CIRA High Altitude Platform Systems (HAPS)

Peter Lobner, 29 February 2024

1. Introduction

Italian Aerospace Research Center (CIRA, Centro Italiano Ricerche Aerospaziali, https://www.cira.it/en/) has been involved in developing high altitude platform systems (HAPS) since about 2002, starting first with heavy-lift stratospheric balloons (2002 – 2010), and then a novel joined fixed-wing HAPS concept known as LVR-HALE (2006 – 2008). CIRA started a program in 2016 that considered a variety of HAPS configurations and led to the selection of a lenticular, lifting body-shaped, Hybrid High Altitude Airship (HHAA) to serve as a medium-size payload (25 to 100 kg / 55 to 220 lb) HAPS for a variety of missions. With a combination of aerostatic buoyancy and aerodynamic lift, the CIRA HHAA can be optimized in each phase of its mission profile and is expected to be able to lift the same payload mass to near space altitudes (about 20 km / 65,600 ft) as a conventional high altitude airship, but with a significantly smaller, though more complex vehicle.

CIRA High Altitude Hybrid Airship (HHAA). Source: CIRA (2017)

A technology demonstration project known as EuroHAPS was selected by the European Commission in July 2022 following a 2021 call for proposals for collaborative research and development projects in the defense sector. The CIRA HHAA was selected in March 2023 as one of three European HAPS design teams that will be contracted to produce HAPS technology demonstrators and conduct flight tests in Sardinia, Italy or Fuerteventura, Canary Islands in 2024. The three different HAPS will demonstrate a variety of intelligence, surveillance and reconnaissance (ISR) sensors and systems, such as:

- Lidar to detect and classify targets at sea or on land
- Communications intelligence (COMINT)
- Electronic intelligence (ELINT)
- Meshed broadband network communications

The three EuroHAPS projects are funded by the European Defence Fund (EDF) via a contract with a value is €43M (about $46M), which represents the maximum EU contribution to the project. This total will be split among the three winning teams projects. The EuroHAPS organization is collaborating with six European defense ministries, the European Commission, the French Sud regional authority and the Canary Islands region.

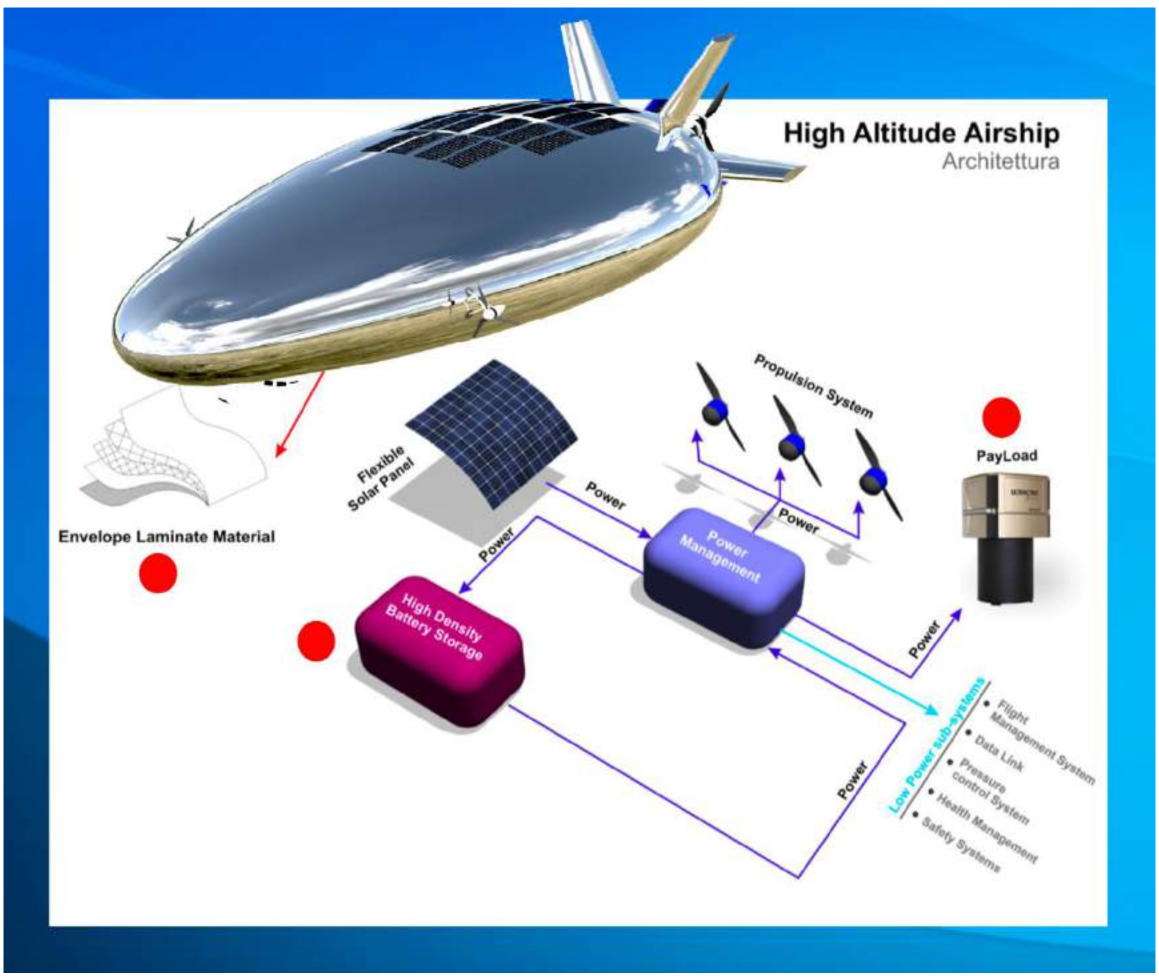
This article provides an overview of the CIRA HHAA and two CIRA HAPS design concepts described in the following Italian patent applications:

- IT202000015880A1, “Tactical hybrid stratospheric airship”
- IT202100002609A1, “Unmanned Type Hybrid Inflatable Aircraft”

