Varialift Airships - variable buoyancy airships

Peter Lobner, updated 10 March 2022

1. Introduction

Varialift Airships Plc, headquartered in Stourbridge, West Midlands, UK, was founded in March 2007 with the goal of developing all-aluminum, rigid, heavy-lift cargo airships that implemented variable buoyancy control based on patents applications filed by in 2004 by Alan Hadley.

Following are the key patents that have been granted:

- US Patent No. 7,568,656 B2, "System for Controlling the Lift of Aircraft," dated 4 August 2009
- European Patent No. EP1591356B1
- Hong Kong Patent No. HK 1083614

Alan Hadley is the current Director of Varialift, Ltd.

In 2010 – 2011, Varialift built and operated a test rig that validated the design of the modular variable lift unit from which Varialift airships will be built. The firm currently is designing and building an operational prototype, the ARH-PT, to train future pilots and attract investors to fund further airship development and certification work. The first "float test" of the ARH-PT is expected in 2019.

The ARH-PT prototype is being manufactured in a repurposed facility in Chateaudun, southwest of Paris by Varialift Manufacturing France SARL, which was established in November 2016. This facility offered the space and structures needed for large-scale modular airship manufacturing and will be used for manufacturing the 50 ton ARH 50 and 250 ton ARH 250 airships. Varialift determined that a similar scale facility was not available in the UK.

At the March 2019 Aviation Innovations Conference – Cargo Airships in Toronto, Canada, Varialift reported that it has received binding orders for the ARH 50 and ARH 250 airships.

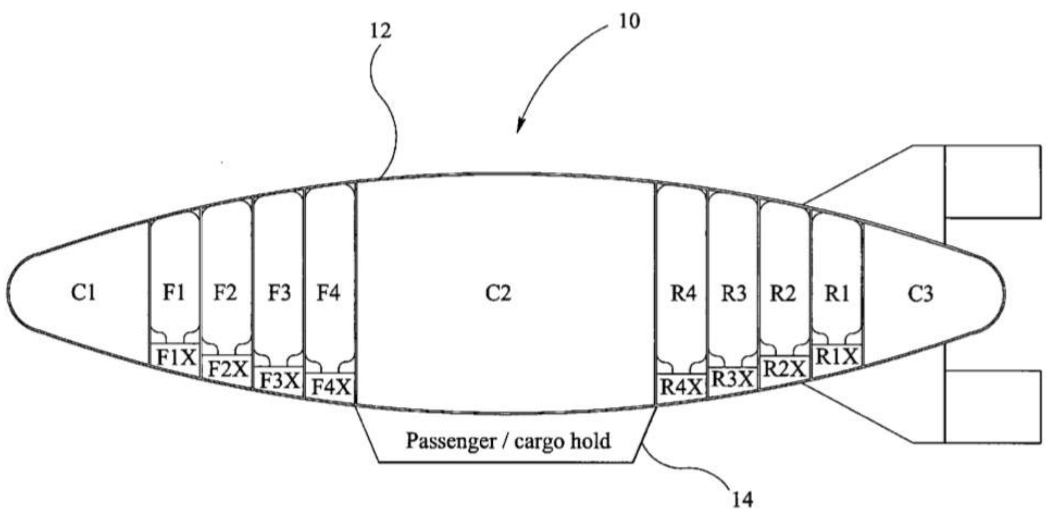
Varialift's also is pursuing opportunities to deploy its variable buoyancy airship technology for use in static and maneuverable airborne communication platforms (pseudo-satellites) that operate at high altitudes (65 – 75,000 feet / 19,812 – 22,860 meters) on long-duration missions. One possible application is for the airship to serve as a node in a 5G wireless telecommunications network.

