AERORAFT
THE ALTERNATIVE AIRCRAFT FOR HEAVY LIFT TRANSPORT OR CRANE USE

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ABSTRACT

Transport of very large, heavy, often indivisible, payloads is a significant problem for governments and industrialists. These goods need to be transported to inhospitable regions (e.g. arctic territories) without roads or rails and without affecting the eco-system. Also, construction projects (such as wind farms) need cranes that can operate continuously and move about over difficult terrain with ever increasing loads to lift-heights beyond current levels. Ships need to be able to load/off-load from off-shore positions. Relief aid needs means for delivery to otherwise inaccessible places. Large awkward items need to be taken from their place of origin directly to their place of need – wherever that may be. There is a need to be able to pick up at A, travel directly through the air to B and then set down. Lighter-than-air (LTA) vehicles offer the ability to utilise both aerostatic and aerodynamic means to lift and carry their payloads. These vehicles are very big, usually require significant ground facilities plus support arrangements for their maintenance and handling, have high operating costs and are affected by the weather. Customers want a cost effective solution that can do the job with little infrastructure or other support arrangements, which also can operate all year round and in weather or environmental conditions in which other aircraft would still operate. This paper describes a new heavy lift transport LTA aircraft (AeroRaft) proposal designed to provide the point to point delivery of outsized loads that satisfies these customer needs.

INTRODUCTION

This paper offers a solution, AeroRaft™[†], to enable heavy lift air transport and difficult construction crane activities in a cost effective, reliable way. AeroRaft is a scalable design, starting with a low cost demonstrator of say 10 to 50 tonne payload capacity, able to be developed as a full scale commercial version to lift large indivisible payloads with a weight of say 500 tonne (500,000 kg or 1,102,310 lb) payload capacity. This document describes the proposed aircraft.

OUTLINE REQUIREMENTS FOR A HEAVY LIFT AIRCRAFT

Requirements for the AeroRaft were drawn up primarily as follows:

- Launch from or settle to land at an operational site without complex ground infrastructure.
- Be able to carry a variety of heavy and or outsized loads, typically: 10, 50, 100, 500 and (as a goal) 1,000 tonne, sized within a 50 m spherical jacket and held in a suitable way (depending on vehicle size developed).
- Transit directly without external assistance.
- Be able to simply pick up or set down payloads directly with vertical lift (as a crane) essentially unaided and without grounding.
- Fly freely under continuous power for periods typically not less than 12 hours.
- Range at least 1,000 km.
- Maximum flight speed typically up to 60 knots (111 km/h) as a goal.
- Be able to withstand storm conditions whilst moored under gusting winds of 80 kn (148 km/h).
- Be able to be assembled, inflated, set-up and maintained at an operating site without a hangar.

Note: These requirements were formulated to provide design guidelines and as an idea of the performance that one may expect. Naturally, they may be adjusted to suit specific customer requirements, within reason.

AERORAFT – THE SOLUTION

AeroRaft is an LTA aircraft invented[‡] to serve as a transport vehicle for outsized and/or heavy mainly indivisible payloads over normally short haul overland routes that should be able to fulfil the basic requirements outlined above. It is not limited to the roles above, since other uses could be taken up – such as general freight transport[§]. Also, development of the concept to carry bigger (or smaller) payloads and with greater performance largely is just a scaling issue. Whilst adaptation or modification of the AeroRaft may be necessary for other uses, the basic concept would remain the same.

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[†] AeroRaft™ is a trademark name of the author for the LTA Transport Aircraft described herein.

[‡] Patent application No: GB 0304124.1 – 24 Feb 2003.

[§] AeroRaft also may be used for stratospheric applications. Configuration provided in Appendix A.

AeroRaft was conceived as a manned vehicle under the control of crew aboard. Nonetheless, unmanned versions could be produced. The AeroRaft must meet national and probably international airworthiness aircraft requirements for the countries of operation.

AeroRaft Uses

AeroRaft may be used as a vehicle for:

1) Transport of very heavy and/or large indivisible objects. The types of things that it may transport are:

- Power station plant, such as generators and boilers
- Oil rigs, well heads, modules and associated plant
- Bridge sections
- Outsized vessels
- Boats or other large vehicles (trains, tanks, cranes, etc) and associated parts
- Large pre-fabricated structures
- Freight or passenger modules

Transport of the payload article could be from the article's manufacture site to a dockyard or the user's site. However, it could be between any two sites within the AeroRaft's range.

2) Transport of general freight, goods, equipment, livestock and people, as a mass transfer system using purpose designed containers that the AeroRaft simply picks up, takes to its destination and leaves.

3) Construction work to lift and then place parts (as a crane) too difficult for normal cranes. Typical applications would include:

- Wind generator construction - where towers exceed crane height capacity or are built in regions that cranes cannot operate or get to. The AeroRaft as an alternative could be used to bring the crane in and move the crane around.
- Bridge construction - to lift sections of the bridge into place (perhaps over water).
- Pylon and pipe laying - to lift large pieces into place.
- Power station construction - to lift large pieces and plant into place.
- Oil rig construction - to lift large pieces, plant and modules into place.

4) Rescue or humanitarian logistics duties. The AeroRaft could be used to transport relief aid, vehicles and plant (without grounding) into regions no longer accessible. It also could be used to lift large items out of the way in rescue operations where structures had collapsed or maybe where trains had derailed, enabling relief to be undertaken swiftly.

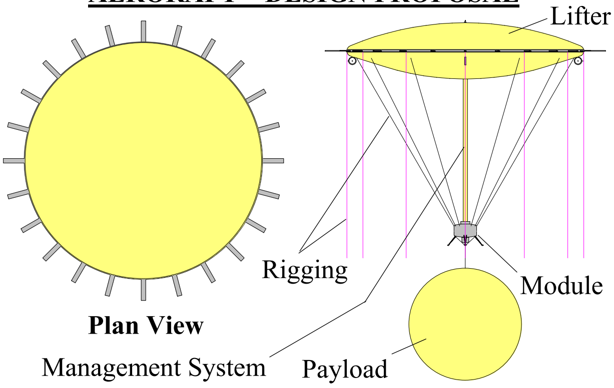
5) Dredging of rivers and canals using a purpose designed bucket.

6) Carriage of construction materials (sand, concrete, etc) using a purpose designed bucket.

7) Loading and/or unloading of ships between ship and shore or ship and ship.

These are the prime commercial applications seen for the aircraft. No doubt, military and other uses would also be found. In addition and with respect to transport issues in Arctic regions, the AeroRaft could be used without endangering the environment to move almost anything during the unstable periods such as spring, when the ice breaks up. This could be of great benefit, since it would help to maintain the flow of goods and materials. It also would help to extend the period for extraction of mineral resources.