2. CIRA HHAA design features

In October 2017, CIRA presented the basic architecture and performance characteristics for their HHAA, which generates both aerostatic and aerodynamic lift to balance the airship weight during the different phases of a mission. Key features of the HHAA design include:

- Lifting body-shaped lenticular hull
- All electric, hybrid solar / battery power system
- Vertical takeoff, nose first, like a partially-inflated balloon
- Powered flight 24/7 while on station
- Short aerodynamic landing, like a tropospheric hybrid airship
- Intended to be maintained / updated and reused after recovery



HHAA power system architecture. Source: CIRA (2017)

The onboard battery and the hull-mounted solar array provide the electric power needed to operate all loads 24/7:

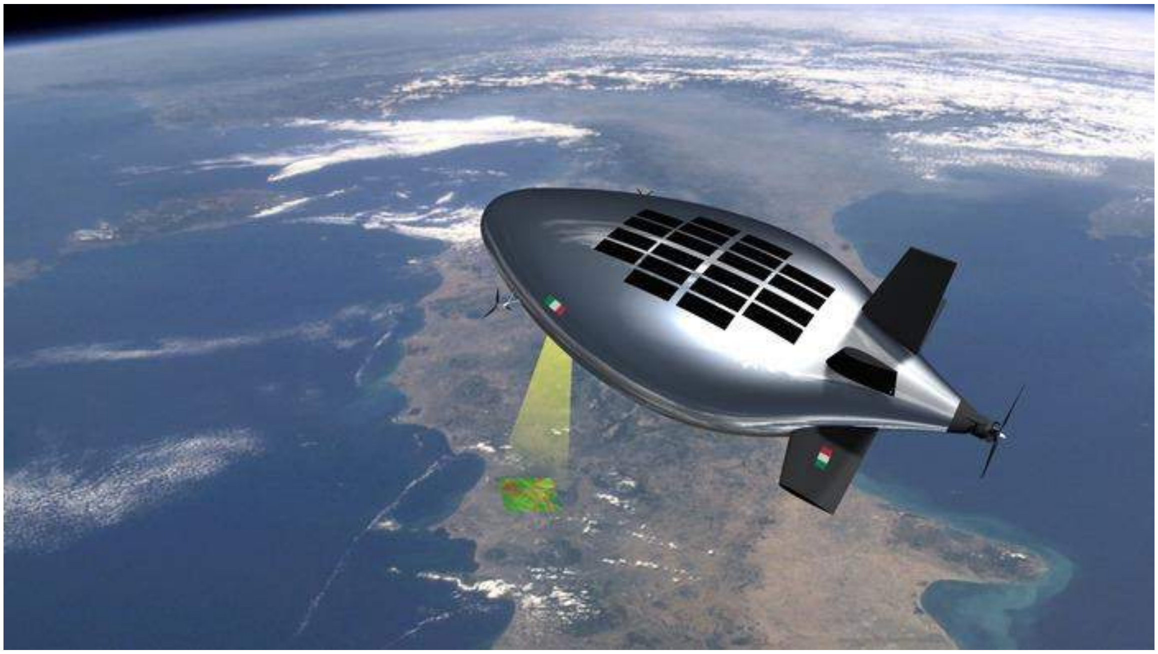
- Propulsion system
- Other airship systems, including flight management, pressure control, health monitoring, safety and communications systems
- Payload systems configured for the specific mission, such as environmental (optical, infrared, hyperspectral, lidar, and/or radar sensors), communications, and military (various ISR, COMINT, ELINT sensors),

The power management system maintains the battery charge at a level that can meet operational needs, even during a seasonal maximum 15 hour night duration.

General characteristics of the CIRA HHAA

Parameter	**CIRA HHAA**
Type	Hybrid airship
Length	29 m (95.1 ft)
Width	14 m (45.9 ft)
Height, overall	5.75 m (18.9 ft)
Envelope	• Lenticular, pressure-stabilized hull • Multi-layer laminated fabric • Air ballonet
Volume	1,210 m^3 (42,731 ft^3)
Buoyancy ratio	0.81 (81% of lift is aerostatic)
Power source	• Hybrid solar photovoltaic / battery system • Flexible, thin-film solar array on the hull • Battery capacity sufficient for 15 hour night duration
Propulsion system	• 1 x large stern-mounted, fixed electric motor-driven, 3-bladed main propeller • 2 x smaller flank-mounted, thrust vectoring (in the vertical plane) electric motor-driven propellers
Altitude, operating	18,000 to 20,000 m (59,055 to 65,600 ft)
Airspeed, cruise	16 m/sec (57.6 kph / 35.8 mph)
Wind resistance, max	25 m/sec (90 kph / 55.9 mph)
Maximum takeoff weight (MTOW)	< 300 kg (661 lb)
Payload weight, max.	25 kg (55.1 lb, at least 12% of MTOW)
Mission duration	4 months

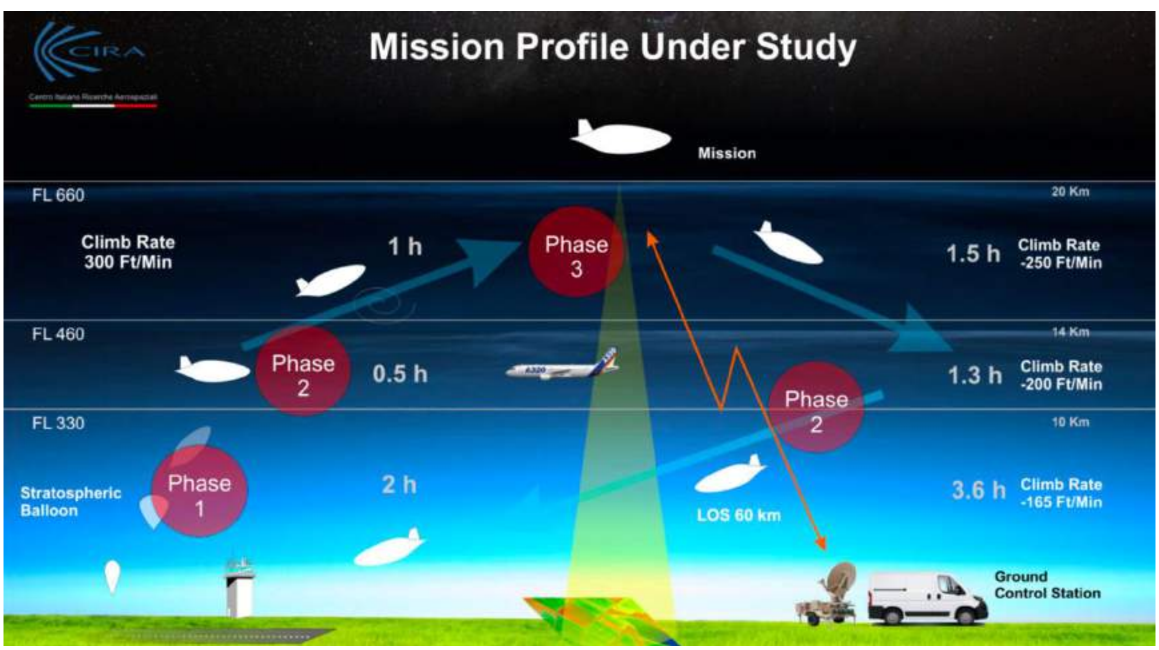
Source: V.R. Baraniello & G. Persechino (2022) + others



