H2 Clipper, Inc.

Peter Lobner, updated 11 March 2024

1. Introduction

H2 Clipper, Inc. was founded in 2011 by Rinaldo Brutoco as a private aerospace development and alternative energy company utilizing existing technologies and innovative composite materials and manufacturing processes to develop a unique hydrogen-powered dirigible intended to enable the widespread commercialization of hydrogen as a carbon-free alternative fuel source. Brutoco invented and patented many of the key technologies embodied in the H2 Clipper airship and serves as CEO of his firm. The company's headquarters are in Santa Barbara, CA. Their website is here: https://h2clipper.com

H2 Clipper airship general layout, circa 2021.
Source: H2 Clipper, Inc.

The primary mission of the H2 Clipper airship is to establish a "pipeline in the sky™" between hydrogen production sites and distant hydrogen distribution centers and large-scale end users worldwide. The airship uses hydrogen as a lifting gas, as a stored source of energy used by its electric motors for propulsion, and as its "payload." The airship is designed for vertical takeoff and landing (VTOL) operations and can operate from remote sites without mooring or dock facilities.

The H2 Clipper is a scaleable rigid airship that can be configured for a variety of manned and unmanned applications other than transporting liquified and gaseous hydrogen. For example:

- Freight transport applications: Low-cost, rapid, intermodal or bulk freight transportation with next-day service even on long-distance routes.
- Telcom / satellite relay applications: Geo-stationary airships at high altitude for long periods as part of a pseudo-satellite network to deliver cellular phone, internet and other communications services.
- Relief and humanitarian applications: Rapid delivery of personnel and supplies without dependence on port or airport infrastructure.
- Fighting wild fires, with retardant drops from hovering flight.

Passenger transport applications may be developed later. In carrying out these missions, the H2 Clipper generates zero CO_2 emissions.

In October 2022, Flight Global reported that "H2 Clipper will seek a maximum of $50 million from the Series A funding round, and estimates a total requirement of $250 million to complete development of the prototype aircraft, with 'significant capital needed' to scale up for production. On top of the equity investments, the company will seek finance from a variety of sources, including collateralization of assets, state and federal government grants or other incentives, plus customer deposits."

H2 Clipper Inc. announced that it planned to begin construction in mid-2023 of a 40% scale, 400-ft (122-m) long prototype airship at an existing hangar. First flight is expected in 2025.

A "greenfield" production facility will be built for the full-scale, 1,000-ft (304-m) long airship, which is expected to be flying late in this decade, with service entry by 2029. In 2023, H2 Clipper was granted a patent for their novel process for building these large geodesic hull airships.

I am grateful to H2 Clipper Inc. for their thoughtful input for this article.

2. Regulatory issues related to the use of hydrogen lifting gas and deployment of an H2 Clipper airship fleet

The H2 Clipper uses hydrogen as its lifting gas (gaining 10% more lift than from helium) and fuel (for its hydrogen fuel cell), and the airship is designed to transport large quantities of liquified and gaseous hydrogen as cargo.

Aviation regulatory changes will be required to permit the general use of hydrogen lifting gas in commercial airships. In the US, Europe and Canada, the following aviation regulations only allow the use of non-flammable lifting gas:

- FAA ADC: "The lifting gas must be non-flammable." (4.48)
- TAR: "The lifting gas must be non-flammable, non-toxic and non-irritant." (TAR 893)
- Canadian Air Regulations: "Hydrogen is not an acceptable lifting gas for use in airships." (541.7)

On 11 February 2021, the European Union Aviation Safety Agency (EASA) proposed a new regulatory framework for the certification of large airships. The proposed document went through a public review and comment period before the final document was issued on 21 January 2022 as Doc. No. SC GAS, "Special Condition 'SC GAS' Gas Airships," which is available for download here: https://www.easa.europa.eu/downloads/134946/en

This EASA regulation creates a new opportunity to use of flammable lifting gases lifting gas in Europe, subject to the following conditions:

- **SC GAS.2355 Lifting gas system**
    - Lifting gas systems required for the safe operation of the Airship must:
        - withstand all loading conditions expected in operation including emergency conditions
        - monitor and control lifting performance and degradation
    - If the lifting gas is toxic, irritant or flammable, adequate measures must be taken in design and operation to ensure the safety of the occupants and people on the ground in all envisaged ground and flight conditions including emergency conditions.

- **<u>SC GAS.2340 Electrostatic Discharge</u>**
    - There must be appropriate electrostatic discharge means in the design of each Airship whose lift-producing medium contains a flammable gas to ensure that the effects of electrostatic discharge will not create a hazard.

- **<u>SC GAS.2325 Fire Protection</u>**
    - The design must minimize the risk of fire initiation caused by:
        - Anticipated heat or energy dissipation or system failures or overheat that are expected to generate heat sufficient to ignite a fire;
        - Ignition of flammable fluids, gases or vapors; and
        - Fire propagating or initiating system characteristics (e.g. oxygen systems); and
        - A survivable emergency landing

It will be up to the airship manufacturer to demonstrate that their airship meets this Special Condition. The first to do so will be setting an important regulatory precedent for the airship industry.

A technique for preventing hydrogen flammability is described in Russian patent RU2441685C2, "Gas compound used to prevent inflammation and explosion of hydrogen-air mixtures," which was submitted in 2010 and posted in 2012. This technique yields a product called deactivated hydrogen, which some Russian airship designers are considering for use as an airship lifting gas

H2 Clipper Inc. is developing a subscale prototype with plans to fly this prototype as early as 2025. The first full-sized airship could be flying four to five years later if work underway continues as planned. Part of that progress depends on the FAA developing regulations that permit use of hydrogen in manned, commercial airships in the US, and/or H2 Clipper focusing its early commercial deployments in countries where – like in the EU – applicable regulations are based on the adequacy of measures for assuring safety.

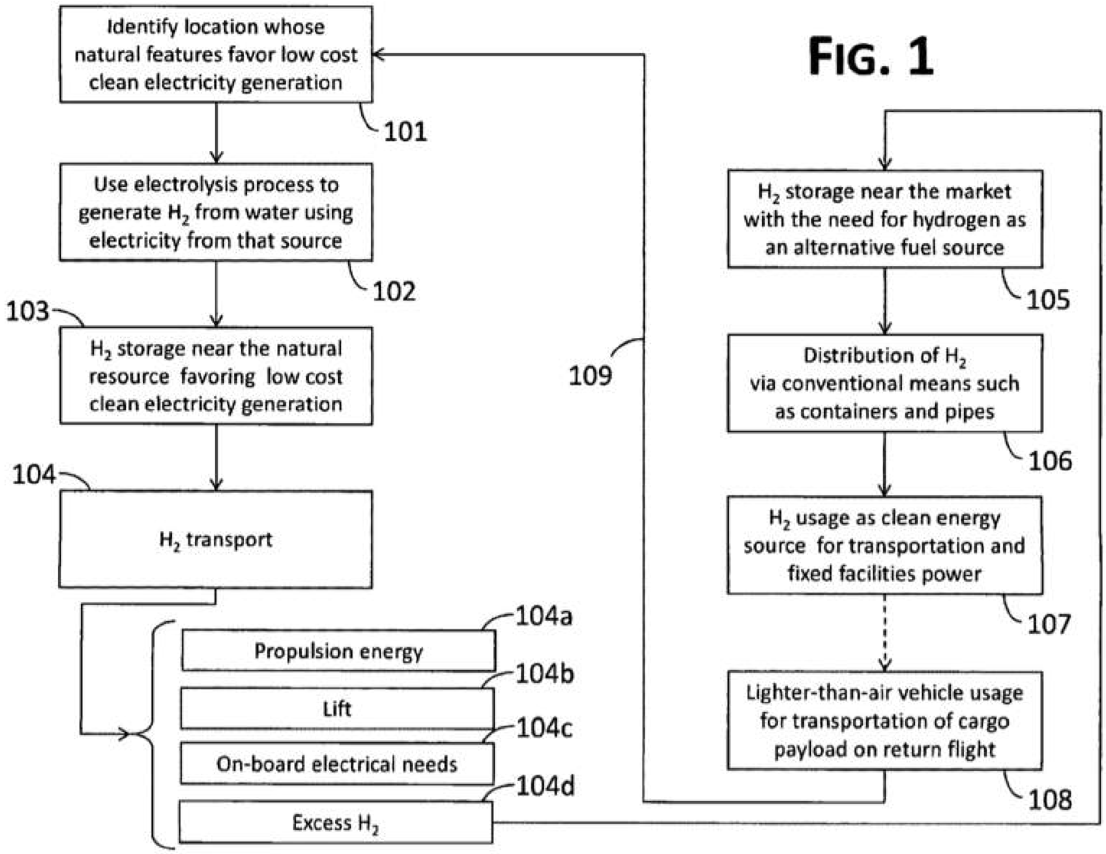
After worldwide regulatory changes are implemented to permit the widespread use of hydrogen in aviation, fleet-scale commercial deployment of H2 Clipper airships could occur.

Even with the needed regulatory changes, the insurance industry will have to deal with the matter of insuring a hydrogen-filled airship.

3. The hydrogen transport Use Case

Robert Shelton, H2 Clipper Vice President for Administration, described the use case for the H2 Clipper airship as follows:

> “The H2 Clipper conception arose out of the work that Rinaldo Brutoco had previously done concerning climate change, where in 2008 he co-authored a 500+ page textbook, entitled ‘End of Mideast Oil.’ The book’s first chapter, entitled ‘Titanic Mistake,’ focused on the environmental challenges the world would face if it did not wean itself off the addiction to fossil fuels; and the final chapter focused on the importance of hydrogen as the single best suited alternative.
>
> An early advocate for the goal of a hydrogen economy, Brutoco was confronted with the challenges summarized in the work of Swiss scientists regarding the problems associated with transporting hydrogen using truck, rail, ocean ships and pipeline. After research, he concluded that the best means to overcome these challenges would be through use of an airship; and the system and method of transporting hydrogen via airship forms the basis for H2 Clipper’s first patent (US8336810), filed in 2008 and issued in 2012.
>
> Figure 1 from that patent illustrates the basic conception of flying low cost hydrogen from where renewable resources such as abundant wind, solar, hydro or geothermal conditions make electricity cost very cheap, to where clean energy is most needed; and on the return flight using the massive volume of the airship to transport traditional cargo and air freight.
>
> To this day, this Use Case, involving hydrogen transport and displacing traditional air freighters, is the principal focus of H2 Clipper.”



