, and increasing fuel costs, these traits of the rigid design could be significant factors.

As indicated earlier, the hard data does not yet exist for the large scale modern heavy-lift airship, although the rigid design does provide a good starting point. We must also move forward in quantifying the impacts of technological advances in adapting the tested rigid designs to the present day. To this end, research is needed to quantify the impacts on vehicle deadweight (the complement of cargo lift) of:

- Strong, lightweight fabrics to replace the canvas “patchwork” of the old envelopes
- Replacement of heavy engines with modern, thrust-vectoring, fuel efficient designs
- Fewer crew members, quarters and corresponding infrastructure
- Lighter, stronger composite frame materials
- A less dense internal framework, allowing a higher percentage of envelope volume for lifting gas
- Fly-by-light avionics and light weight control systems

The deadweight of the LZ129 was, by some accounts, about 118 tons, leaving 143,000 lbs. (72 tons) of its 380,000 lbs. of Hydrogen dead-lift to go towards cargo lift. Even if the technological advances described above only brought the deadweight from 118 tons to 90 tons, the 70 year old basic design could have carried about 86 tons of cargo (even using Helium instead of Hydrogen). This would boast cargo lift as a percent of gas dead-lift to about 49%, which is comparable to that of the much larger ZRCV. If evidence supports the idea of an efficiency of scale, even this expected percentage is conservative

In Table 3, we “reverse engineer” several rigid designs incorporating the technological developments discussed, and affixing some plausible cargo lift/gas dead-lift percentages moving into and past the 50 percent range. Rigid airships of 100 ton capacity would be well within the scale of what was in the air 70 years ago, or on the

drafting boards in 1937 (i.e. ZRCV). A modern airship about 20 percent larger than the Akron or Macon could possibly handle railway car-sized loads.

Table 3: Hypothetical Second Generation Rigid Airships

Envelope Volume (cu. ft.) (assuming gas cell volume of 75% of Envelope)	Useful Lift	Vehicle Deadweight	Cargo Lift as a % of He Gas Dead-lift
8,204,000	100 tons	100 tons	50%
15,753,000	200 tons	184 tons	52%
22,357,000	300 tons	245 tons	55%

A rigid (or rigid-emulating) design, using an envelope volume only about 80% that of the proposed Cargolifter CL160, could perhaps be used to handle loads of up to 200 tons. A design 15% larger than the Cargolifter’s envelope could move a rigid airship into the 300 ton payload realm.

Moving from the previous engineering discussion to hypothesized ton/mile costs for the various designs requires complex analysis. Again, much of the information to support that analysis is unavailable. At least in the case of the rigid designs, however there is some precedence in the historical record of airships such as the Graf Zeppelin, which logged 590 flights, and more than one million miles (Althoff, 1990). Updating cost information is more complex than adjusting for the effect of inflation on 1935 data. For example, newer fabrics would have a much longer useful lifespan and hence their replacement costs could be amortized over an extended period.

The complexities of quantifying direct operating costs are challenging, but there is also the need to calculate the fixed costs of design, construction, financing, certification and training. The costs of these other aspects would be spread out over the life of each vehicle and the number of vehicles of a given design being constructed. Manufacturing costs also need to include some overhead contribution for the construction and maintenance of a fabrication hangar.

At least in part, these tasks have been addressed by Chester (1992), using the British R100/R101 airships as a model. For the most part the analysis used the airships as they were in 1930, with little adjustment for the effects of technological development. The 5,500,000 cu.ft. envelope of these British airships puts them somewhat below the range of the 100 ton design discussed in the previous table. Chester’s direct operating costs associated with shipping freight were calculated in the range of \$0.06 to \$0.07 per nautical ton-mile. This is likely too favourable a freight rate^{xiv}, but Chester’s work represents an important step in addressing the dearth of useable economic case studies. As with several other technical issues, more work is needed to incorporate all costs associated with an airship program, and also to allow for the effects of technological development on these costs.

In addition to hard costing data, also lacking in the analysis is a model for a loading/unloading mechanism required to transfer cargo to or from the rigid airship. Any

on-board cargo handling mechanism would reduce the operational cargo capacity of the airship design. The simplest design (and possibly the lightest) will be needed, but at the same time, it must be safe and rapid. “Mules”(mobile anchoring equipment) could be used to hold the airship over the cargo module and then winch the airship down to facilitate lock-up with, or unloading of, the cargo module. The design of the cargo handling component is outside the scope of this paper, but is discussed later.