The Varialift Airships Plc website is here: https://www.varialift.com

2. Variable buoyancy patent

As described in patent US7568656B2, which was granted in 2009, the airship (10) includes a metal body shell (12), a load-bearing hold for cargo and passengers (14) and the following features related to the variable buoyancy control system:

- C1 - C3 are fixed compartments containing the lighter-than-air gas.
- F1 - F4 are forward variable displacement compartments (lift cells).
- F1X – F4X are forward fixed-volume pressurized receiver cells.
- R1 – R4 and R1X – R4X are the comparable rear compartments.



The patent describes operation of the buoyancy control system as follows:

> "A system for controlling lift of an aircraft comprises an inflatable compartment for containing a gas which is lighter than air. A receiver receives and stores the gas in a compressed condition. Means are provided for compressing the gas and transferring it from the inflatable compartment into the receiver thus reducing the lift force on the aircraft."
> "The system ………further comprising a plurality of expansion systems to expand and transfer the gas from one of the receivers into the associated inflatable container thus increasing the lift."
>
> "The system may further comprise a fixed displacement compartment containing a gas which is lighter than air. This compartment provides a fixed lift to overcome the dead weight of the airship, with the variable displacement compartments being used to vary the lift."

Other aspects of the patent pertain to the use of diaphragm pumps for efficient helium compression and the design of the aluminum body shell, which must allow air to enter and vent as needed to maintain atmospheric pressure within the shell while the inflatable helium compartments expand or contract.

3. General characteristics of Varialift airships

Varialift has identified the following main features of their airships:

- Rigid aluminum aeroshell; insulated to limit heat input to helium cells; well suited for installation of solar cells.
- All lift is aerostatic (from the lifting gas), managed by a variable buoyancy control system.
- Designed for modular construction. The airship's hull is built up from many standardized "variable lifting units" that can be manufactured separately and assembled into the complete airship at the factory.

- Capable of vertical takeoff and landing (VTOL) and hovering indefinitely without the need for lift from engines (vectored thrust).
- Capable of operating in strong front and cross-wind conditions (up to 50 knots), largely due to the high inertial mass of the airframe supplemented by bow and stern lateral thrusters.
- Capable of operating from any flat space large enough for the airship to land vertically. No airport or runway infrastructure, ground crew or hanger is needed.
- Designed for operation in full IFR (instrument flight rules) conditions.
- Capable of flying at higher altitudes than conventional and hybrid airships; cruise at 6,096 m (20,000 ft); maximum altitude 9,144 m (30,000 ft). At maximum altitude, solar power generation would increase by a factor of 2 over generation at sea level.
- Capable of flying faster than conventional and hybrid airships; 250 - 350 kph (155 – 218 mph), with the higher speeds at higher altitudes.
- Capable of flying long range missions; 11,112 km (6,000 naut. miles) or more with conventional aero engines. Range with solar-electric power can be longer.
- Costs 80-90% less to purchase and operate than an equivalent cargo aircraft.
- With conventional aero engines, burns 80 - 90% less fuel than an equivalent fixed-wing cargo aircraft.
- Can implement a solar-electric propulsion system with zero carbon emissions. If an EU aviation carbon tax is implemented, a solar-powered airship may be eligible for aviation carbon credits.
- Very large internal cargo hold; enables roll-on, roll-off (Ro-Ro) cargo handling and economic transport of high-volume / low-weight cargo.
- Able to carry outsized bulky cargo as an underslung load supported by cables, and deliver the cargo from a hover, without landing.

- Operating costs rival truck or rail (point to point) transportation costs.
- At least 40 years airframe operating life expected.