The hydrogen transport Use Case.
Source: Patent US8336810, Fig. 1

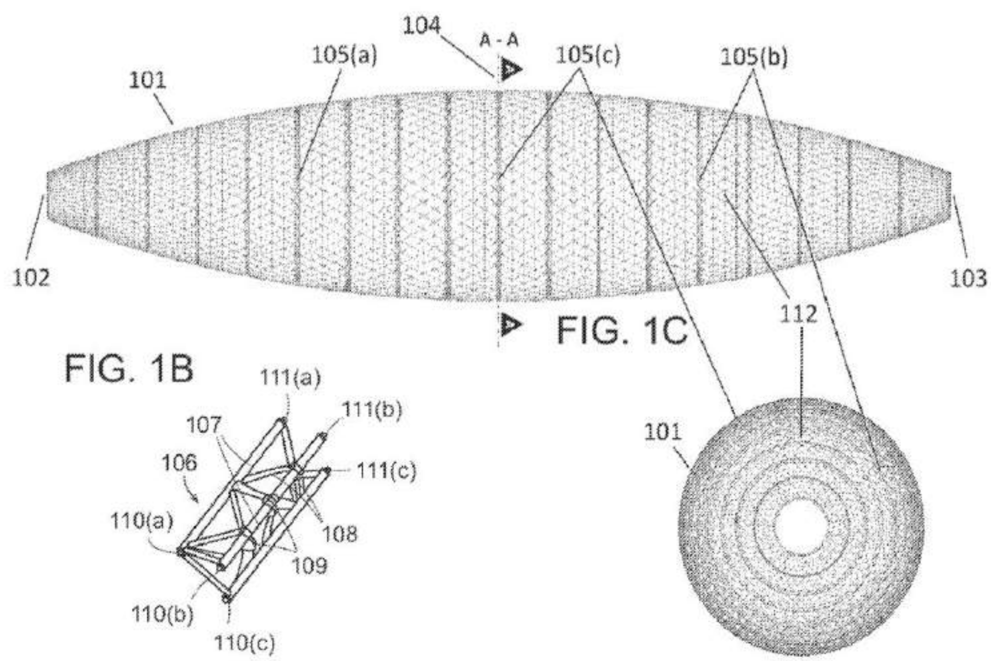
4. H2 Clipper airship design features

With a targeted cruising speed of 175 mph (281.6 kph) and range of 6,000+ miles (9,656+ km), the H2 Clipper airship is a high-speed, multi-mission dirigible that transports hydrogen and uses hydrogen as its lifting gas and primary source of power. Many patents defining features of this airship have been granted, and the company has numerous pending U.S. and International patents. Several patented airship features are described in this section.

Rigid, geodesic, highly-streamlined hull structure

Patent US11851214B2, Figures 1A, 1B and 1C show the latest design of the primary hull structure, which is a lightweight, composite geodesic exoskeleton (101). This hull structure may include circular structural frames [105(a), (b), (c)] that may be used to provide added rigidity. Each of these circular structural frames in patent Fig. 1A is a transverse triangular truss structure comprised of many of the standard truss modules shown in patent Fig. 1B.

FIG. 1A

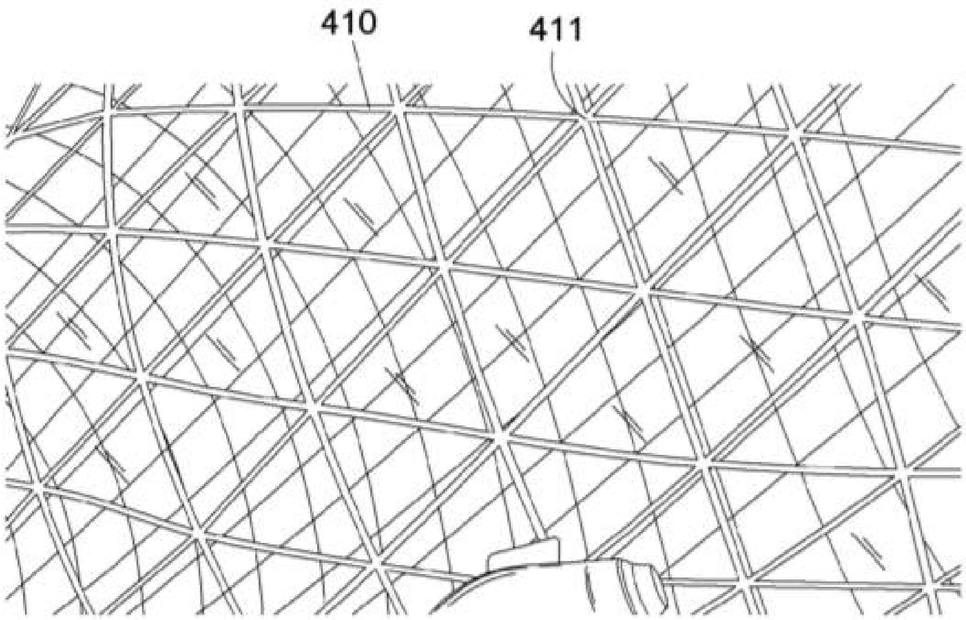


Exoskeleton hull and standard truss structure design of the H2 Clipper. Source: Patent US11851214B2, Figures 1A, B, C

This exoskeleton hull is designed to support 100% of the structural bearing weight of the craft without internal load-bearing structures.

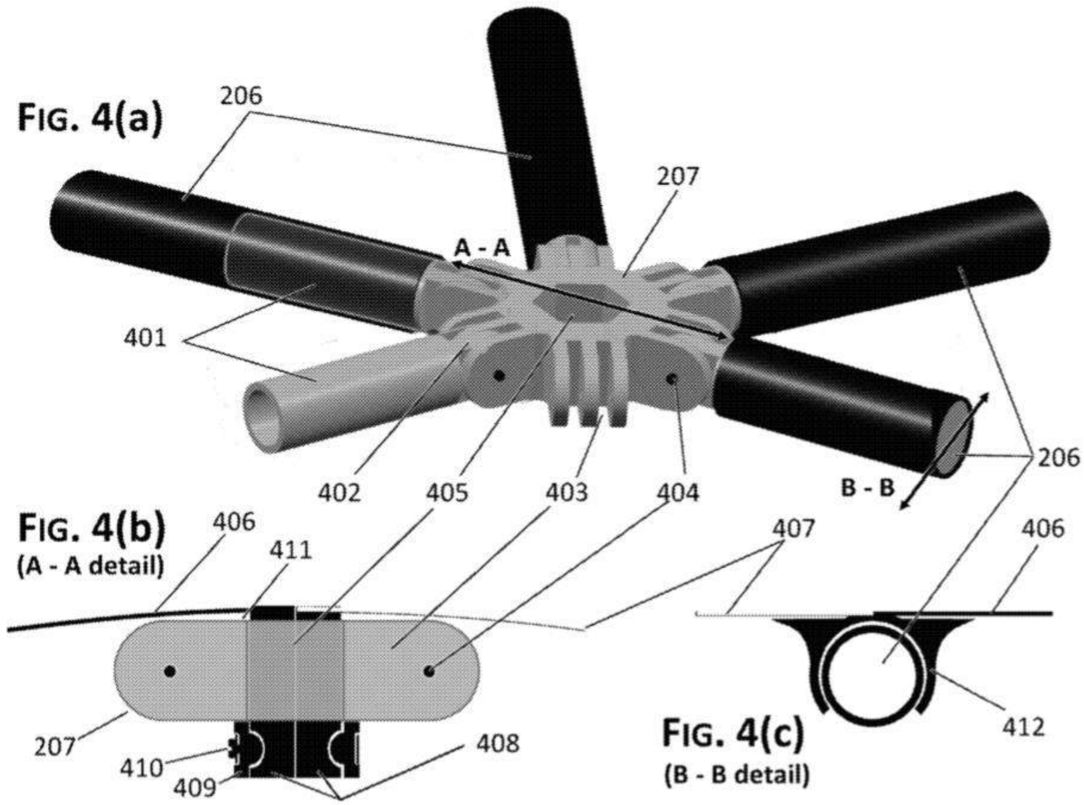
At the midline of the H2 Clipper airship (section A-A), the hull diameter is 150 ft (45.7 m). Separately fabricated nose and tail cones attach to the ends of the exoskeleton (102, 103), where the diameter is about 24.3 ft (7.4 m).

The exoskeleton hull was first introduced in patent US9102391B2, where it was described as being made entirely from equal-length composite spokes (206), all with a standard diameter (2 – 3 inches), that terminate in identical hubs.



General form of the geodesic exoskeleton hull, comprised of composite spokes (410) and universal hubs (411). Source: Patent US9102391B2, Figure 7

In patent US11066145B2, the exoskeleton design was revised to make use of variable-length composite spokes (206), all with a standard diameter. Spoke length ranges from 10 feet (3 m) in the mid-section of the airship to 5 feet (1.5 m) in the smaller-diameter nose and tail sections. The spokes are joined at universal, articulated hubs (207) to form the large-scale geodesic framework of the rigid hull. The use of the variable-length spokes and the articulated hubs enables the connecting angle to change as needed to conform to the local radius of curvature of the hull.

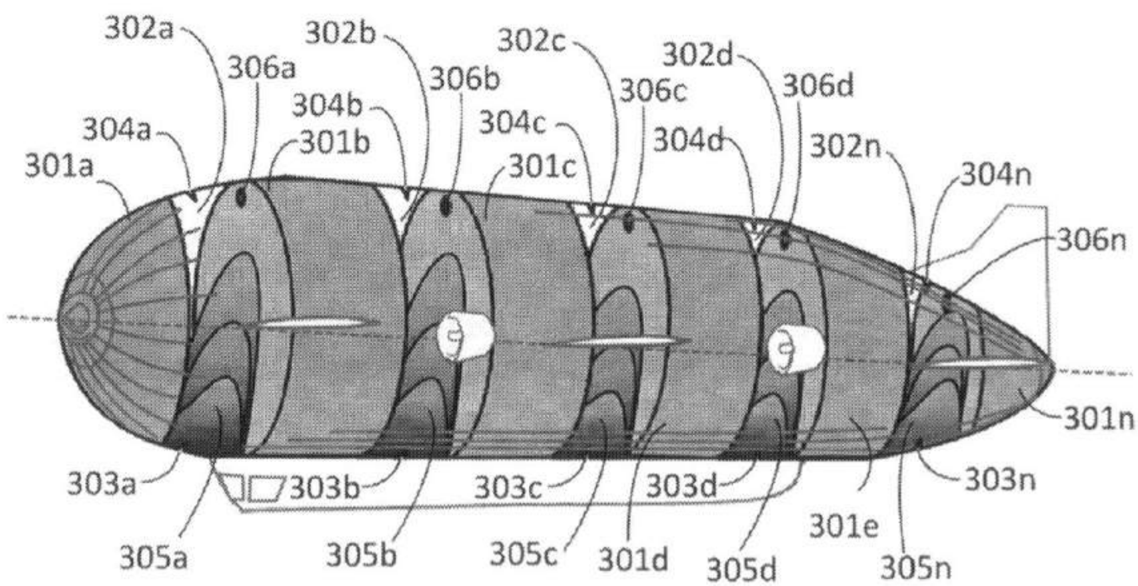


Typical hub configuration joins variable-length spokes (206) at the universal, articulated, central hub (207). Source: Patents US11066145B2 & US11396356B2B2, Figures 4(a), (b), (c) (2020 & 2022)

The external skin is made of lightweight composite material, such as bonded aramid fiber coated with PTFE (Polytetrafluoroethylene) to produce a low density and high tensile strength covering with a slick, non-wetting surface that is highly resistant to extreme temperatures (−50° C to +200° C), is fire resistant and flame retardant. With reference to the above figure, a flat or curvilinear outer skin panel (406) may include a layer containing thin-film photovoltaic (PV) solar cells (407).

Internal arrangement of gas and liquid hydrogen volumes

The internal gas cell arrangement and operation were first described in patent US8336810B2. Hydrogen storage tanks (301a – n) are high-pressure tanks or other storage devices that carry the pressurized gaseous or liquified hydrogen cargo. These liquid hydrogen storage tanks are distributed along the length of the airship, alternating with air-filled compartments (302a – n) containing expandable gaseous hydrogen bladders (305a - 305n).