AERORAFT – DESIGN PROPOSAL



The AeroRaft, as depicted in its drawings**, is an LTA vehicle. It comprises the following main assembly, modular or system features:

- The Lifter
- A main underslung working Module
- The Rigging
- Lifter Management System
- Payload suspension and containment system

Lifter

The Lifter comprises an essentially lenticular gas containment envelope (referred to as the Lifter body) together with thrust units and an aerodynamic lift generation method.

Lifter Body

The Lifter body is a lenticular aerostat arranged with a large outer tubular ring (a torus) that provides a stiff chassis – to be a consistent main mounting structure able to hold its shape for the other parts. This torus may be of rigid or non-rigid pressure stabilised construction (preferred).

** See Appendix B

A means to pressure stabilise the torus will be necessary if it is of a non-rigid form. Air may be used for this purpose, but gas enables buoyancy to negate its weight. It is not intended as the main chamber for gas containment but, because it needs high pressure for stabilisation purposes, perhaps also may be used to adjust weight of contained air a little.

The torus also is fitted with regular bulkheads that stabilise its form and are used for attachment of other parts. The bulkheads may be of fabric materials and should freely allow the passage of gas (& people) between each cell. The bulkheads also are used to transmit load from the rigging arrangements that restrain the aerostatic lift (buoyancy).

The torus integrates with the Thrust Unit Support Structures (4 off), provided as hard structures (rigid tube sections) each with a pylon (not shown) to support the respective thrust units. The thrust units are mounted below the torus. Integration of the torus with the thrust unit hard structure may be by simple clamp ring techniques. In addition, the torus provides the mounting base or hub for an aerodynamic vertical lift system fitted around it.

An upper dish connects to the upper surface of the torus at a tangent position via a continuous gas tight joint (adhesively bonded or welded). A clamp plate method (similar to envelope penetration reinforcement clamp rings) also may be used to make the joint, which will be necessary if a rigid torus is adopted.

The upper dish closes the upper half of the main chamber for the gas and is subject to moderate gas pressure levels that stabilise its membrane. As such it can be made from reasonably lightweight fabric, acceptable since it is not a main structural feature – the torus being used to carry primary loads. In addition, the upper dish can be used to provide the mounting surface for solar energy collector panels, for power generation purposes. However, more conventional motor driven electric generation systems are envisioned for primary power.

A lower dish connects to the lower surface of the torus via a continuous gas tight 'T' joint, closing the lower part of the main chamber. The joint position for lower dish attachment ultimately depends on the thrust Unit configuration.

The lower dish is approximately the opposite half of the Lifter body main gas chamber, with a similar mirrored profile to the upper dish. The difference to the upper dish is its connection position on the torus and that it also may be provided with a ballonet[††] for gas expansion accommodation and pressurisation purposes – similar to non-rigid airship envelopes. It may be made from lighter weight fabric (compared with the upper dish), since it is not subject to such high gas pressure (due to gas pressure head effects).

Together, the upper and lower dishes with the torus between provide an overall essentially lenticular gas containment envelope, the Lifter body, with two chambers:

- the torus (stiffened with high pressure) and
- the main chamber (stiffened with low pressure), bounded by the upper and lower dishes and closed by the inner wall of the torus.

The Lifter body therefore has a stiff outer equator profile used to mount other AeroRaft features. The lenticular form enables overall AeroRaft height to be reduced[‡‡] when moored and provides a low drag solution unaffected by wind direction during flight plus whilst moored.

<u>Thrust Units</u>

For horizontal translation and rotational (yaw) control, propeller thrust units, which may be ducted fans, driven by motors behind the propeller are used. The propeller itself should have variable blade pitch angle control to enable varying amounts of thrust both forward and rearwards to be developed or be driven by motors that can be easily reversed. This will be necessary to provide precise control, particularly during launch or capture and payload pickup or set down.

Power for/from the thrust unit motors either may be drawn from electrical installations housed in the thrust unit support structure or (as an engine with generators) may be supplied to the power distribution system. Additional small and self contained auxiliary power units may also be installed in the thrust unit support structures, to boost or provide power for the aerodynamic lift system.

4 thrust units are shown in the drawing, needed for yaw and horizontal translation control. The units are aligned tangentially with the ring. A different number of units could be installed but does not alter the concept.

The thrust units also may be provided with a vector system to rotate them for alignment of the thrust,

[††] Unless a 100% ballonet is fitted – See Appendix A

[‡‡] As shown from view 3 to view 2 of the drawing. See Appendix B.

although not needed with this configuration. Several airships and other aircraft have used such arrangements.

Vertical Lift System

The Lifter normally would be provided with an aerodynamic vertical lift system (a Rotordyne) as part of the means to carry and transport the payload. This system might not be fitted for initial test work, or for special applications such as stratospheric variants.

The Rotordyne is similar to a very large fan. It has aerofoil blades, equi-spaced around the lifter body's circumference, held from a rigid ring that freely rotates around the lifter body (as a hub). The blades are wings each with an inboard torque tube, mounted and retained in bearings for pitch movement about their radial axis in the rotatable rigid ring. The rigid ring rotates on rollers held in sleepers that constitute a track-way on the outer face of the Lifter body's stiffening ring and, of course, is of exceptionally large diameter.

The upper part of the rigid ring accommodates a rack and pinion gear set. There is a gear set for each wing. Each pinion gear engages with a rack on the respective torque tube, so that rotation of the pinion gear alters the pitch of the blade. The pinion gears of each wing are interconnected by a flexible torsion shaft (not shown) independently supported by bearings and universal joints around the rigid ring to ensure synchronisation and collective movement of each wing. This torsion shaft is driven independently at say 4 equi-spaced positions around the ring to control the pitch attitude of the wings (+ or -).

Aerodynamic lift would be generated on the wings as they rotate around the Lifter body and the direction of this lift may be controlled by the pitch control mechanism. More importantly, however, the action of the wings would be to induce a vertical flow of air that passes over and around the Lifter body. In so doing this should generate additional lift on the Lifter body (possibly of a greater amount than the wings themselves) due to the resulting aerodynamic pressure distribution on the Lifter body. In this respect, the aerodynamic lift system is a new feature for aircraft (akin to circulation control methods). In the absence of a suitable term to describe the device, the aerodynamic lift system is referred to as a 'Rotordyne'.

Rotation of the Rotordyne may be undertaken in a variety of ways:

- By thrust units mounted on the wings or rigid ring
- By an electrical linear motor system between the rigid ring and the fixed track-way
- Pneumatically by an air jet system between the rigid ring and the fixed track-way
- By a mechanical drive system between the rigid ring and the fixed track-way
- By jet efflux at the trailing edge of the wings

The methods for motivation and the track arrangements are used in other industrial applications.