Other Considerations

Environment

Airships have the potential of becoming the cleanest form of intercontinental transport since the sailing ship. Airships have inherently low greenhouse gas emissions because of the static lift provided by the Helium gas. There is also the possibility of full or partial reliance on effectively zero emission solar power. The large dorsal surface of an airship could support a massive solar array. For example, the proposed Lockheed-Martin stratospheric airship, which is 500 feet long and 160 feet in diameter, is being designed with a solar collector to provide regenerative power. Solar energy equipment that will operate at 65,000 feet should be adaptable to the 1,000 to 5,000 foot level where a cargo airship would operate.

The low power requirements of airships will also assure that noise and air pollution associated with airports will be much less problematic. A better understanding of noise propagation might also help in situating “blimp ports”, such that disturbance to neighbours is minimized.

Mixed freight/passenger potential

Potential exists for mixed, freight/passenger long haul movements. The rising popularity of cruise ships, underscored by the recent maiden voyage of the Queen Mary II, suggests that a growing market could exist for more leisurely travel options. Just as airships could provide an attractive middle ground between costly, but fast conventional air, and cheap, but slow marine transport, they could also satisfy demands for passenger transport as entertainment without the very lengthy commitments of cruise ships.

Studies by de Heer (1980) and Hochstetler (2001) conclude that airships could provide competitive short haul passenger services between the islands. de Heer also concluded that a 420 ton airship could ferry passengers and their cars competitively from the U.S. mainland to Hawaii.

Military Interest in LTA Technology

New technology requires significant investments in research and development for the construction and airworthiness testing to obtain commercial certification. While some technical problems are as yet unsolved regarding giant airships, none appear to be

insurmountable given sufficient investment. However, what would constitute “sufficient investment” could be significant. It is unreasonable to expect that a completely new airship could be designed, built and certified in less than three years, and a five-year schedule might be closer to reality. Like a new fixed wing aircraft, the development costs of a new cargo airship could easily lie between \$400 million and \$1 billion to reach full commercial status.

Many innovations now taken for granted in the private sector were funded by the military. Airships appear poised for this boon. The U.S. Defense Department is interested in airship technology for long distance transport of heavy and large cargoes as well as for possible roles in missile defense (Woodgerd, 2003). In addition to helping to offset development costs, the military could provide a stipend to help sustain airships for stand-by airlift to difficult to reach conflicts. For example, the U.S. Department of Defense gives U.S. airlines an annual stipend in return to access to their crews and craft in the event of need. A similar program for cargo airships could lower average costs and encourage a wider range of trade goods by enabling lower cost goods to compete. At the same time, it would create a valuable reservoir of strategic airlift for emergency response and conflict situations.

Weather

Contrary to the image held by many, airships are not powerless victims of extreme weather conditions. Indeed, one airship developer indicates its ships will be able to “operate in all weather conditions open to a standard civil aircraft,” (Advanced Technologies Group). Airships would have sufficient power to overcome all but the strongest and most persistent headwinds. Modern weather prediction and monitoring capabilities would allow airships to avoid potentially hazardous storms. Indeed, with their considerable speed and ability to move over both land and water, they would be much better able than marine transport to avoid severe weather conditions. And when they could not, experience of the US Navy (1940-62) with blimp operations in severe weather conditions suggests that survival is not a major concern. Colder temperatures generally impose greater stresses on all transportation equipment, but airships do benefit from greater lift as the density of the air increases. However, some details of cold weather operations, like de-icing systems, have yet to be demonstrated.

Rather than survivability, the greater weather concern is the impact on utilization. Strong headwinds and routings to avoid severe weather will require more fuel and reduce utilization. Like all forms of transport, severe weather will also limit the operating window for airships and affect ground handling. Like a ship standing off the coast, or an airplane holding at an alternative airport until weather clears, in some instances airships may have to remain aloft until conditions permit docking and the on/off loading of cargoes. Again, weather extremes affect all transport modes. Airship vulnerability to weather extremes will likely be no greater, and probably less, than for conventional air transport and should be able to avoid potentially dangerous storms (Woodgerd, 2003).

