CARGO AIRSHIPS: AN INTERNATIONAL STATUS REPORT

Dr. Barry E. Prentice, Professor University of Manitoba and
Robert Knotts BA MBA M Phil (Engineering), Chairman Airship Association

Giant airships were built and operated primarily by the German Zeppelin company, from 1909 to 1940. The Imperial Airship Scheme of the British Government, the military airships of the U.S. Army and the Italian airships of Forlanini and Nobile also furthered airship technology.

A negative perception of airship exists because of accidents that cloud the important achievements of this period. The giant Zeppelins could cruise at 80 miles per hour and carry useful loads of 70 tons on scheduled flights across the oceans. Of particular note is the *Graf Zeppelin* that made over 150 Atlantic crossings and circumnavigated the globe. These records were established without sophisticated communication equipment or navigation facilities.

The ability to adapt this technology for cargo transport is recognized and has created interest internationally. Small inflatables (blimps) and semi-rigid airships are available for research, advertising or surveillance purposes. But, no heavy-lift airships exist currently.

Over the past 15 years, new strategies have been developed to overcome the drawbacks of airship for cargo applications. The competition for the dominant cargo airship design is worldwide. This paper reviews the status of cargo airship developments on three continents. The technological approaches are compared and examined for the emergence of a dominant design.

Search for the Dominant Design

The last large airship capable of commercial cargo haulage was built before the invention of the strain gauge in 1938. All rigid airships were built on the basis of trial and error; more art, than science. Since that time, many advances in materials, engines, engineering, navigation and control systems have occurred. Modern technology also offers fire sensors and suppression, modern anti-static systems, GPS and other equipment that enhances safety. New airship designs are possible in the 21st century that could not have been contemplated during the prior age of giant airships.

The laws of physics do not change and some issues that confront airship designs remain the same. Two fundamental problems from the prior era of rigid airships that have yet to be proven are structural integrity and buoyancy control.

Airship Structures

The advent of electronic instrumentation and computer modelling has eliminated the guesswork of material requirements. Stronger materials that can accommodate lighter weight designs, like composite materials, new plastics and metal alloys are available. The range of different airship structures includes:

a. Cigar-shaped rigid shell
b. Rounded rigid shell
c. Catamaran rigid shell
d. Catamaran with semi-rigid envelope
e. Catamaran with flexible envelope (non-rigid)
f. Cigar-shaped with flexible envelope (semi-rigid and non-rigid)

Rigid shell airships can retain their shape, whether or not the internal gas cells are inflated to provide lift. The external shell supports all appendages and cargo bays. The gas cells operate at atmospheric pressure.

Semi-rigid airships require the internal gas pressure within the envelope to maintain their shape, in combination with a rigid spine or keel that holds the engines, fins and cargo space.

Non-rigid airships hand all the appendages from the envelope. Some parts, such as the fins, are connected to the envelope externally. The gondola, engines and cargo space is held by a catenary curtain that is suspended internally from the top of the envelope.

Buoyancy Control

Buoyancy control refers to the ability to manage the assent and descent of the airship. The different means of altering vertical location are changing weight, altering displacement of the lifting gas, engine propulsion and aerodynamic lift. Altitude can be altered by loading or unloading material.

Airships achieve lift by the displacement of air with a lighter than air gas. Air weighs approximately 1 kilogram per cubic meter. A perfect displacement would be achieved by a vacuum, but holding the walls of a vacuum-lift airship from being crushed by the weight of the atmosphere makes this design impractical. The airship gains one kilogram of lift, for every cubic meter of air displaced by a lighter lifting gas, minus the weight of the lifting gas.

Hydrogen is the lightest gas and can obtain 96 percent of the lift that would be available with a vacuum. Helium is next best at 92 percent of the lift. Even gases like methane and ammonia could be used but they would only lift 50 percent of the vacuum.

Airships need a minimum of buoyancy control to offset the weight of the fuel they burn. The giant Zeppelins use to seek rain clouds to gather water ballast to gain weight. They also captured water vapour condensed from the engine exhaust. Dumping the water ballast would provide lift. Of course, water or other ballast material can be added on the ground. The Zeppelins also used to vent hydrogen to descend, but helium is too expensive to waste in this manner.