Rotordyne Principles

The principle of a large swept area (propeller disc area) and a low velocity increase through the swept area, rather than a small swept area (jet disc) with a high velocity increase, stands as the most efficient way to generate lift (or thrust). Thus, propellers/rotors are more efficient than jets and the bigger the swept area the better - leading to the minimum power solution. What was needed was a departure from the normal way to generate rotor lift, to overcome the natural barrier rotor blades have reached, enabling one to go beyond (like breaking the sound barrier). That is what the Rotordyne does. The principles are largely the same. However, the logic is a little different. Where are the changes?

1) The rotor's hub region provides little benefit to generate lift, so is removed - blade span therefore does not run from the centre to the outer disc (limited to an outer annulus).
2) The sound barrier is a natural limit not to exceed - no change, but ways to increase disc radius (accepting reduction of rotational speed $\boldsymbol{\omega}$ to stay below sonic conditions) are used.
3) Ways to support the blade without running to the centre of the disc are used.
4) The number of blades that can be effectively used before they interfere too much with each other are optimised - helicopter rotors are limited here because of restrictions at the hub and proximity with each other within the small disc area they naturally operate within (limited by the sound barrier). More blades can be fitted further out.
5) Centrifugal loads are investigated to see how these may be covered and the limits they impose – also needing a limit on $\boldsymbol{\omega}$.
6) Ways to introduce low speed aerodynamics for the blade design are introduced - enabling blades of greater chord **c** and thickness.

At the much greater blade radius **r** of the Rotordyne centrifugal loads will have a more significant effect, since the force $\mathbf{F = (m.v^2)/r = m.r.\omega^2}$ (where **v** is the linear blade velocity and **m** is the mass). So 1kg at 50m radius and 340m/s (speed of sound at ground level) would generate a force of 2.3 kN (0.235 tonne). One may suspect that centrifugal loads will be the natural limiting barrier, rather than the speed of sound. That is why the more conventional aeroplane low speed wing forms and sizes will be more appropriate for the blade design, designed for speeds of perhaps 80 – 100m/s (in the range of a single engine aeroplane). So it should not be anywhere near the speed of sound (hence quiet).

Now for the question of scaling. There must be limits on the AeroRaft and its Rotordyne, since one could not just scale to any size (e.g. to lift say a large ship like the Queen Mary 82,540 tonne). The limits haven't been established yet, but the restrictions will be similar to those of helicopter designers - although not necessarily the same, since there will be different conditions.

If one takes an envelope diameter of 100m (50m radius) and a blade with span **s** = 10m and chord **c** = 2m (so wing area **A** = 20m^2) and wing loading of 981 N/m^2 (100 kg/m^2 or 20.5 lbf/ft^2), then each blade will generate 19.62 kN (2 tonne). If we have 24 blades at this diameter (as shown on the drawing) then a total of 48 tonne would be generated and that is without any additional effect from the envelope. Blade separation at this radius is 15m (49.2 ft), which should be OK to obviate interference. Rotordyne rotational speed would be just 15 rpm, giving a speed of 90 m/s (175 kn) at the blade's mid span position.

No doubt the Rotordyne could be run faster to get more lift (proportional to $\mathbf{v}^2$) but then one would need more power. The trades here give an upper limit. The power needed to run the Rotordyne near sonic conditions is likely to be prohibitively large - just like trying to run an airship at 100m/s (if it were possible) and the loads frightening. So, on balance, a limit will be reached based on cost and ability. When this limit is established the aerodynamic lift should scale with $\mathbf{V}^{2/3}$ (where **V** = Volume of the envelope), whilst the aerostatic lift scales with **V** (of course) - so it will be more difficult to generate aerodynamic lift. Just what this natural limit is, is not known yet (needs flight science analysis).

The fact is though, that it does scale to bigger sizes in a relatively straightforward way (compared to other proposals). A 500 tonne or perhaps a 1000 tonne load is not beyond the bounds of credibility – so may be adopted as a goal for future development. Beyond this one may have doubts, although aerostatically it should be possible to do more.

Aerostatic Lift Principle

If the lenticular Lifter body, as shown in the drawings, is configured with an aspect ratio of 4 to 1 (i.e. its height is ¼ of the plan diameter) and the plan diameter **d** is 100 m then the volume **V** will be approximately 116,200 m^3. This volume easily would enable a gas fill of say 100,000 m^3 helium. Taking very simply 1 kg aerostatic lift per 1 m^3 air displaced, then we may expect buoyancy of 100 tonne. Now, the basic vehicle's weight is unlikely to exceed 50 tonne, so we will have a reserve of 50 tonne for payload carrying purposes.

Underslung Working Module

The working module is the main housing for the AeroRaft's primary systems, such as: Ballast, Pressurisation, Electrical, Control, Avionic, Fire Detection and Suppression, Environmental Control, Auxiliary Power and Miscellaneous plus Equipment. These are all typical of airship and other aircraft installations. Existing technology would be adapted and used to fulfil the needs.

The working module also provides environmentally controlled facilities for the crew. It will comprise three main sub-modules, as follows:

- Systems Capsule
- Pilots' Command and Control Capsule or Cockpit
- Lifter Systems Module

Systems Capsule

The systems capsule is the main vessel for containment of the AeroRaft working systems and provides housing for crew furnishings, equipment and essential facilities. It would have two main levels:

- An upper floor region for the mainly dry systems and personnel facilities
- A large lower tank level for necessary ballast water containment

It would be constructed as a vertical cylinder with dished upper and lower end caps, as a pressure vessel. It would be provided with a mid level floor, upper ceiling, upper level windows and doors, lower level integral water tanks plus central vertical access shaft and interface positions suitably reinforced or stiffened as necessary to suit the purpose. It probably needs to be pressurised to a low level, to provide the necessary environment for the systems and personnel aboard. Its development and construction would follow normal aircraft practices.

Cockpit

The cockpit is an under-slung turret below the systems capsule, which provides the housing for the pilots plus their controls, instruments, displays, etc. It also would be constructed as a vertical cylinder with a dished bottom cap, as a pressure vessel. It would have a floor, windows and door suitably reinforced or stiffened as necessary to suit the purpose. Its development and construction would follow normal aircraft practices.

Lifter Systems Module

The Lifter systems module is a unit that sits atop the systems capsule to house the blowers and valves plus other systems necessary for pressurisation and management of the Lifter body as an inflated structure. These systems are typical of aerostat installations.

Ground Fenders

Shock absorber legs (fenders) are provided for when the AeroRaft returns to the ground. Various types of fender may be used, such as: bumper, pontoons, wheeled legs, skids, etc, to suit the operational circumstances. The author's choice is a sprung leg/skid arrangement at three positions around the working module that use a large rotating dish as the skid (similar to some castors) and with legs to support the working module. The arrangement is a simple effective development fitted and successfully used on CargoLifter's *Joey* airship.

