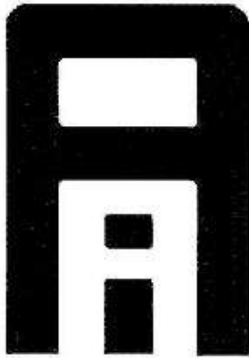# All American Industries, Inc. - Aerocrane

Peter Lobner, updated 8 March 2022

1. Introduction

In 1972, Donald Doolittle was President of All American Engineering (AAE), which was a diverse engineering and manufacturing firm in Wilmington, Delaware. He invented the Aerocrane in 1972 and filed his first patent application for this lighter-than-air (LTA) hybrid aircraft in May 1973. At the time, Arthur G. Crimmins, the future inventor of the Cyclocrane, was the AAE marketing director.

The Aerocrane is an unusual aerostat / helicopter hybrid aircraft in which a large, spherical aerostat is the "hull" of the aircraft, and four helicopter-style rotors (or wings) project at right angles from the equator of the aerostat. The whole assembly rotates around the aerostat's vertical axis, powered by four propellers mounted near the tips of the wings.

During operation, the hybrid airship rotates at a constant speed of about 10 rpm to generate a controllable thrust vector for lift and propulsion. A stabilized (non-rotating) crew cab is suspended beneath the aerostat and the payload is carried as a sling load suspended below the control cab. The adjustable wings provide the additional lift needed to pick up a load. When the load is being delivered, the wings are adjusted to provide the downforce needed to maintain control of the buoyant aerostat after the load is released.

15-foot diameter subscale Aerocrane model in flight at AAE in 1974. Source: Mechanix Illustrated, Jan 1976, p. 44

The Aerocrane is best suited for short-range, high load/unload cycle missions where loads are in excess of helicopter capabilities. Potential applications of this type included:

- Logging in inaccessible areas
- Pipeline construction
- Electric transmission line construction
- Offshore container ship loading and unloading
- Other heavy construction
- House moving

Under contracts with Aerospace Corporation (1973) and the Advanced Concepts Division of the Naval Air Systems Command (NAVAIR, 1974), AAE performed design and sensitivity studies and conducted wind tunnel tests on their Aerocrane concept. One important finding was that an Aerocrane has an operating empty weight between 31 – 35% of its design gross weight. In comparison, the operating empty weight of a heavy lift helicopter is between 57 – 72% of its design gross weight, leaving much less margin for carrying cargo. Pound-for pound, an Aerocrane can carry a much larger payload than a heavy-lift helicopter, as shown in the following chart.
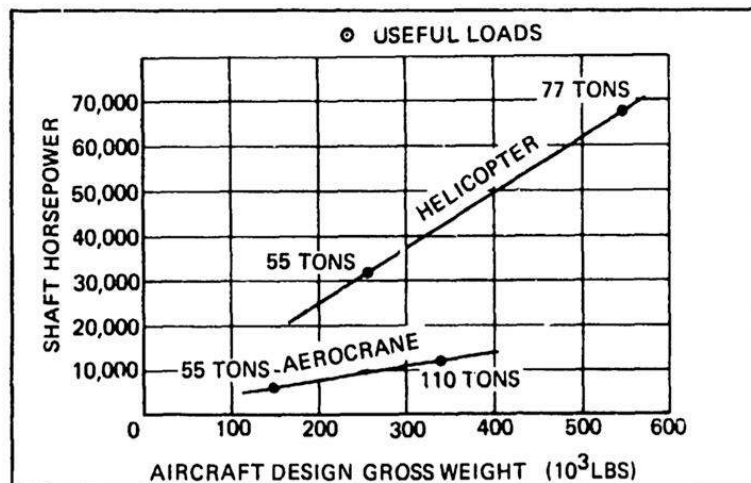
Source: Doolittle & Perkins (1975)

However, Aerocranes do not compete directly with helicopters because the concept does not scale down to typical helicopter load sizes. An Aerocrane also does not compete with airships because it cannot offer efficient long-range service comparable to an airship.

Based on the work for NAVAIR, Doolittle and Russel Perkins (NAVAIR) reported the following in 1975:

> "The Aerocrane concept offers a potential for order of magnitude improvements in maximum VTOL lift capacity and reduced acquisition cost; compared to an equivalent lift helicopter. The mechanism which allows this is the partial substitution of low cost, heavy lift balloon technology for high cost, rotor technology. The penalties are the reduced forward speed envelope and the reduction of the excellent flying qualities of the helicopter. …… The Aerocrane's design simplicity, benign flight environment and potential for rugged construction because of a relaxed emphasis on minimizing structural weight fraction may result in a substantial improvement in aircraft operational availability."

In 1975, Doolittle resigned as President of AAE to devote full time to the Aerocrane. By then, Aerocrane international patents had been granted in the UK, France, Germany, Australia, Brazil and Canada.

Under Navy contracts issued in 1975 and 1975, AAE designed and built remotely controlled flying models that were flown in two test series in a blimp hangar at Lakehurst Naval Air Station to investigate stability, control, and flying qualities.

AAE continued promoting the Aerocrane and developing advanced variants until the end of the 1970s, when government funding ended and this work was discontinued. A full-scale Aerocrane was never built.

Not giving up on the concept, Doolittle filed a patent application in 2000 for a significantly revised concept for an Aerocrane-like composite vehicle that addressed some of the operational issues with the original designs.

This article reviews Doolittle's 1970s designs, AAE's 1980s advanced designs, and Doolittle's 2000 updated concept.

2. Basic design and operation of an Aerocrane

Donald Doolittle filed his first Aerocrane patent on 3 May 1973. Patent US3856236A, "Composite Aircraft," was granted on 24 August 1976 and assigned to All American Industries, Inc. The patent provides a detailed description of the basic design and operation of an Aerocrane LTA hybrid aircraft and is available at the following link: https://patents.google.com/patent/US3856236A/en?oq=US3856236

Patent Figure 1 shows the basic structural design of the first version of an Aerocrane (10). The spherical fabric aerostat envelope (14) contains eight helium lift gas cells (16, referred to as ballonets in the patent) made of elastomer coated Dacron or Mylar film and arrayed in the eight quadrants of the sphere. A small air blower establishes a slightly positive internal pressure that maintains the spherical shape of the fabric envelope.

A strong central mast (18) is the axis of the rotating aerostat and wings. The four wings (24) have an adjustable angle-of-attack and are mounted via rotatable couplings to horizontal spars that all connect together at the central mast. The spars are supported from the central mast by an array of guy wires inside the sphere. External guy wires fastened to the envelope support the wings. Engines (50) mounted on the outer section of the wings drive puller-propellers to generate balanced, tangential forces that causes the whole Aerocrane to rotate. A swivel fitting (Fig. 1A) at the base of the central mast (at the "south pole" of the aerostat) carries the loads from the non-rotating, stabilized control cab (40) and the payload (12, shown as a whole tree being lifted out of the forest).

The Aerocrane is always positively buoyant without a load attached. In operation, aerostatic lift supports two-thirds of the Aerocrane's design gross takeoff weight, including payload. This means that the aerostat supports the full structural weight of the vehicle and up to 50% of the design sling load. During a load pickup, aerodynamic lift from the wings only needs to support the remaining 50% of the sling load and provide the thrust vector for forward flight. During a load drop-off, aerodynamic downforce from the wings is needed to compensate for 50% of the former sling load, which is no longer attached. In this way, Aerocrane load exchanges (pickup and

delivery) can be accomplished without an exchange of ballast and the airship can fly safely with or without an attached load.