Ground handling

Ground handling procedures for the safe exchange of cargoes and ballast require development for large airships. A great deal of effort has been directed to developing ground handling systems, but none of the proposed systems have undergone extensive field-testing. There are a variety of potential solutions.

Fixed ground facilities able to attach to and guide airships to the ground,

Mobile ground handling equipment (staffed or robotic) able to attach to and guide airships to the ground.

Docking facilities carried onboard and lowered to the ground, with the airship hovering aloft during on/off loadings.

Hybrid airships landing under their own power employing hovercraft technologies to ensure smooth landings and reversing thrust to anchor the vehicle in place.

Tail and bow thrust engines on airships that improve lateral control and reduce the number of ground crew necessary.

Problems related to developing viable ground handling systems appear surmountable by existing technology. “Modern robotic technologies have reached a technological maturity to permit the design of extendable, articulated mooring mast systems fully automated launch and recovery capability. Such a system could safely capture and launch an airship in all but the worst weather conditions, and would minimize ground personnel requirements.” (Hochstetler, 2001, p. 11) Whatever the final configuration of the ground handling system, it seems clear that airships will not require anywhere near the extensive land area and capital of conventional airport facilities. For the sake of economic analysis, the cost of ground handling future airships could be approximated by the ground handling costs of fixed wing aircraft.

A Potential Early Application: Hawaiian Cargo Airship Service

The primary goal of this paper is to acquaint readers with the potential of airships as a significant mode for moving freight and, to a lesser extent, passengers, and to stimulate thought and discussion about the routes and cargoes for which it is best suited. To that end, in the balance of this paper one likely early use will be discussed: a cargo service between Hawaii and North America, with particular focus on movements of Hawaiian produce. The basic reason for identifying this market are listed below and later presented in further detail:

1. No land transport option: As airships prove themselves and associated technologies improve, competition with rail and truck could increase. However, in the early years of development, it seems most likely that large airships would be employed over water, where they will enjoy clear speed

advantages relative to marine transport and cost advantages relative to conventional airfreight^{xv}.

2. Distance: It is 5,007 kilometers (3,113 miles) from Hawaii to Los Angeles. This distance is long enough to make significant the airship's speed advantage over marine freight, particularly for perishable and more valuable cargoes. At 20 mph, a ship could make the crossing in just under one week, versus 36 hours for an airship (at 80 miles/hour). This distance is well within the operational parameters of several airships currently in planning, and certainly within the range of the Atlantic Zeppelin services of the 1930s.
3. Congested and sensitive port/coastal areas: One of the principal advantages of airships is the ability to avoid congested or otherwise sensitive areas for on/off loading. The attraction of this capability for Hawaii and the West Coast of North America is evident.
4. Sufficient market size: The large volume of freight passing through Hawaiian ports is coming from or going to North America. Perishables account for a considerable part of that volume. From Hawaii eastbound perishable cargoes consists primarily of papaya and pineapples, as well as some ornamentals. Going to Hawaii is a wide array of produce and meats. Both westbound and eastbound trade flows are fairly steady throughout the year.
5. Moderate weather conditions: As already discussed, evidence from U.S. Navy experience with blimps as well as manufacturer simulations indicate that airships will be able to operate in a wide range of weather conditions. Nevertheless, it seems likely that initial uses will tend to be along routes having few weather extremes. The Hawaii-North American Mainland route over the Pacific Ocean is subject to temperate weather conditions.
6. High potential for mixed freight/passenger: Both Hawaii and the west coast of North America are significant tourist destinations. Hawaii already serves as a Pacific Ocean crossroads for air travelers. Passengers could use the airship for all or one leg of their trips.
7. Hawaiian interest: A study was prepared in 1980 by de Heer (State Representative, Thirteenth District) that considered the use of airships for inter-island and mainland service. This study concluded that "not to pursue LTA airships for Hawaii's transportation needs would be a regrettable disservice to Hawaii's future in general, and the viability of the neighbor islands in particular."