Rigging

The rigging comprises the working module suspension system plus mooring/handling lines. Except the lower line, the various rigging lines connect at bulkhead positions to the main stiffening ring between the upper and lower envelope joints. These lines can be used early in the AeroRaft assembly and inflation sequence, enabling in-field build and inflation arrangements without a hangar.

All mooring/handling lines will be of the same long length – to enable Lifter haul down against the aerostatic lift from the main chamber (filled with gas). Also the working module suspension lines should have lockable release facilities from the working module so that they also can be used for storm mooring purposes.

Rigging line parts may be made using existing materials and fittings that generally are stock items, although some parts (such as attachment brackets) may need to be developed to suit. Development and construction would follow normal aircraft practices.

The rigging arrangements allow the working module to be moved to one side, as shown from view 2 to view 1 of the drawing, further allowing the Lifter to be held near to the ground (without affecting lower end features). Ability to hold the Lifter close to the ground in a stationary manner and permit construction without a hangar are significant benefits compared with current airship and other balloon or aerostat practices. These aspects will aid deployment of the AeroRaft over wide regions, reduce maintenance costs and access difficulties, and enable severe storm conditions to be endured. The arrangements also facilitate decommissioning for transport to another site or back to production facilities for repair work.

Suspension Lines

The working module itself is supported via an independent suspension system from the main stiffening ring, obviating effects due to gas expansion and contraction. Suspension lines, in plan similar to the spokes of a bicycle wheel, extend down from the main stiffening ring's bulkhead connection points directly to releasable attachment parts (not shown) on the upper edge of the working module.

Vertical load from the working module is carried directly to the stiffening ring. Each suspension line applies an inward load on the stiffening ring that must be reacted. The load initially is carried by the stiffening ring's bulkheads, which in turn transfer the load in shear and tension to the stiffening ring tube. The radial loads cause compression across the section of the stiffening ring. As a flexible fabric structure, this compression is resisted through the stiffening effect of its pressurisation, thus enabling the support without significant change to the overall geometry. Vertical load from the suspension lines is carried by the aerostatic and aerodynamic lift methods of the Lifter.

The working module with its payload and necessary AeroRaft systems will be very heavy and is underslung at a very low position from the Lifter. Most of the weight will result from ballast (if there is no payload), to counteract the buoyancy, or results from a combination of ballast and payload. This mass will provide strong pendulum stability to keep the essentially lenticular Lifter body upright (i.e. stable).

Handling Lines

The handling/mooring lines enable the AeroRaft to be restrained at its full height (as shown in View 3 of the drawing). This normally only would be prior to a launch or after capture. The lines would be used with winch gear to haul down or let up the Lifter against buoyancy to heights where the module suspension lines may be connected or disconnected (as shown in View 2 of the drawing) or to take up load (as shown in View 3 of the drawing). When properly secured by all of the mooring lines (as shown in View 2 of the drawing) the working module may be carefully moved to one side – out of the way. The Lifter may then be hauled right down to its lowest level and additionally secured by the suspension lines (as shown in View 1 of the drawing) to hold it safely against adverse weather.

Capture (recovery action, when the AeroRaft is first caught by the ground crew and connected to ground restraint facilities) and Launch (the release action, when the AeroRaft is finally let go by the ground crew from its last restraint point) are facilitated by a single line below the working module. The line is used to pull the floating AeroRaft down to the ground and then tie-off to hold it in position. This action possibly can be undertaken using manpower effort assisted by the AeroRaft thrust units and aerodynamic lift system. It will require a central mooring site anchor fitted with a ring to pass the cable through and a tie-off point to one side (not below the working module), which also can be a ring on a ground anchor. Once captured, the handling/mooring lines would be connected followed by haul down of the Lifter. When restrained by the handling/mooring lines as shown in View 2 of the drawing the lower recovery/release line may be disconnected from the anchors and the working module suspension lines disconnected to permit movement of the working module to its side parking position.

Further Lower Line Considerations

If needed, for whatever reason, the recovery/release line also may be used to move the AeroRaft to a new position using a floating technique, where the AeroRaft is connected to a heavy surface mover (tug or tow vehicle) then ballasted to a light condition (where buoyancy exceeds gross weight) to maintain line tension and finally towed to its new position. The handling/mooring lines also may be used for this purpose with additional surface movers to provide restraint during the transit using techniques similar to those devised for the CargoLifter CL 75 AirCrane.

The lower recovery/release line also may be used as an alternative or under abnormal circumstances, as a mooring line. In this case a longer retractable line would be connected, enabling the AeroRaft to be let up under static light conditions to a higher position (as a tethered aerostat) where it can then freely ride the weather conditions without excessive line loads.

Additional or alternative automated facilities may be adopted to help overcome problems due to sheer size and the resulting high forces that must be managed. The lower line may therefore be extendable via a winch system affixed below the working module and be provided with a lower hook. Since during launch or capture the AeroRaft would not be transporting a payload, this line may be used for the recovery/release action in a manner similar to that described above but simply connected to a central restraint point. The AeroRaft under its own power may then draw itself down or let itself up using the winch facility to a position that is safe for ground crew personnel to connect/disconnect the line.

This last line connection or disconnection process also may be automated. If, instead of a simple hook at the lower end of the line an automated calliper jaw mechanism is provided, then the pilot could utilise this to undertake the operation unaided. Precise control of the AeroRaft and visual plus sensing systems would be necessary to assist the pilot in this operation. The automated system also would be useful for pickup or delivery of pre-packaged payloads.

Alternatively, the automated capture mechanism could be a facility installed and operated on the ground at the central mooring site position. A simple pendant fitting at the line's end would then be all that was needed.

Lifter Management System

The Lifter management system comprises the systems in the Lifter systems module together with a fabric umbilical trunk between the Lifter systems module and the lower envelope surface. Conduit lines from the Lifter systems module to their respective Lifter positions and associated passages (not shown) in the Lifter also are part of the Lifter management system.

The fabric umbilical trunk provides for the passage of air (contained in the ballonet compartment) to regulate the main envelope chamber super-pressure. The trunk also would be provided with means for maintenance personnel to use it as a passage for access into the Lifter's ballonet compartment.

It should be noted that normally aerostat pressurisation and management systems are mounted directly below on the underbelly of the respective aerostats that they serve. Also, the air valves, which release air from the ballonet, usually are mounted on the lower envelope. Grouping them together in the Lifter systems module atop the systems capsule and using the fabric trunk is a new method that facilitates maintenance without the need for high reach equipment. Indeed, access to the Lifter systems module and subsequent access to the Lifter plus its systems and parts via the fabric trunk and subsequent air passages will be possible during flight.