FIG. I

FIG. IA
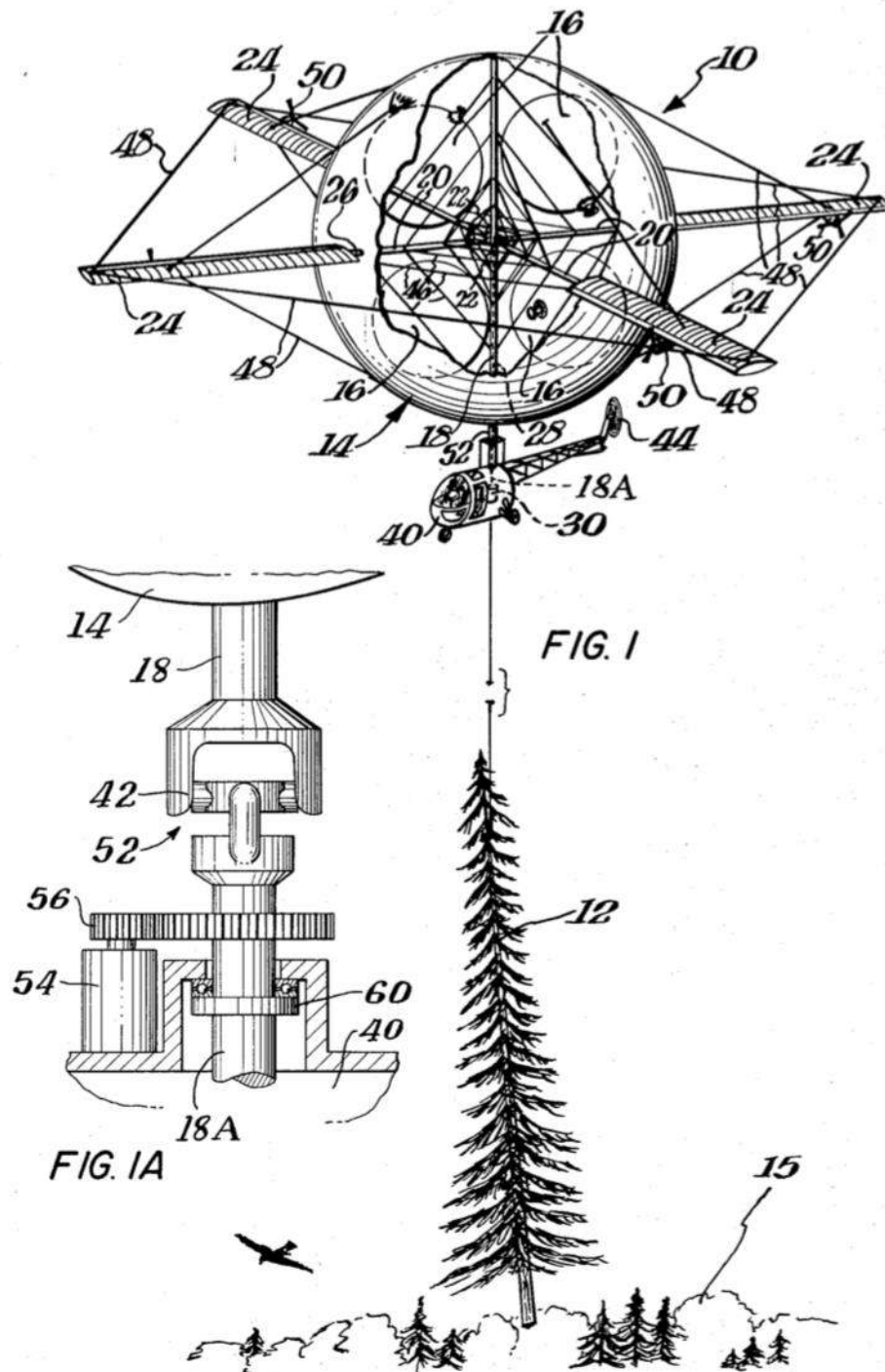
Flight control is accomplished with helicopter style controls that adjust the angle-of-attack of the symmetrical wings individually, collectively or cyclically to generate the desired direction and magnitude of the thrust vector. Engine power is modulated to maintain a constant rotational speed of about 10 rpm.

- The wing angle-of-attack is controlled collectively to generate an upforce (lift) or a downforce. When trimmed to generate a dynamic upforce, the wings augment aerostatic lift and enable the Aerocrane to lift a heavy load. When trimmed to generate a dynamic downforce, the wings balance the excess aerostatic buoyancy when flying the Aerocrane without a load.

- The control system also can cyclically vary the wing angle-of-attack during each rotation. This alters the lift profile around the aerostat, tilts the axis of rotation up to 30° in a particular direction, and causes the Aerocrane to translate in the selected direction (360° vectorable thrust).

When carrying a heavy load, the Aerocrane's center-of-buoyancy is far above its center-of-gravity and it exhibits good static stability. It is capable of vertical takeoff and landing (VTOL) operations using collective lift control only. Without a payload, the Aerocrane static stability is much lower, but adequate due to the suspended weight of the crew cabin, which contains the fuel, and the cargo sling.

3. Subscale models, circa 1974 - 1975

AAE's first flying Aerocrane was the 15 foot (4.6 m) diameter subscale remotely controlled flying model that was flown in 1974 at the company's facilities in Wilmington, DL.

Under two contracts with the Advanced Concepts Division of the Naval Air Systems Command (NAVAIR) in 1975 and 1977, AAE designed and built remotely controlled flying models to investigate stability, control, and flying qualities. The two sets of flight tests were conducted in a former airship hangar at Lakehurst Naval Air Station in New Jersey, with support from Howard C. Curtiss, a professor of mechanical and aeronautical engineering, specializing in helicopter dynamics at Princeton University.

The first flying Aerocrane subscale model.
Source: AAE, 1974, AAE via Rob Crimmins
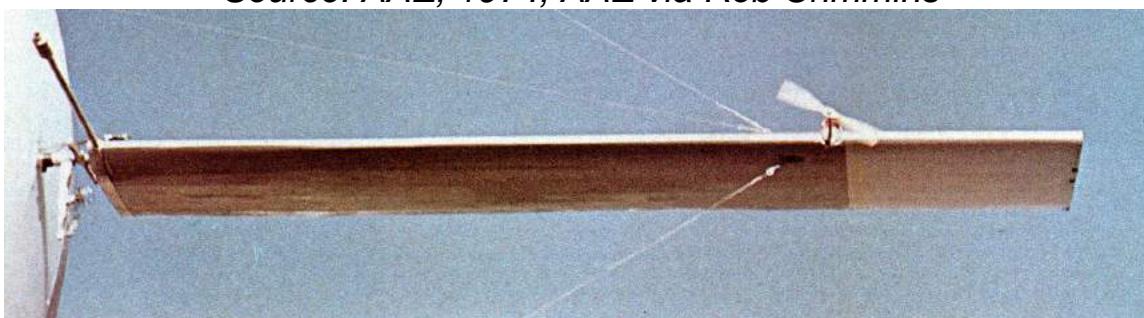
An articulated wing on the 15-foot subscale model.
Source: Mechanix Illustrated, Jan 1976, p. 44, via Rob Crimmins

General characteristics of the 15-foot test model

Parameter	
Diameter, aerostat	15 feet (4.6 m)
Wing dimensions	9 feet (2.7 m) long
Wing span, total	33 feet (10.1 m)
Lift gas	Helium
Envelope volume	About 1,767 ft^3 (50.1 m^3)
Payload	About 25 lb (11.3 kg)
Propulsion system	4 × electric motors @ 1/4 hp (0.2 kW) each, mounted on the outer section of the four wings

The Aerocrane 15-foot test model. Source: Vertical Flight Society, Vertiflite, September/October 1975, page 14

*Aerocrane test model undergoing flight dynamics testing
at Lakehurst Naval Air Station. Source:
https://www.researchgate.net/publication/290082639_The_technical_l
egacy_of_Prof_Howard_C_Pat_Curtiss_Jr/figures?lo=1*

Results demonstrated that the Aerocrane was controllable and should be scaleable. Dr. Howard Curtiss reported that the large aerodynamic forces generated by the Aerocrane wings provide stability in gusts better than for dirigibles. The model tests also helped identify design issues and operational limitations.