Rendering of HHAA on station. Source: CIRA (2017)

3. CIRA hybrid high altitude airship operations

The CIRA HHAA is designed for a nominal four month mission, with recovery at a designated landing site after the end of the mission. The basic mission profile is shown in the following graphic.



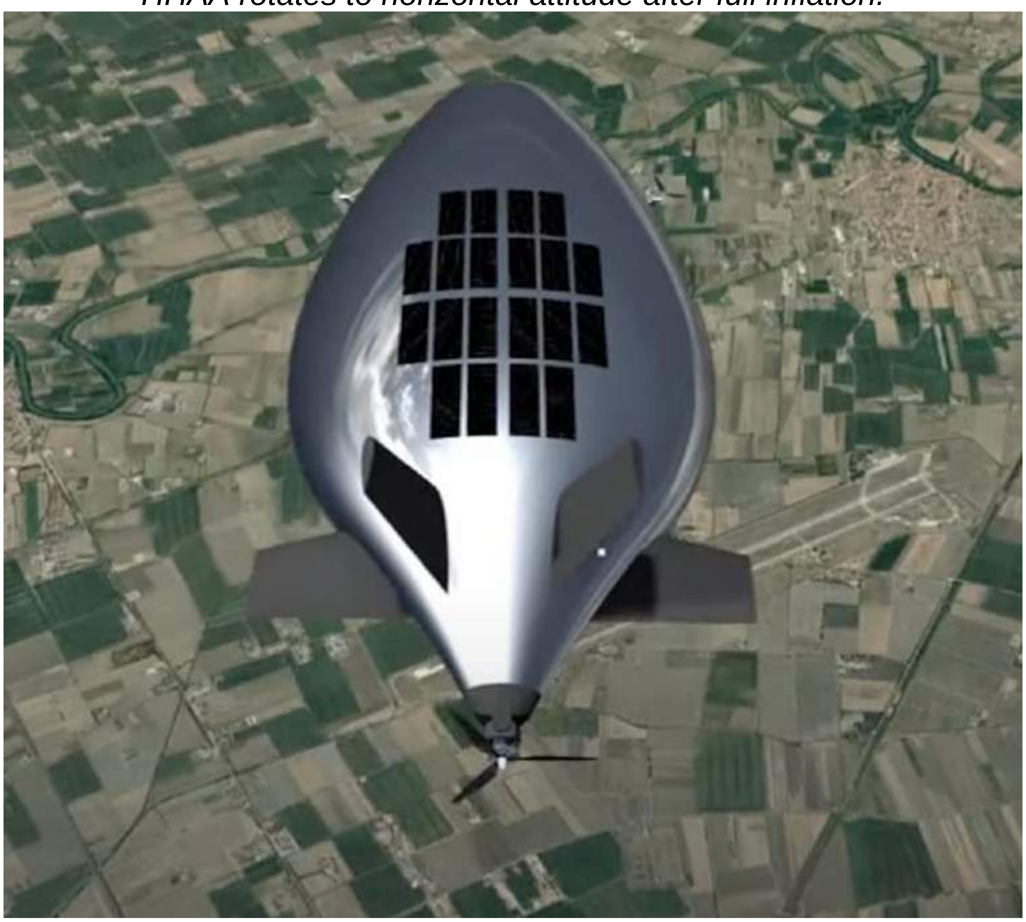
Source: CIRA (2017)

The vehicle launches vertically like a partially-inflated balloon and climbs under the influence of aerostatic buoyancy only. It can launch from a runway, an unprepared field or a ship. During ascent, the helium lifting gas expands and internal pressure will reach the superpressure necessary for the envelope to achieve its designed shape. The envelope will be completely inflated at an altitude of 10 to 12 km (32,800 to 39,370 ft) and will transition to an approximately horizontal attitude. Up to this point, the ascent of the HHAA is quite similar to ascent of the Southwest Research Institute (SwRI) HiSentinel stratospheric airship, which operated from 2005 to 2010.

The HHAA's aerodynamic ascent phase begins at an altitude of about 12 km (39,370 ft) and the electric motor-driven propellers are used to drive the hybrid airship to its operating altitude of 18 to 20 km (59,055 to 65,600 ft).

HHAA vertical launch (left) and initial vertical ascent (right).
Source, two graphics: Screenshots from CIRA video (2019)

HHAA rotates to horizontal attitude after full inflation.



View from above and behind the HHAA at a medium altitude.
Source, two graphics: Screenshots from CIRA video (2019)

The CIRA HHAA reaches its operating altitude about four hours after launch. From this vantage point, it has a viewing range of about 70 km (43.5 miles) with optical sensors and 140 km (87 miles) with radar.

The HHAA is a hybrid airship with a buoyancy ratio of 0.81 (81% of lift is aerostatic and 19% is from aerodynamic lift). This means that the vehicle must maintain airspeed to generate the needed aerodynamic lift to balance the gross weight of the HHAA. It is designed to cruise at 16 m/sec (57.6 kph / 35.8 mph) and can maintain position against a 25 m/sec (90 kph / 55.9 mph) head wind. On station, the HHAA maintains powered flight 24/7 in order to remain at its assigned operating altitude in the vicinity of its assigned geolocation.