Generic interior arrangement of the liquified hydrogen transport airship. Source: Patent US8336810B2, Figure 3

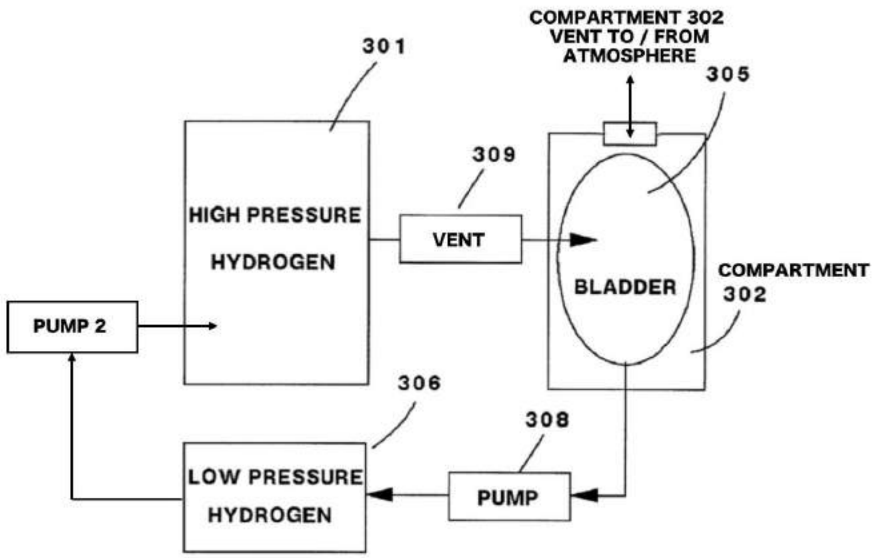
The air-filled compartments (302a – n) are at ambient pressure. The large expandable bladders (305a - 305n) in these compartments can contain variable amounts of gaseous hydrogen as needed to provide more or less aerostatic lift. These bladders are managed by a variable buoyancy and trim control system.

Operation of the variable buoyancy and trim control system

Patent US8336810B2 provides the following description of airship flight operations:

> "The bladder system allows simultaneous control of both lift and fore-aft trim. When the craft is not moving horizontally, adjustment of bladders in different parts of the ship allow trim control. After the craft acquires a horizontal speed, trim can also be controlled by the airfoils and engine directions…. At altitude and speed, the bladders can be set to achieve approximately neutral buoyancy with trim and with part of the lift then being provided by the structure itself according to aeronautical principles, with trim being almost exclusively controlled by the airfoils and the engine directions. In general, the craft …..ascends and descends at relatively slow horizontal speeds, relying on buoyancy control, and moves at high horizontal speeds at altitude for long distance travel, relying on airfoils and engines for thrust and/or control."

The general schematic for the variable buoyancy control system is shown in the following diagram, which has been modified from the original patent figure to show additional system features described in the patent text.



Variable buoyancy control system process flow diagram.
Source: adapted from Patent 8336810B2, Figure 4 (2008)
to show Pump 2, as described in the patent.

When additional lift or trim is desired, hydrogen from a high pressure hydrogen tank (301) is vented via a control valve (309) into a particular bladder (305), expanding it into the associated compartment (302). As the bladder expands, air at ambient pressure is forced out of the compartment and is vented to the atmosphere. The compartment becomes lighter, increasing overall aerostatic lift and possibly affecting trim.

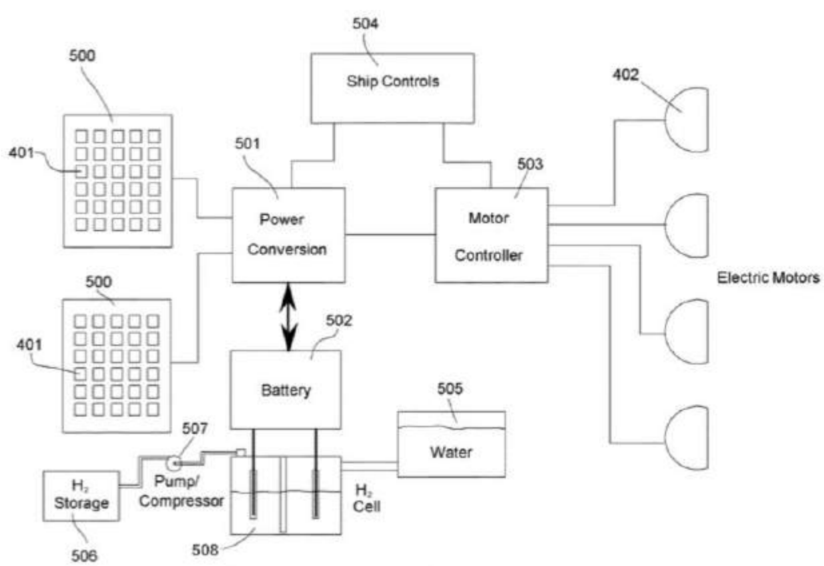
When less lift or trim is desired, a pump (308) draws hydrogen out of a bladder (305), causing the bladder to contract, and delivers it to a low pressure hydrogen tank (306). In this manner, no hydrogen is mixed with air, vented or wasted. The low pressure hydrogen can be saved in the low pressure tank, transferred to another tank, ducted to the engines for use as fuel, or it can be pumped back into the high pressure tank using a second high pressure pump. As a bladder contracts, atmospheric air is drawn in to maintain the compartment (302) at ambient pressure. The compartment becomes heavier, decreasing overall aerostatic lift and possibly affecting trim.

Power conversion system

As described in Patent US10308340, a hybrid battery / photovoltaic system is the primary source of power for the H2 Clipper. Solar panels on the top of the airship (500) charge the battery (501) during daylight hours and supply airship loads.

Excess power production can be used to drive a "hydrogen conversion cell" (508, an electrolyzer) to produce hydrogen and oxygen from water stored on board. The produced hydrogen is stored and the oxygen is vented to atmosphere.

None of the issued H2 Clipper patents propose using hydrogen fuel cells as the primary source of power for the airship. However, that is expected to change. With the huge hydrogen inventory available from the cargo and the lift gas, a hydrogen fuel cell would have an almost inexhaustible, 24/7 supply of reactants (hydrogen and oxygen) for fuel cell generation of electricity to power electric engines, and the solar array would provide supplemental power. Water generated from hydrogen fuel cell operation could be used to augment ballast and/or for trim control.



H2 Clipper hybrid battery / solar photovoltaic power conversion system with a "hydrogen conversion cell" (508, an electrolyzer) for hydrogen production. Source: adapted from Patent US10308340B2 Fig 6 (2016) to correct the item number of the hydrogen conversion cell (508).

UAV-assisted mooring

While the airship is designed for VTOL operations from remote sites without mooring or docking facilities, two approaches have been developed for securing the airship at a destination, one using a mooring tower and one using a docking cradle.

A means for mooring the nose of the airship to a mooring tower was first defined in 2008 in Patent US8336810B2. In patent Figure 2-C, a lightweight guide cable (216) fastened at one end to a reinforced connector (215) at the nose of the airship is carried through a gimbaled attachment (218) at the top of the mooring tower by an unmanned aerial vehicle (UAV, 217). Once the light-weight guide cable is engaged, a larger diameter cable is hauled through the attachment. Then the airship can be hauled in and secured to the mooring tower. A mooring mast allows the airship to swivel 360º to keep its nose pointed into the wind. The H2 Clipper airship requires an outdoor landing area with a radius of 1,200 feet (366 m) with the mooring mast at the center. A hangar would measure about 1,100 x 165 feet (335 x 50 m).

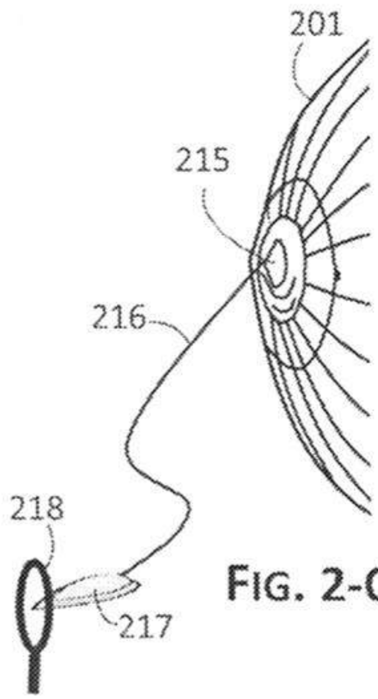
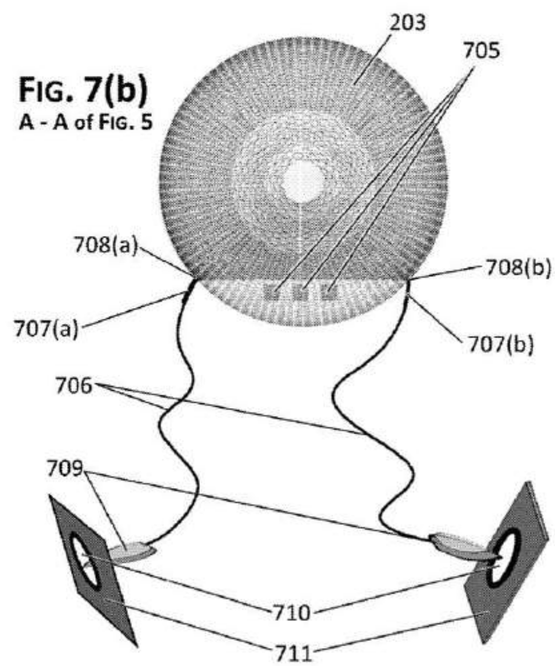


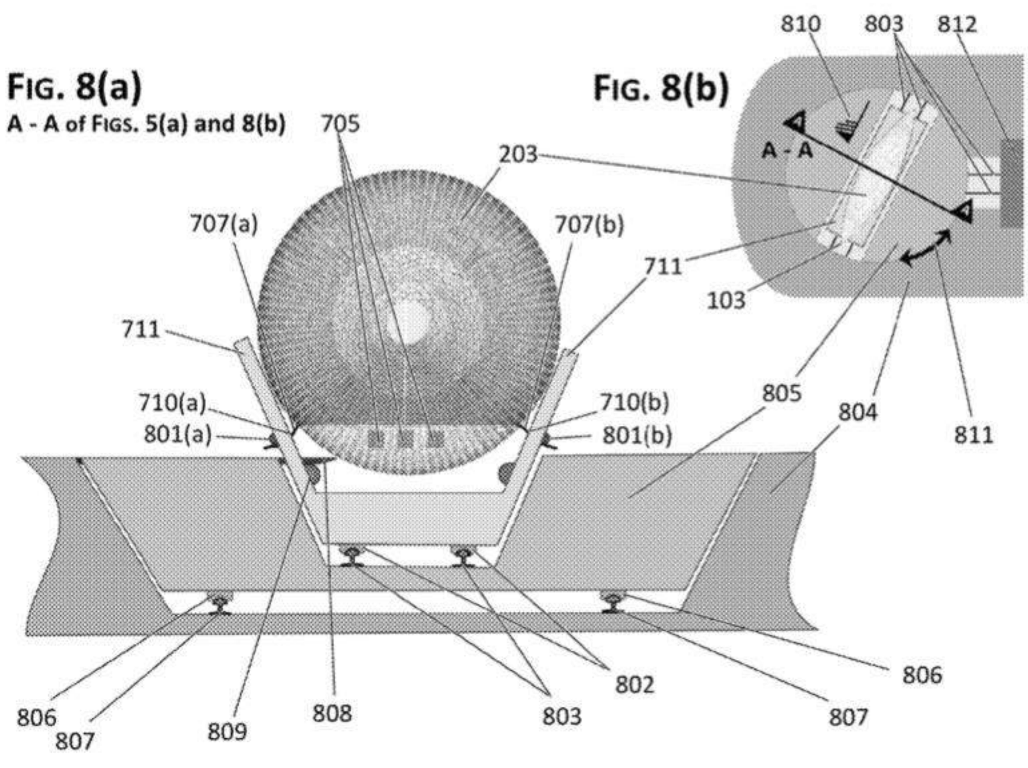
FIG. 2-C

A small UAV carries a guide cable into a mooring tower catchment. Source: Patent US8336810B2, Figure C-2 (2008)

Patent US11066145B1 Figures 7(b), 8(a) and 8(b) introduced an alternative approach in 2020 of using UAVs (710) to draw at least two guide cables from the lower part of the hull through two or more ports (710) in a rotating docking cradle (711). The airship is hauled in and secured to the docking cradle, which can rotate 360º to point into the wind or to align the airship for transfer into a hangar (812).