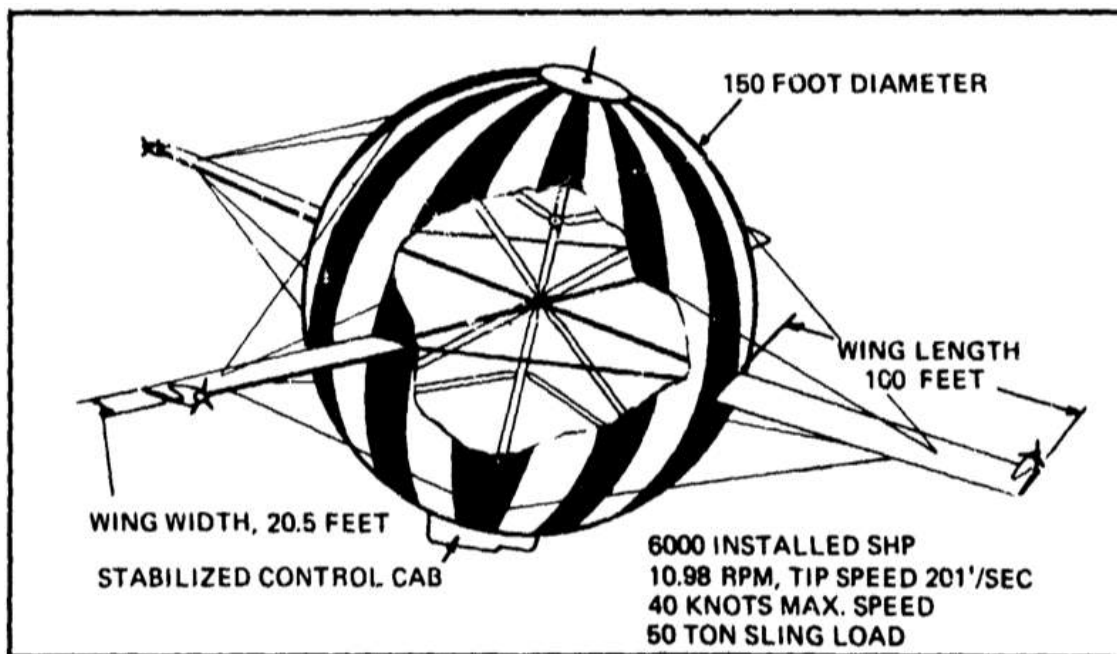## 4. Production Aerocrane concepts

In 1975, Perkins & Doolittle were promoting an initial production-scale Aerocrane with a 50-ton (45.4 metric ton) useful load capacity and an aerostat diameter of 150 feet (45.7 m). Since aerostatic lift increases as the cube-power of balloon diameter, while structural weight increases as the square-power, the Aerocrane becomes more efficient as a heavy-lifter at larger sizes.

Much larger Aerocranes were contemplated, as shown in the scaling chart (Figure 2) in patent US3856236, which includes aerostat diameters up to 250 feet (76.2 m) capable of carrying a 285 ton (259 metric ton) sling load. AAE described a 400-foot (122-meter) diameter aerostat with 200-foot (61-meter) wings. The total span of such a craft would have been 1,000 feet (305 meters).

AAE did not produce any full-scale Aerostats.

50-ton Aerocrane design concept

The 50-ton Aerocrane design concept, circa 1975, had an aerostat diameter of 150 feet (45.7 m). Each rectangular wing measured 100 feet (30.5 m) long by 20.5 feet (6.4 m) wide, yielding a wing aspect ratio (AR) of 4.9 and a total wingspan of 350 feet (106.7 m). Powered by four wing-mounted, turbo-prop engines rated at 1,500 hp (1,119 kW) each, the Aerocrane was designed to carry a useful load of 50-tons (45.3 metric tons). With the payload carried as a sling load, the Aerocrane was designed to fly at a maximum airspeed of 40 knots (74 kph). The Aerocrane would be limited to operating in surface wind speeds less than 15 knots.

Production-scale Aerocrane cutaway drawing.
Source: Perkins & Doolittle (1975)

The production Aerocrane would be factory constructed. Once it had been assembled and inflated, it would remain outdoors. An Aerocrane without an attached payload is very buoyant, with a net buoyancy equal to about one-half of its design payload. Thus, a 50-ton Aerocrane would have a net positive buoyancy of about 25 tons without the payload attached. When not flying, the Aerocrane has to be moored. The aerostat's symmetrical shape simplifies mooring by presenting the same cross-section to the wind from all directions.
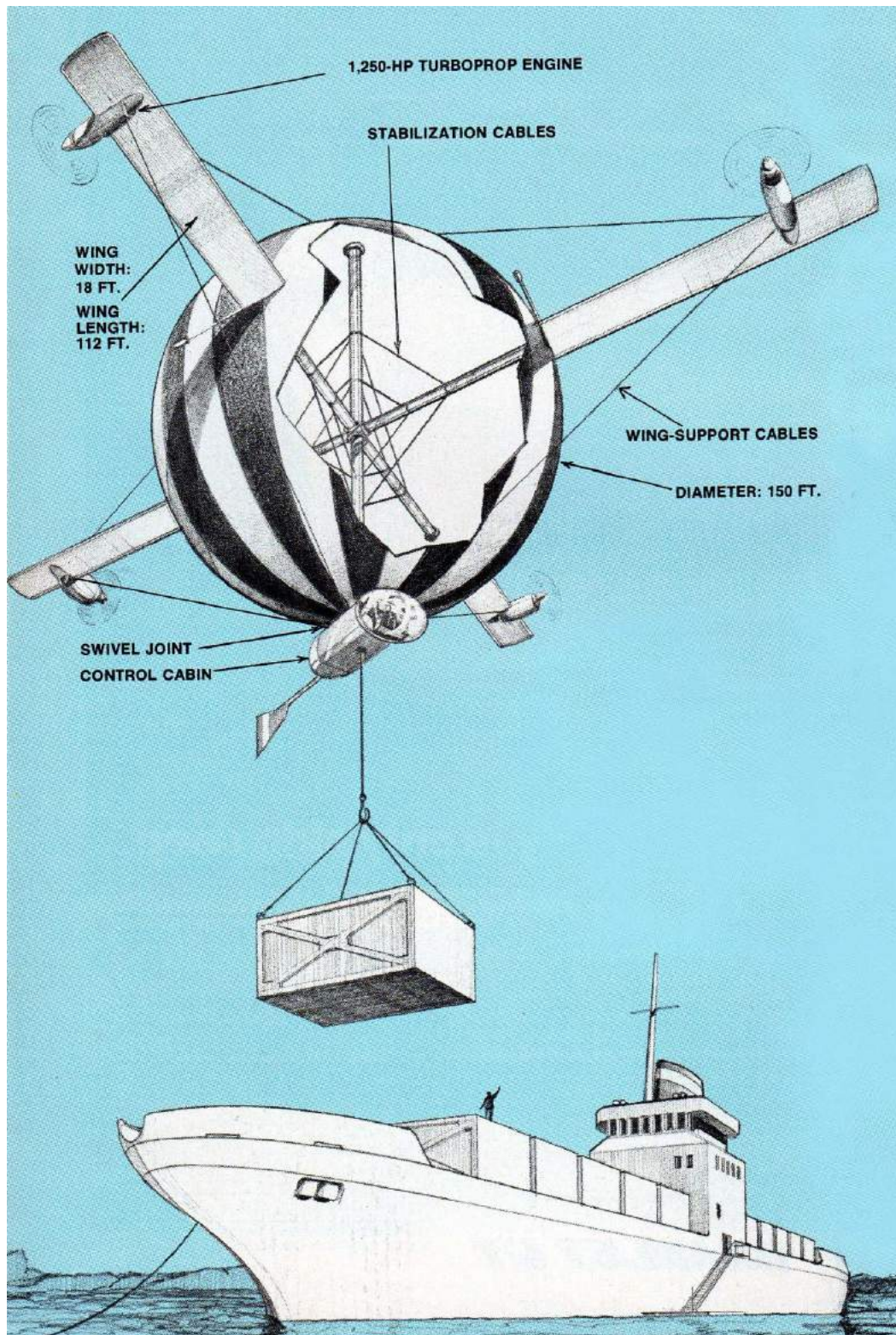
Its great wingspan (350 feet for a 50-ton Aerocrane, and much greater for heavier lift versions) precludes bringing the airship into a hangar during high wind conditions. The Aerocrane requires multi-point moorings in severe weather to enable it to withstand high wind loads and ride out the storm. For example, in 60-knot wind, a moored 150-foot diameter Aerocrane would generate about 25 tons of drag.