Loss of integrity of the gas envelope or failure of all engines while on station in the stratosphere would terminate the mission, but the hybrid airship is expected to fall slowly back to the ground, perhaps with some possibility of control on the way down.

At the end of a mission, descent and return to base takes about 6-1/2 hours, during which time the descent of the heavier-than-air vehicle is controlled by vehicle aerodynamics. Descent speed is controlled to limit wing loading on the hybrid airship. Envelope internal pressure in maintained by inflating the ballonet with air during the descent.

After recovery, the vehicle will be maintained and, if needed, updated or reconfigured for the next mission.

Under the EuroHAPS program, a CIRA HHAA demonstrator is expected to fly in 2024.

4. CIRA patent application for a tactical hybrid stratospheric airship

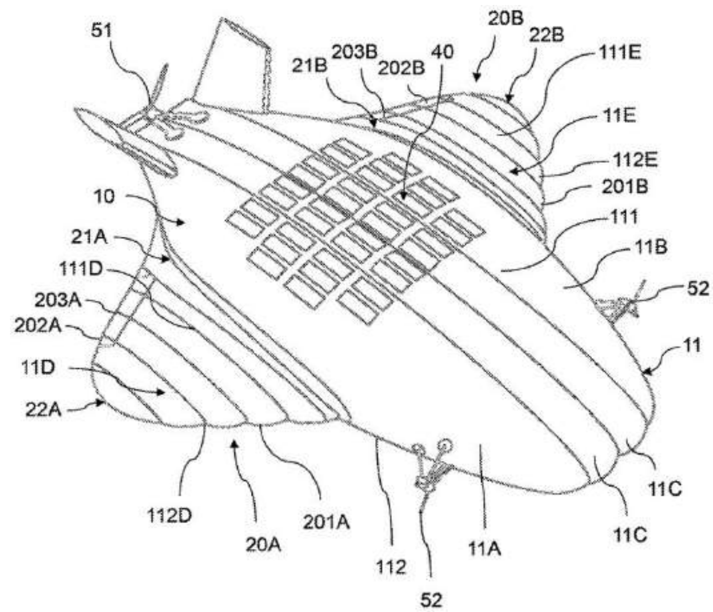
In July 2020, CIRA filed Italian patent application IT202000015880A1, "Tactical hybrid stratospheric airship," which describes a stratospheric airship design concept that is functionally similar to, but different in design, from the lenticular, lifting body HHAA described in the preceding sections. The "first embodiment" of this airship has inflated wings, as shown in patent Figures 1 to 4, which are reproduced below.

According to one embodiment, this scaleable airship has a length in the range from 10 to 40 m (32.8 to 131 ft), a width in the range 8 to 35 m (26.2 to 115 ft), a maximum takeoff weight (MTOW) in the range 25 to 450 kg (55 to 992 lb) and a payload in the range from 5 to 100 kg (11 to 220 lb). This is in the same size range as the CIRA HHAA described previously.

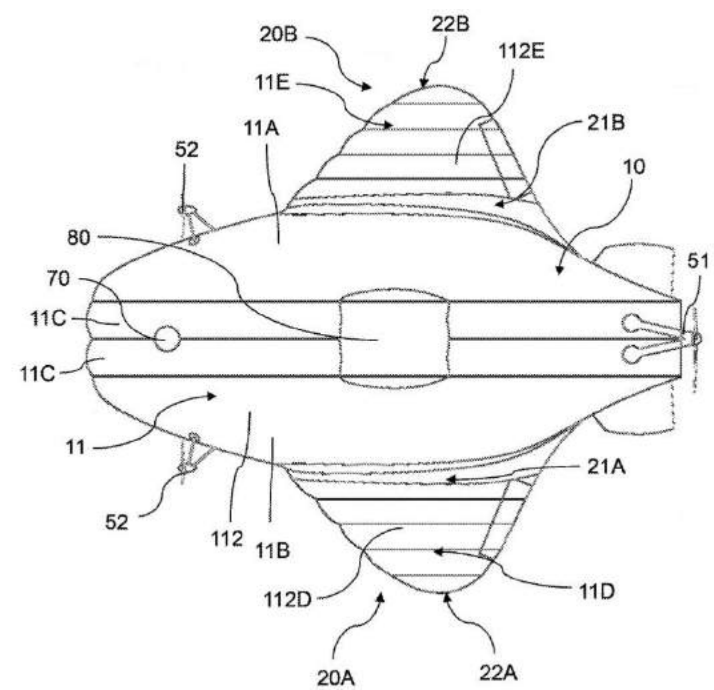
In the patent, CIRA notes that the airship may be employed in a variety of applications, "such as, but not limited to, border monitoring, environmental monitoring, precision agriculture, telecommunications, homeland security and emergency support."

The airship is fabricated from a combination of inflatable structural elements with different internal pressures, which are coupled to rigid substructures made from composite materials, aluminum or other suitable materials. All the inflatable elements of the airship are made from multi-layer laminated materials comprised of gas retention layer(s), structural layer(s), and protective layer(s).