Two small UAVs carry guide cables into two ports on a docking cradle. Source: Patents US11066145B2 & US11396356B2, Figure 7(b) (2020 & 2022)



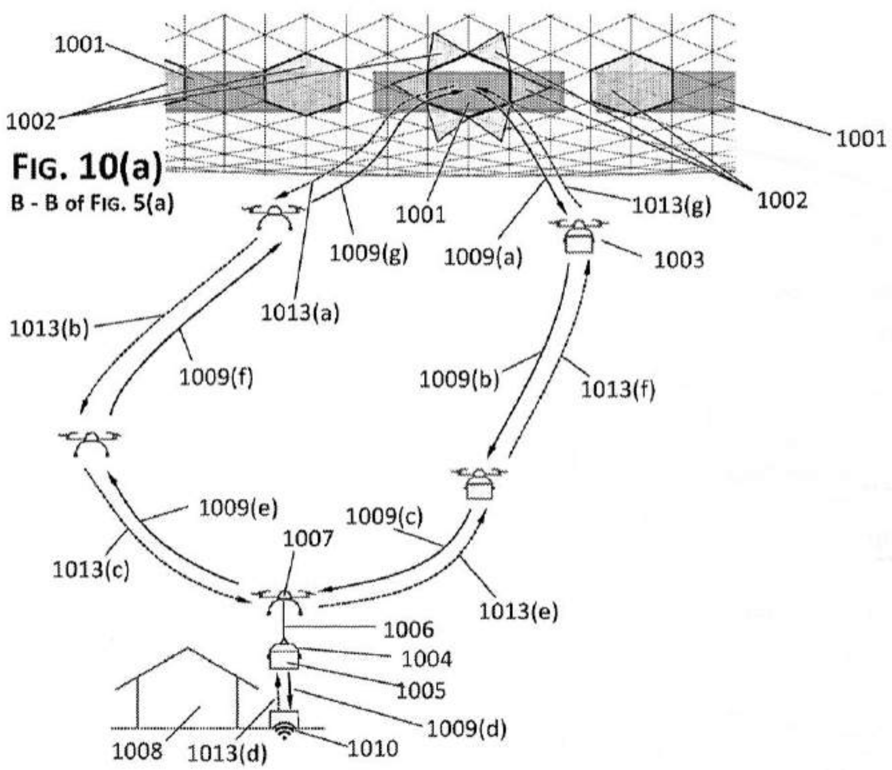
The airship (203) secured in a rotating docking cradle (711) via anchor points (710a & b). Source: Patents US11066145B2 & US11396356B2, Figures 8(a) & 8(b) (2020 & 2022)

Flying warehouse functionality

The H2 Clipper is conceived as a multi-mission airship. One potential role is to serve as a flying warehouse.

As described in Patent US11066145B1, the airship could land at a customer's distribution center to load new deliveries and off-load items picked up on the previous flight. Then the airship would deploy on a specified delivery route to make in-flight deliveries and pickups with the aid of cargo UAVs that are launched and recovered from a cargo bay located inside the airship's exoskeleton hull.

Details of the UAV launch and retrieval apparatus are not disclosed in this patent.



Cargo UAVs are launched and recovered from a cargo hold (1001) within the exoskeleton and make deliveries to, and pickups from, customers on the ground. Source: Patents US11066145B2 & US11396356B2, Figure 10(a) (2020 & 2022)

5. H2 Clipper airship design evolution

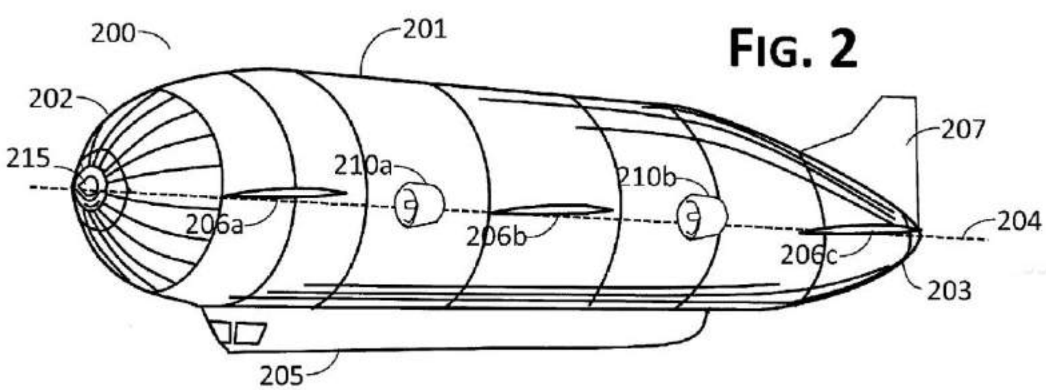
From the outset, the H2 Clipper was designed as a scaleable airship that can be mass produced and built in various sizes to meet the needs of a specific application. The design of the H2 Clipper has evolved since its introduction in 2012. Four design iterations of the full-size H2 Clipper airship are addressed in this section.

H2 Clipper Inc. is developing a 40% scale, 400-ft (122-m) long prototype airship that completed its preliminary design stage in 2019. Work was expected to start on shop drawings 2022. Design details for this prototype have not yet been released.

Airship design is being developed in a 3-D CAD environment using the Dassault Systemes 3DEXPERIENCE® platform.

Notional hydrogen transport airship design, circa 2008 - 2013

The original H2 Clipper Inc. design concept for a hydrogen transport airship is described in patent US8336810B2, which was filed in 2008 and granted in 2012. This appears to be a notional design intended primarily as a point of reference for describing the basic internal structure of the airship and the operation of the liquified hydrogen cells, the gaseous hydrogen bladders and air cells and the buoyancy / trim control system.

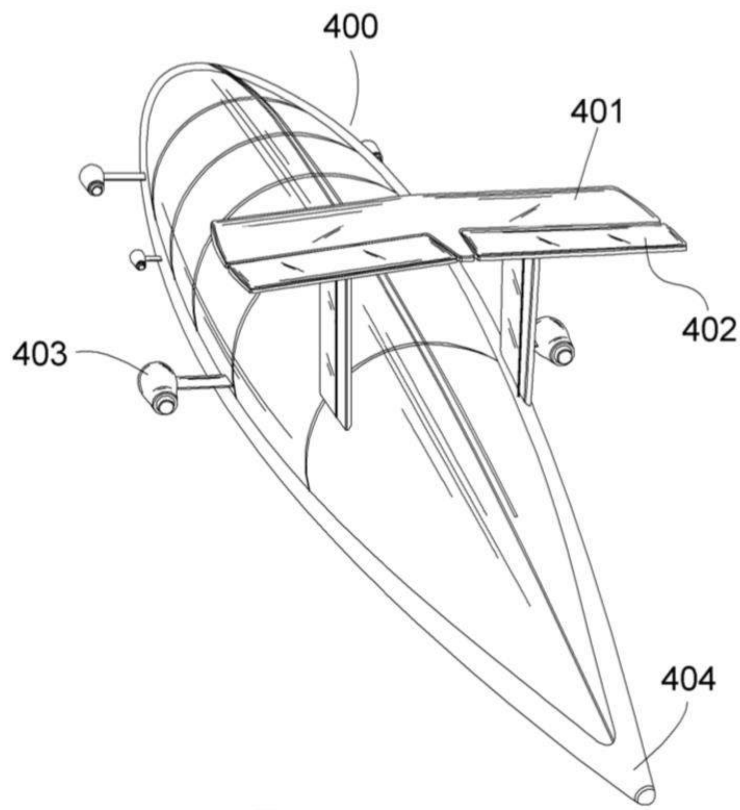


Legend: exterior shell (201), nose & tail cones (202, 203), gondola (205), vertical stabilizer / rudder (207), *thrust vectoring external engines (210a, b), horizontal all-moving* horizontal stabilizers / *elevators (206a, b, c)*

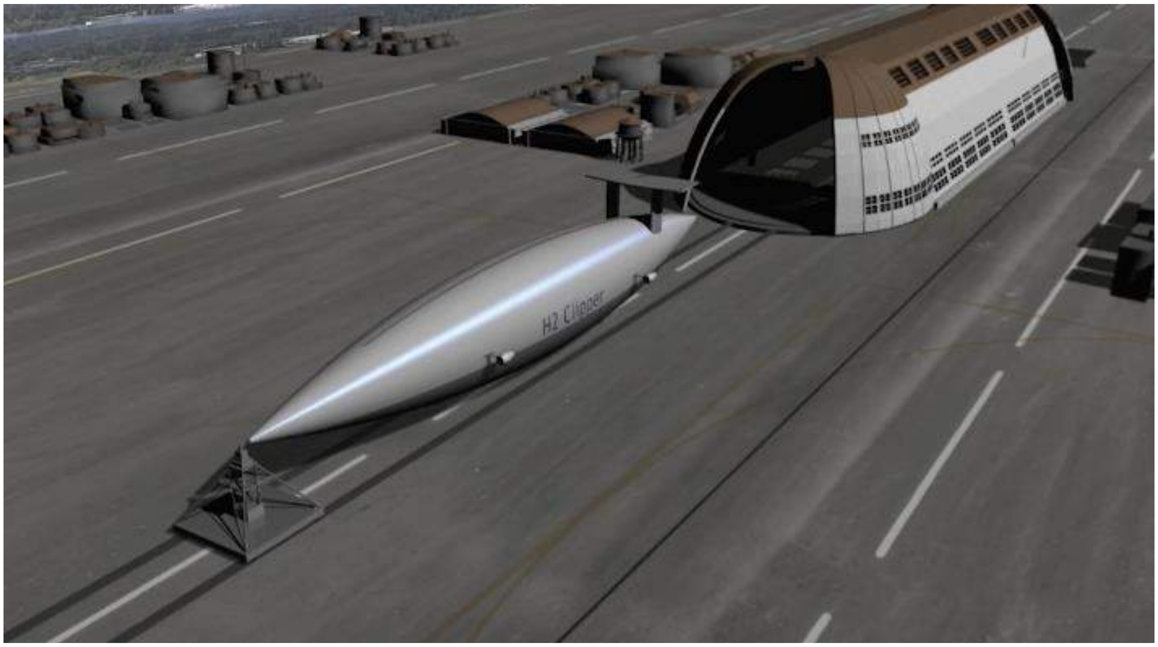
Generic exterior arrangement of the liquified hydrogen transport airship Source: Patent US8336810B2, Fig. 2