Buoyancy control can be obtained by changing in the space occupied by the lifting gas. Any change in pressure or temperature of the gas can effect vertical movement. Ballonets are used by inflatable airships to control buoyancy. Air can be pumped in and out of an inner bladder, called a ballonet, to add weight and increase the helium pressure.

The airship's propellers can be used to push the airship up or down. Airships can also use aerodynamic lift and drag to control altitude. By point the nose of the airship up or down, aerodynamic forces will cause it to change vertical location.

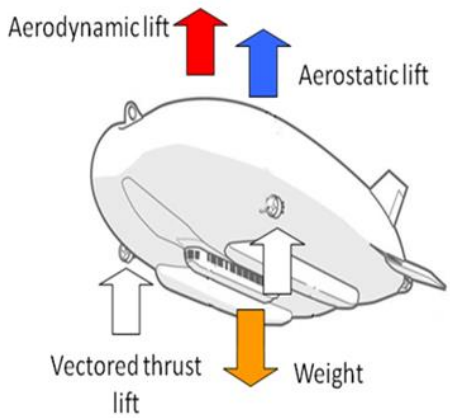
Structure and Cargo Exchange

Buoyancy control is necessary to ascend and descend at will, but it is essential to cargo exchange. Most airship developers have chosen one of two routes to address load exchange and ground handling issues. A hybrid aircraft technology has been designed in which the vehicle is heavier-than-air when empty. Engine thrust is used to create aerodynamic lift to carry the cargo and fuel. The manufacturers that have embraced this approach are Lockheed Martin (U.S.), Hybrid Air Vehicles (U.K.) and AeroVehicles (Argentina).

Approximately 60 to 80 percent of a hybrid airship's lift is static, while the remainder is produced by the airship's aerodynamic shape. Although not necessarily critical to flight, some hybrid airships also combine hovercraft technology for ground handling. Rather than wheels, these airships float on modified air cushions. When moored, the fans in the air cushions can be reversed to create suction that (in theory) holds the vehicle while loading and unloading.

The idea is shown in figure 1 [DOD, 2012]. A hybrid airship's varied sources of lift give it more flexibility to deliver cargo to an unprepared site. This could be particularly important for a military exercise or humanitarian logistics that has no prepared terminal facilities. The combination of sources of lift reduces the complication of cargo loading and unloading, but hybrid airships burn much more fuel than traditional airships to obtain this benefit.

Figure 1 - Hybrid Airship - Methods of Dynamic Lift

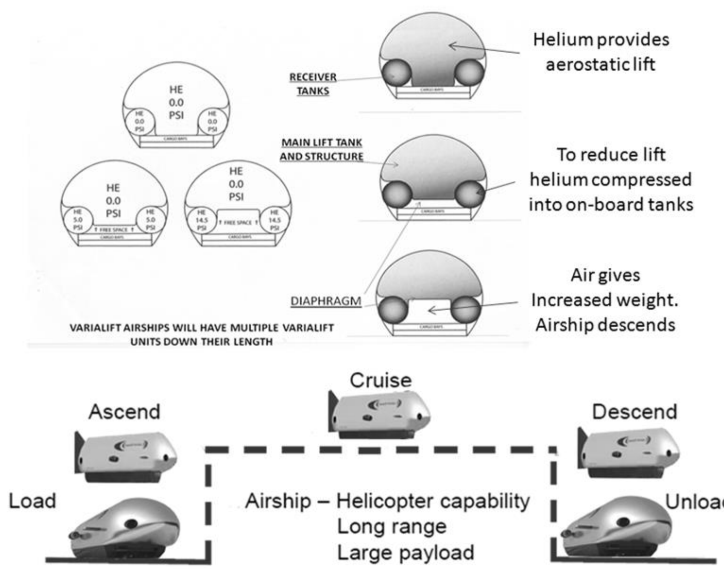


A conventional airship has enough buoyancy to lift itself and the payload. An amount of weight equal to the cargo must always be present. As the airship offloads cargo, it must either load an equal weight of cargo or some ballast, such as water, to its stowage.

A new approach to controlling buoyancy is to compress the lifting gas to offset the cargo weight. Built with a rigid structure, these designs can control lift at all states with Vertical Takeoff and Landing (VTOL) capabilities. They can also carry maximum payload while in hover. The leading companies taking this approach are Worldwide Areos (U.S.), RosAeroSystems (Russia) and Varialift (U.K.).