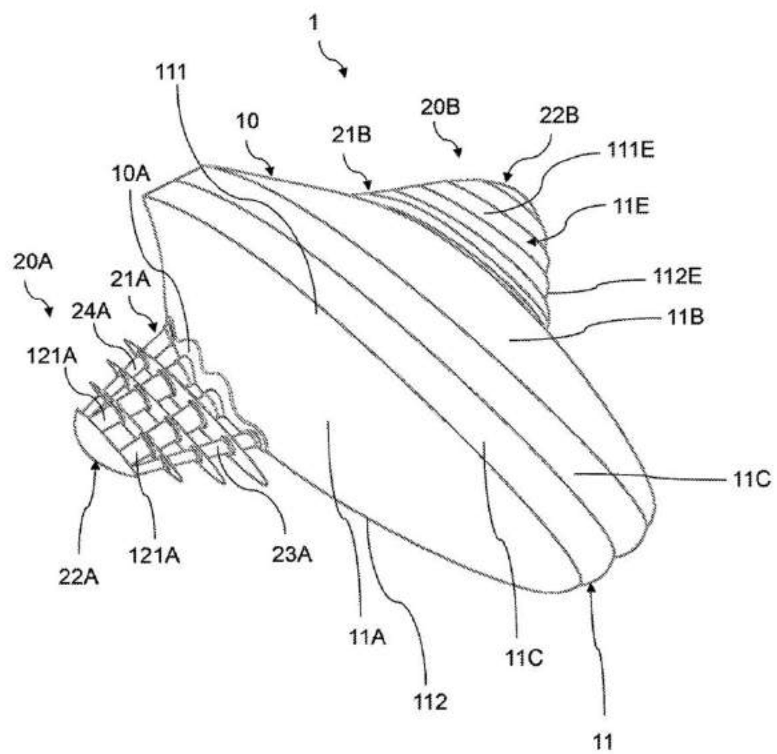
- The inflatable elements are the central body (10), the wings (20A, 20B), the main wing spar(s) (12) and the secondary wing spars (23A, 24A, 23B, 24B).
- The rigid substructures are the central body interfaces to the wings *(*10A, 10B), wing tips (22A, 22B) and rib interfaces with the spars (13A in the central chamber, 311A-313A, 321A-323A and 331A-333A in the wings).



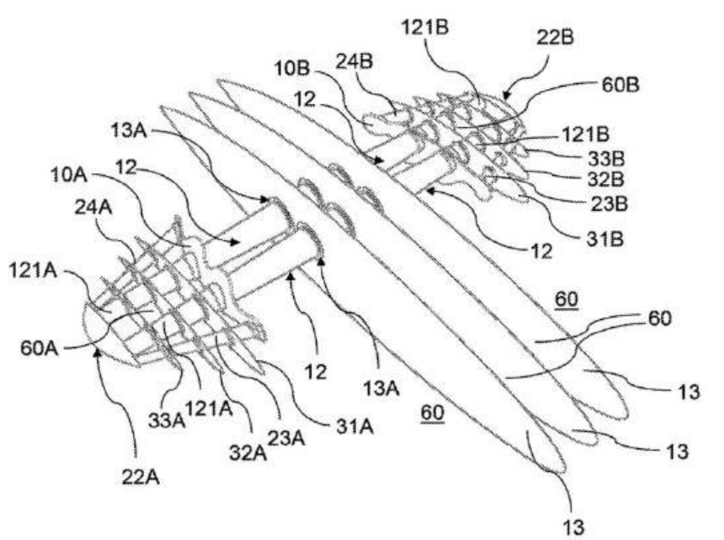
Legend: *Inflatable central body (10), center body outer surface (11, 11A – 11E), inflatable wings (20A, B) with wing upper surface (111D, E) and lower surface (112D, E), wing joint to center body (21A, B), wing tips (22A, B), wing leading edge (201A, B), trailing edge (202A, B) and aerodynamic control surfaces (203A, B). Propulsion system is comprised of a fixed rear propeller (51) and vectoring forward propellers (52). Solar array is on the top of the hull (40). Equipment is housed in bays accessed from the bottom surface (70, 80).*



General arrangement of the tactical hybrid stratospheric airship, top oblique view (above) & bottom view (below). Source: IT202000015880A1, Figs 1 & 2

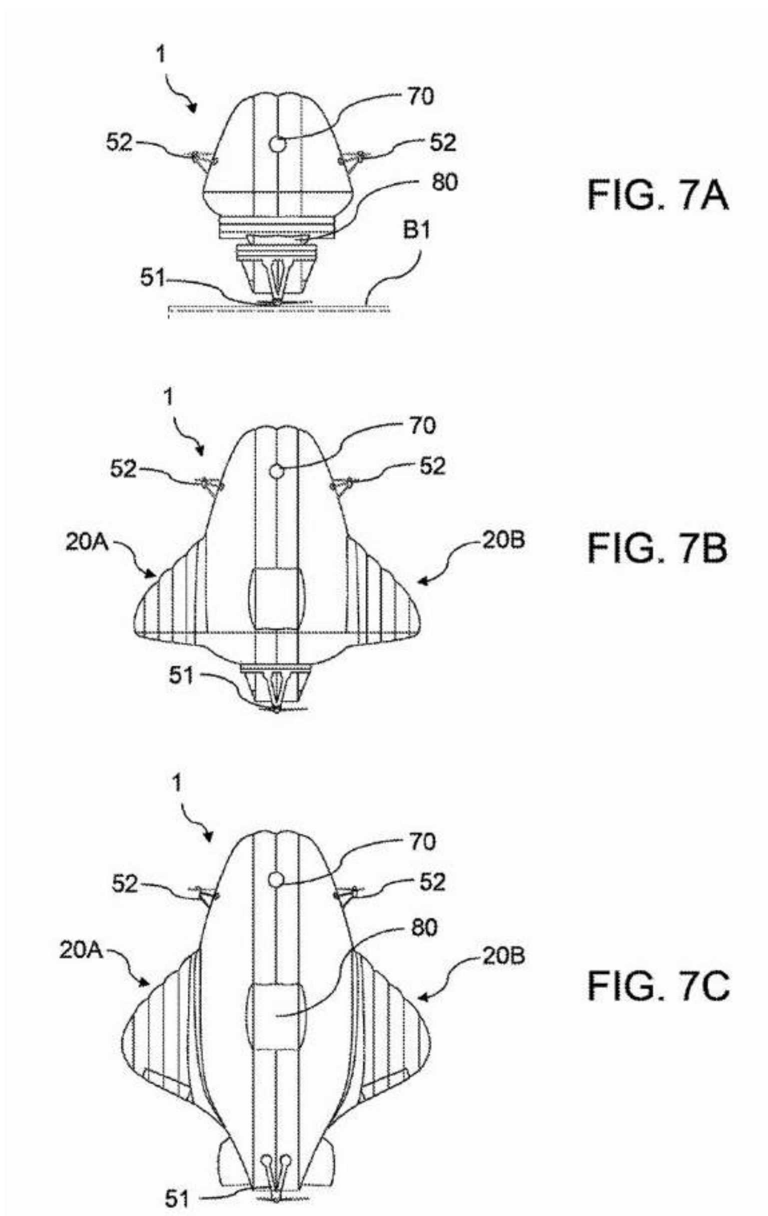


Legend: *The airship outer surface (111, 11A – 11E) is a multi-layer laminated fabric. Central body chamber (60) has ribs (13) that join the upper and lower surfaces of the hull and establish the aerodynamic profile. Wings (20A, 20B) have an internal structure comprised of inflatable main spar (12) and secondary spars (23A, 24A, 23B, 24B), with ribs (31A, 32A, 33A, 31B, 32B 33B) that join the upper and lower surfaces, and wing tips (22A, 22B). The wings join the fuselage at the central body interfaces (10A, 10B) and are supported from the ribs (13) at the rib interfaces (13A).*