Early H2 Clipper design, circa 2013 - 2015

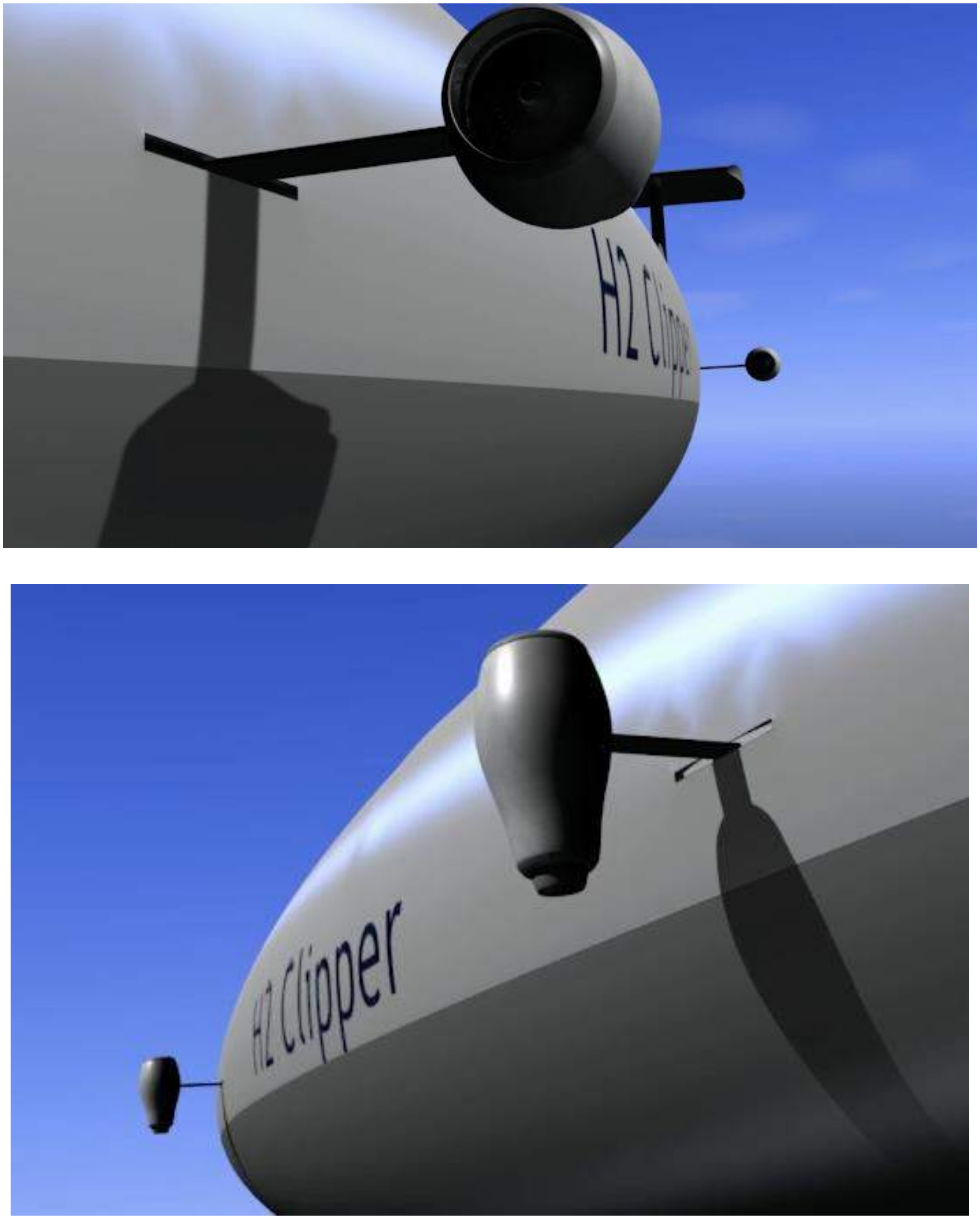
H2 Clipper Inc. introduced a highly-streamlined hydrogen transport airship as an "alternative embodiment" in patent US9102391B2, which was filed in 2013 and granted in 2015. This basic streamlined hull design has become a hallmark design feature of the H2 Clipper airship, with readily recognizable external refinements in propulsion engines and aerodynamic control surfaces.



Stern quarter view showing the double-T tail assembly (401) with control surfaces (402) and flank-mounted, thrust vectoring engines that burn gaseous hydrogen fuel.
Source: Patent US9102391B2, Figure 5A



Early design concept of the H2 Clipper airship shown outside of its hangar and taking off vertically from a mooring tower. Source, both graphics: H2 Clipper, Inc.



Vectoring high-bypass ratio turbofan engines burn gaseous hydrogen fuel.
Source, both graphics: H2 Clipper, Inc.

Intermediate H2 Clipper design, circa 2020 - 2021

This intermediate design, which is described in patent US11066145B1, replaced the flank-mounted, high-bypass ratio turbofan engines with large, vectoring propellers in the same locations.

H2 Clipper profile view. Note the large, flank-mounted propellers.
Source: H2 Clipper, Inc. (circa 2020)

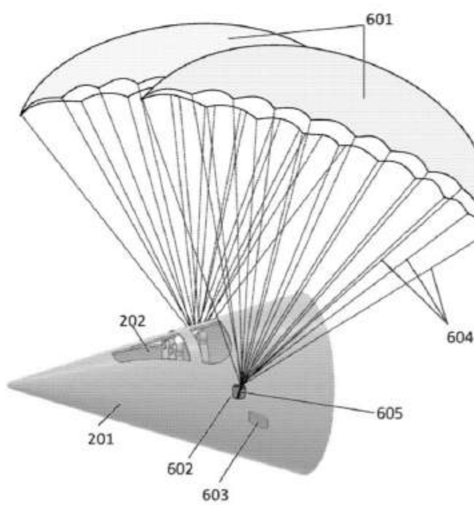
Patent US11066145 provides the following basic airship parameters:

Parameter	Early H2 Clipper design, circa 2020
Length	1,000 ft (304.8 m)
Diameter, max.	150 ft (45.7 m)
Propulsion	4 x flank-mounted, gaseous hydrogen-burning turbo-props
Speed, max.	Greater than 200 mph (322 kph)
Operating altitude	1,000 to 15,000 feet (305 to 4,572 m)
Payload, max.	220 tons (200 metric tons)

The H2 Clipper has a high fineness ratio (length / diameter) of 6.7, which is higher than the LZ 129 Hindenburg, which was 5.95. This streamlined design is intended to help maintain laminar flow over the outer surface of the airship and thereby reduce the drag coefficient.

The geodesic structure of the rigid hull terminates before the highly curved “pointy ends” of the airship. The crew compartment and the tail cone will be separate fabrications that are attached to the ends of the geodesic hull. This provided an opportunity to design a crew compartment that can be separated from the exoskeleton hull during an in-flight emergency, enabling the crew to descend safely with the aid of parachutes.

FIG. 6



Crew compartment with parachutes deployed after separation from the airship. Source: Patents US11066145B1 & US11396356B2, Figure 6 (2020 & 2022

H2 Clipper bow quarter view showing the crew compartment at the nose, the flank-mounted propellers and the solar array on top of the hull. Source: H2 Clipper, Inc

Current H2 Clipper design, circa 2021

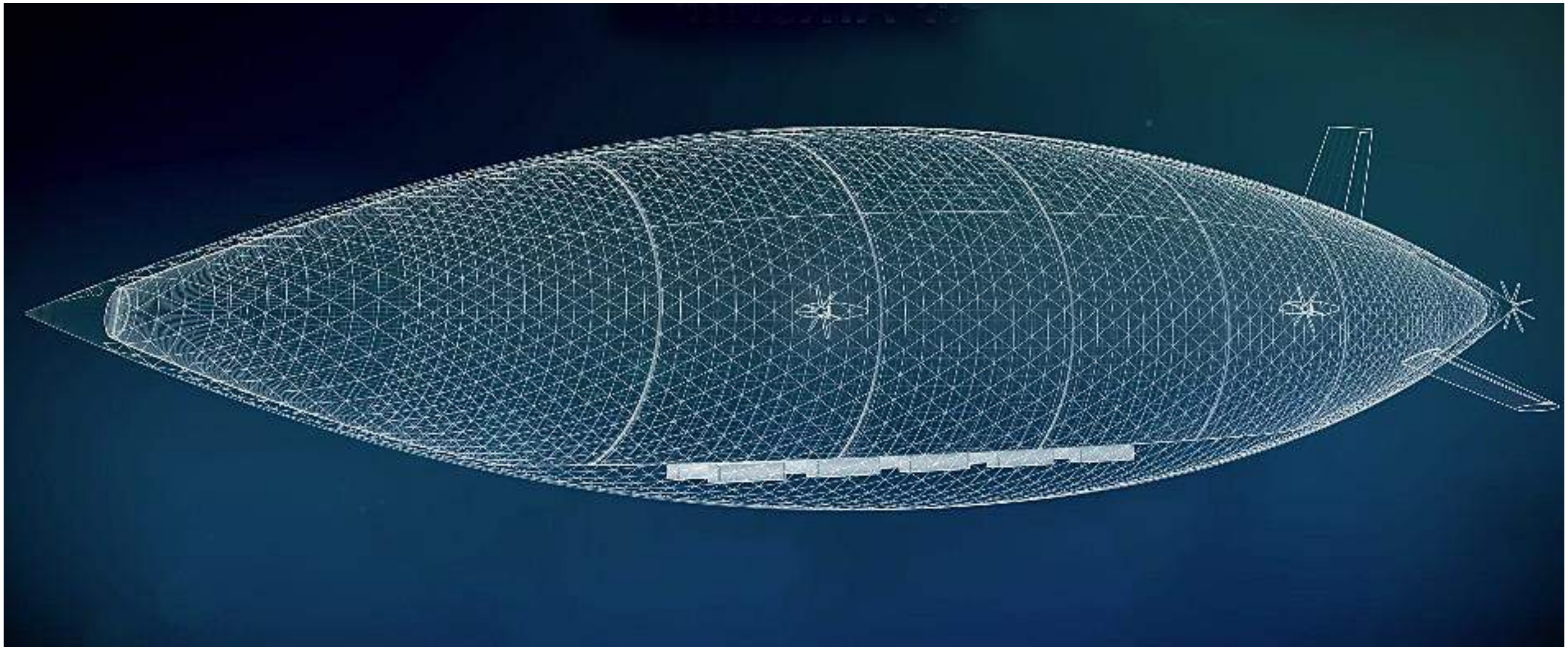
The current version of the H2 Clipper airship is a further refinement of the original streamlined design, with two notable external refinements: inverted Y-tail control surfaces replace the double T-tail, and a large propeller was added at the stern. H2 Clipper Inc. claims that the airship can deliver goods directly from a factory in China to a distribution center in the U.S. in less than 36 hours or virtually anywhere on the globe in 48 hours, with VTOL at both ends.