By 1976, the design was refined with higher aspect ratio wings (AR = 6.2), and lower turbo-prop power of 1,250 hp (932 kW) each, as shown in the following diagram. With a total wingspan of 374 feet (114 m), the wingtip speed would be 150 mph (241 kph) at 10 rpm, yielding a constant acceleration of about 6g on the engines.

General characteristics of a 50-ton Aerocrane, circa 1976

Parameter	
Airship type	Hybrid, composite aircraft
Diameter, aerostat	150 feet (45.7 m)
Wing dimensions	112 feet (34.1 m) long x 18 feet (5.5 m) wide
Wing span, total	374 feet (114 m)
Lift gas	Helium
Envelope volume	About 1.77 million ft^3 (50,000 m^3)
Helium lift	About 116,845 lb (53,000 kg) @ 1.06 kg per m^3 at STP
Accommodations	2 - 3 crew in a suspended control cabin
Propulsion system	4 × turboprop engines @ 1,250 hp (932 kW) each, mounted on the outer section of the four wings
Rotational speed	10 rpm
Translational speed	40 knots (74 kph), maximum

1,250-HP TURBOPROP ENGINE

STABILIZATION CABLES

WING WIDTH: 18 FT.

WING LENGTH: 112 FT.

WING-SUPPORT CABLES

DIAMETER: 150 FT.

SWIVEL JOINT

CONTROL CABIN

A production-scale Aerocrane transferring containerized cargo between ship and shore. Source: adapted from Mechanix Illustrated, Jan 1976, p. 45, AAE via Rob Crimmins

Rendering of a production-scale Aerocrane in flight.
Source: All American Engineering Co. brochure via Rob Crimmins

110-ton Aerocrane design concept

AAE developed the following weight estimates for a 110-ton Aerocrane:

- Empty weight: 110,700 lb
- Useful load: 220,720 lb, which included 20,000 lb for fuel, 600 lb for the crew, 120 lb for residual fluids, and 200,000 lb (100 tons) for the payload.
- Gross weight: 331,420 lbs

This Aerocrane design had an empty weight-to-gross weight ratio of 0.334.

5. Issues with the original Aerocrane design

Operationally, an Aerocrane was much larger, more cumbersome, and had a significantly lower forward speed envelope than a helicopter. The Aerocrane's spherical shape has high aerodynamic drag, and hence, the vehicle has a low cruise speed, with a practical upper limit in the range from 40 – 50 knots. This low speed means that operation in winds over 20 knots probably is not possible and that the efficiency of operation in even light winds is significantly degraded. Even with no wind, the low cruise speed will result in low productivity. Thus, the original Aerocrane concept was limited to very short-range applications in very light winds.

In their January 1975 paper, Donald Doolittle and Russel Perkins reported three significant technical issues with the original design of the Aerocrane described in patent US3856236A. In NASA Technical Paper 1921, Mark Ardema identified one more significant issue. There issues were:

- The impact of the Magnus effect on a large rotating sphere
- The effect of the turbulent wake behind the aerostat on the wings and propellers rotating through that region
- The dynamics of aircraft motion related to the control cab and payload being suspended from the edge of the aerostat, well below the center-of-buoyancy.
- The impact on the engines and propellers of continuous operation in a high-g environment on the rotating wings.

Impact of the Magnus effect

Perkins and Doolittle reported, "Presently, the most serious technical unknown is the increase in basic drag and lift of the Aerocrane centerbody due to Magnus forces. Magnus lift and drag are the result of the rotation of a body of revolution about its principal axis perpendicular to the free stream velocity."
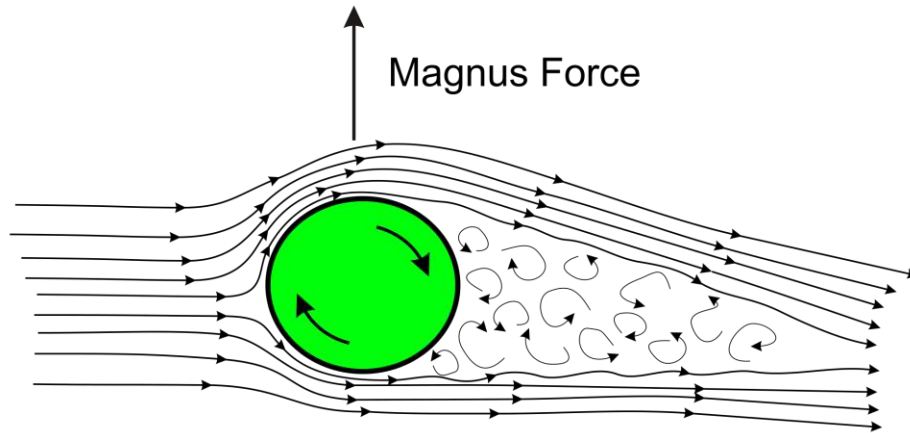
Magnus Force

Source: Aircraftnerds.com

Consider the above diagram to be an overhead view of an Aerocrane moving from right to left thru the air and rotating about its vertical axis as shown. The Magnus force generated by the rotating Aerocrane is perpendicular to the direction of travel and pulls the craft away from its intended direction of travel. To maintain the intended flight path, a cyclic control action is required to create an opposite thrust vector by tilting the plane of rotation to oppose the Magnus force.