Internal structure of the tactical hybrid stratospheric airship.
Source: IT202000015880A1, Fig 3 (above), Fig. 4 (below).

Unlike conventional stratospheric airships, which include a large ballonet to control internal pressure as the lifting gas expands by a factor of almost 20:1 during the airship's ascent to its operating altitude, CIRA's tactical hybrid stratospheric airship dispenses with the large ballonet in order to significantly reduce the weight and size of the airship. Instead, the airship only has a small ballonet designed to manage envelope pressure variations due to diurnal temperature changes during each day-night cycle.



Vehicle expansion during ascent.
Source: IT202000015880A1, Figs 7A - C

Like CIRA's HHAA described previously, a compact, partially-inflated tactical hybrid stratospheric airship takes off vertically, with only the nose section inflated (patent Fig. 7A). It ascends only under the influence of aerostatic buoyancy and expands to an intermediate shape (patent Fig. 7B) at about 8,000 m (24,250 ft). Continuing its ascent, the airship becomes a fully-expanded, pressure-stabilized vehicle (patent Fig. 7C) at an altitude of about 15,000 m (49,200 ft).

Thereafter, the propulsion system is in operation and the ascent continues under the combined influences of aerostatic and aerodynamic lift. Without a large ballonet to control internal gas pressure, excess internal pressure will be released during ascent. Aerodynamic lift will balance the vehicle weight no longer supported by the released lifting gas.

At its operating altitude of 17 to 21 km (55,800 to 68,900 ft), the vehicle can maintain a geostationary position in headwinds in a range from 5 to 18 m/s (18 to 65 kph / 11 to 40 mph) with the relative wind generating substantial aerodynamic lift. At higher or lower wind speeds, the vehicle will move on trajectories that enable it to generate the aerodynamic lift needed to maintain altitude while "orbiting" near its assigned geolocation. Aerodynamic lift can compensate for loss of aerostatic lift from slow helium leakage on a long mission.

During the descent phase, the loss of internal pressure at lower altitudes will be compensated for by introducing air, in a controlled and continuous manner, into the gas envelope to maintain the shape of the pressure-stabilized hull, and thereby, retain aerodynamic control and powered flight throughout the descent and return to a designated landing site.

CIRA has not developed a semi-buoyant aircraft based on this patent.

Rendering of a CIRA tactical hybrid stratospheric airship. Source: CIRA

5. CIRA patent application for a unmanned, semi-buoyant, hybrid inflatable aircraft with a semi-elliptical closed wing

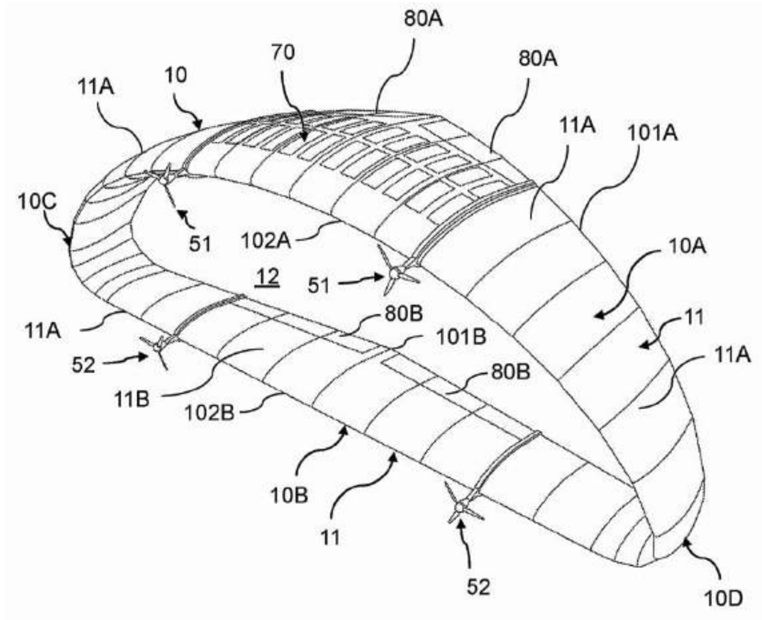
In February 2021, CIRA filed Italian patent application IT202100002609A1, “Unmanned Type Hybrid Inflatable Aircraft,” which describes a semi-buoyant hybrid aircraft with a unique semi-elliptical “closed wing.” One version is designed for operation as a HAPS, at an altitude of 16 to 21 km (52,500 to 68,900 ft), carrying payloads weighing 5 to 100 kg (11 to 220 lb) to support a wide range of applications. CIRA claims the basic design concept also is applicable for a semi-buoyant aircraft operating at lower altitudes in the troposphere or for a tethered, semi-buoyant aerostat.

CIRA claims the novel, semi-buoyant, semi-elliptical “closed wing” generates 40% to 20% of its total lift aerostatically and 60% to 80% of its total lift aerodynamically.