8. Military interest: The potential for a partnership between commercial operators and the U.S. military is greater because this application is domestic.
9. Value of Freshness: Not ripening or getting sweeter after being picked, is a logistical problem of strawberries and pineapples. Ripe pineapples if shipped by sea, deteriorate before they arrive at markets on the mainland. Del Monte shipped the first ripe pineapples by air to the United States mainland markets in 1976. Maui Jet-Fresh pineapples arrive within thirty-six hours of their harvest. Consumers are willing to pay a premium for ripe pineapples, relative to sour green pineapples.

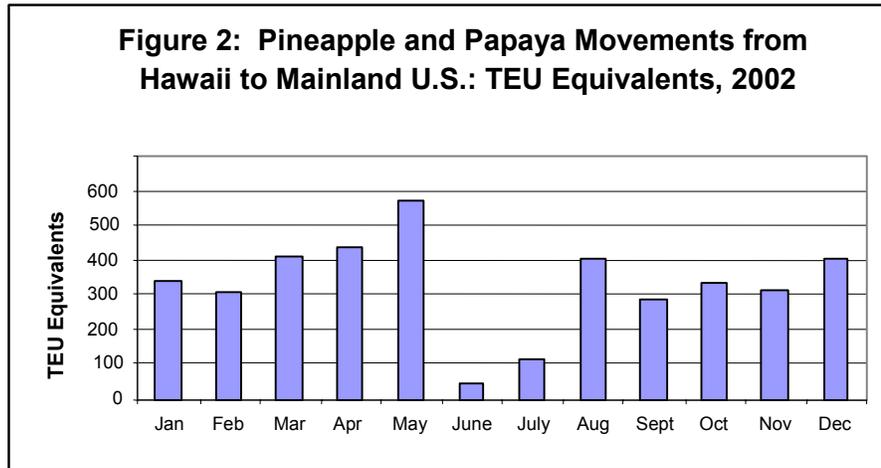
The very large majority of Hawaiian pineapples and papayas are marketed in North America. Approximately half of these are shipped via air and the balance by boat (53 and 47 percent, respectively in 2002). Additional cargoes to fill out mainland-bound movements or complementary cargoes for return haulage would normally be available. The Port of Honolulu, alone, handles over 150,000 containers annually, with 90 percent shipped between Hawaii and the U.S. Mainland (Choo, 2003).

The freight rates for refrigerated 40 foot marine containers between Hawaii and Los Angeles were quoted in 2004 at \$3,678 for eastbound loads and \$4,828 for westbound shipments of fresh fruits and vegetables (Matson, 2004). Assuming a 20 ton load, the ocean rates are between 9 and 12 cents per pound. Though airships could be two or three time more expensive than marine movements, they would be three and five times faster. The reduction in indirect logistics costs (packaging, inventory in transit, damage/spoilage) and market premiums for freshness could help airships capture part of this marine market share. With regard to conventional airfreight, airships should have the potential to charge lower cargo rates and capture part of the more perishable goods market, e.g. papayas.

A potential land route through the southern U.S. might enable airships to surmount the west coast mountain barrier and deliver fresh produce from Hawaii into the center of the continent. Initially, however, the cost and door-to-door advantage of trucks is likely to encourage transshipment once airships clear congested coastal areas. This is not to say that airships will never operate deeply into the interior of North America. Rather, it seems likely that the initial applications will be over routes for which the comparative advantages of the mode are greatest. Those advantages are not over continental areas with highly developed surface transport infrastructures (except for indivisible loads). Usage of airships over such areas is likely to increase gradually as their costs lower and/or congestion and environmental costs associated with other modes increase.

Year round utilization is imperative to justify the fixed costs of large airships. As can be seen in Figure 2, with the exception of June and July, Hawaiian produce exhibits very little seasonality in outbound shipments. Outside these summer months, pineapple/papaya shipments ranged from 300 to 600 TEU-equivalents (20 foot

containers). Inbound shipments to Hawaii could include perishables like strawberries, lettuce and other fresh produce, as well as general freight and mail. The lower cost of airships might enable Hawaii to lower its average inbound freight costs, as well as expand its agricultural sector. Hawaii might also serve in the future as a transshipment point where horticultural trade between North America, Asia and Australia are sorted and dispatched to their final markets.