Perkins and Doolittle said, "Its most serious effect …..is the increase in angular tilt of the Aerocrane required to produce compensating forces and the subsequent effects on rotor control moments, blade stall and other design considerations……. Practical aircraft designs must demonstrate lift and drag coefficients permitting reasonable skew (tilt) angles for the forward flight design conditions."

Magnus effect instabilities were caused by differing magnitudes of boundary layer velocities around the circumference of the rotating sphere.

Impact of the turbulent wake

The spherical aerostat generates a large, turbulent wake during forward flight. The wings and propellers pass through this wake at a constant rotational speed of about 10 rpm. As a minimum this creates complex structural loads that need to be considered in the design of the wings and propellers. In addition, the turbulent wake may cause wing angle-of-attack variations that affect aircraft flying qualities.

Impact of unusual aircraft dynamic motion

Computer analysis indicated that a control cabin and load suspended from the south pole (the edge) of the aerostat would oscillate in flight with a period between 10 to 13 seconds.

If the control cabin and load are suspended from an attachment at the center of the aerostat, there would be a common center-of-buoyancy, rotor thrust vector, and load attachment. In this case, analysis predicted that the control cabin and load would experience much greater stability, with only a long-period (minutes) oscillating motion.

Impact of continuous high-g environment on engine operation

The engines are mounted on the wings at about the ¾ span location. While the wing rotational speed is only about 10 rpm, the centripetal force on the engines is about 6g in most designs. This may affect the design and operation of service systems (i.e., fuel, lubrication, pneumatics) and components (i.e., bearings) and engine operating life. Special engine design features, comparable to engines used in aerobatic aircraft, may be required.

6. Doolittle's improved Aerocrane design

Donald Doolittle filed his second Aerocrane patent on 23 December 1974, describing substantially revised designs of the Aerocrane. Patent US3976265A, "Semibuoyant Composite Aircraft," was granted on 24 August 1976 and assigned to All American Industries, Inc. This patent is available here:
https://patents.google.com/patent/US3976265A/en?oq=us3976265

The updated Aerocrane described in this patent includes the following significant design changes shown in patent Figures 3, 4 and 6:

- The control cab (40B) and the payload are supported by a suspension tube (18B) from a swivel joint (50B) at the center of the rotating balloon sphere (14B) instead of at its south pole. This improves vehicle stability by eliminating the periodic motion of a control cab and load attached at the south pole.

- A rigid interior polygonal girder framework replaces the central mast and the network of interior guy wires that supported the wing spars in the original design concept. This interior girder framework also carries the loads from the exterior wing support guy wires (48B) and the swivel joint (50B) for the stabilized control cab and payload.

- The altitude of the aircraft is controlled by maintaining the lift gas at a constant temperature using heat obtained via heat exchangers (198B) in the engine exhaust (201B), as shown in patent Figure 6.

- In this embodiment of the Aerocrane design, helium aerostatic lift supports 46% of payload weight + all empty structural weight + fuel + crew. The wings support 54% of the sling load and generates the thrust vector to propel the vehicle in forward flight.

Patent Figures 3 and 4 show the interior polygonal girder framework, which is comprised of 12 triangular sections (72B). The four wing support girders (96B) connect at the center of the polygon, which is the suspension point for the control cab. A 30° conical void space under the suspension point allows the rotating airship to tilt in flight while the control cab remains suspended vertically.

In patent Figure 5, note that the engine (50B) is mounted on the leading edge of the wing (24B) at about ¾ span. The wing spar (82B) carries the weight of the engine and the aerodynamic load on the wings and is supported externally by guy wires (48B) connected to the interior polygonal girder framework. At the interface between the wing and the aerostat, a rotating fitting allows the wing's angle-of-attack to be adjusted while being supported inside the aerostat by a rigid girder (96B). Various service lines (84B) for the wing and engine run through the girder and connect to the wing via flexible connectors. The heat exchanger (198B) on the engine exhaust (201B) is part of a closed-loop system that provides heating for the lift gas.
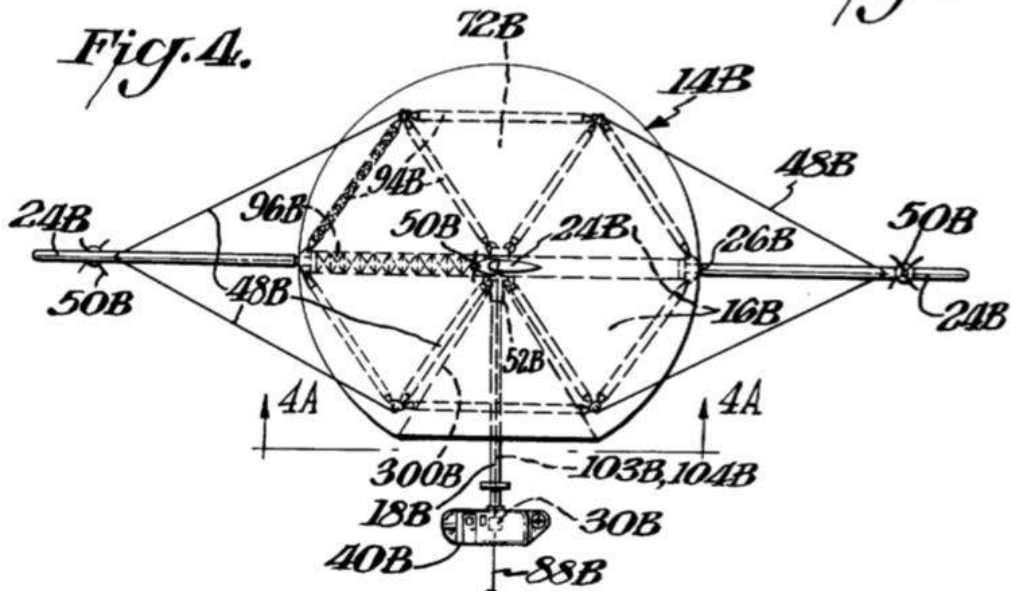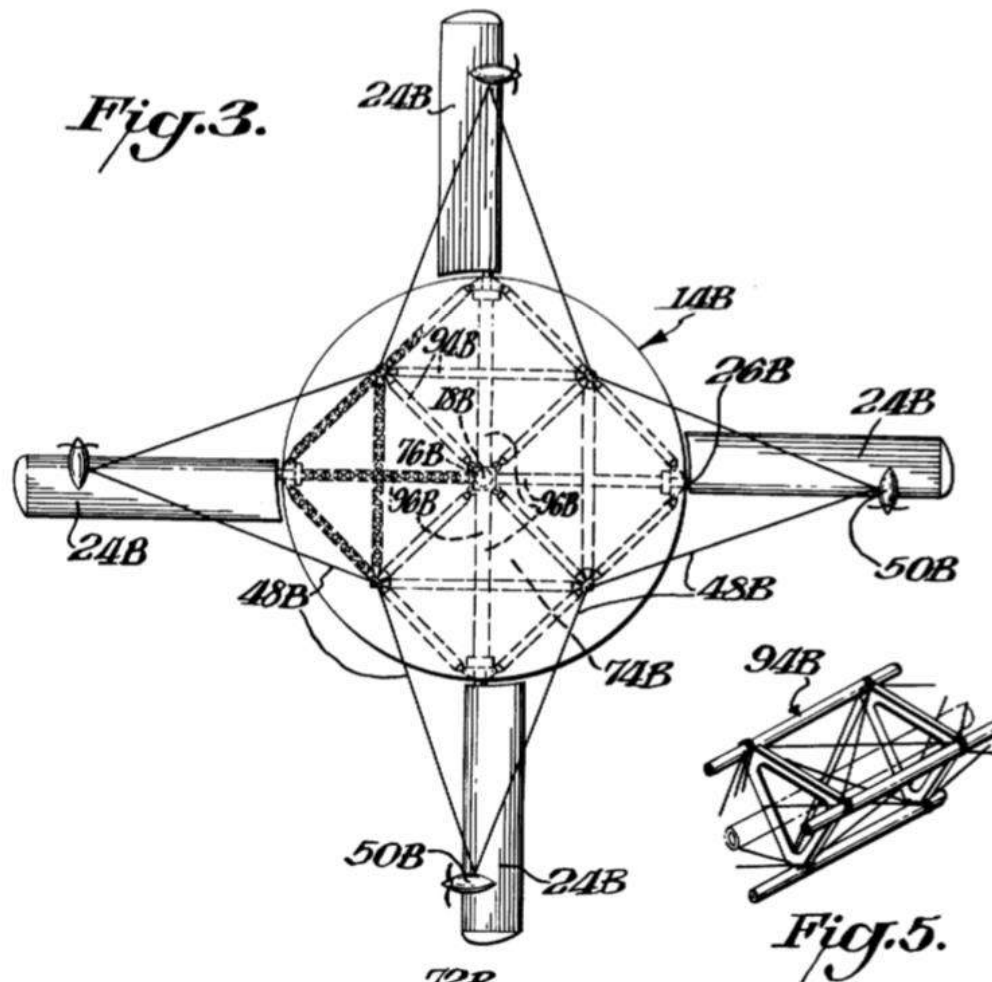
Source: Patent US3976265A
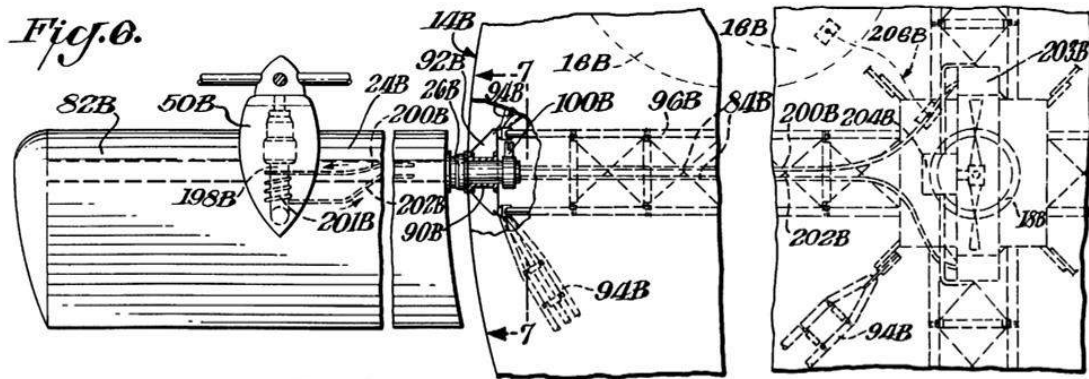
Source: Patent US3976265A