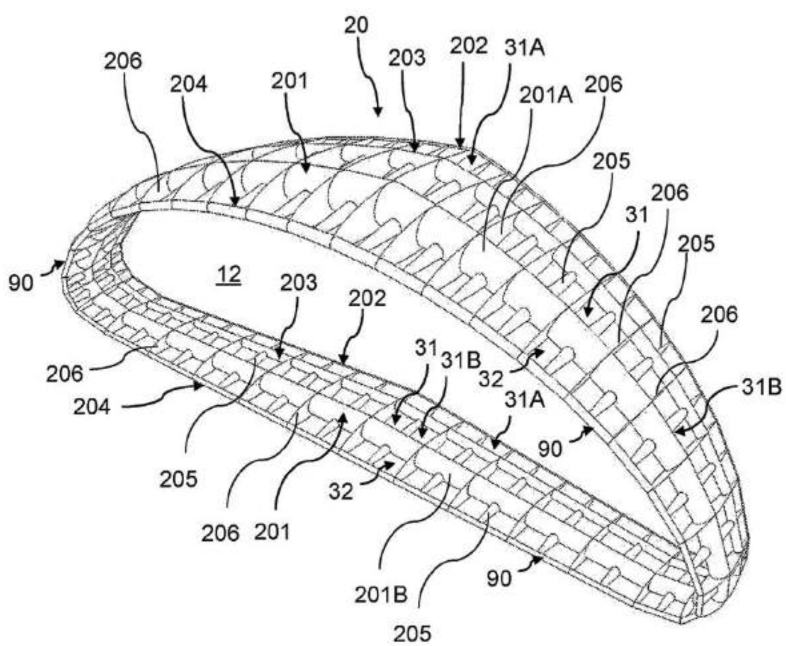
The structural design is summarized in the patent application:

> “From an aerodynamic point of view, the closed wing operating configuration represents an optimal solution for reducing induced drag without necessarily having to consider large wingspans. The aerodynamic load is greater on the arched wing (10A) than on the straight wing (10B). Furthermore, the arched wing (10A), due to its arched configuration, develops, in addition to the lift, a lateral aerodynamic force which puts the straight wing (10B) in tension, which helps support the flexural loads of the latter.”

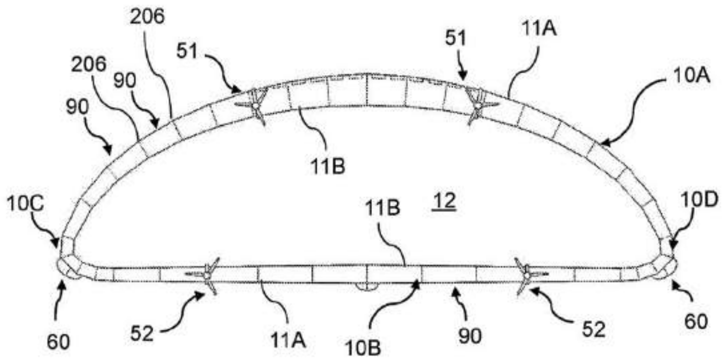
The complex structural design is described in detail in the patent application.

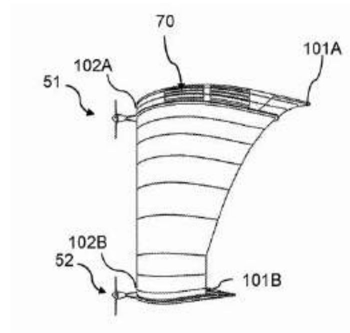


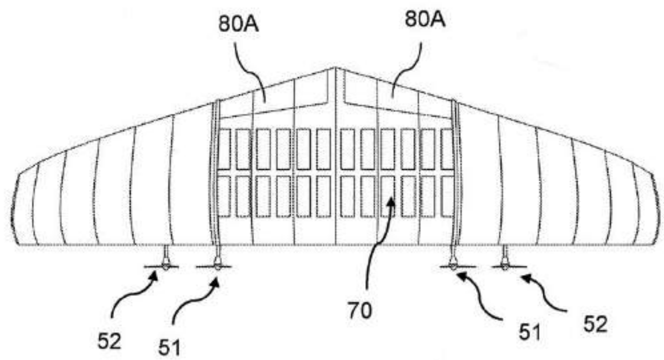
Legend: *The vehicle's semi-buoyant inflatable body (10) is formed from a semi-elliptical arched upper wing (10A) and straight lower wing (10B) joined at their ends (10C, D), with wing leading edge (102A, B), trailing edge (101A, B) and rigid aerodynamic control surfaces (80A, B). The external surface of the closed wing (the outer casing) is a multi-layer fabric (11, 11A, B). A solar photovoltaic array (70) is installed on the arched upper wing (10A). The craft is propelled by electric motor-driven propellers (51, 52) installed on the leading edges of the wings (102A, B). The complex wing internal structure is comprised of an inflatable main spar (201), secondary spars (202 – 204) and struts (205). Rigid ribs (206) join the spars and form pneumatically-connected annular chambers (31, 31A, B, 32).*



General arrangement & structural design of the closed-wing, semi-buoyant vehicle. Source: IT202100002609A1, Fig 1 (above) & Fig 2 (below)