Figure 2 illustrates Varialift's approach to variable buoyancy control. Lift is altered by moving helium between lifting-gas cells and pressurized tanks inside the airship. Compressing the helium makes the vehicle heavier than air for easier ground handling and cargo unloading. Releasing the helium expands the gas cells and displaces air inside the vehicle which makes it neutrally buoyant.

Figure 2 – Varialift's Variable Buoyancy Concept



Rigid airships must be larger than semi-rigid and non-rigid airships to obtain the same useful cargo lift. More lifting gas is required by rigid airships to overcome the deadweight of their structure. However rigid airships lose less gas through leakage. The rigid shape is maintained by the hull, and the gas cells operate at atmospheric pressure. Semi-rigid and non-rigid airships pressurize the gas within their envelope above the ambient atmosphere. At higher pressures the tiny molecules of the lifting gas are pushed out of every pinhole and leaky seam.

Current and Developing Heavy Lift Airships

Twice as many "paper" airship projects can be found on the internet as there are actual projects in which a physical airship is tested at some level. The current state of heavy lift airship technology is outlined below for the leading airship companies.

Worldwide Aeros Corporation

Worldwide Areos was founded at San Bernardino, California in 1987. They built aerostats and small blimps, before taking on a cargo airship project called the Aeroscraft. This airship has a rigid, catamaran structure, and a variable buoyancy system. The half-scale began tethered flight testing in September 2013. A photo of the Aeroscraft is shown in Figure 3.

Figure 3 – Aeroscraft

This airship can compress a certain amount of its lifting gas and put it into fabric tanks. The density of the compressed gas is higher so that it is no longer lighter than air, and therefore causes the airship to change its buoyancy. The company calls this system COSH, an acronym for "Control of Static Heaviness." [Govers, 2013]

The Aeroscraft prototype is 266 ft (79 m) long and 97 ft (29.5m) wide. It is powered by three swivelling engines – two on the sides and one in the back – that provide both aerodynamic lift and thrust to propel it forward. The rear engine gives control at low airspeeds by pushing the tail around, side to side or up and down. Two sets of wing-like control surfaces are mounted fore and aft, and two large rudders push up vertically from the tail end. These aerodynamic surfaces are used at higher speeds (above 20 mph / 30 kph).

The structures under airship are landing pads; a type of inflated hovercraft skirt that allows the airship to rest on ground, water or ice. The airship is a one-half scale prototype – the final design is expected to be more than 400 feet (121m) long and be able to lift a cargo weight of 66 tons [Govers, 2013].

Auguar Aeronautical Centre

Moscow-based, Auguar Aeronautical Centre was founded in 1991. They build aerostats and small blimps, under the name RosAeroSystems. They have announced a new dirigible program, the Atlant. The Atlant-30 is a rigid, round-top airship with a flat bottom that is designed to carry 30 tons. Figure 4 gives an artist's impression of the Atlant.

Figure 4 – Auguar Atlant

An active ballasting system is proposed for the Atlant to help control the dirigible's free lift (in-flight and parked) by compressing air or helium [Russian Radio, 2013]. A unique feature of this design is side opening cargo doors that form ramps to facilitate loading. The Atlant

shape can provide aerodynamic lift, but it is designed to operate principally as a vertical take-off and landing vehicle.
The company recently reported that it expects to receive its first round of funding in August 2013. Expectations are that the Atlant 30 will fly in 2017 and the larger Atlant 100 in 2018 [Talesnikov, 2013].

Hybrid Air Vehicles (HAV)

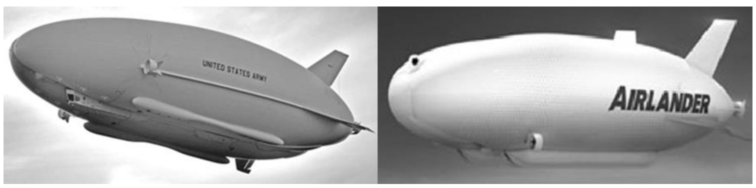
Hybrid Air Vehicles (HAV) at Bedford, England is the successor company of a series of corporations founded originally in 1971 by Roger Munk. With the exception of the Zeppelin Company, HAV can claim the longest pedigree in the modern field of lighter-than-air technology.