In the original design, the Magnus effect had a significant impact on Aerocrane performance. Patent 3976265A identified the following measures to reduce or eliminate the Magnus effect:

- Boundary layer control of air pressure about the sphere reduces the Magnus effect and thereby reduces the Magnus side-force and drag on the sphere.
- An alternate and more complex solution is a drag reduction envelope designed to eliminate Magnus forces entirely. An external, non-rotating "shield" can be attached in the form of two hemispheres of fabric attached to the main rotating aerostat near the equator by means of roller bearings or other system that allows for relative rotation between the aerostat/wing assembly and the external shield. The external shield would be driven so as to present a non-rotating surface to the air stream, thereby eliminating the Magnus effect.

AAE did not build a subscale model of this Aerocrane design.
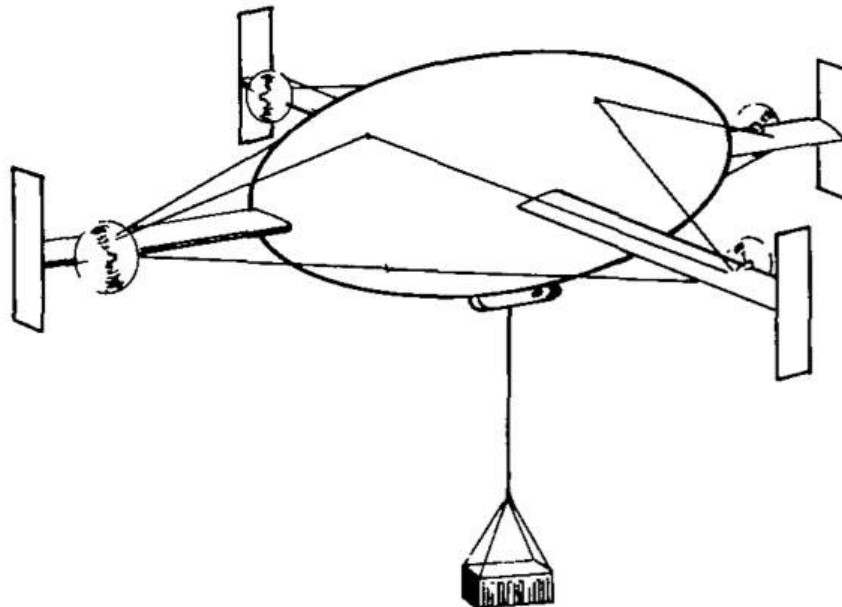
7. Advanced Aerocrane Concepts

AAE continued to develop advanced Aerocrane designs intended to reduce some of the operational issues identified in the original spherical aerostat design and to broaden the potential applications for the Aerocrane.

Lenticular Aerocrane

This advanced concept provided a means to mitigate two significant issues with the original Aerocrane design.

- The lenticular aerostat shape was adopted to reduced aerodynamic drag in forward flight and reduce the turbulent wake vortex behind the airship. This would yield a higher cruise speed and/or reduced power requirement. It also would alleviate some of the wake-induced forces on the rotating wings. The basic concept of flattening the original spherical aerostat into a lenticular shape was introduced in Doolittle's second Aerocrane patent, US3976265A.

- Winglets with aerodynamic control surfaces were fitted at the wingtips to allow generation of large lateral control forces for yaw control. This alleviates the need to tilt the vehicle to generate a thrust vector for forward flight and compensate for the Magnus side-force on the rotating vehicle.

These changes resulted in an increase in vehicle weight and complexity. In 1975, Doolittle and A.G. Crimmins built a subscale model of the lenticular Aerocrane.

Advanced Aerocrane general arrangement.
*NASA Technical Paper 1921 (September 1981)*

Lenticular Aerocranes transporting a boat and other heavy cargo. Note the stabilized control cabin immediately under the rotating lenticular envelope. Source: AAE via Rob Crimmins.