General characteristics of the H2 Clipper

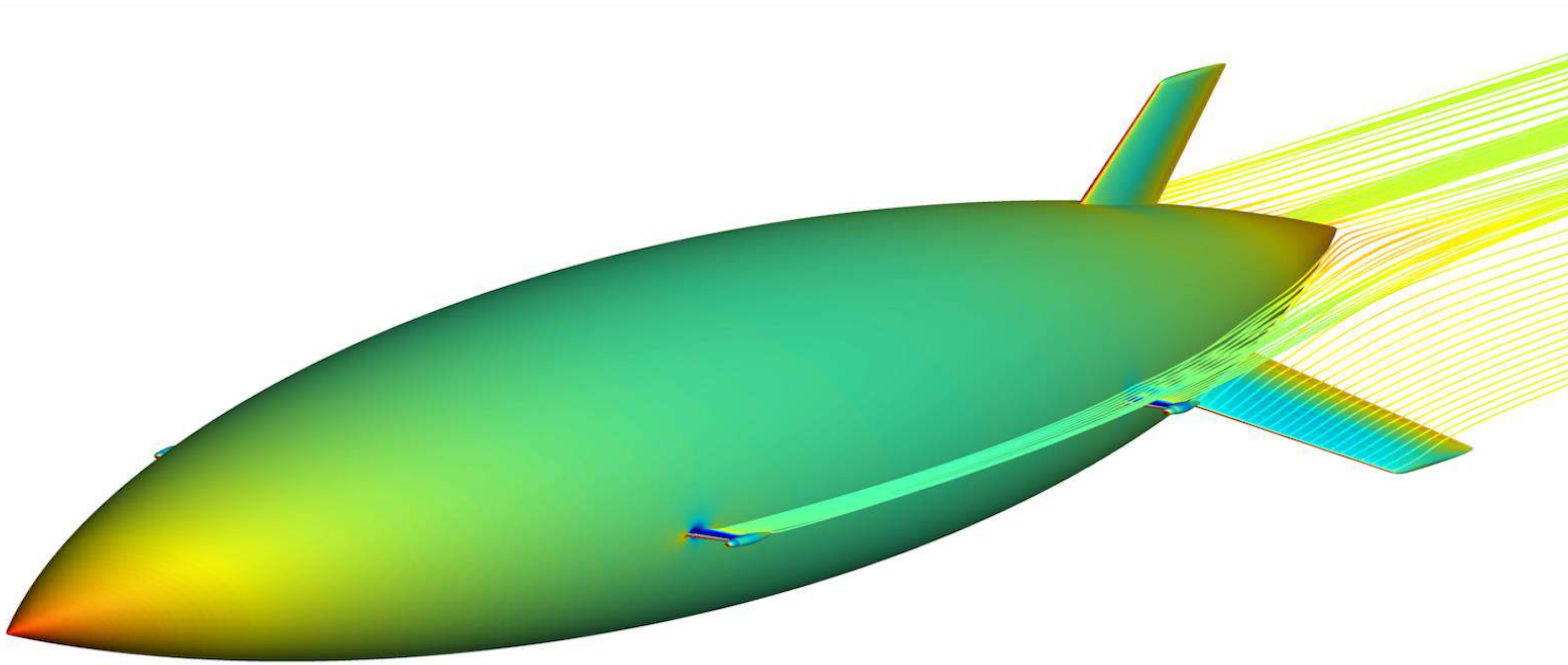
Parameter	**Current H2 Clipper design, circa 2021**
Type	Conventional, rigid, variable buoyancy, fixed-volume
Length	1,000 ft (304 m)
Diameter, max.	150 ft (45.7 m)
Lifting gas	Hydrogen
Fuel	Hydrogen
Power source	Hybrid system with hydrogen fuel cell production of energy for propulsion supplemented by a photovoltaic (PV) solar array on the hull
Propulsion & maneuvering	5 x propellers, powered by electric motors: • 4 x flank-mounted, 6-blade, thrust vectoring props • 1 x stern-mounted 8-blade fixed prop Capable of vertical takeoff and landing (VTOL)
Total power	33,200 shp (24,757 kW) from the 5 propulsion motors
Speed, max.	• 175+ mph (280 kph) • 7 to 10 times faster than contemporary cargo ships
Cargo volume	265,000 ft^3 (7,530+ m^3)
Range vs. payload	A function speed: • 6,000+ miles (5,200+ naut. miles / 9,656+ km) at 175 mph (280 kph) with a 170 ton (340,000 lb / 150,000 kg) payload • 1,000 miles (1,609 km) at 175 mph (280 kph) with a 245 ton payload (490,000 lb / 222,260 kg) • In addition to its hydrogen payload, the airship also has a cargo bay with a capacity for forty-five 20 ft ISO freight container
Estimated cargo transportation cost	About ¼ the cost of a contemporary air freighter: • < $0.25/ton-mile for ranges from 1,000 to 6,000 miles (1,609 to 9,656 km) (circa 2021)
Carbon emissions from operation	• Zero

H2 Clipper bow quarter view at takeoff. Source: Screenshot from H2 Clipper, Inc. video

H2 Clipper bow quarter view. Note the revised tailplanes. Source: H2 Clipper, Inc. (2021)



H2 Clipper bow quarter cut-away view showing the rigid geodesic frame within the smooth external skin, the placement of the flank- and tail-mounted propellers, the inverted-Y tail planes, and the cargo bay along the centerline keel at the bottom of the hull. Notice that the geodesic structure terminates before the fabricated nose and tail sections.
Source: H2 Clipper, Inc. (2022)



Simulated wind tunnel test using computational fluid dynamic (CFD) analysis illustrates the refined aerodynamic shape of the H2 Clipper's hull, with smooth airflow over the full length of the hull. Source: H2 Clipper, Inc. (2022)

H2 Clipper viewed from the bow.

H2 Clipper viewed from the stern quarter.
Note the inverted-Y tailplanes and tail-mounted propeller.

Rendering of an H2 Clipper flying over a metropolitan area.
Source, all graphics: H2 Clipper Inc. (circa 2021)

6. Manufacturing an H2 Clipper airship

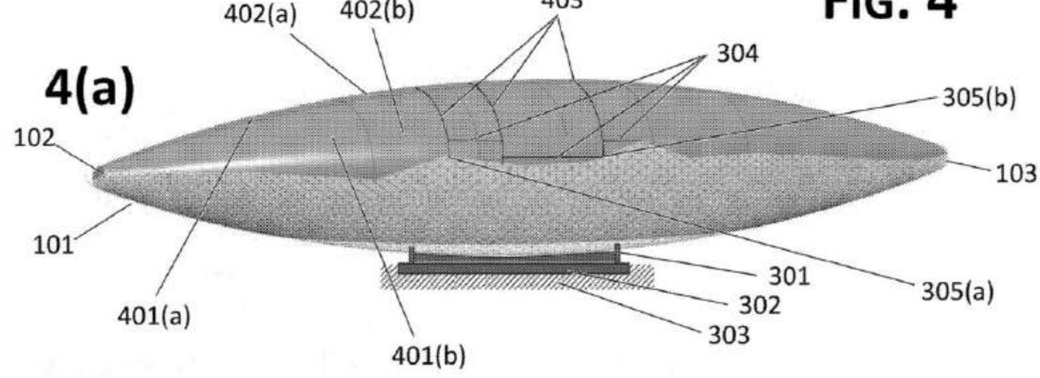
H2 Clipper Inc. is positioning itself as a supplier of midstream enabling technology to industry, with a mission to “develop and commercialize a global fleet of 100% green airships, to be built some by itself and 90% built by other licensee companies that will transform the hydrogen and air transport industry.”

H2 Clipper Inc. applied an advanced robotic technology called “swarm robotics” in its patented and licensable manufacturing process for geodesic exoskeleton airships. This process uses a team of mobile and floor-mounted robots, working in concert as a "swarm," to efficiently construct the massive exoskeleton at lower cost and in less time than would be possible using conventional, labor-intensive airship manufacturing techniques. H2 Clipper Inc. claims that the average time to construct an airship could drop to 12 months or less using the manufacturing processes described in patent US11851214B2, which filed in November 2022 and granted in December 2023. This patent describes both “bottoms-up” and “top-down” methods for robotically assembling a giant airship.

Bottoms-up approach

One bottoms-up approach starts with assembling the airship’s reinforced frame structures that later will support the interior cargo bay along the bottom centerline of the hull. In patent Fig. 4(a), a partially completed hull (101) is shown seated on a sled (301) that is coupled on a landing base (302) sitting on a reinforced foundation (303).

FIG. 4



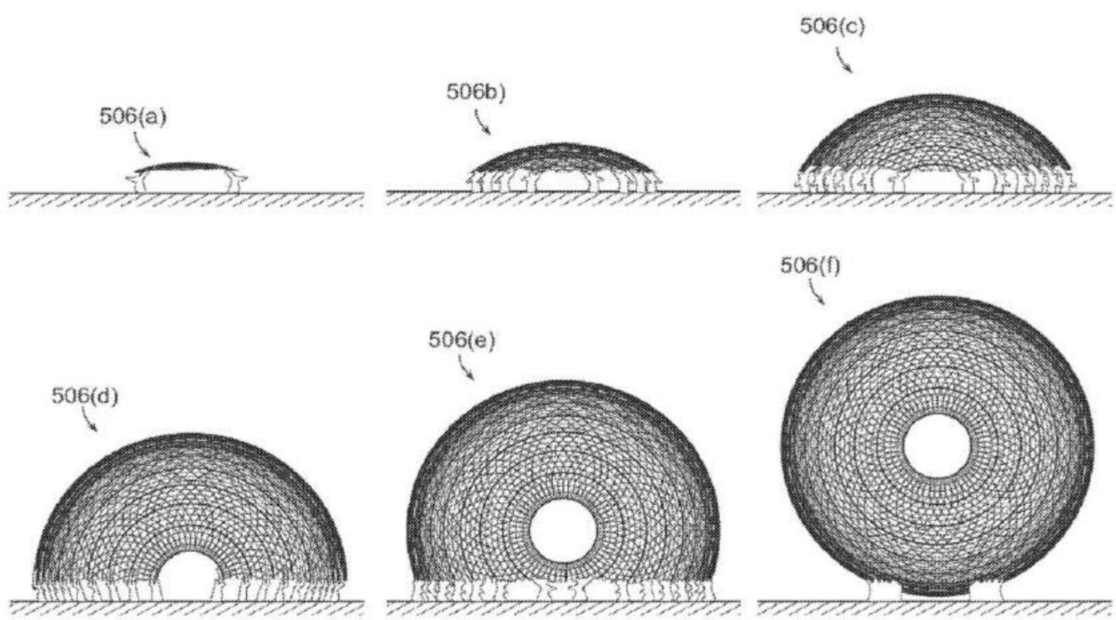
Partially-complete airship. Source: Patent US11851214B2, Fig. 4(a)

The sled may remain attached to the completed airship and serve as a water ballast tank and as the interface with compatible landing bases at any landing site. The landing base may include electrical and communications connections and the plumbing for loading and unloading liquid and gaseous hydrogen cargo and water ballast.

Air-filled cells [401(a), (b), 402(a), (b)] occupy the interior space of the airship and assist in stabilizing the partially completed exoskeleton during assembly. Vertical cables (403) over the top of the air-filled cells connect to posts [305(a), (b)] on opposite sides of the partially-completed exoskeleton and maintain a tension on the structure until the upper part of the exoskeleton is completed. The air-filled cells used during assembly are removed and replaced with the gas and liquid hydrogen volumes defined in patent US8336810B2, and described previously.