In June 2010, the US Army commissioned HAV and Northrup-Grumman to build a full-size hybrid air vehicle for surveillance purposes. The program called the Long Endurance Multi-Intelligence Vehicle (LEMV) specified a hybrid airship optimised for surveillance purposes. The airship was designed with a relatively small 1,100 kg (2,425 lbs) payload and large fuel tanks to enable the aircraft to stay aloft for up to 21 days. If the same 92 metre (301 feet) long vehicle were optimised for heavy lift (cargo) operations, it would offer a 20 metric tonne payload capacity [Giesler, 2013].

The 300-foot long, LEMV was the largest lighter-than-air vehicle to fly since the early 1960s. Despite a successful test flight in August 2012, the LEMV programme faced mounting problems: the vehicle was overweight; the programme was behind schedule; and, its original need, the war in Afghanistan was winding down. The US Army cancelled the programme in February 2013.

From its LEMV experience HAV has developed the Airlander 50 design, an aircraft that can be used for manned persistent surveillance and heavy lift. In the heavy lift configuration, the Airlander 50 is designed to carry 50 metric tonnes. It can also be operated like a helicopter with vertical take-off, landing and hovering, but its cargo lift is cut by 60 percent. A photograph of the LEMV's first flight and an artist's impression of the proposed Airlander 50 are shown in figure 5.

Figure 5 - LEMV and Hybrid Air Vehicles Airlander 50



The immense size of an airship allows it to feature a huge cargo bay, with loading ramps at each end. The payload area of the Airlander 50 is sized to take six 20 feet containers in two rows of 3 each, sitting abreast, whilst still having space for 50 passengers (subject to the 50 tonne maximum payload weight) [Hybrid Air Vehicles].

In October 2013 the US Army sold the LEMV to its original designer HAV [Schechter, 2013]. HAV has brought the airship to the UK, where they plan to air-inflate what it as the HAV 304. It could be flying again by the end of 2014, on a quest for civil certification. [Pocock, 2013]

Lockheed Martin

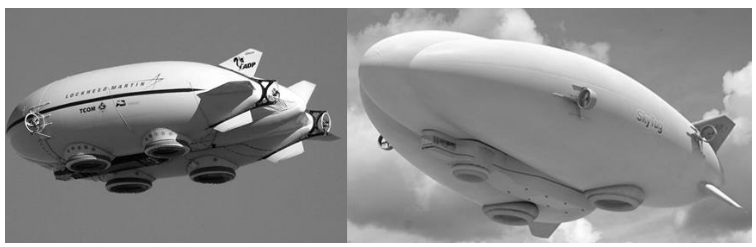
Lockheed Martin (LM) has two divisions that research airships. LM researches traditional airships at the former Goodyear Aircraft Airdock at Akron, Ohio and hybrid airships at their Skunk Works research centre at Palmdale, California. In January 2006, they flew the P-791 hybrid airship demonstrator.

The P-791 was designed as a multi-mission capable of manned or unmanned intelligence gathering or for transport [Dornheim, 2006]. This is a non-rigid, catamaran-shaped hybrid airship that depends on aerodynamic lift for buoyancy control. The LM airship is very similar to the HAV AirLander. Both these airships were designed by Roger Munk, although no commercial linkage exists between the two firms.

LM announced in 2011 that they had reached an agreement with a commercial partner to develop a scaled-up hybrid airship version of the P-791 demonstrator. The planned initial variant, the SkyTug, would have a 20-ton capacity payload. One version of SkyTug will have diesel engines and conventional takeoff and landing capability. Another will have more powerful turboshaft engines giving a vertical take-off and landing capability.

Figure 6 presents a photograph of the P-791 together with an artist concept of the SkyTug cargo airship.

Figure 6 – Lockheed Martin P-791 and SkyTug

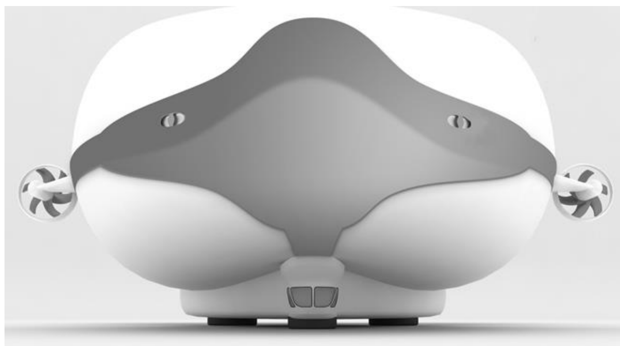


Aerovehicles Inc.