Aerocrane strategic missile launcher

Another advanced concept was a spherical Aerocrane adapted to serve as an airborne strategic missile launcher for a single missile.
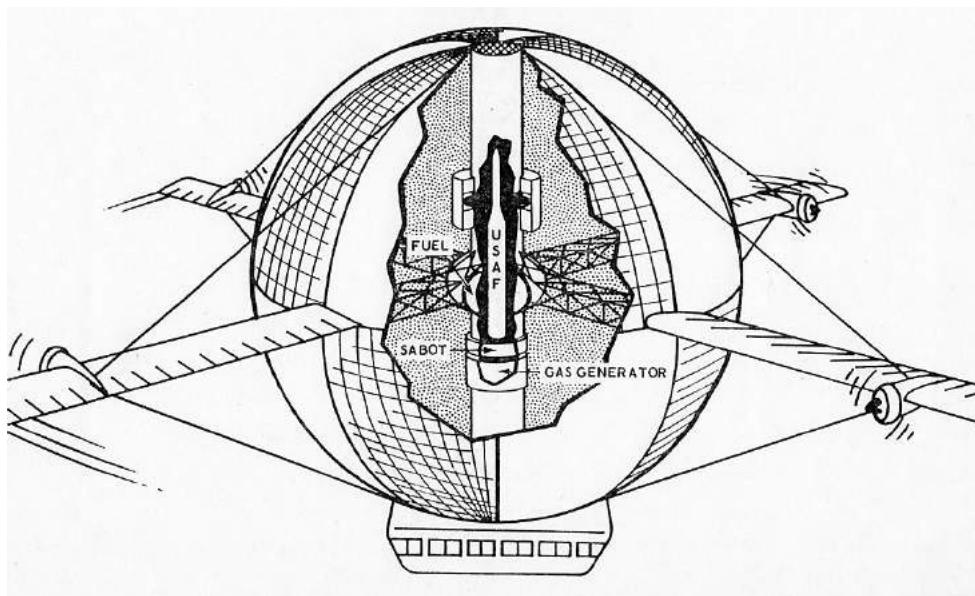

Source: AAE via Rob Crimmins.

At launch, a gas generator pushes a sabot and missile out of the vertical launch tube at high velocity and the rocket engine ignites after the missile has safely cleared the airship. Presumably the airship is designed to survive the launch, but, in a global nuclear conflict, that may be immaterial.

Aerocrane passenger carrier

The heavy-lift configuration is readily adaptable to carrying a high-capacity, stabilized passenger module. At its destination, the passenger module would be delivered at a terminal where the passengers would disembark while the Aerocrane moved on to pick up another passenger module that had been boarded and was ready to depart.
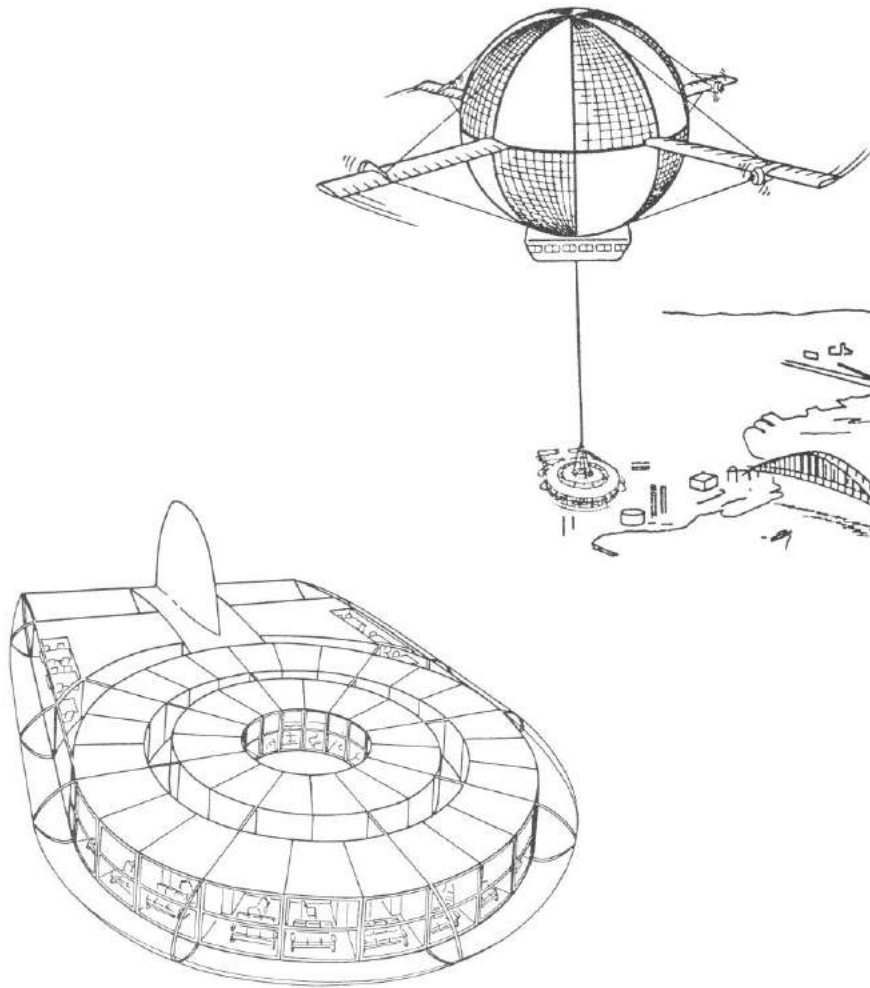
Aerocrane passenger carrier and passenger module.
Source: AAE via Airships for the Future (1976)

Aerocrane fire fighter

The heavy-lift Aerocrane can readily transport and employ specialized pallets configured to fight fires in high-rise buildings or open areas.
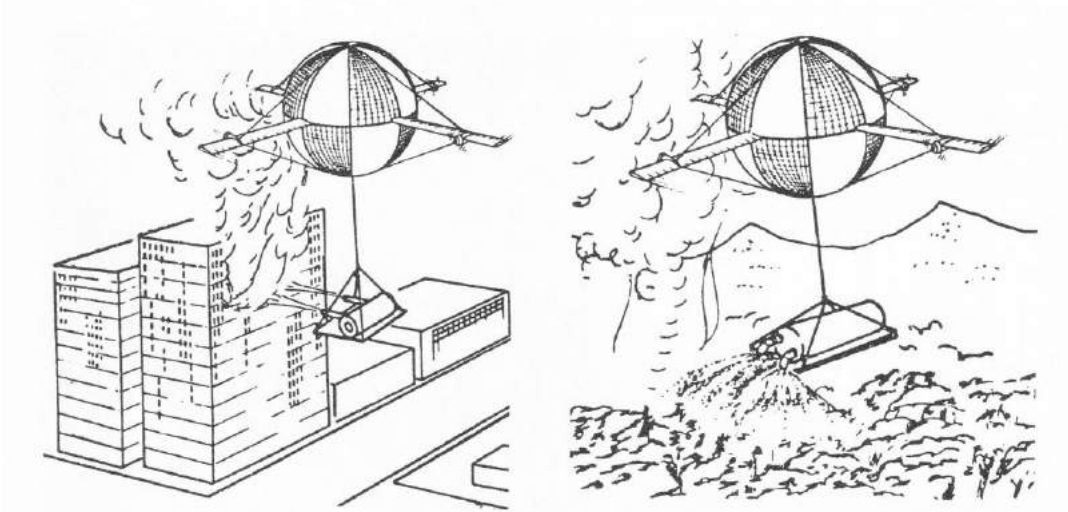
Source: AAE via Airships for the Future (1976)