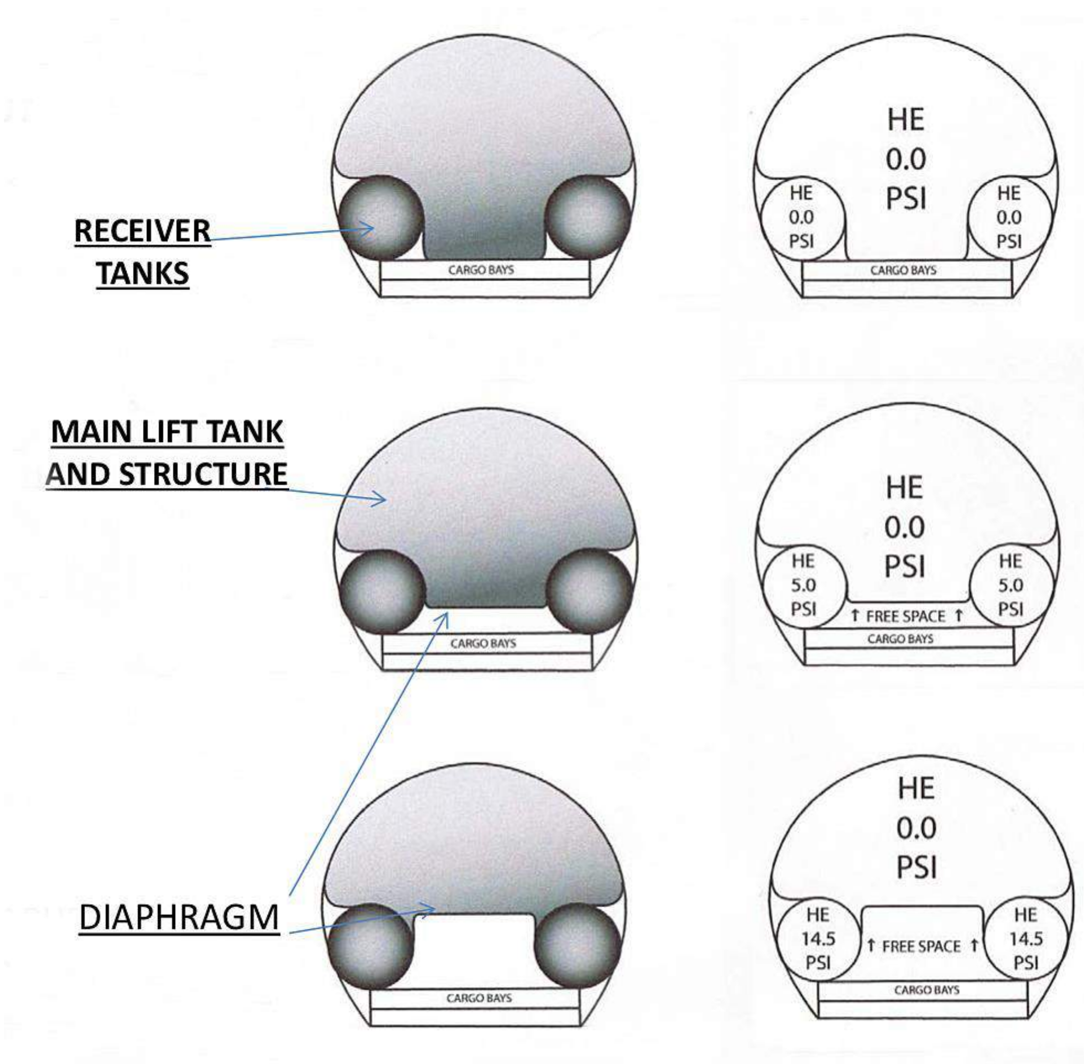
4. Implementing variable buoyancy control on a Varialift airship

Variable buoyancy control is implemented as follows:

- The variable buoyancy system and associated low-speed control system enable the airship to maintain position and orientation during vertical takeoff and landing (VTOL) and hover. Varialift airships can hover indefinitely in suitable wind conditions.
- Main lift volumes operate at atmospheric pressure. Maximum pressure in the pressurized receiver tanks is 14.5 psig.
- When on the ground, the airship can be made heavier-than-air by compressing some of the helium in the main lift volume and moving it into smaller pressurized receiver tanks. In response to the reduced size of the main lift volume, ambient air enters the aeroshell and maintains atmospheric pressure. With the added mass of the air, the now heavier-than-air airship is stable for loading and unloading without the need for additional ballast control.
- Following loading, the cargo bays are secured, the main lift tank is recharged with helium from the pressurized receiver tanks and some ambient air within the aeroshell is vented to the atmosphere until positive buoyancy is achieved. The now lighter-than-air airship lifts vertically into the air without the need for the engines to generate propulsive lift or forward motion to produce aerodynamic lift.
- Bulky underslung loads (i.e., electricity pylons, wind turbine blades and towers, large power plant components, prefabricated structures) can be picked up and dropped off from precise locations without the airship having to land. The variable buoyancy control system manages changes in mass as cargo is picked up or dropped off.