The fabric trunk plus sealable air passages from the ballonet compartment to the stiffening ring would also be utilised as the main conduit route for electrical, control, signalling and other lines. In this way inspection, maintenance or repair may be undertaken any time.

Other Systems

Self contained power units would be installed on the top deck of the systems module to provide power mainly for the working module systems and payload package. A minimum of two independent units, each able to provide the necessary power is desirable for redundancy and to facilitate maintenance.

In addition to thrust and lift control other controls will be necessary, such as:

- Ballast dump – to reduce weight
- Helium valves – to reduce displacement
- Envelope rip or holing system – to destroy aerostatic lift

These are standard airship features.

Navigation lighting and a transponder (not shown) will also be necessary, to comply with the Air Navigation Order. These are mandatory, but standard aircraft features.

Payload Suspension and Containment System

The payload suspension and containment system effectively is a separate packaging method (not part of the AeroRaft) that enables efficient transport of the payload as an underslung load beneath the working module. The lower line, discussed previously, is used for its suspension – connected via an automated mechanism to the top of the payload transport jacket or vessel. The mechanism would be the same as that described previously at the mooring site centre for Launch/Capture.

The payload transport jacket is a spherical fabric pressure stabilised envelope, similar to a balloon (inflated and stabilised with air), that completely enshrouds the payload within it. Rigid carriage structure (not shown) located at the top, within the transport jacket, would support both the payload and the transport jacket plus provide the necessary interface for connection to the AeroRaft's lower line. Systems to pressure stabilise the spherical envelope in a manner similar to those used for non-rigid airship envelopes also would be provided on the carriage structure and be powered via an umbilical line from the AeroRaft (not shown). Large ground blowers would be used to initially and rapidly inflate the jacket with air, its own system being used just to maintain levels for pressurisation after inflation.

A variety of methods familiar to those in the heavy lift industry may be used to support and restrain the payload from the rigid carriage structure. Also, the payload is an unknown quantity that may need particular methods for its support. Whatever, these methods will need to be arranged to suit the payload and be provided in a way that complies with aircraft requirements and the operating conditions of flight.

It is envisioned that the support arrangement and transport jacket would be prepared and be inflated beforehand, ready for the AeroRaft to transport the package. If the jacket is provided in two hemispherical halves (upper and lower) with zipped seals and lacing methods to hold the hemispheres together, then:

1) the payload may be put into the lower hemisphere (spread on the ground)
2) the upper hemisphere with the rigid carriage may then be lifted over the payload and held whilst the payload support arrangements are connected and rigged
3) whilst still holding the rigged payload the hemispheres would then be joined, sealed and the jacket inflated
4) support of the payload would then be transferred to temporary rigs and steadying facilities positioned inside, around and below the jacket, as necessary.

Since the payloads are an unknown quantity that will vary in size, weight and form, the transport jacket will thus standardise the package to be transported (enabling flight characteristics that are known). Several differently sized transport jackets and shapes perhaps should be developed to cover the circumstances that will be needed for transport operations. Some operations may also require transport without the jacket and these will need special consideration.

Lastly, instead of a jacket, a bucket or containment vessel may be employed to hold the payload contents. These vessels would work in the same way as a jacket, able to be loaded on the ground by whatever means and with whatever needs transporting: lumber, cattle, water, people, general goods, construction materials, etc, enabling all purpose use. The AeroRaft would then simply pick it up, transport it and put it where wanted.

OPERATING SITE ARRANGEMENTS

Operating Site

Operating sites are expected to be just a suitable open field that will need to have been set-up previously and be ready for use when the parts arrive. The mooring site would be used as the assembly & inflation area, so this will need preparation (flat, horizontal, smooth and clean) with all mooring points installed. New AeroRafts would be delivered in container boxes to their operating site as a set of separate parts to be assembled, inflated, checked out and then operated.

Assembly and Inflation Procedure

In essence, this is a simple 3 part procedure involving: assembly of main parts under air inflation, air evacuation and helium inflation, final assembly.

Assembly of Main Parts

The large fabric assembly parts would be delivered direct to the prepared area. If the three major assembly groups of the lifter body (upper and lower envelope plus stiffening ring) have not been finally joined at the factory before delivery, then this would need to be undertaken (after inspection) first. This should only be the case if the main stiffening ring is of rigid construction. In that case, because of its large size (affecting transportability), it will need to be assembled from sections. Such assembly work is standard practice in the aircraft industry. Following assembly of the ring the lower (probably first) and then upper envelope assemblies would be attached using the clamp plates described previously.

Alternatively, if a flexible fabric stiffening ring was adopted then this previously will have been integrated with the upper and lower envelope parts at the manufacturing factory, obviating the above stage. Whichever way is adopted, the next stage would be to layout the assembly central to the site the right way up ready for subsequent operations.

The thrust unit rigid support structures integrate as a part of the main stiffening ring so must be connected next (to complete the ring). Assembly of the thrust unit rigid support structures is a straightforward process adopting the clamp ring techniques described above.

Using a ground blower system, the main stiffening ring will be inflated with air. Necessary operations to assemble parts that will be difficult to install later should follow. In particular, the rigging should be connected and used to restrain the assembly against adverse weather effects. Also, systems to be installed in the rigid thrust unit support structures (batteries, electrical panels, blower systems, fire detection and suppression systems, auxiliary power units, control and monitoring systems, etc) should all be installed. When these systems have been installed the vector system (if used) and other arrangements necessary for attachment of the thrust units should be undertaken, although the thrust units should not be installed at this stage. The Rotordyne also should not be installed until later.

Again, using a ground blower system, the main envelope chamber will be inflated next with air (whilst maintaining pressure in the stiffening ring). By closing all upper envelope apertures, slackening the rigging and then blowing more air into the main chamber, it will be possible to raise the upper assembly from the ground (supported by the lower envelope as an air cushion). This will permit internal/external actions and necessary work to assemble parts that will be difficult to install later. Solar panels (if to be fitted) and their backing insulation, valves, lights, instruments, reinforcements, helium fill fittings and all other upper or lower envelope parts (as far as possible) should be fitted. In addition conduit and systems lines should be routed/fixed in place.

In order to get into the tubular ring and main chambers, suitable manhole positions plus aperture reinforcements will be needed. These must be closed and sealed before gas inflation. Also, as air is exhausted from the chambers prior to gas inflation, the Lifter body needs to be able to collapse completely (without restriction).

Air Evacuation and Helium Inflation

Systems checks, as far as possible should have been undertaken to confirm correct operation before helium inflation. When the work necessary on the Lifter body has been completed, its manhole covers should be finally fitted and then the air allowed to vent through the upper envelope by simply removing a cover (allowing the air to vent) until the main stiffening ring is seated once more on the ground, taking care not to damage the manhole covers beneath in the process. Air may then be released from the stiffening ring as well.