Aerocrane police surveillance vehicle

Configured as a police surveillance vehicle, an Aerocrane could provide persistent surveillance over a particular location or survey a broader area.
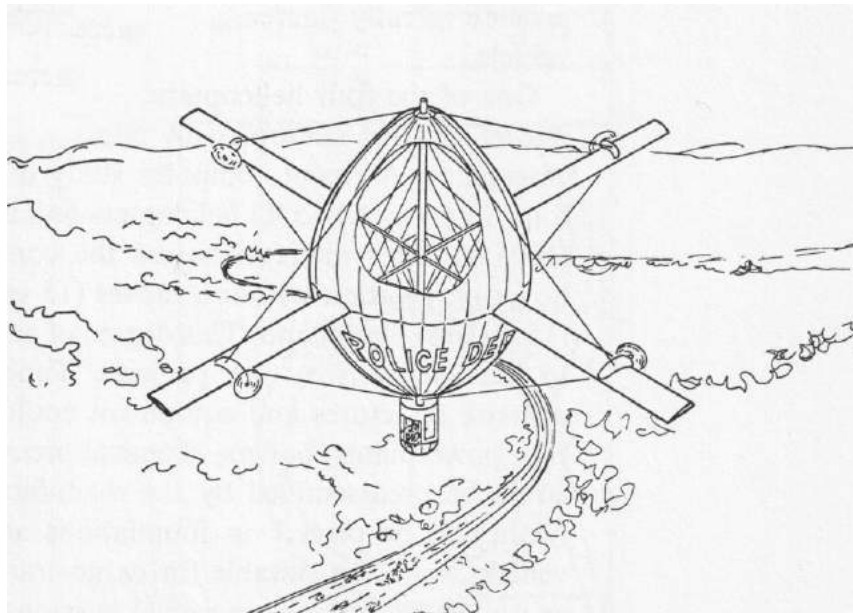
Source: AAE via Airships for the Future (1976)

8. Doolittle's third Aerocrane design

In 1999, Donald Doolittle filed another Aerocrane patent, US6142414A, "Rotor-Aerostat Composite Aircraft," which describes a composite aircraft that designed to lift loads up to 500 tons, provide stable flight, hover, and move at slow-to-moderate forward speeds. The updated Aerocrane designs addresses key technical issues with the original design.

- The spherical aerostat does not rotate. This eliminates the Magnus force and its impact on airship control and performance.

- A separate rotating section with the wings and propellers is mounted below the aerostat, via an axle. This places the rotating section below the worst of the turbulent wake behind the aerostat and reduces the impact of the wake on the wings and propellers.

- As with the lenticular Aerocrane, winglets with aerodynamic control surfaces are fitted at the wingtips to allow generation of large lateral control forces for yaw control. This alleviates the need to tilt the vehicle to generate a thrust vector.

Patent US6142414A was granted on 7 November 2000. You can read this patent here: https://patents.google.com/patent/US6142414A/en?oq=US+Patent+6142414A

As with the original Aerocrane, the aerostat (10) provides buoyancy to lift the empty weight of the aircraft plus a significant portion of the payload connected to the aircraft. The wings (14) generate a 360° thrust vector to lift the load and provide propulsion got forward flight. The winglets (16) are located at the wing tips, along with the engines (15).

An upper control cab (22) and a normally-manned lower control cab (23) are provided. The load is connected to the lower control cab, creating a long pendulum between the center of buoyancy and the load. Patent US6142414A describes a technique for flying a composite aircraft with pendulous stability.

For mooring in normal weather conditions, the load cable (26) is attached to a mooring weight, aircraft rotation is stopped, and the crew disembarks from the lower control cab. Then, the aircraft is allowed to rise to a safe distance above the ground on its tether and the blades / winglets are allowed to rotate freely to minimize drag. In severe winds, the aircraft is hauled down to ground level and the rotor assemblies are secured to the ground. Additional actions can be taken to further secure the aircraft.

FIG. 1
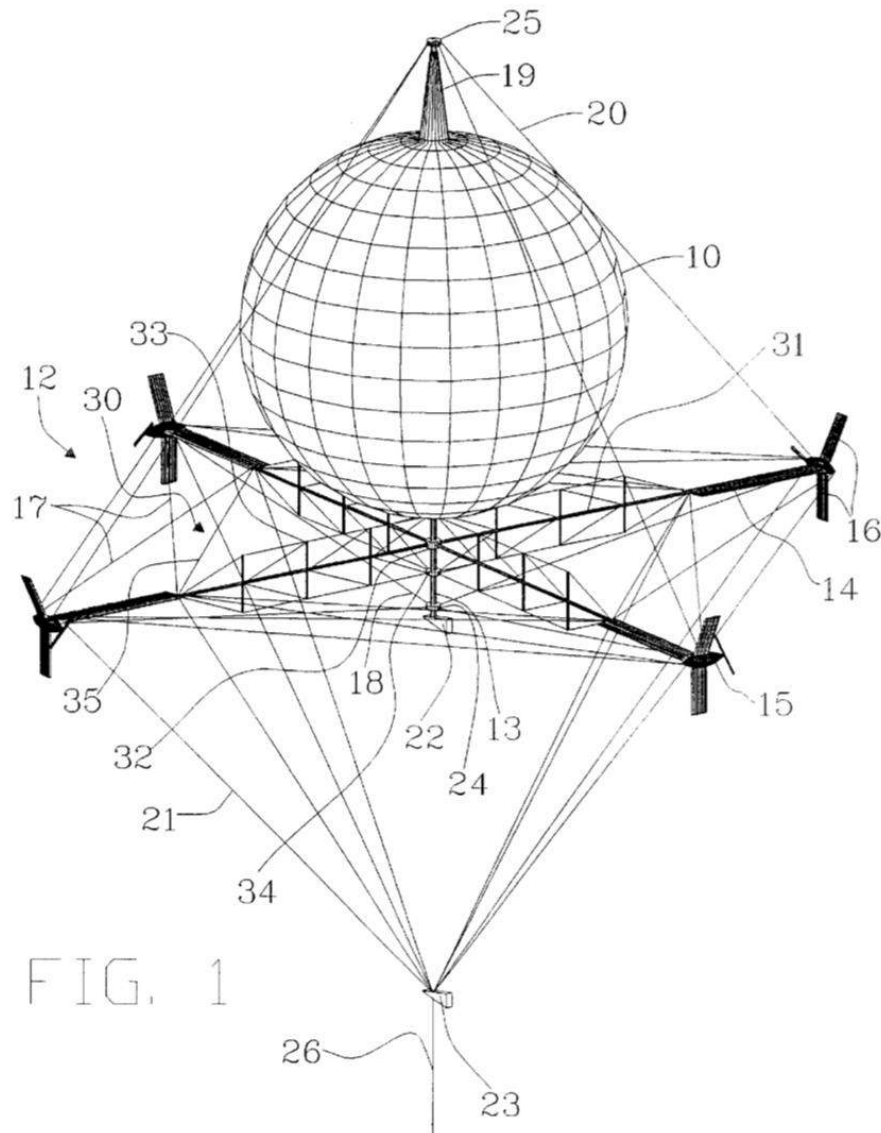
Source: Patent US6142414A

9. For more information

- "Helicopter-Balloon Concept Developed for Navy," Aviation Week & Space Technology magazine, p. 19, 6 May 1974
- "Armed Services Considering 'Aerocrane' Transport Concept," Army Research and Development News Magazine, p. 5, November – December 1974: https://asc.army.mil/docs/pubs/alt/archives/1974/Nov-Dec_1974.PDF
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