Source: USDA TEU equivalent assumed to be 20 MT

At the dawn of the 20th Century, a new transport mode came into being, the airplane. In the early years, it was little more than a novelty, but the airplane became one of the two or three most significant developments of the modern age. The same phenomenon may be happening again at the beginning of this century with regard to the airship. Reasons for suspecting this might be true have been reviewed in this paper. They are, primarily, the confluence of technological advances that promise to improve greatly the performance of airships over their predecessors, the potential of airships to mitigate many of the negative externalities in transport ---- congestion, pollution, and depletion of liquid fuels, and the opportunity to serve the large transportation requirements gap of lower value perishables.

Based upon the comparative advantages of airships, relative to other modes, a likely early application was discussed, mixed freight/passenger service between Hawaii and the West Coast of North America with particular focus on perishables transport. History shows that world food markets become integrated over time with advances in transportation technology. A large latent demand exists for better trans-oceanic transport that can provide a mid-point in cost and speed between existing aircraft and surface shipping. Airships could fill this niche. The global market for perishable food products in the 21st Century is certainly large enough to justify a world scale airship manufacturing industry.

The case for using airships to serve the Hawaiian market needs more research, but the concept is already proven. The feasibility of the large airship technology was demonstrated in the 1930s. A modern version of these basic rigid airship designs could show sufficient improvement to be a competitive mode of transport today. It would seem

that it is only a matter of time before the economic incentive brings together sufficient public and private investors to put this theory to the test.

No doubt there are many more potential uses for trans-oceanic airships. The primary goal of this paper has been to acquaint readers with airships and encourage them to consider the probability of their rebirth and what will be its role in our world. Although precise economic analysis is impossible at this point, the weight of evidence suggests that airship technology deserves a second hard look.

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ⁱ The Wright Brother's first flight occurred on December 17, 1903

ⁱⁱ In contrast to the Zeppelin Era of the 1930s, the goal of most current efforts is freight haulage. Similar to the early development of the railways, smaller vehicles are envisioned primarily for passenger carriage. It seems almost certain that the return of large airships will occur within the next ten to twenty years and will be based on cargo, but mixed carriage of freight and passengers is both conceivable and likely the next step in the path.

ⁱⁱⁱ Trans-Eurasian caravans over the so-called Spice Route predated improvements in sailing ships by several centuries. However, the volume of spice traffic carried overland was extremely small.

^{iv} Fuel and speed can be fine tuned on an airship because some dynamic lift and engine thrust can be used to take off "heavy". As the fuel is burned, the airship loses weight and may need to condense engine exhaust to capture ballast. Hence, more fuel and more cargo are obtainable within a certain range.

^v The captain has a route choice other than a straight line. With good meteorological data, airships could take routes that avoid headwinds and pickup advantageous trade winds or the slip streams of storms.

^{vi} Mountain ranges are the one physical barrier to commercial airship transport. While an empty airship may be able to cross a mountain range, a loaded airship might not.

^{vii} Indivisible loads are not considered in this paper, but are a particularly interesting case for transshipment by airships across topographical barriers. Airships are likely to reinforce transportation gateways where efficient topography yields favourable routes and freight rates. New gateways may be formed at locations where other forms of surface transportation infrastructure end.

^{viii} See Dave Barlow, President, TCOM, *Airships to the Arctic Symposium, 2002*, www.umti.ca

^{ix} AVI is AeroVehicles Inc. personal interview Bob Fowler, VP Operations

^x World Aeros Fred G. Edgeworthy. "Applications for Northern Transportation: Proceedings", *Airships to the Arctic Symposium*. Winnipeg, MB: University of Manitoba Transport Institute, October 2002, available at www.umti.ca

^{xi} Dick, Harold G., *The Golden Age of the Great Passenger Airships, Graf Zeppelin and Hindenburg*, 1985 p. 159

^{xii} Van Treuren, Richard, , *Hindenburg, The Wrong Paint; Hydrogen, The Right Fuel*, Atlantis Productions, Edgewater, Florida, 2001 p.198

^{xiii} The NT design with an internal frame does appear to offer some tradeoff on the envelope. Zeppelin notes that its envelope is only half the weight of other airships. (Airship No.143, March 2004)

^{xiv} This rate is in the range of that estimated by ATG for their gigantic 1,000 tonne capacity design.

^{xv} The same logic applies to airship transport over road-less terrain. Prentice and Thomson (2003) examined the use of a large airship to carry fuel to an Arctic diamond mine.