With all inspection, assembly, and checkout work completed, preparations for gas inflation follow. After removal of all equipment and personnel from inside, all air will be evacuated from the main chamber and the stiffening ring, as necessary, causing the assembly to collapse flat against the ground.

Note: If this action would damage solar panels or any other systems then these should be installed after gas inflation instead of before.

Following removal of the ground blower system tubes all apertures and manhole positions must be finally closed. These apertures would be provided with sleeves that can be quickly tied off to arrest any flow before installing the covers.

When the lines to restrain the AeroRaft have been checked and adjusted to suit, the gas plant positioned, inflation pipes connected to the main envelope chamber and the stiffening ring pressurisation system primed (ready to transfer gas from the main envelope chamber to fill the tube), gas inflation may commence. Gas inflation should proceed at a steady rate whilst monitoring the behaviour. It is expected that a bubble will rise from the upper envelope and gradually spread out until the main chamber is filled. In addition, as gas transfers to the main stiffening ring (needing operator control) this also should rise until it is full. No net, sandbags or other devices, as used in small gas balloon inflations, are expected to be necessary – the mooring system being all that is necessary for restraint. The mooring lines, however, will need to be let out (via winches) as the chambers inflate, to allow the Lifter body to take up its lenticular form and to float.

System monitoring (pressure watch) will be necessary from this time onwards. Also, tension in the mooring lines will have increased considerably, so this will need checking and adjustment to balance the loads.

Inflated with its gas (trapped in the main chamber above the ballonet) subsequent operations that require work inside the lower envelope may be safely conducted in an air environment. The ballonet (filled with air) will accommodate gas expansion through distension of its membrane. Otherwise, pressure may be increased in the main stiffening tube to draw off gas from the main envelope chamber. Buoyancy then also may be used to raise the Lifter for subsequent work.

Final Assembly

Completion of assembly work should follow with installation of the thrust units plus Rotordyne, followed by functional checkout of the systems involved. If the Lifter needs to be raised for this then the handling systems may be used to do this, allowing buoyancy to raise the Lifter to the height desired as the lines are paid out. Also, if the solar panels were not installed (if to be fitted) this should be completed. When assembly work is complete the Lifter may be let up sufficiently, restrained by the handling lines, to enable lower end work to be undertaken.

The working module is a self contained system the assembly work of which can be undertaken in parallel with the envelope inflation, so that it is ready for integration when the envelope work is complete. It also is envisioned that the module could be factory completed to a fairly high degree before site delivery. Delivery of this module is expected to be on a maintenance cradle that can be removed after the ground fenders are installed. After installation of the fenders and removal of the cradle, the module should be able to be freely moved and be free standing on the fender legs without need for anything further.

After the Lifter has been let up the module suspension lines will hang down freely in a natural way from their upper attachments. Final assembly activities to fit the lower end components and interconnect with the module are the last things to do. The module should be connected to the suspension system and the lower envelope interconnected by the trunk. With the suspension lines loaded, system and control lines finally may be connected to complete the AeroRaft.

Final functioning checks and inspections of all the systems need to be undertaken to ensure that everything is working properly and conforms to the standards defined. A build report, verifying the standard of construction and confirming that all systems function correctly will also be necessary as part of formal documentation to be completed.

Finally, approval from the authorities to commence operations will be necessary. Provided the development complies with national or international requirements (as appropriate) and can be shown to be fit for operation (normally through the records and documents produced, but also from test) a certificate of airworthiness for the particular operational uses may be granted.

OPERATIONS

Sphere of Operations

Operation of the AeroRaft is expected to be over industrialised populated areas, as well as isolated (inhospitable) regions where other transport methods have severe difficulties. A radar reflector would be provided to enable tracking. Systems also would be provided that enable the pilot to communicate and navigate in a manner consistent with other aircraft in the same airspace.

Lift and Ballast Choices

The AeroRaft specifically is configured to provide both aerostatic and aerodynamic lift. Whilst aerostatic lift normally would be available, the aerodynamic lift must be generated through action of the Rotordyne. This may be varied through a range of negative, neutral or positive lift conditions, depending on the rotational speed of the Rotordyne and the pitch of its wings.

When the AeroRaft is not carrying a payload then it may operate using aerostatic principles alone – without the Rotordyne. The excess aerostatic lift will need ballast (water) for compensation and this is carried in the working module. A rapid ballast fill and discharge system will be employed for load exchange purposes when the payload is to be picked up or set down. Pumping systems for this may be ground based. In addition, ballast for trim purposes using separate tanks and system features will be used to compensate against aerostatic lift changes during flight – due to environmental changes.

For most jobs, the AeroRaft may be operated with or without ballast, since the Rotordyne can be used to wholly counter the imbalance of payload set down. It can then fly to a different position where either a return underslung load (payload or any kind of ballast material) or ballast water can be pumped into its tanks.

Also, when payloads are picked up there is not an immediate need to drop ballast if the payload remains within the capacity of the Rotordyne to counter - making it possible to return to EQ after set down for the return journey. Alternatively, for special overweight payloads, the full aerostatic plus aerodynamic capacity may be employed to transport the load, when ballast exchange would be necessary for set down. For the scenario where ballast exchange is not undertaken pickup or set down of the underslung payload would be quick (perhaps just a few minutes), since it remains airborne, minimising dangers from weather changes and requiring little ground infrastructure.

Except for the provision of specific AeroRaft equipment and procedures, operation is expected to follow similar arrangements to that for other LTA craft.

Launch

To launch the AeroRaft a simple routine would be followed. It is assumed that the AeroRaft starts from its fully moored position with the payload capsule parked to one side. The launch activities commence after preparatory activities are complete. As discussed previously, the routine involves raising the Lifter to an intermediate height followed by movement of the lower module from its side parking position to its central position and then connection of the suspension and systems interfaces. Launch may then be conducted as follows:

- Check/adjust the AeroRaft buoyancy to suit the necessary buoyancy condition.
- Disconnect ground power facilities and start AeroRaft power systems, if not running.
- Switch the flight control systems on (if not already on) and carry out pre-flight routines.
- Disconnect envelope rip system and AeroRaft earthing lines from the ground and stow.
- Simultaneously operate the winches to permit the Lifter to ascend until the handling lines slacken and the winch disconnect joint is available.
- Disconnect the handling lines.
- Undertake launch by disconnecting the central Recovery/Relief line, gradually paying the line out and then letting go.
- Pilot takes command to undertake full control.