- The time it takes for the airship to change buoyancy during a load exchange depends on the amount of buoyancy compensation required and the pumping / venting capabilities of the variable buoyancy system.

The arrangement of the main lift tank (the helium volume), the receiver tanks and the ambient air volume are shown in the following diagrams, which also show the expansion of the air volume (labeled "FREE SPACE") as the receiver tanks are pressurized.



Source: Adapted from Varialift / University of Manitoba, Canada

The Varialift airship's VTOL capability depends entirely on helium lift. This is quite different than the short takeoff and landing (STOL) capability of hybrid airships that depend on the combined aerostatic lift from the buoyant lifting gas, propulsive lift from thrust-vectoring engines, and aerodynamic lift from the shaped fuselage once the airship is in forward flight.

When performing a load exchange, the variable buoyancy system must precisely manage helium lift by compressing helium from the main lift tanks or by releasing compressed helium into the main lift tanks. Compression will be the slower process, and will dictate how quickly a neutrally buoyant Varialift airship that has just landed will be able to discharge cargo. In this case, the helium compression system must make the airship heavier-than-air, at least equal to the weight of the cargo to be discharged plus some margin to ensure stability of the airship on the ground. Failure to make the airship heavy enough could result in the airship floating upward or moving in the wind during cargo unloading.

When hovering for an in-flight load exchange, the Varilift airship will be neutrally buoyant throughout the load exchange, with small variations in lift being managed by the airship's station keeping system.

5. The Varialift ground test rig

In 2010 – 2011, Varialift built a ground test rig that was representative of a single variable lift unit of their modular variable buoyancy airship. The rig was built and tested at Halfpenny Green Airport in Wolverhampton, UK. Varialift reported, "The project was completed in November 2011 when the test flight was successfully conducted and the unit lifted off the ground under full control using its variable buoyancy units. The first man to be lifted into the air was Mr. David Bacon."

During the tests, the maximum operating pressure of the receiver tanks was 14.5 psig. One receiver tank was later tested to determine its burst pressure, which was found to be 45.2 psig; providing a wide safety margin. The scale of a receiver tank is apparent in the following Varialift photo.

Receiver tank prior to installation in the test rig. Source: Varialift.

The validated design of the variable lift unit is the basis for the modular units that will be manufactured and assembled to produce an airship hull.

Following is a series of Varialift photos showing the construction of the variable lift unit for the test rig. These photos also provide insights to the actual design of the Varialift airship.

Wooden "jig" on which the semicircular hull frames are built.
The frames measure 40 m (131 ft) along the curve;
25 m (82 ft) in diameter. Source: Varialift.

Start of the tubular framework for one variable lift unit showing the positions of the two receiver tanks. Source: Varialift.

Tubular framework for one variable lift unit nearing completion. Source: Varialift.

Installation of aluminum skin on a variable lift unit.
Source: Varialift.

The gas envelope installed in one variable lift unit.
Source: Varialift.

6. The Varialift ARH-PT prototype

The role of the ARH-PT is to train future pilots and attract investors to fund further airship development and certification work. This airship is designed to carry a 4 metric ton (8,800 lb) payload.

Material for the ARH-PT began to arrive at the Chateaudun, France factory in March 2017 and, at that time, completion of the first ARH-PT was expected by late summer 2019, with flight testing to commence later in the year. The ARH-PT schedule has slipped, perhaps by three years. Several ARH-PT airships will be manufactured to meet the needs for pilot training around the world.