Top-down approach

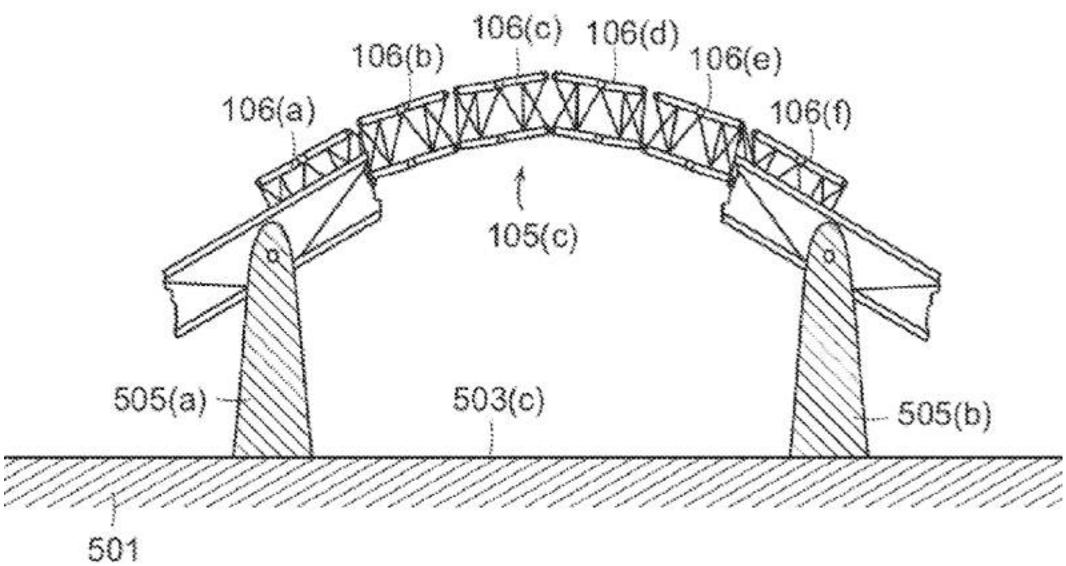
An alternative manufacturing approach described in the patent is a top-down process that starts by building the top of the exoskeleton first, then builds down the sides and finishes at the bottom of the exoskeleton, while the structure is supported by the heavy-lift, floor-mounted robots.



Top-down exoskeleton manufacturing process, starting at top left, and finishing at bottom right. Source: Patent 11851214B2, Fig. 5C

This top-down process is describes in the patent as follows:

> "….. a special class of heavy lift robots may be used in conjunction with other specialized robot worker classes to permit the airship to be produced from the top down, with the active assembly work surface remaining within a comfortable distance of the manufacturing facility floor. In such an embodiment, as upper sections of the airship are completed, the partially completed hull is pushed upward, making it possible to assemble more of its structure below the completed top, whereupon the process is repeated until the full airship has been assembled.
>
> In an illustrative embodiment of this approach, the outside surface material for the airship is attached to the structure as each successive portion of the hull is assembled rather than after the full hull is complete. And in yet an additional illustrative embodiment, other subsystems inside the airship and extending from the outside surface are also added as the working surfaces of the partially completed hull are added, rather than waiting to add such components until after the entire hull has been physically completed."



Schematic illustration of heavy lift robots [505(a), (b)] holding a partially-assembled transverse circular structural frame [106(a) to (f)] in place while robotic construction activities continue to add new sections of the structural frame along the lower edges. Source. Patent US11851214B2, Fig. 5(b)

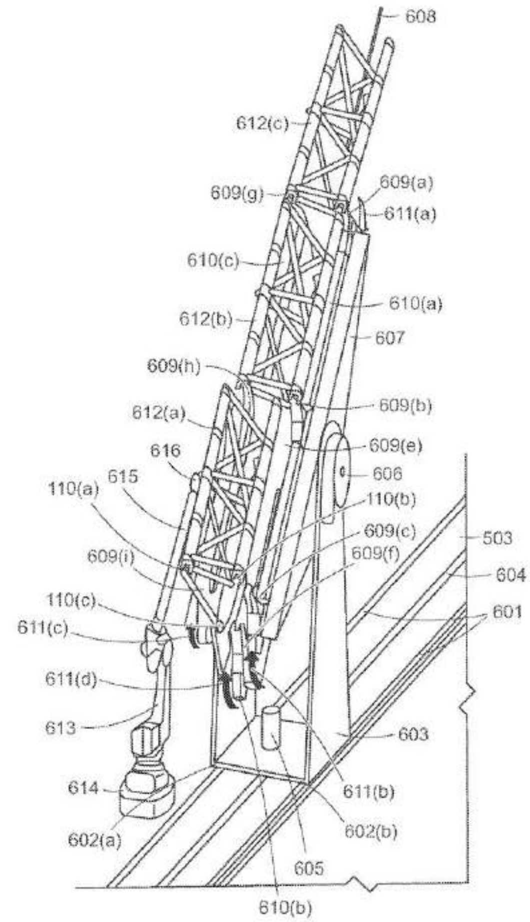


FIG. 6A

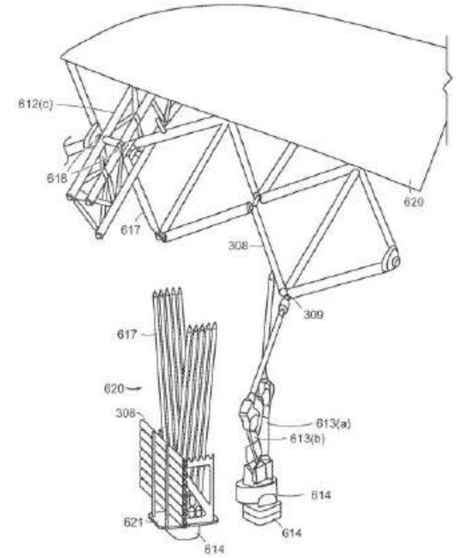
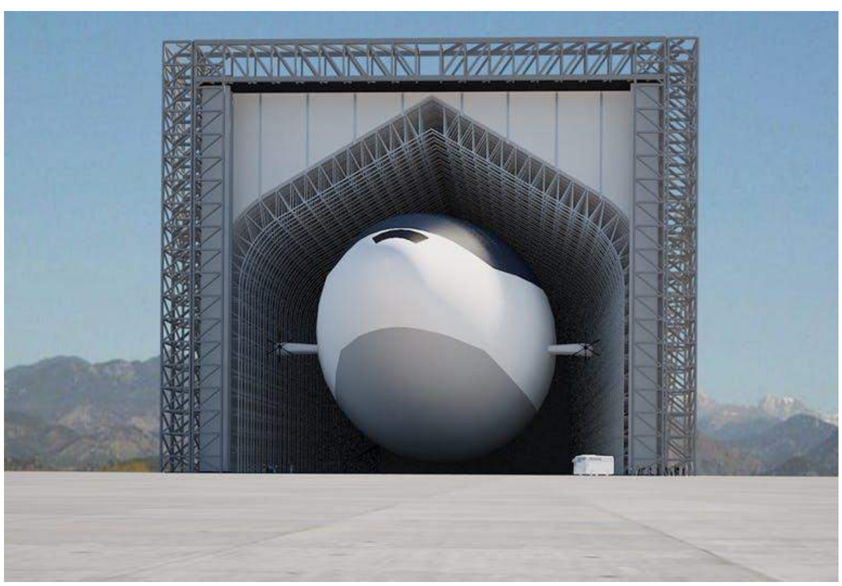


FIG. 6B

Floor-mounted heavy-lift robots, as shown in patent US11851214B2, Fig. 6A, move laterally on tracks as they assemble the exoskeleton's transverse circular structural frames. Mobile robots, as shown in patent Fig. 6B, complete the geodesic structure between each of the transverse frames. Source. Patent US11851214B2



A completed H2 Clipper in a hangar.
Source: H2 Clipper Inc. (circa 2022)

7. Hydrogen production and distribution processes

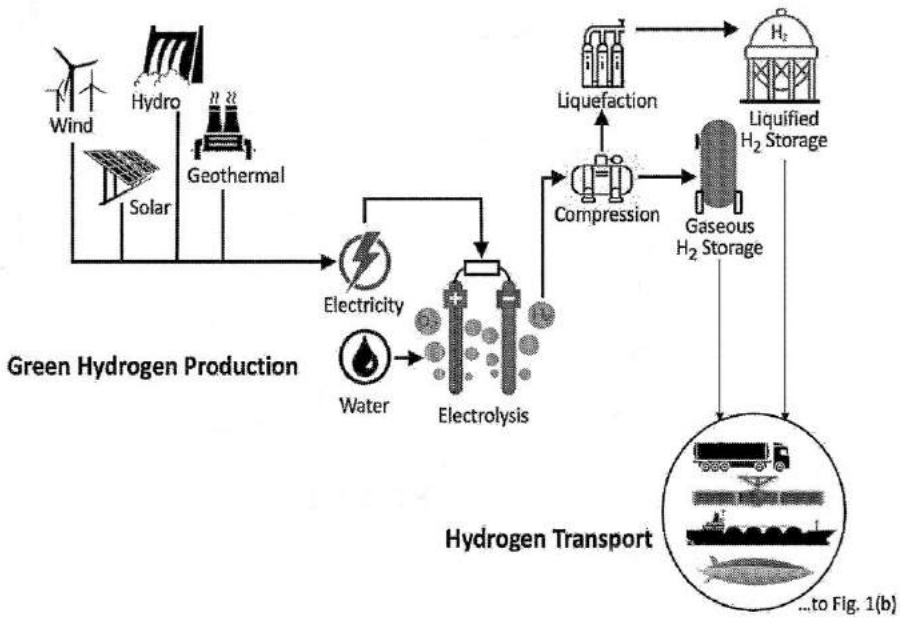
The market demand for H2 Clipper airships is predicated on there being a robust worldwide demand for hydrogen. In patent application US2023/0272883A1, Hydrogen Clipper Inc. provides an overview of hydrogen production and distribution infrastructures, their interfaces with various modes of transportation, including airships, and safety features intended to facilitate safe and efficient operation and transportation.

> "A system and method for transporting and distributing hydrogen, reducing the risk of hydrogen leakage, maintaining a record of provenance, and measuring and recording its purity level as it flows from source to destination to assure it complies with a predetermined range of values. The system includes a hydrogen delivery line made from metallic or non-metallic pipe that may be placed inside a safety pipe such that a channel is formed between an exterior of the hydrogen delivery line and an interior of the safety pipe. A sweeper gas or liquid may be injected into the channel to purge any hydrogen that might escape from the hydrogen delivery line, and one or more sensors may be used to detect and avoid the presence of an unacceptable level of hydrogen, or to stop the flow of hydrogen and remediate the problem well before a safety or environmental risk can occur."

In this patent application, Fig. 1(a) depicts the industrial process for producing "green hydrogen" from renewable electric power sources (i.e., wind, solar, hydro, geothermal), preferably in regions of the world where the price of electricity is low. The liquified and gaseous hydrogen products can be exported from a local storage terminal by a variety of means, including tanker truck, pipeline, surface vessel and specialized airships like the H2 Clipper.