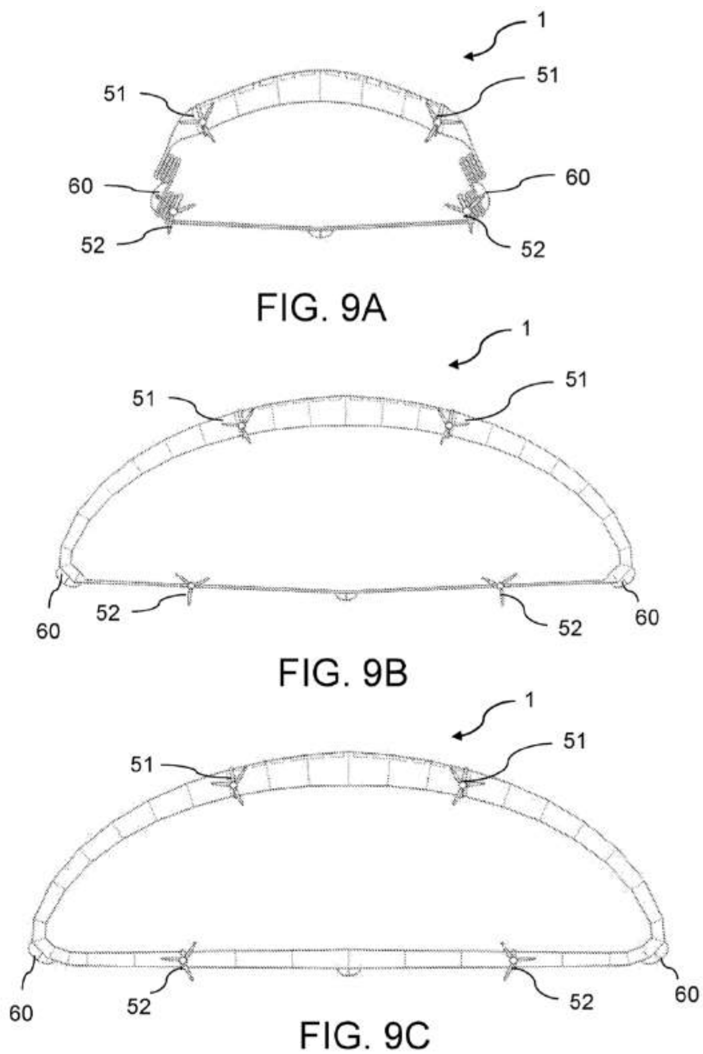
Legend: *Semi-elliptical arched upper wing (10A) and straight lower wing (10B) are joined at their ends (10C, D) where the payload bays are located (60). The multi-layer outer casing (11A, B) carries the solar array (70) on its upper surface, along with aerodynamic control surfaces (80A, B). Propellers (51, 52) are mounted on the wing leading edge (102A, B). Rigid ribs (206) between the leading edge and trailing edge (101A, B) form casing segments (90) and establish the wing profile.*

General arrangement of the closed-wing, semi-buoyant vehicle. Source: IT202100002609A1, Fig 3 (above, left), Fig 5 (above, right), Fig 6 (below, left)

Like CIRA's HHAA described previously, the partially-inflated closed wing hybrid aircraft takes off vertically, only under the influence of aerostatic buoyancy. During ascent, the vehicle expands from a folded minimum volume at launch (patent Fig. 9A) to a fully-expanded, pressure-stabilized vehicle (patent Fig. 9C) at an altitude of 5,000 to 10,000 m (16,400 to 32,800 ft), at which time it is able to generate aerodynamic lift.

Thereafter, ascent continues under the combined influences of aerostatic and aerodynamic lift. The patent notes, "this invention has no ballonet and this considerably reduces both the volume and the size of the platform." As noted in the patent, during ascent, excess internal gas pressure will need to be released.

At its operating altitude of 16 to 21 km (52,500 to 68,900 ft), the vehicle can maintain a geostationary position in headwinds in a range from 7 to 25 m/s (25 to 90 kph / 15.6 to 56 mph) with the relative wind generating substantial aerodynamic lift. At higher or lower wind speeds, the vehicle will move on trajectories that enable it to generate the aerodynamic lift needed to maintain altitude while "orbiting" near its assigned geolocation. Aerodynamic lift can compensate for a loss of aerostatic lift from slow helium leakage on a long mission.



Vehicle expansion during ascent.
Source: IT202100002609A1, Figs (9A- 9C)

During the descent phase, the loss of internal pressure at lower altitudes will be compensated for by introducing air, in a controlled and continuous manner, into the outer casing to maintain the shape of the pressure-stabilized hull, and thereby, retain aerodynamic control and powered flight throughout the descent and return to a designated landing site.

CIRA has not developed a semi-buoyant aircraft based on this patent.

6. For more information

- G. Persechino & V.R. Baraniello, "Advantages in the Employment of Hybrid Airships as HAPS," paper presented at HAPS 4 ESA, Noordwijkerhout, The Netherlands, October 2017: https://www.researchgate.net/publication/325514620_Advantages_in_the_Employment_of_Hybrid_Airships_as_HAPS
- "L'Italia prepara il drone per la stratosfera," (Italy prepares the drone for the stratosphere, in Italian), Gioirnale de Sicilia, 16 December 2021: https://gds.it/speciali/scienza-tecnica/2021/12/16/l-italia-prepara-il-drone-per-la-stratosfera-074fda3e-345c-40e6-ab65-f614a4e8c4eb/2/
- V.R. Baraniello & G. Persechino, "Preliminary CDF analysis of an innovative hybrid HAPS configuration," paper presented at the 9th European Conference for Aeronautics and Space Science (eucass-3AF 2022), Lille, France, July 2022: https://www.eucass.eu/doi/EUCASS2022-4397.pdf
- "Stratospheric EuroHAPS programme kicks off," The Engineer, 9 March 2023: https://www.theengineer.co.uk/content/news/stratospheric-eurohaps-programme-kicks-off/
- "In the EDF EuroHAPS project, CIRA leads the development of the Italian stratospheric platform," Italian Defense Technologies, 20 March 2023: https://www.italiandefencetechnologies.com/in-the-edf-eurohaps-project-cira-leads-the-development-of-the-italian-stratospheric-platform/

Video

- "Hybrid High Altitude Airship," (1:57 min), posted by CIRA, 2 December 2019: https://www.youtube.com/watch?v=kLSaLEQr2CY

Patent applications

- IT202000015880A1, “Tactical hybrid stratospheric airship,” Filed 1 July 2020, Published 1 January 2022, Assigned to CIRA: https://patents.google.com/patent/IT202000015880A1/en
- EP EP4175880A1, “Tactical hybrid stratospheric airship,” Filed 16 June 2021, Published 10 May 2023, Assigned to CIRA: https://patents.google.com/patent/EP4175880A1/en
- Similar “Tactical hybrid stratospheric airship,” patent applications have been filed in Canada, Japan, USA, Australia & Israel
- IT202100002609A1, “Unmanned Type Hybrid Inflatable Aircraft,” Filed 5 February 2021, Published 5 August 2022: https://patents.google.com/patent/IT202100002609A1/en

Other *Modern Airships* articles

- *Modern Airships - Part 1*: https://lynceans.org/all-posts/modern-airships-part-1/
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    - TAO Group - SkyDragon
    - Thales Alenia Space – Stratobus
- *Modern Airships - Part 3*: https://lynceans.org/all-posts/modern-airships-part-3/