While Varialift currently does not plan to manufacture a large number of ARH-PT airships, several potential customers have expressed interest in a commercial cargo version of this airship.

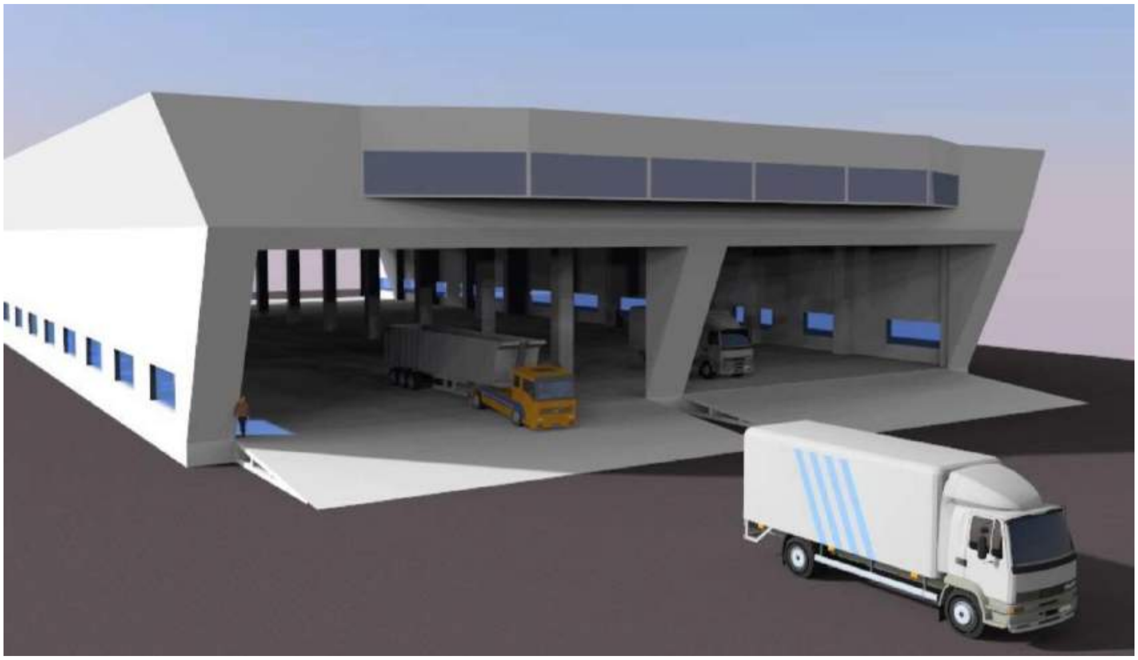
7. The Varialift ARH 50 airship

The first heavy-lift commercial Varialift airship, the ARH 50, is expected to be certified to carry up to 50 metric tons (50,000 kg; 110,200 lb) of cargo and will be powered by standard aero gas turbine engines. The rigid aluminum exterior offers the potential for adding thin-film solar panels on the hull and batteries to power a distributed propulsion system on future versions. There is space for almost 10,000 square meters (107,600 square feet) of solar panels on an ARH 50 hull.

Basic design characteristics of the ARH 50

Parameter	**ARH 50**
Length	150 meters (492 ft)
Span	52 meters (170)
Weight, empty	175 metric tons (386,000 lb)
Cargo hold dimensions	L 100 x W 50 x H 10 m (328 x 164 x 33 ft)
Cargo volume	50,000 m^3 (1.76 million ft^3)
Speed	250 kph (155 mph) @ sea level, 350 kph (218 mph) @ 6,096 meters (20,000 ft)
Range at max payload	11,112 km (6,000 naut. miles)

General arrangement of an ARH 50 airship The cargo deck is the dark structure below the aluminum hull. Note the lateral thruster ports near the nose and the side-mounted propulsion gas turbine. Source, both graphics: Varialift.