Aerovehicles was originally founded in California in 2002, but now operates out of San Luis, Argentina. They are proposing the Aerocat R40 that is a semi-rigid, hybrid design that will carry 40 tonnes. The Aerocat differs from the SkyTug and AirLander by the use of a composite nose cone and internal structure. This innovation was added to deal with the effect of high winds. It is also designed with a smooth top to eliminate the collection of snow and ice. Like these other hybrid designs, the Aerocat is designed to use a hovercraft cushion system for landing.

Despite significant investment in engineering and design, no prototype has been flown as yet. An artist's depiction of the airship is presented in Figure 7.

Figure 7 - Aerocat R40



Airship do Brasil Industria Aeronautica (ABD)

Airship do Brasil Industria Aeronautica (ADB) is one of the biggest logistics companies in Brazil and is involved in cargo shipping, storage facilities, road equipment construction and naval dockyard construction. About 80% of Brazil's roads are unpaved. This presents major problem to cargo transporting vehicles. Mud and congestion seriously hamper road transport. ABD is developing and planning to operate cargo airships to serve their own transportation needs. Figure 8 presents an artist's impression of ABD's proposed airship.

Figure 8 - Airship do Brasil

Details are sketchy on this semi-rigid cargo airship. The proposed capacity is 30 tons. Their first flight is expected in July 2016. The company aims to carry out a test flight of the craft in July 2016 [Transportes Bertolini, 2013].

Varialift Airships

Varialift Airships is a U.K. based airship company that has designed an all-metal, rigid airship. They are establishing manufacturing facilities at a former French Air Force base near to the city of Cambrai in the north east of France. Pending funding, the company plans to complete the design of the ARH 50 and construct the airship within 24 months of the site being opened. Cranfield University in the UK is assisting in the design work. A production line is planned together with a pilot training school [AAJ, 2013].

The ARH 50 has a length of 150 metres (492 feet) and a payload capacity of 50 tonnes. It will use the company's patented helium compression technology, previously shown in figure 2, for buoyancy control. The compression system is also designed to alter the lift along the length of the airship to provide trim and stability. An artist's impression is given in figure 9.

Figure 9 – Varialift

Varialift Airships plans an initial production rate of one ARH per month using modular assembly. A second production line will be installed during months 36 to 48. When the ARH50 development work is complete larger airships are planned [AAJ, 2013].

CURRENT AND FUTURE AIRSHIP CAPABILITIES

A decade ago, the only commercial market for airships was advertising and carrying TV cameras at a football game. All these airships were inflatables, or “blimps”. There is now a worldwide competition to develop cargo airships. The dominant design of the cargo airship has yet to emerge. Designs with rigid hulls that are made of aluminum or composite materials are being put forward, as well as non-rigid designs, and even some semi-rigid variants.

The proposed cargo lift for this first generation of cargo airships varies from 20 to 66 tonnes. However, the cargo bays are much larger than the dimensions of trucks or containers. Consequently, these aircraft will be able to carry much lower density cargoes without reaching their volume limit. Most designs have vertical takeoff and landing ability so they can carry slung loads. Hybrid vehicles are more limited than traditional airships in this configuration.

Modern cargo airship designs have vectoring engines, tail thrusters and modern aircraft avionics that give pilots sufficient control to land and take off independently. The issue still in flux is the role of aerodynamic lift versus static lift. One camp favours static lift with active buoyancy adjustment (gas compression), while the other side favours a heavier-than-air design with aerodynamic lift to provide control of buoyancy. Both ideas have merits and the dominant design could incorporate elements of each.

The most important remaining barrier to a cargo airship industry is the lack of business confidence. Any of the projects described in this report could have a vehicle ready for certification within three years of funding, and some are even further along. However, no project has yet announced success in financing. Once any cargo airship does reach this stage of commercialization, more investors will step forward to take advantage of the latent market for air cargo transportation. As this occurs the dominant design will emerge.

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