Capture

Recovery of the AeroRaft largely is a reversal of the above procedure. In general terms, the pilots will set-up the AeroRaft for its descent applying normal LTA practices and bringing it to an overhead position above the mooring site. Prior to capture, a weigh-off will be conducted to set the state of equilibrium (static heaviness or lightness) for capture. Whilst the pilot controls position and height of the AeroRaft relative to the mooring site the Crew Chief will coordinate and control ground operations. After touch down of the recovery/release line (to discharge static electricity) this will be connected to the central ground anchor. At this point the AeroRaft is ‘Captured’ and the Crew Chief assumes control for subsequent actions. Nonetheless, the Pilot will continue to control the AeroRaft’s behaviour until fully secured by the other lines.

CONCLUDING REMARKS

The author has developed the AeroRaft proposal in private and without financial assistance. Clearly, such an undertaking requires serious collaboration, management and financial backing for its development. The author does not have the means to take it any further.

The conceptual idea for the AeroRaft has been established in some detail; further development work would be necessary to produce a prototype. A prototype of the design (10 to 50 tonne payload capacity) could be realised and be produced under a short programme (within 3 years) and with limited budget (ROM $20,000,000). The author would be happy to collaborate with interested parties who would like to take up the opportunity to produce the world’s first viable heavy lift transport aircraft.

APPENDIX A – AERORAFT CONFIGURED FOR STRATOSPHERIC APPLICATIONS

A previous proposal also has been produced defining a similar vehicle for stratospheric use called StratRaft™[§§]. The StratRaft invention[***] is an LTA vehicle that operates with its main gas containment chamber unpressurised – in a way similar to naturally shaped stratospheric balloons that are only partially filled and accommodate expansion of the gas through distension of their envelopes. The AeroRaft on the other hand adopts a pressurised method, similar to non-rigid airships, which enables its hull form to be essentially constant. As such, it is provided with a ballonet, valves and blower systems that accommodate the expansion or contraction of the gas due to environmental changes.

The main problem that LTA aircraft must overcome for stratospheric applications is expansion or contraction of the contained gas over respective ascent or descent stages. This also can be undertaken using a large ballonet. If a ballonet of 100% capacity compared to the gas chamber is used then any height is possible.

Stratospheric use thus may be accommodated by fitting a 100% ballonet at the inner centre position of the main tube, instead of the smaller ballonet defined in the AeroRaft proposal. This should drape against the lower envelope when empty and fill to fit against the upper envelope when full.

The 100% ballonet also would aid initial inflation, since this may be used to stabilise the Lifter body shape before the gas is introduced, so this should be considered by developers in any case. Such a ballonet was proposed for CargoLifter's spherical CL 75 AirCrane envelope, to enable field inflation without a hangar. The lenticular form of the AeroRaft's Lifter body, on the other hand, is a better shape to use a 100% ballonet with, since the distension is less.

Under stratospheric use with just a small initial gas fill, buoyancy will be much less. If weight needs to be reduced then an arrangement without the Rotordyne configured similar to the StratRaft using the StratRaft's capsule and thrust unit arrangements instead would enable similar roles to be fulfilled. Also, the lower envelope may adopt a mirrored arrangement of the upper envelope to provide a true lenticular Lifter body profile (without the shoulder). If larger payloads need to be carried then the Rotordyne should be fitted to enable these to be carried, although endurance would be affected. Nonetheless, this would enable considerable loads to be carried to the stratosphere – where the AeroRaft may subsequently be used as a launch pad.

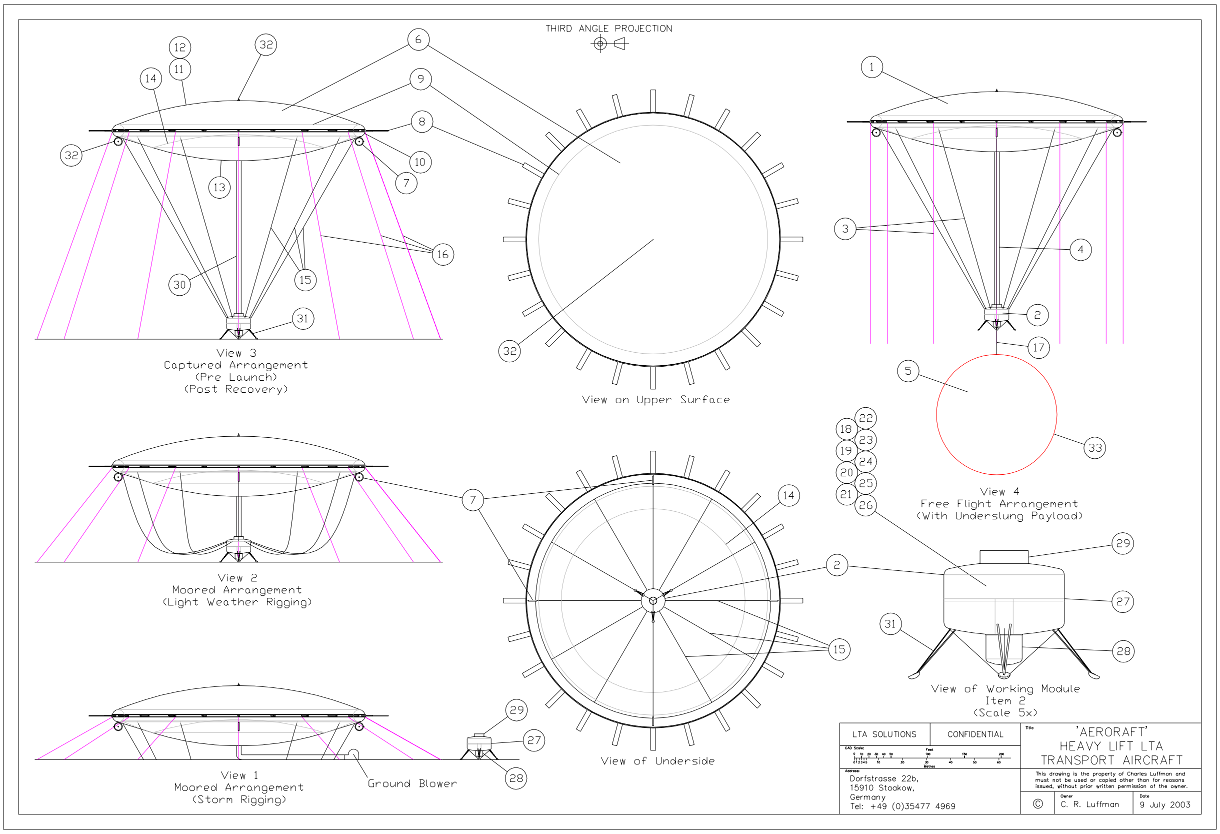
[§§] StratRaft™ is a trademark name of the author, for a hybrid LTA aircraft designed for deployment in the Stratosphere, described separately.