ARH 50 cargo deck is 50 m (164 ft) wide. Source: Varialift

In 2019, ARH 50 roll out was expected in 2021, with a 24-month certification process before commercial deliveries began. By 2021, that schedule has slipped by several years and is dependent on new funding.

8. The Varialift ARH 250 airship

Varialift also is developing the design for the much larger ARH 250 airship, which will share the same basic design as the ARH 50, but on a much larger scale.

Basic design characteristics of the ARH 50

Parameter	**ARH 250**
Length	300 meters (984 ft)
Span	110 meters (361 ft)
Weight, empty	max. 250 metric tons (551,000 lb)
Cargo hold dimensions	L 250 x W 100 x H 20 meters (820 x 328 x 66 ft)
Cargo volume	500,000 cubic meters (17.6 million cubic feet)
Speed	250 kph (155 mph) @ sea level, 350 kph (218 mph) @ 6,096 meters (20,000 ft)
Range at max payload	14,816 km (8,000 naut. miles)

Scale comparisons of the ARH 50 and the much larger ARH 250.
Source, both graphics: Varilift

ARH 250 airship hovering and handling heavy external cargo at a remote site. Source: Varialift

9. Beyond the ARH 50 and ARH 250

Varialift claims that much larger airships, with payloads up to 3,000 metric tons (3 million kg; 6.6 million lb), can be developed based on the same technology as the ARH 50 and ARH 250.

A high-altitude version of the ARH 50 is being contemplated. This airship may use the same size variable lifting hull as the cargo version, but without the large cargo hold. This airship would be capable of carrying about four metric tons (4.4 short tons, 8,818 pounds) on long-duration, high-altitude missions.

10. Development of the factory in the Chateaudun, France

Progress in developing the factory site is reported in the Varilift website here: https://www.varialift.com/page/news-events

By June 2019, Varilift reported: “Assembly towers made of containers have been customized and prepared for the assembly of the module canopies and helium tanks. The overhead of height 30 meters and span 27 meters crane was tested, assembled and placed on its rails. The assembly of the cargo bays has begun."

Assembly towers. Source: Varilift

Construction started on the cargo bays. Source: Varilift

11. For more information

- "Varialift Patent Granted and Proof of Concept Demonstration," Airshipworld Blog, 7 January 2009: http://airshipworld.blogspot.com/2009/01/varialift-patent-granted-and-proof-of.html
- Alan Handley, "Varilift Airships," presentation at Airships to the Arctic VI Conference, Seattle, 2011: https://isopolar.com/wp-content/uploads/2013/04/Alan-Handley-presentation-Varialift_A_New_Horizon.pdf
- Donna Lu, "A solar-powered airship is being built to transport cargo more greenly," New Scientist, 2 October 2019: https://www.newscientist.com/article/2218360-a-solar-powered-airship-is-being-built-to-transport-cargo-more-greenly/

<u>Patents</u>

- US7568656B2, "System for controlling the lift of aircraft," Inventor: Alan R. Hadley, Filed 26 April 2005, Granted 4 August 2009: https://patents.google.com/patent/US7568656B2/en

- EP1591356 (B1), "System for controlling the lift of an aircraft, "Inventor: Alan Roy Hadley, filed 27 April 2005, published 24 December 2008: https://patents.google.com/patent/EP1591356B1/en?oq=•EP1591356+(B1)

Videos

- "Varialift in French Television December 2016," (2:05 minutes): https://www.facebook.com/100057253309559/videos/varialift-in-french-television-december-2016/1017328101705672/
- "The Varialift Airship - Sir David King at the Arctic Circle Assembly," (1:31 minutes), Arctic Circle Assembly, 9 November 2018: https://www.youtube.com/watch?v=HNAzkAuXsJg

Other *Modern Airships* articles

- *Modern Airships - Part 1*: https://lynceans.org/all-posts/modern-airships-part-1/
- *Modern Airships - Part 2*: https://lynceans.org/all-posts/modern-airships-part-2/
- *Modern Airships - Part 3*: https://lynceans.org/all-posts/modern-airships-part-3/