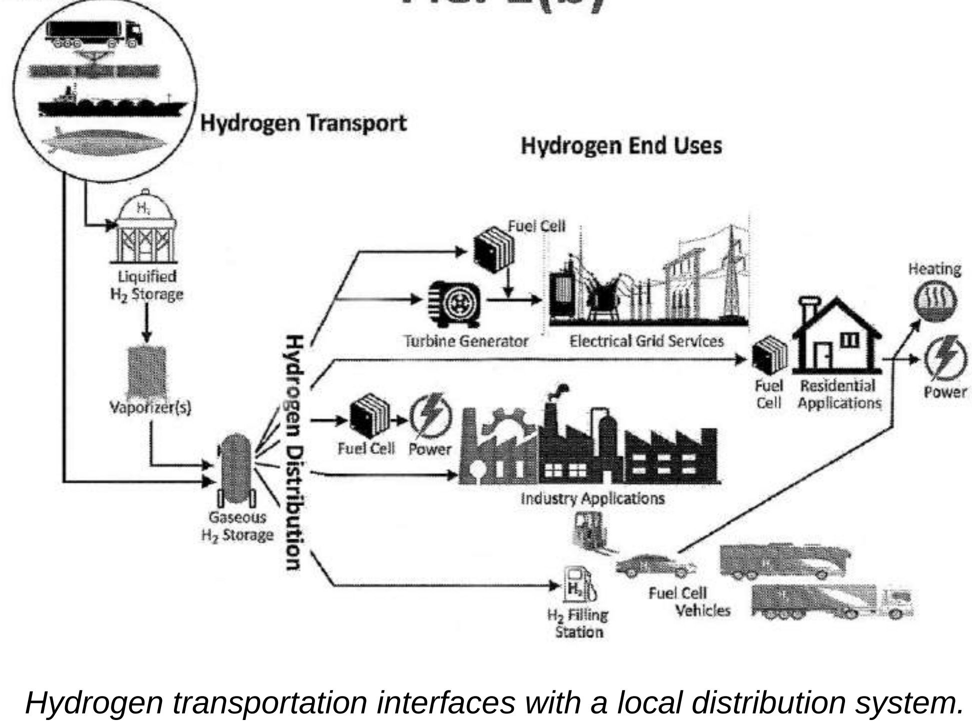
Figure 1(b) depicts the delivery of liquified and gaseous hydrogen to a region of the world with suitable hydrogen receiving and distribution infrastructure.

FIG. 1(a)



Hydrogen production infrastructure & interfaces with export transportation systems. Source: US2023/0272883A1, Fig. 1(a)

FIG. 1(b)

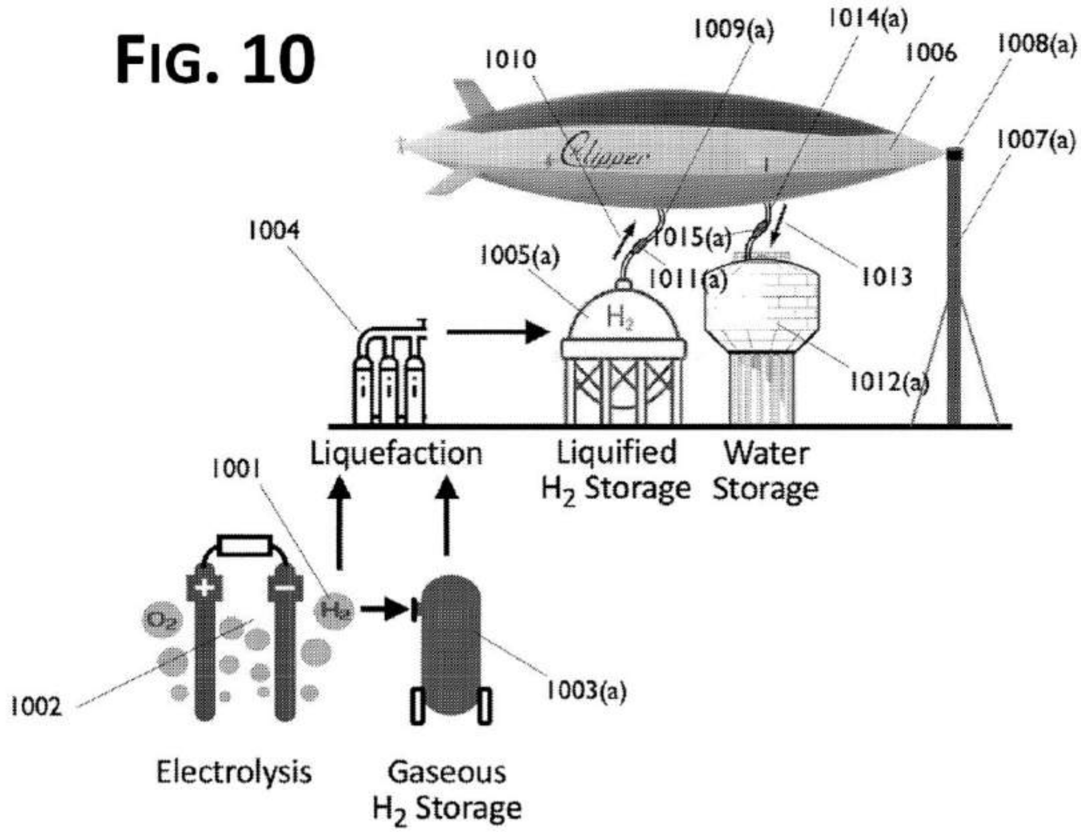


Hydrogen transportation interfaces with a local distribution system. Source: US2023/0272883A1, Fig. 1(b)

In international patent application WO2024/015906A1, H2 Clipper Inc., provides additional details on the interfaces between their H2 Clipper airship and the hydrogen production and distribution infrastructure.

Patent application Fig. 10 is a schematic diagram depicting the production and loading of liquid hydrogen (LH2) onto a hydrogen transport airship (1006) that is moored (1007, 1008) and hovering at a location where hydrogen is stored, awaiting export. As liquid hydrogen cargo is loaded (1010) from a ground storage facility, a corresponding weight of ballast water is simultaneously removed (1013) in order to maintain neutral buoyancy of the hovering airship within reasonable tolerances. The LH2 loading line (1010) and water discharge line (1013) are equipped with safety release valves [1011(a), 1015(a)] that ensure that no fluid (LH2 or water) escapes when flow in the respective line stops.

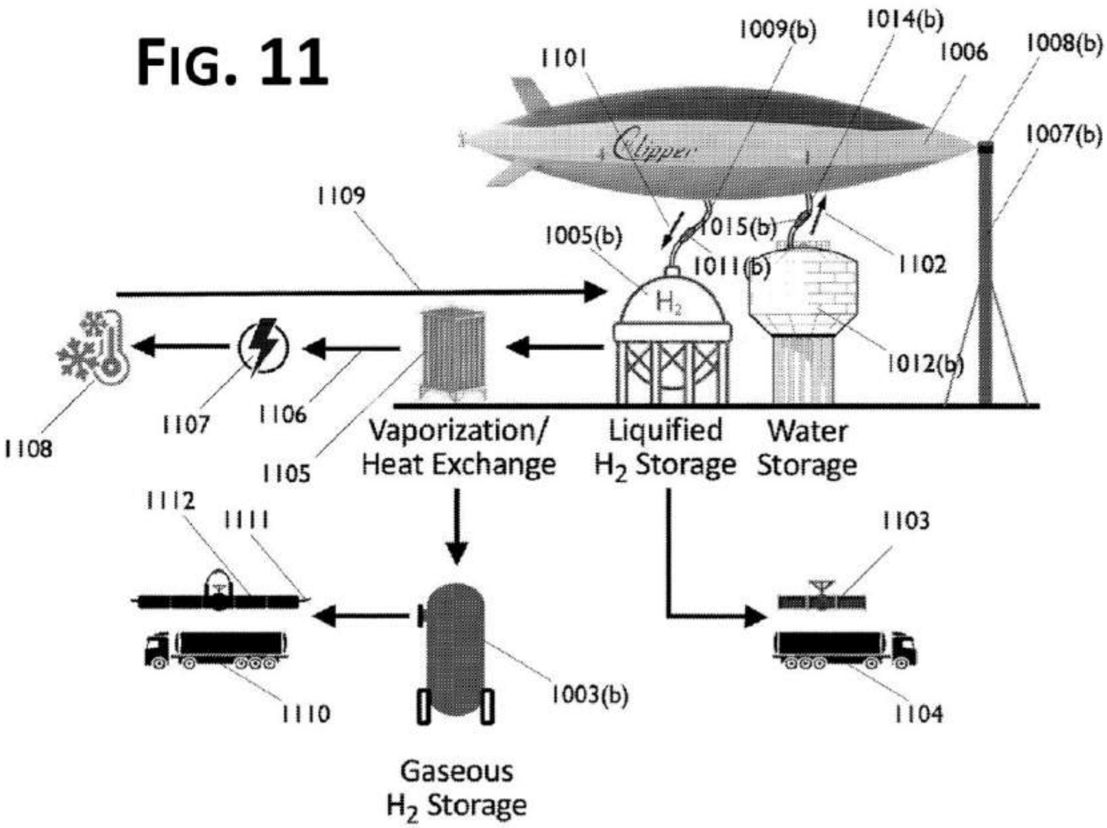
FIG. 10



H2 Clipper loading at a hydrogen terminal.
Source: WO2024/015906A1, Fig. 10

Figure 11 is a schematic diagram depicting the unloading of LH2 from a hydrogen transport airship moored and hovering at a receiving facility, and the temporary storage of hydrogen in liquid and/or gaseous form prior to distribution.

FIG. 11



H2 Clipper unloading at a hydrogen terminal.
Source: WO2024/015906A1, Fig. 11

As liquid hydrogen cargo is discharged (1101) from a hovering airship, a corresponding weight of ballast water is simultaneously uploaded (1102) from a ground storage tank [1012(b)] in order to maintain neutral buoyancy of the airship within reasonable tolerances. This diagram includes a gaseous hydrogen side-stream (1106) that supplies fuel to an on-site generator (1107) to power a refrigeration plant (1108) that maintains cryogenic conditions in the LH2 storage vessels [1005(b)].

Hydrogen can be distributed from the receiving facility as LH2 or as gaseous hydrogen via pipelines or land vehicles.

While WO2024/015906A1 depicts loading and unloading operations from a moored, hovering airship, these same operations can be conducted from an airship docked on the ground. As discussed previously, patent US11851214B2 describes several processes for assembling an H2 Clipper airship and notes that a sled may be attached under the hull of the airship to serve as a water ballast tank and as the interface with a compatible landing base. A hydrogen terminal can be fitted with a landing base that includes electrical and communications connections interfaces and the plumbing connections for loading and unloading liquid and gaseous hydrogen cargo and water ballast. Then hydrogen and water loading and unloading operations can be conducted on the ground, with the airship secured to the landing base.

8. For more information

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Videos

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- “Hydrogen airship vehicles may be used for green H2 transportation,” (2:26 min), posted by Hydrogen News, 10 January 2022: https://www.youtube.com/watch?v=A8nl_l2yyZI

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Other *Modern Airships* articles

- *Modern Airships - Part 1*: https://lynceans.org/all-posts/modern-airships-part-1/
    - LTA Research and Exploration LLC – Pathfinder 1 & 3 (geodesic exoskeleton hull)
    - Megalifter hybrid aircraft (geodesic exoskeleton hull)
    - Shell / Aerospace Developments (AD) - methane gas carrier
    - UPship - 150 meter natural gas carrier
    - Wendel R. Wendel - STAR*FLITE Airship (geodesic exoskeleton hull)
- *Modern Airships - Part 2*: https://lynceans.org/all-posts/modern-airships-part-2/
    - Kiev OKBV - Aerostatic fuel transportation system (SATT)
    - Lightspeed USA Inc. (LSI) airships (geodesic exoskeleton hull)
    - Novosibirsk OKB - Natural gas carrier airship
- *Modern Airships - Part 3*: https://lynceans.org/all-posts/modern-airships-part-3/