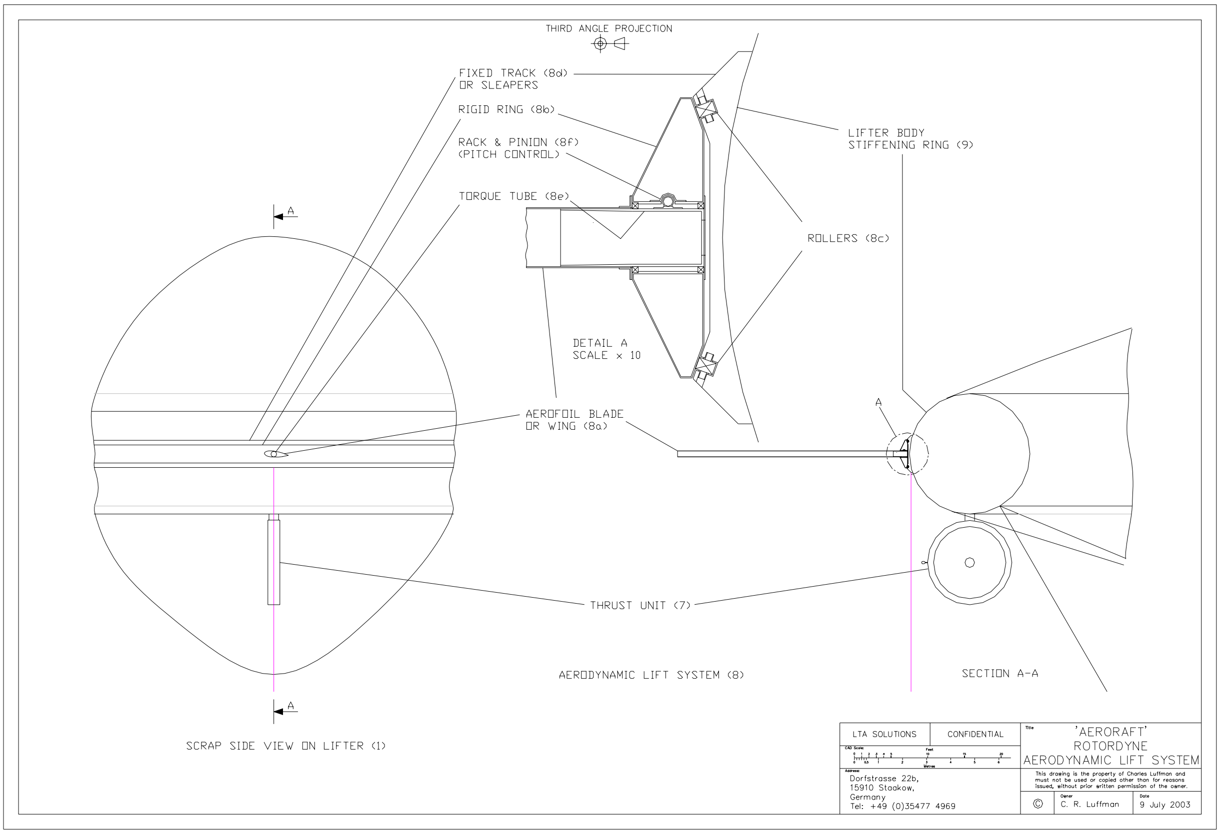
[***] Patent application No: GB 0225483.7 – 1 Nov 2002.

APPENDIX B – AERORAFT DRAWINGS

Component List

Item	Description
1	Lifter
2	Working module
3	Rigging
4	Lifter management system
5	Payload suspension and containment system
6	Lifter Body
7	Thrust Unit (generally comprising: Duct, Propeller, Motor, Drive and Pitch Systems, Stators and Cowls)
8	Aerodynamic Lift System (Rotordyne)
	a) Wing or Blade
	b) Rigid Ring
	c) Roller Assemblies
	d) Fixed Track – Sleepers
	e) Torque Tube
	f) Rack & Pinion Assembly
9	Stiffening Ring Tube Assembly (Torus)
10	Thrust Unit Pylons and Support Structure
11	Upper Envelope Assembly (Upper Dish)
12	Upper Envelope Membrane
13	Lower Envelope Assembly (Lower Dish)
14	Ballonet
15	Suspension System
16	Mooring/Handling Lines
17	Recovery/Release Line
18	Ballast Provision
19	Pressurisation System
20	Electrical System
21	Control Systems
22	Avionic, Instrumentation and Monitoring Systems
23	Fire Detection and Suppression Systems
24	Environmental Control System
25	Auxiliary Power Unit (Self contained, including fuel and oil)
26	Miscellaneous Systems and Equipment
27	Systems capsule
28	Pilots' command and control capsule or cockpit
29	Lifter systems module
30	Trunk
31	Ground Fender Arrangement
32	Lighting System
33	Payload transport jacket


THIRD ANGLE PROJECTION
View 3
Captured Arrangement
(Pre Launch)
(Post Recovery)
View on Upper Surface
View 4
Free Flight Arrangement
(With Underslung Payload)
View 2
Moored Arrangement
(Light Weather Rigging)
View of Underside
View of Working Module
Item 2
(Scale 5x)
View 1
Moored Arrangement
(Storm Rigging)
Ground Blower
LTA SOLUTIONS
CONFIDENTIAL
'AERORAFT'
HEAVY LIFT LTA
TRANSPORT AIRCRAFT
Dorfstrasse 22b,
15910 Staakow,
Germany
Tel: +49 (0)35477 4969
This drawing is the property of Charles Luffman and must not be used or copied other than for reasons issued, without prior written permission of the owner.
C. R. Luffman
9 July 2003


THIRD ANGLE PROJECTION
FIXED TRACK (8d)
OR SLEEPERS
RIGID RING (8b)
RACK & PINION (8f)
(PITCH CONTROL)
TORQUE TUBE (8e)
LIFTER BODY
STIFFENING RING (9)
ROLLERS (8c)
DETAIL A
SCALE x 10
AEROFOIL BLADE
OR WING (8a)
THRUST UNIT (7)
AERODYNAMIC LIFT SYSTEM (8)
SECTION A-A
SCRAP SIDE VIEW ON LIFTER (1)
LTA SOLUTIONS
CONFIDENTIAL
'AERORAFT'
ROTORDYNE
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C. R. Luffman
9 July 2003

End Word - December 2017

The paper was given at the November 2003 Denver AIAA conference when the concept was fresh. Inevitably, with the passage of time since then, ideas develop and errors are noted. The paper here essentially is as it was given without evolution of the concept since originally produced, but with corrections and adjustments of the text to help readers understand the design a little better - so with terminology now used. Even so, not much has changed since then and the particular design still awaits serious development as an aircraft.